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DIGITAL 3D RECONSTRUCTION AS A RESEARCH ENVIRONMENT IN ART AND ARCHITECTURE HISTORY. INFRASTRUCTURE FOR DOCUMENTATION AND PUBLICATION.

Presentata da: Igor Piotr Bajena

Coordinatore Dottorato

Matteo Cassani Simonetti

Supervisore

Fabrizio Ivan Apollonio

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Abstract

This dissertation addresses the still not solved challenges concerning digital 3D reconstruction regarding its documentation, publication, and representation in archaeology, art, and architecture history. An effort is also being made to create an infrastructure in the form of an open-access 3D model repository that meets modern requirements concerning the aspects above. The practical operability of the created platform will be examined in the context of higher education, as well as in the scientific and cultural context.

The digital turn in the sciences and humanities gave a possibility to reclaim lost Cultural Heritage (CH) and visualise never-built architectural and urban projects in the form of digital 3D models. The field of a sourced-based hypothetical 3D-reconstruction of CH allows the investigation of the building's history and presentation of research results in an easy-to-understand visual way (UNESCO, 2003). At the same time, it evoked unpredicted challenges related to the creation of vast amounts of heterogeneous digital data. The lack of standards for documentation of source-based 3D reconstructions and publication of 3D models resulted in the loss of knowledge and information. Over the years, the cultural heritage sector has produced tons of data that is outdated, unreadable or unusable (Kuroczyński, 2017). The main requirements and principles regarding documentation were outlined in the London Charter for the computer-based visualization of CH (Denard, 2012) or the Principles of Seville for archaeological 3D reconstructions (Lopez-Menchero & Grande, 2011), while problems of data management, availability, accessibility and readability were also already described in the FAIR Principles (Wilkinson et al., 2016). Despite this, the community still struggles to properly enforce these rules due to the lack of well-established solutions for CH models. The frequent lack of funding and the need for advanced digital documentation methods based on information technology (IT) knowledge leads to non-compliance with the recommendations of the documents mentioned above. Although a direction has been defined, the lack of indication of methods for obtaining adequate documentation or ways of publishing the results has resulted in a long-standing discussion in the community preventing the introduction of standardised solutions (Fernie, 2020).

The scientific community has responded to this challenge with a wide range of methods and platforms for publishing CH models, presenting different approaches to the documentation, often neglectfully responding to international guidelines. Many of those platforms focus only on a selected group of digital models of CH or blur the boundaries between reconstruction and digitisation that should have been distinguished (Münster et al., 2018a). The methods for acquiring or creating a model often cannot be documented, and the classification of CH objects in terms of their status (destroyed, never realised, etc.) or scale (city, building, etc.) is omitted. Even the issue of the storage of data itself in a variety of repositories is not fully transparent. Leaving aside the complex legal and copyright issues, the established principles of Web 3.0 define the necessity of using linked open data (LOD) to show not only the characteristics of published data, but also the interconnection between them with a structure of subject-predicate-object, allowing the creation of a semantic web (Auer et al., 2014; Berners-Lee et al., 2001). This requires storing data using tirpplestores based on Resource Description Framework (RDF) and Web Ontology Language (OWL) technologies and considering the use of informative 3D file formats like Industry Foundation Classes (IFC) or City Geography Markup Language (CityGML) to store data and its relationships within the models (Kuo et al., 2018). The advancing use of artificial intelligence in digital humanities (HistKI Project, 2021) also demonstrates the need to develop machine-learning-based documentation methods (Farella et al., 2021; Maiwald et al., 2023), which is not even considered in most repositories.

The following study considers documentation methods for different levels of a digital asset's life cycle (Golubiewski-Davis et al., 2021), with special emphasis on phases of creation, publication and reuse. In terms of 3D model creation, an attempt will be made to systematize techniques, modelling programs and methods for creating CH reconstruction models, along with determining the implications of use for the reconstruction process and expected results. Regarding the creation of a 3D model, an attempt will be made to systematize techniques, modelling programs and methods for creating CH reconstruction models, along with determining the implications of use for the reconstruction process and expected results, based on a us study of the reconstruction of the synagogue in Speyer in 1250 and the St. Johannis Church in Mainz in 800, 1250 and 1450.

The publication phase will be discussed in three aspects: repositories and services enabling process documentation, metadata schemas used to describe 3D CH models, and ontologies enabling semantic encoding of documented information. Their analysis will include possible use objectives and level of versatility, outlining recommended use cases. It will also allow the definition of a minimum core metadata schema and the development of a publication method with a low threshold of difficulty, enabling anyone, regardless of their level of knowledge or time and financial resources, to publish CH 3D models. The conclusions of this analysis will also be used in the creation of a universal, open repository for CH digital models, which will be created using a virtual research environment WissKI based on semantic web technology (Hohmann & Schiemann, 2013). It is planned to translate the developed metadata documentation scheme using concepts (classes) and relationships (properties) based on the tool for information integration in the field of cultural heritage, the CIDOC Conceptual Reference Model (CRM) (Doerr, 2005) and application ontologies (Menzel, 2003) and implement it into the new system. The repository's functionality will be tested with a different group of users to provide a user-friendly interface, establish the main assumptions, and promote it among the community.

The reuse stage, in turn, will be considered in terms of the various 3D file formats and the possibility of publishing the model. For what purpose can 3D models be reused and how should they be prepared? The analysis of the 3D formats used in the 3D graphics community (obj, dae, fix or alb) or architects and urban planners (IFC, CityGML) is expected to cover issues related to the visual perception of the models, the encoding of information about their form, geometry, or scene settings, as well as the possibility of storing the metadata itself, which could potentially be a document associated with the model regardless of the repository used.

The research's final result is the creation of an infrastructure for the documentation and publication of digital models based on prevailing standards and guidelines. The goal is to reach the largest possible audience and promote and facilitate access to CH's digital resources.

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I. Introduction

The history of art and architecture is marked by numerous gaps left by the stigma of time. Many designs by eminent artists and architects exist today only as drawings despite their significant historical and cultural value. An abundance of architectural heritage sites has been lost due to human conflicts and neglect. Reclaiming the physical form of lost heritage is often impossible due to the high costs involved, the evolution of urban structures, and the changing needs of contemporary society regarding architecture.

Digital 3D models emerged in architecture in the 1980s (Messemer, 2020), offering a new way to visualise the past like never before. This development sparked a new discourse on presenting historical structures using digital multimedia tools, facilitating simpler and faster information transfer. The potential of 3D models in (re)creating the past was so immense that they began to be viewed not just as tools for visualisation but as subjects of scientific research. However, the scientific community has stringent requirements for the research studies. The 3D model, as a research outcome, is often questioned due to the absence of specific regulations, requirements, and standards that determine its quality and reliability in the context of art and architecture history.

Despite the increase in the production of 3D models across various disciplines, such as heritage studies (focusing on human culture and behaviour related to heritage), museology (heritage presentation and public education), archaeology (visualisation of the past and site documentation), and the history of art and architecture (as a visualisation and research tool), there is currently a lack of shared methods for the publication and exchange of digital heritage 3D assets (Münster, 2022). Diverse approaches to methodologies, technologies, and workflows for digital models have led to the development of numerous individual solutions for documenting and disseminating 3D resources. Consequently, published 3D content is not subject to any standardisation to ensure the models are prepared for future reuse, nor is it evaluated for its scientific merit.

This work aims to embed 3D models of digital reconstructions in a scientific context and find ways to make them transparent, verifiable, referable, and usable. It requires investigation of different stages related to the creation and publication of digital 3D reconstruction to distinguish the elements of the process worth documenting and other methods of sharing 3D models with the public. The core of this issue is setting a framework that provides a solid basis for digital 3D reconstruction as a scientific discipline on the sub-study of applied practical solutions to two significant problems: **documentation** and **publication**.

Documentation for 3D models must uphold the academic rigour inherent in studying architectural history. It requires clear referencing and the integration of research results into the 3D model. Additionally, the 3D model should be presented publicly openly, not limiting access to the research. The methodology for this part of the research includes a critical analysis of existing studies, standards, and guidelines and an evaluation of the methods used in selected digital 3D reconstruction projects within the community. The conclusions of this part of the study can serve as a guideline for future researchers who face the challenges of digital reconstruction documentation.

Publication of 3D models as scientific works requires a suitable platform specifically designed to document hypothetical digital reconstruction research. This part of the study involves an analysis of the available repositories for 3D models of cultural heritage, their classification, and their evaluation against criteria for

scientific 3D models. The documentation schemas and metadata standards will also be examined, with an effort to develop a schema that addresses the specific needs of hypothetical digital reconstruction projects.

The digital nature of 3D models necessitates studying documentation and publication methods within the World Wide Web (WWW) environment. In particular, the forthcoming iteration of the internet, known as Web 3.0, may present significant opportunities. By adding semantics to published data and decentralising the flow of information, research results will become more easily accessible, transparent, and conducive to collaboration between researchers from different scientific fields (Bikakis et al., 2023). Therefore, the ultimate goal of this work is to create an open infrastructure within the Semantic Web framework for advanced scientific documentation of digital 3D reconstruction models. This aims to facilitate sustainable, low-threshold documentation and publication of the process in line with the latest web-based data-sharing standards. The objective is to develop ready-to-use services that provide storage space, a pre-designed template for metadata documentation, and an easy-to-use interface.

A. What is digital 3D reconstruction?

Before commencing the actual work, it is essential to define precisely what digital 3D reconstruction is. The term 'digital 3D reconstruction' is a topic of debate within the scientific community, and its exact definition remains somewhat unclear. The term 'reconstruction' itself is etymologically derived from two parts: the prefix '*re-*' meaning '*again*', and a derivative of the verb '*construct*', indicating the act of building something anew.[1] '*3D*' is a commonly used abbreviation in the computer graphics community, derived from '*three-dimensional*'. It defines an object created in a three-dimensional, computer-generated space that simulates reality. The adjective '*digital*' refers to storing information using computer technology and numerical digits.[2] This suggests that digital reconstruction pertains to objects already built and then (re)created in a digital environment. According to this definition, '*digital 3D reconstruction*' would be interpreted as digitising an object. This interpretation is indeed used, particularly by researchers involved in conserving historic buildings and creating digital twins of existing heritage.[3]

Nevertheless, this is not the only definition of the term. A different perspective is taken in the field of digital humanities, where digital 3D reconstruction means:

> "*the creation of a **virtual model** of a **historical entity** that requires an **object-oriented, human interpretation**. Object-relation stands in*

[1] Etymology and definition of the word '*reconstruction*' was taken from the Oxford English Dictionary (2023), online: https://doi.org/10.1093/OED/9571127806.

[2] Etymology and definition of the word '*digital*' was taken from the Oxford English Dictionary (2023), online: https://doi.org/10.1093/OED/1297556308.

[3] Voulodimos describes digital reconstruction as "*the process of capturing the shape and appearance of real objects.*" Nikolov and Madesen, on the other hand, define it as: "*The process of capturing the 3D shape of an object or part of an object, as opposed to images that capture a 2D representation of an object from a specific direction*". In both cases, the emphasis is on capturing the shape of the actual object. See: Athanasios Voulodimos and others, "Image Clustering and Video Summarization for Efficient 3D Modelling and Reconstruction", In: *Recent Advances in 3D Imaging, Modeling, and Reconstruction*, ed. by Athanasios Voulodimos and Anastasios Doulamis, Hershey, PA: IGI Global, 2020, p. 193-214., online: https://doi.org/10.4018/978-1-5225-5294-9.ch009 and Ivan Nikolov, and Claus B. Madsen, "Calculating Absolute Scale and Scale Uncertainty for SfM Using Distance Sensor Measurements: A Lightweight and Flexible Approach" In: *Recent Advances in 3D Imaging, Modeling, and Reconstruction*, ed. by Athanasios Voulodimos and Anastasios Doulamis, Hershey, PA: IGI Global, 2020, p. 168–9, online: https://doi.org/10.4018/978-1-5225-5294-9.ch008.

contrast to process-relation human interpretation, which is required, e.g. for algorithm development in context of data-driven acquisition." [4]

Here, the determinant is the human factor of data interpretation, which would completely eliminate the digital twins from under the scope of digital reconstructions. This definition is oriented towards hand-made 3D models, which may have much lower accuracy, but the human input is much greater.

In the same discipline, this expression is used interchangeably with the term '*virtual reconstruction*', which has a slightly different connotation. '*Virtual*' means something that, although it has no physical form, appears to exist by simulation of certain aspects of reality.[5] This change avoids emphasising data storage with digits and focuses more on visual simulation, which is not so strongly associated with the digitisation of objects. The origin of the term '*virtual reconstruction*' is deeply rooted in virtual archaeology and is defined in the Seville Principles (SP)[6]. It is a document outlining the scientific foundations for this discipline. It states that '*virtual reconstruction*' is:

"*(…) using a virtual model to* ***visually recover*** *a* ***building or object made by humans*** *at a* ***given moment in the past*** *from available* ***physical evidence*** *of these buildings or objects, scientifically reasonable* ***comparative inferences*** *and in general* ***all studies*** *carried out by archaeologists and other experts in relation to archaeology and history"*

Here, the determinant is the physical evidence that forms the basis of the reconstruction. In the context of archaeology, this can mean physical remains, like ruins or foundations of a building. This definition omits cases of 3D reconstructions of objects that have never been realised, or which physical evidence has not been discovered. Of course, the statement '*physical evidence*' can be seen in a broader context, considering historical photographs or drawings as well. However, this raises the issue of the certainty of the evidence. Historical sources (especially drawings) are not precise, often show distorted reality, or are not consistent. As a result, they may not provide a solid basis for the application of this particular definition in disciplines other than virtual archaeology. SP comes up with a term that seems more appropriate, which is '*virtual recreation,*', defined as:

"*(…) using a virtual model to* ***visually recover*** *an* ***archaeological site*** *at* ***a given moment in the past****, including material culture (movable and immovable heritage), environment, landscape, customs, and general cultural significance"*

In this context, there is no requirement for physical evidence of the object's existence, and the recreation pertains to a specific site. Therefore, this term appears more suitable for describing reconstructions based on historical sources rather than physical excavations. There is some doubt about the reference to '*archaeological sites',* while this still implies the need to use excavations as a basis for reconstruction. Consequently, '*virtual*

[4] Sander Münster, Wolfgang Hegel, and Cindy Kröber, "A Model Classification for Digital 3D Reconstruction in the Context of Humanities Research", In: *3D Research Challenges in Cultural Heritage II*, ed. by Sander Münster, Mieke Pfarr-Harfst, Piotr Kuroczyński and Marinos Ioannides, Cham: Springer, 2016, p. 3-31. online: https://doi.org/10.1007/978-3-319-47647-6_1.

[5] Definition of the word '*virtual*' was taken from the Oxford English Dictionary (2024), online: https://doi.org/10.1093/OED/3615821478.

[6] Seville Principles (2017), online: http://sevilleprinciples.com/ (accessed 08 August 2024).

recreation' also does not adequately encompass the recreation of projects that were never realised or those which are based on design drawings.

The ambiguity of the terminology has led to significant consequences. For years, it has been impossible for the community to establish shared standards for documenting work on hypothetical reconstructions, making it virtually impossible to treat 3D models as scientific resources (Kuroczyński, 2017). As a result, different terminologies have emerged depending on the discipline and research focus.[7] One may begin to question whether digital 3D reconstruction should really be called '*reconstruction'* at all, and where the term actually comes from in the context of work on the hypothetical visualisation of relics of the past.

A.1. If not '*reconstruction*'...then what?

The problem described leads to the exploration of further alternative terms for the '*reconstruction*' process. Going back to LC, the term reconstruction was not used, but '*computer-based visualisation*'. The term '*reconstruction*' appears instead to be already in use in the cited SP document. The SP gives also a number of other terms related to virtual operations on relics of the past. In addition to the aforementioned '*virtual reconstruction*' and '*virtual recreation*', the SP defines '*virtual anastylosis*' as:

> *"(…) restructuring existing but dismembered parts in a virtual model"*

and also '*virtual restoration*', as:

> *"(…) using a virtual model to reorder available material remains in order to visually recreate something that existed in the past. Thus, virtual restoration includes virtual anastylosis."*

Reaching out to early publications in the field of virtual archaeology, we can also come across other terms describing this process, such as '*simulation*' or '*reproduction*'.[8] A bit later, the use of the term '*digitisation*' was also noted, as a reference to the creation of 3D models based on reality-based data.[9] A total number of eight potential terms, including 'reconstruction,' were identified in scholarly publications to describe the process of creating 3D models of cultural heritage. Each of these terms, aside from those specifically referring to virtual or digital space, has a distinct definition, which can be found in Tab. 1.

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[7] An analysis of the terminology used in the field of 3D digital reconstruction was one of the themes addressed in Irene Cazzaro's PhD thesis. She carried out a complex analysis of the vocabulary used by the community over the years. The study presented in this thesis, should be considered as a complement, concerning the definition of the scope of the field itself, which was not addressed in Cazzaro's study. See Chapter "1.5 Terminology" (p. 27-47) in: Irene Cazzaro, "Digital 3D Reconstruction as a Research Environment in Art and Architecture History: Uncertainty Classification and Visualisation", Bologna: Alma Mater Studiorum - Università di Bologna, 2023, online: https://doi.org/10.48676/unibo/amsdottorato/10817, and Irene Cazzaro, "A Shared Terminology for Hypothetical 3D Digital Reconstructions in the Field of Cultural Heritage", In: *AMPS Proceedings Series 29.2, University of Kent, ISSN 2398-9467*, 2023, online: https://www.academia.edu/97104599/A_shared_terminology_for_hypothetical_3D_digital_reconstructions_in_the_field_of_Cultural_Heritage (accessed 15 March 2023).

[8] See: Paul Reilly, "Data Visualization in Archaeology", In: *IBM Systems Journal*, 28.4 (1989), pp. 569–79, doi:10.1147/sj.284.0569, and J. M. Burridge et al., "The WINSOM Solid Modeller and Its Application to Data Visualization", In: *IBM Systems Journal*, 28.4 (1989), p. 548–68, doi:10.1147/sj.284.0548.

[9] See: Kotsakis, K., S. Andreou, A. Vargas, and D. Papoudas. 'Reconstructing a Bronze Age Site with CAD'. In: *Computer Applications and Quantitative Methods in Archaeology 1994*, p. 181–88. Oxford: Tempus Reparatum, 1995, online: https://proceedings.caaconference.org/paper/28_kotsakis_et_al_caa_1994/.

Tab. 1 *Overview of the definitions of the surveyed terms.*

reconstruction[10]	the process of building something again after it has been damaged or destroyed;
simulation[32]	to do or make something that behaves or looks like something real but which is not real;
visualisation[32]	the act or an example of creating an image, etc. to represent something;
restoration[11]	a return of something to a former, original, normal, or unimpaired condition;
anastylosis[33]	the restoration of a ruined monument or building by reassembling fallen parts and, when necessary, incorporating new materials;
reproduction[33]	a copy of something, especially a work of art or a piece of furniture;
recreation[33]	to make a copy, representation, duplicate, or close imitation of *(something);*
digitisation[12]	The action or process of conversion analogue data into digital form;

Recognising that the word 'reconstruction' is inaccurate in the context of the field under study, one would expect higher usage of other terms in the academic community. To test the validity of this statement, 457 academic publications on the topic of digital 3D reconstruction from the 1980s to the present were selected to analyse the frequency of occurrence of each term. To select reviewed materials, the initial focus was on publications authored by members of *Die Arbeitsgruppe Digitale Rekonstruktion* (AGDR)[13], a group dedicated to digital hypothetical 3D reconstructions of Cultural Heritage (CH). The selection criteria required that the publications be in English and pertain to subjects related to visualising cultural heritage, particularly architectural heritage, using computer techniques. Additionally, the articles needed to be digitised and available for download to facilitate semi-automatic text analysis. The initial pool of selected publications served as a foundation for identifying further articles through selected bibliographic references. If an article originated from a conference series or journal that met the initial criteria, the search was expanded to include all relevant publications within that issue. Finally, to avoid bias, the search was extended to scientific paper databases such as Scopus[14], Academia.edu[15], and ResearchGate[16], using keywords like '*virtual 3D reconstruction'*, '*digital 3D reconstruction*', and '*computer-based 3D reconstruction*'. A complete list of publications covered is included in Appendix 1.

The first step of the study involved sorting the articles by year of publication and checking the number of occurrences of the terms listed in Tab. 1. In the case of words with different forms in American and British English, both forms were considered and their results were summed. The process was automated with the help

[10] Definitions are taken from Cambridge Dictionary, https://dictionary.cambridge.org/dictionary/ (accessed 28 August 2024)

[11] Definitions are taken from Dictionary.com, https://www.dictionary.com/ (accessed 28 August 2024)

[12] Definition is taken from Oxford Dictionary, https://www.oed.com/ (accessed 28 August 2024)

[13] AGDR is a working group that emerged from the 1st annual conference of the "Digital Humanities in German-speaking countries" (2014, University of Passau). The founding members of the working group took the opportunity to establish a platform for a closer exchange and a firm establishment of the digital reconstruction of cultural heritage within the Digital Humanities. Although the group focuses on German-speaking countries, it is also inching toward partnerships in the UK, Italy, Poland, Cyprus, Belgium and the US. More info available at: https://digitale-rekonstruktion.info/ (accessed 30 July 2024).

[14] https://www.scopus.com/ (accessed 30 July 2024).

[15] https://www.academia.edu/ (accessed 30 July 2024).

[16] https://www.researchgate.net/ (accessed 30 July 2024).

of a Python programming script and the use of a library that enables analysis of PDF files - pdfminer.six.[17] The results are presented as a heat map diagram (Fig. 1). Each cell in the heat map table shows the percentage of term usage in publications from a specific year. To calculate this percentage, the total occurrences of the term for the given year are summed and divided by the total occurrences of all terms studied for that year. The darker the cell's colour, the higher the percentage of the term's usage. Next to the heat map is an additional column showing the number of publications taken each year. On the right is a column chart illustrating the total occurrences of all the surveyed terms for each year. Above the heat map is another column chart presenting the overall number of occurrences for each term across all the studied publications.

The study revealed that the term '*reconstruction*' was used almost twice as often as the combined frequency of all other terms in the analysed articles. While the usage trends of individual terms fluctuated over the years, '*reconstruction*' consistently maintained a clear advantage. The only exception was before 2000 when terms like '*visualisation*', '*restoration*', and 'simulation' appeared more frequently. However, these early years of the field likely saw greater flexibility as habits in terminology were still forming within the community. It's also important to note that the number of digitally available articles from this early period is limited, so these results may not fully reflect reality. Despite this, the study demonstrates how deeply ingrained the term '*reconstruction*' is globally. Efforts to replace it with alternative terms now might be unsuccessful.

The term '*reconstruction*' appears to be the most universal, encompassing both the recovery of a damaged or destroyed object and the creation of a duplicate. Other terms are used more narrowly. '*Visualisation*' refers to the visual representation of the outcome of the reconstruction process. '*Simulation*' may refer to the representation of an object's past form, acting as a synonym for reconstruction, but is more often associated with representing dynamic processes of change rather than a static object. '*Restoration*' describes restoring a damaged object, usually applied when most of the original material remains. While it can involve reconstruction, it focuses explicitly on filling in the gaps of the original substance. '*Reproduction*', however, implies the creation of a copy, aligning more with the idea of duplication. Similarly, '*digitisation*' refers to creating digital equivalents of an object. 'Anastylosis' is a specialised form of reconstruction, limited to reassembling separated parts with possible additions. Finally, '*recreation*' seems the closest synonym to reconstruction, though it does not necessarily imply the object is damaged or destroyed. It can refer to both duplication and imitation. However, this term has not gained widespread use within the community. The potential relationships between these terms in a hierarchical arrangement are shown in the Fig. 2.

Despite criticism from researchers, the term 'reconstruction' is widely used in the digital context. [18] The use of substitutes for the term has so far received little response. However, the question still remains as to what type of reconstruction correctly describes the hypothetical re-construction of a historical object in a digital environment. To answer this issue, it is necessary to check the variations and interpretations of the term in the academic community.

[17] pdfminer.six is an open source python package for extracting information from PDF documents, available on GitHub: https://github.com/pdfminer/pdfminer.six (accessed 26 August 2024).

[18] Juan Barcelo, 'Visualizing What Might Be. An Introduction to Virtual Reality in Archaeology', in *Virtual Reality in Archaeology*, 2000, pp. 9–36; Federico Fallavollita and others, 'Terminological Study for Scientific Hypothetical 3D Reconstruction', *Heritage*, 7.9 (2024), pp. 4755–67, online: https://doi.org/10.3390/heritage7090225/.

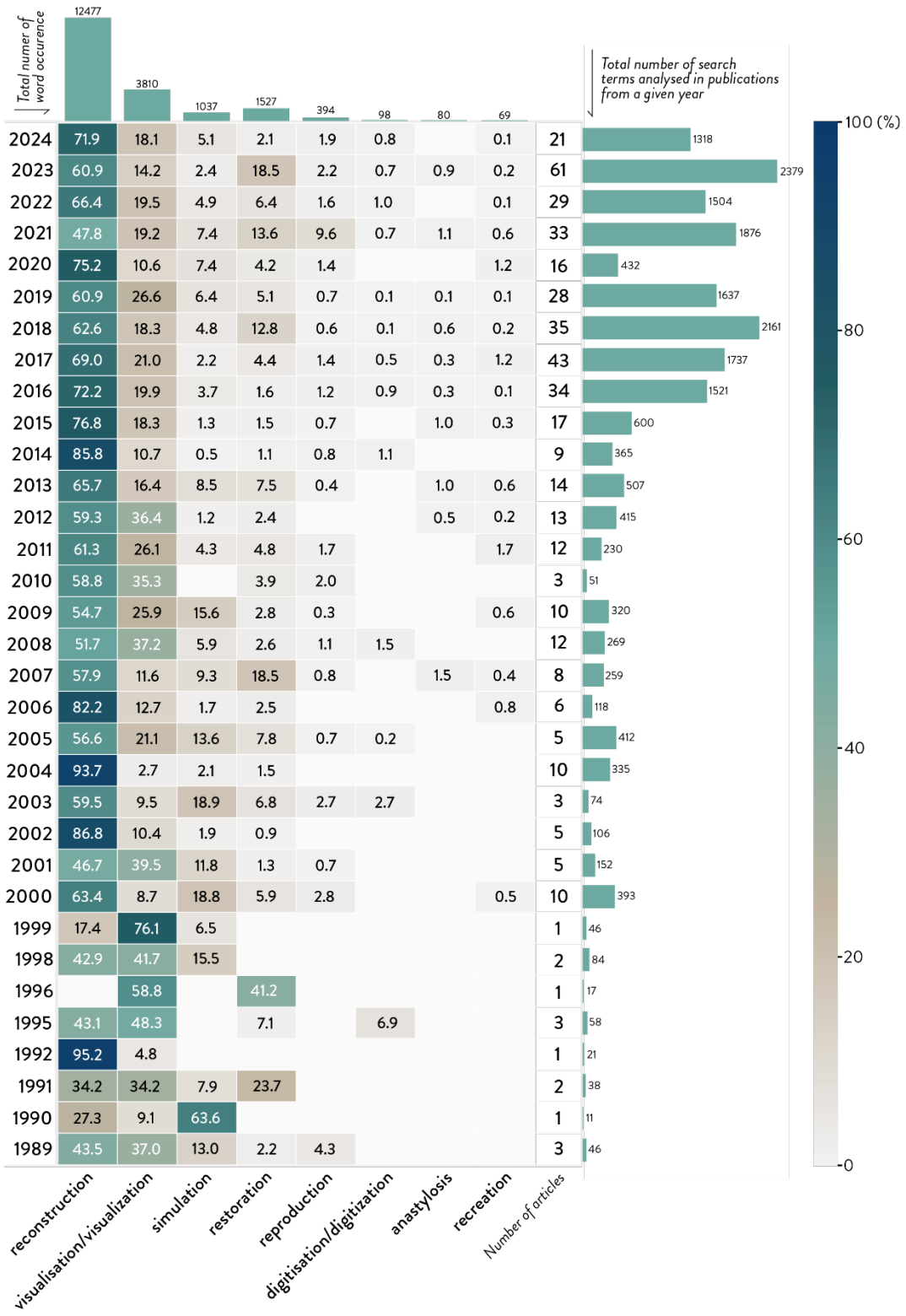

Fig. 1 Heatmap diagram illustrating the frequency of terms defining the digital 3D reconstruction process over the years. The diagram is enhanced by the total number of occurrences of each term (above the main diagram) and the sum of the occurrences of the surveyed terms for each year (next to the main diagram).

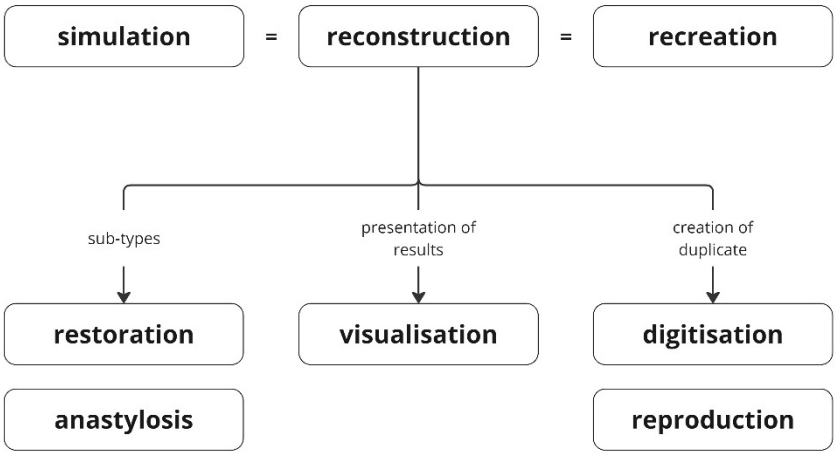

Fig. 2 Diagram illustrating potential hierarchical relationships between the terms studied.

A.2. If 'reconstruction'...then which?

The ambiguity of the term 'reconstruction' has led researchers to develop variations that more precisely capture the nuances of this discipline. Some researchers have introduced alternative spellings which highlight the separation of the prefix 're-'. This indicates that the process described is not an actual reconstruction but only a virtual one. Expressions such as '*(re)construction* (Schreibman & Papadopoulos, 2019)' or '*re-construction* (Apollonio et al., 2021; Senior, 2018)' belong to this group. The second group comprises expressions using adjectives indicating the carrying out of reconstruction in a computer environment. The expressions in this group are most commonly used to describe the process of reconstruction and have been the subject of long-standing discussion among the community. Four terms describing this process were found in the pool of publications surveyed: '*digital reconstruction* (Bendicho, 2013; Münster et al., 2016; Zuk et al., 2005)', '*virtual reconstruction*[19]', '*computer reconstruction*[20]' and '*computer-based reconstruction* (Dworak & Kuroczyński, 2016; Miller & Richards, 1995)'. Expressions related to the definition of the three dimensions of reconstruction are also included in the same group. Although three-dimensionality does not directly imply a computer environment, current society has a strongly encoded association between the term 3D and computer graphics. Three reconstruction descriptors indicating three-dimensionality were identified: '*3D reconstruction*' (Demetrescu, 2015; El-Hakim, 2002; Münster et al., 2018a), '*three-dimensional reconstruction*' (De Luca et al., 2007), and '*3D-reconstruction*' (Soto-Martin et al., 2020). A distinct term is '*visual reconstruction*',[21] which refers to the outcome of the work—a graphic visualisation of the object. The last identified term is related to an indication of work's scientific value, and it is '*scientific reconstruction*' (Breitling et al., 2017).

[19] Reilly, P. 'Data Visualization in Archaeology'. *IBM Systems Journal* 28, no. 4 (1989): 569–79, online: https://doi.org/10.1147/sj.284.0569.

[20] (Grün et al., 2004; Jablonka et al., 2002; Pikulski, 2020)

[21] Danielle van den Heuvel, and Julia Noordegraaf. 'Unpacking Urban Life in the Past: "Time Machine" as a Data Visualization and Analysis Tool'. In *Visual and Multimodal Urban Sociology, Part A*, edited by Luc Pauwels, 18A:63–95. Research in Urban Sociology. Emerald Publishing Limited, 2023, online: https://doi.org/10.1108/S1047-00422023000018A003.

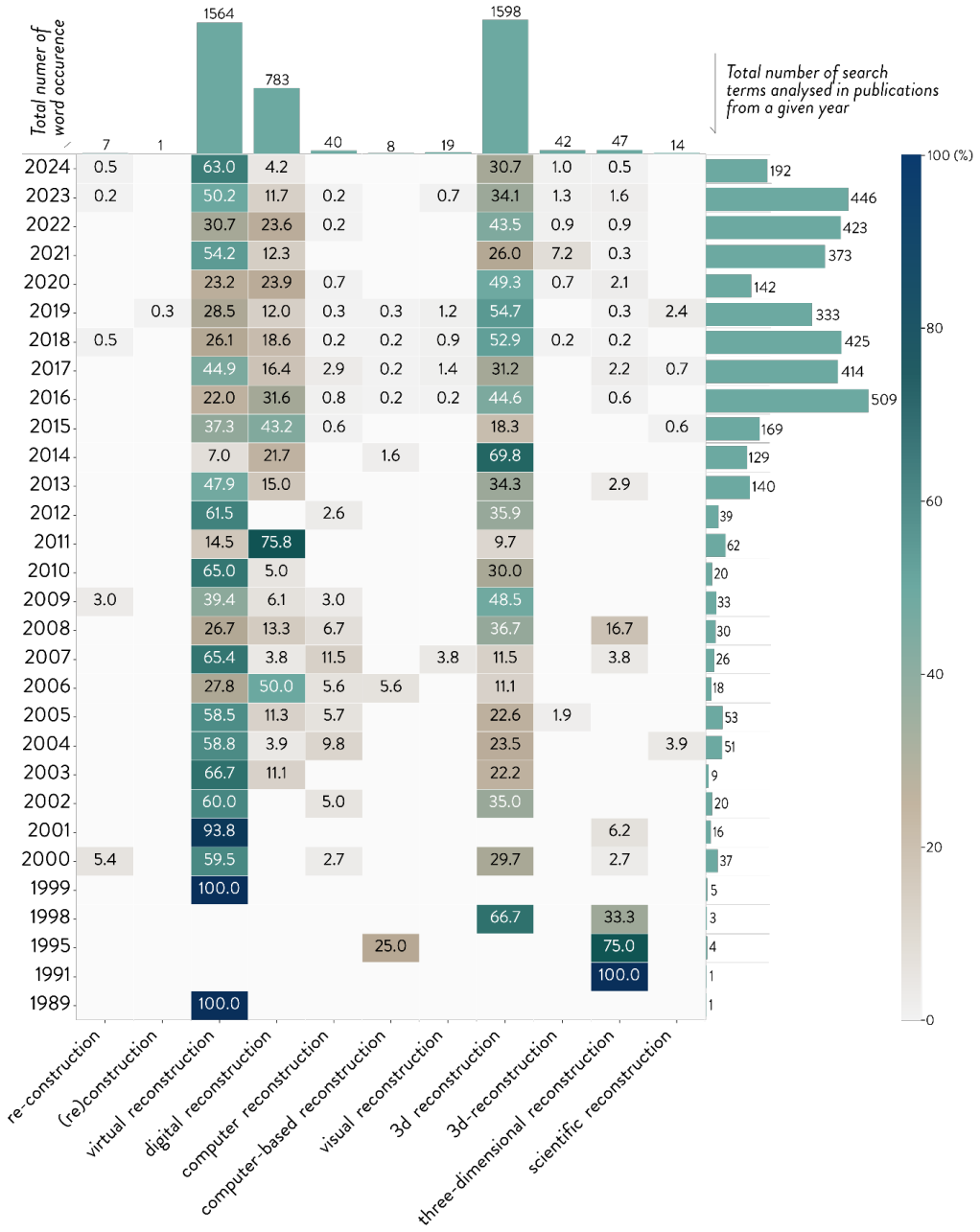

Fig. 3 Heatmap diagram illustrating the frequency of expressions defining the digital 3D reconstruction discipline over the years. The diagram is enhanced by the total number of occurrences of each expression (above the main diagram) and the sum of the occurrences of the surveyed terms for each year (next to the main diagram).

As in the previous study, a Python script was used to automatically count the frequency of the specified expressions in the selected articles. The results were once again summarised in a heat map, organised by year (Fig. 3). Above the heat map, there is a column chart with the total number of occurrences for each expression. The study revealed that the terms '*virtual reconstruction*' and '*3D reconstruction*' have the highest number of occurrences. Their relatively high frequency has been consistent since the early development of the discipline. Interestingly, '*digital reconstruction*' appears only half as frequently as these terms, first emerging in 2000 and gaining more usage only after 2011. The other terms show limited acceptance within the community, maintaining a low percentage of occurrence.

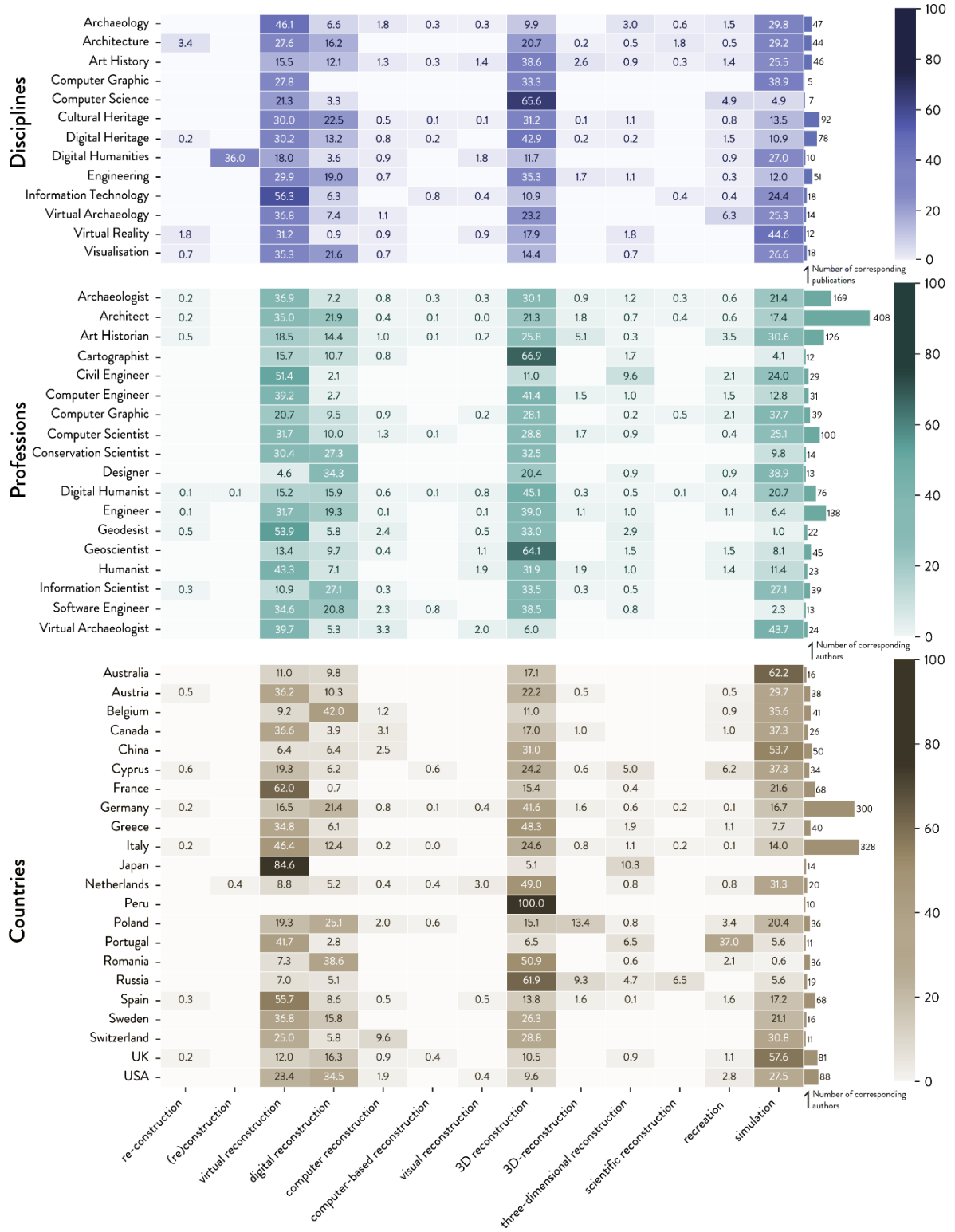

Fig. 4 Compilation of heatmap diagrams illustrating the frequency of expressions defining the digital 3D reconstruction discipline concerning disciplines of publication audiences, authors' professions and countries of authors affiliation. The diagram is enhanced by column charts showing the sum of the occurrences of each attribute: country, profession, and discipline (next to the main diagrams).

The attributes assigned to authors and publications formed the basis for compiling heat map charts for the selected terms (see Fig. 4). The workflow followed the same process as in previous studies. In addition to the terms used in the second study, terms identified as synonyms for digital reconstruction in the first study, such

as '*simulation*' and '*recreation*', were added to the list of analysed terms. Attributes that did not reach enough occurrences to provide reliable research material (a minimum of 10 repetitions for the authors' characteristics of country and profession and a minimum of 5 repetitions for the publication's discipline) were excluded from the compilation. On the right side of each heat map, a column chart was added to show the number of occurrences for each attribute in the study. This includes the number of publications targeting a specific field or the number of authors with a particular profession or country of affiliation.

The contextualisation of the collected publications confirmed that the frequency distribution of terms varies across the categories studied (discipline, profession, country of affiliation). Three terms of disciplines showed clear predominance in usage: '*virtual reconstruction*', '*3D reconstruction*', '*simulation*', and '*(re)construction*'. However, identifying a consistent pattern based on discipline preferences remains challenging. '*Virtual reconstruction*' is most frequently used in archaeology, virtual archaeology, information technology, and visualisation publications. '*3D reconstruction*' is preferred in art history, computer science, cultural heritage, digital heritage, and engineering, while '*simulation*' is commonly used in architecture, computer graphics, and virtual reality. Notably, the term '*(re)construction*' is predominant in digital humanities, though its high usage stems from just one publication. The term '*digital reconstruction*' did not dominate any discipline and only reached around 20% frequency in cultural heritage, engineering, and visualisation. Additionally, in art history, the frequency of '*virtual reconstruction*' and '*digital reconstruction*' is similar, suggesting that the terms may be used synonymously. In other disciplines, the significant disparity in usage suggests that the terms may have different meanings.

The most significant differences are observed in the distribution of terms by authors' countries. Again, the three most common terms are *'virtual reconstruction'*, *'3D reconstruction'*, and *'simulation'*. However, for the first time, the term *'digital reconstruction'* dominates in several countries, including Belgium, Poland, and the United States. Interestingly, Romania and Germany also show a higher frequency of *'digital reconstruction'* than *'virtual reconstruction'*. Additionally, five other countries—Australia, China, the Netherlands, Russia, and the UK—demonstrate similar usage levels for these terms. It was also noted that *'virtual reconstruction'* predominates mainly in European countries. This suggests that the differences in term usage may stem from linguistic variations or possibly even preferences influenced by the author's native languages.

The discrepancy between interpretations of the term digital 3D reconstruction led to the creation of the author's definition for this study. The author directs his reasoning towards the field of digital humanities, assuming that '*digital 3D reconstruction'* is a shorter form for the term '*hypothetical digital 3D reconstruction of lost, not accessible, or never-built architectural heritage based on human-interpreted sources'*. Therefore, the developed infrastructure for documentation and publication is based precisely on examples of 3D digital reconstruction strongly linked to the human interpretation of source materials and the creation of hypotheses for knowledge gaps. The author knows the strong connection between hypothetical reconstructions and digitisation or automatic or semi-automatic digital reconstruction methods, but these are treated as side topics. The research core is based on hand-made digital models and the possibility of documentation of reconstructions using algorithms, whereby procedural modelling is omitted. It needs to be highlighted that the following work focuses on digital 3D reconstruction, understood as the process of creating a 3D model of a destroyed, not accessible, or never-built architectural heritage based on human-interpreted sources, (Münster et al., 2018b) which results in adding a certain amount of hypothesis to the created model. Although digitisation of cultural heritage and

automatic or semi-automatic reconstruction would also be considered, they will be treated as side topics. At the same time, the core of the research will be focused on hand-made digital models.

B. Contentious Constructs

Although terminology makes it difficult to understand the field of digital 3D reconstruction correctly, it is not a primary problem. The publications analysed revealed many other problematic aspects that are still being investigated today. Nineteen terms have been identified to define the challenges in the field of 3D digital reconstruction, which are: '*modelling/modelling*', '*documentation*', '*interpretation*', '*hypothesis*', 'transparency', '*segmentation*', '*traceability*', 'reproducibility', '*visualisation/visualisation*', '*representation*', '*perception*', '*publication*', '*preservation*', '*presentation*', '*accessibility*', '*accuracy*', '*reliability*', '*uncertainty*', and '*plausibility*'. The semantic connotations of these terms were not explored further, as this topic was thoroughly examined in Irene Cazzaro's doctoral dissertation[22]. However, these terms were grouped into categories based on common themes, and the frequency of their appearance in the surveyed articles was analysed (see Fig. 5). This analysis highlighted four main issues related to scientific digital reconstructions. The first and most extensive concern is the challenge of transparency in research, documentation, and the reproducibility of results. The numerous factors influencing digital reconstruction make it extremely labour-intensive to capture all relevant details,(Münster et al., 2016) and in projects where visualisation of results is the primary goal, complete documentation is often not prioritised. As a result, researchers are now focusing on identifying what should be documented and finding ways to minimise the workload and accelerate the process.(Bruschke & Wacker, 2016; Grellert & Pfarr-Harfst, 2019). The difficulty in achieving transparency in research also arises from copyright issues related to source material. Historical materials processed in archives often require authorisation for publication and the appropriate licensing. As a result, researchers are frequently unable to publish visual versions of their sources. This limitation, in turn, raises doubts about verifying the historical accuracy of the presented reconstruction.

The second group of issues pertains to the visualisation of results and their perception. One challenge is determining how to present the reconstruction, particularly in terms of materials. Often, researchers lack sufficient information to reconstruct the original materials and their colours accurately. In realistic reconstructions, this can be misleading, as the visual medium inherently suggests a specific material. If the entire reconstruction is rendered in a uniform material, it may also be misinterpreted as the correct finishing material. More broadly, the problems associated with the perception of reconstruction materials are addressed in the Critical Digital Model (CDM) concept, which proposes the use of abstract surface finishes derived from the architect's drawings (Apollonio et al., 2021). This approach is intended to highlight the lack of information about the correct materials and to adhere to the original vision of the project creator.

[22] See Chapter "1.5 Terminology" (p. 27-47) in: Cazzaro, Irene (2023) Digital 3D reconstruction as a research environment in art and architecture history: uncertainty classification and visualisation, [Dissertation thesis], Alma Mater Studiorum Università di Bologna. Dottorato di ricerca in Architettura e culture del progetto, 35 Ciclo.

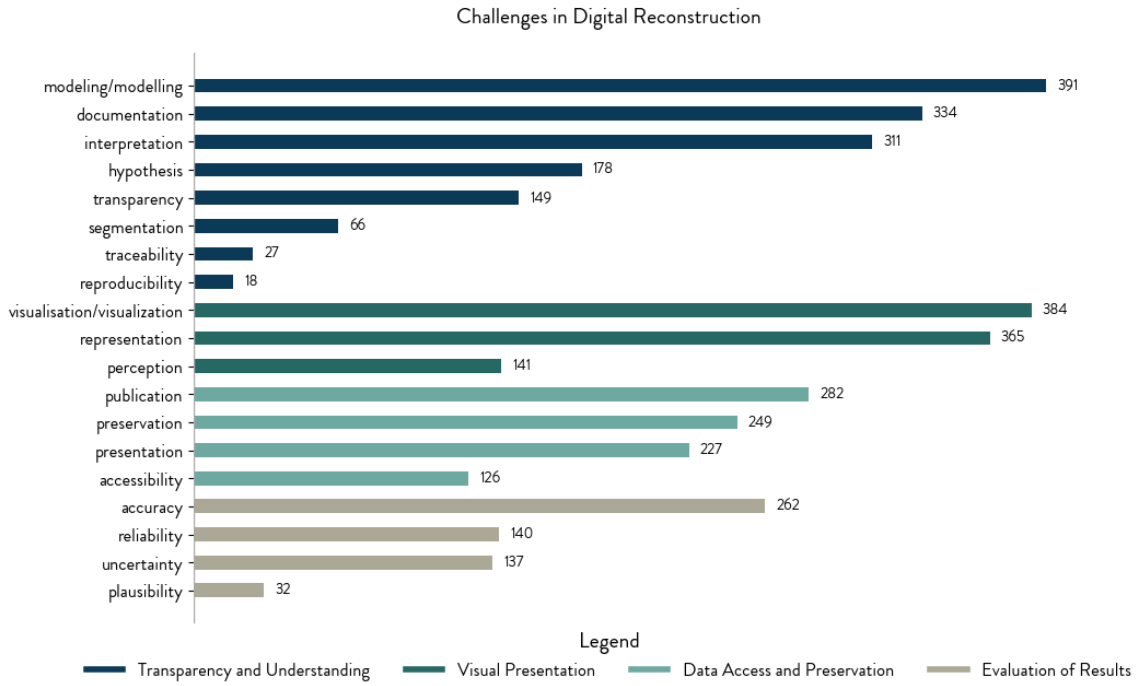

Fig. 5 Graph showing the number of occurrences of each term related to challenges in the field of digital restoration in the pool of publications surveyed.

The third group of issues concerns the publication and accessibility of data. The problem of preserving results and avoiding the creation of 'data graveyards' has already been recognised (Kuroczyński, 2017), leading to the establishment of infrastructures aimed at preventing this (Naujokat & Helas, 2024). This challenge is particularly relevant to digital libraries and archives, whose primary task is data preservation. However, these institutions are often not equipped to handle the preservation of 3D data. Addressing this concern is the main focus of the Community Standards for 3D Data Preservation (CS3DP) working group, which is developing guidelines to address this issue[23].

The final group of issues pertains to the evaluation of reconstruction results, focusing on terms related to the accuracy and uncertainty of the reconstruction. Researchers exploring this topic frequently introduce additional visualisations using false colours, where the colour symbolism reflects the level of uncertainty associated with each element (Apollonio, 2016; Cazzaro, 2023b; Hermon et al., 2006; Lengyel & Toulouse, 2017). However, the methods for evaluating these reconstructions remain non-standardized and are still under active investigation. The lack of a universally accepted evaluation framework makes it challenging to consistently assess and compare the reliability of different reconstructions, underscoring the need for further research and the development of standardised practices in this area.

The presented groups of issues highlight that in the field of digital 3D reconstruction, there are numerous factors that researchers must consider. However, not all research adequately addresses these concerns. Most researchers tend to focus on issues that align more closely with their specific study background or that are directly required by their project goals. Among the challenges, data preservation stands out as a significant problem. Scientific publications often lack links to datasets, making it challenging to find the necessary information. Even when publications refer to project websites, many of these sites are no longer accessible after the project ends, as

[23] More about the activities of CS3DP on their website: https://cs3dp.org/ (accessed 02 September 2024).

maintaining them requires ongoing funding that is typically unavailable post-project. Consequently, many researchers store data on personal drives without implementing proper preservation strategies, leading to outdated datasets that may become inaccessible as technology advances.

Given these challenges, it is crucial to approach digital 3D reconstruction not merely as a visualisation tool but as a multifaceted discipline that demands careful consideration of several key aspects:

1. **Visual Work**: Addressing perception issues and determining how to visualise findings accurately and effectively.
2. **Research Work**: Ensuring transparency by thoroughly documenting the reconstruction process in a way that allows others to replicate the work.
3. **Digital Work**: Making data accessible to others and implementing robust preservation strategies to ensure valuable work is not lost over time.
4. **Creative Work**: Recognizing the creative aspects of reconstruction, which involve copyright considerations and ensuring that all contributors receive appropriate credit.

By integrating these aspects into the research process, the field can advance more holistically, ensuring that digital 3D reconstructions are scientifically rigorous, sustainable, and properly credited.

C. International guidelines …

The research community has recognised, as analysis has shown, the issues and challenges within digital 3D reconstruction. However, the field still lacks clear, universal standards despite some attempts to establish them. It is important to remember that 3D models, as research tools, are not used exclusively in digital 3D reconstructions but across many disciplines. Therefore, to evaluate and refine guidelines for certain aspects of reconstruction, we must delve deeper into more universal standards. This chapter provides a summary of international guidelines, reflecting the collaborative efforts of researchers and professionals worldwide. The analysis of the guidelines presented was shared at the CHNT26 conference, held November 2-4, 2022, in Vienna, and published as an article in conference proceedings.[24] A summary of all extracted Principles from the documents analysed, relating to documentation and publications, has been compiled in Appendix 2.

C.1. … for Computer-based Visualisation of Cultural Heritage (CVCH)

Researchers of digital 3D reconstructions initially viewed them mainly as a tool to visualise their findings. As the analysis showed (see Chapter I. A.1), in the 1990s, the focus was more often on the visualisation process than on reconstruction. Therefore, the London Charter (LC), a guideline for computer-based visualisation of cultural heritage, is considered the official first guideline in this field.[25] The LC emphasises the need for interdisciplinary

[24] See more: Bajena, I. P., Kuroczyński, P. (2021). 'Challenges faced in documentation and publication of 3D reconstructions of Cultural Heritage. How to capture the process and share the data?', Proceedings of the 26th International Conference on Cultural Heritage and New Technologies, held in Vienna and online, November 2021. Heidelberg: Propylaeum.

[25] The first draft of the document was called "The London Charter for the Use of 3D Visualization in the Research and Communication of Cultural Heritage." Hugh Denard produced and circulated it in 2006, see: https://londoncharter.org/fileadmin/templates/main/docs/london_charter_1_en.pdf (accessed 27 August 2024). Currently, researchers are using version 2.1 of the document published in 2009, see: https://londoncharter.org/fileadmin/templates/main/docs/london_charter_2_1_en.pdf (accessed 27 August 2024).

collaboration. It defines principles in terms of implementation (Principle 1), methods and aims (Principle 2), sources (Principle 3), documentation (Principle 4), sustainability (Principle 5) and access (Principle 6). Implementing these principles demands intellectual and technical rigour, which allows the recognition of 3D reconstruction models as scholarly viable. Following the LC, the Seville Principles (SP), published in 2011, further elaborate on the application of LC to virtual archaeology, of which 3D reconstruction is an integral part. In addition to digitally bringing the excavated object back to life, the SP stipulates points specific to digital CH work that do not appear in the LC. Eight categories of principles are specific to SP: interdisciplinarity (Principle 1), purpose (Principle 2), complementarity (Principle 3), authenticity (Principle 4), historical rigour (Principle 5), efficiency (Principle 6), scientific transparency (Principle 7) and training and evaluation (Principle 8). The principles in the two said documents set out basic criteria for assessing the scholarly value of work related to the use of digital visualisations in the study of lost CH, emphasising the need to document the 3D model in terms, inter alia, of uncertainty, sources, authenticity, and historical rigour. Although these documents emphasise the importance of documentation in the computer visualisation of cultural heritage, which coincides with noting the highest occurrence rate in the analysed publications for the documentation problem, they give no examples of how to prepare the documentation, leaving the interpretation of these general principles open. Consequently, in object-oriented disciplines such as archaeology, art, and architectural history, accessibility and reusability of 3D datasets within 3D reconstruction are not ensured.

Addressing this desideratum, it was noted that it is necessary to provide the author's definition of documentation in the context of 3D digital reconstruction. Therefore, the author attempted to define this term, and it is understood as a collection of both digital and non-digital materials, including texts and multimedia (such as 3D models, 2D images, videos, presentations, etc.), that complement the 3D reconstruction model. This documentation includes additional information about the authenticity of the reconstruction, the hypotheses involved, the source materials and their analysis, as well as the archival, historical, archaeological, and architectural research conducted. It also encompasses other materials that support a comprehensive understanding of the reconstruction process.

Preparation of the documentation materials for 3D reconstruction can be challenging. For this reason, a significant part of the LC and the SP is dedicated to this concern. All those rules have been extracted and compiled in the Appendix 1. Each sub-point relates to a different aspect of the documentation (the Topic column in Appendix 2 - Tab. 25). Three main thematic groups have been identified (the Group column - Tab. 25):

- **Documentation Content**: Principles containing information on what the documentation should contain in addition to visual materials.
- **Visual Presentation**: Principles defining what kind of issues visual materials should address and how they should be prepared.
- **Documentation Output**: Principles defining how to combine all the collected materials into a homogeneous document that the reader can understand.

According to the said principles, **Documentation Content** should include a list of the source materials used (LC Principle 4.5) along with their paradata, which stands for critical analysis and interpretation of collected sources (LC Principle 4.6, SP Principle 4.5.1). In addition, there should be a description of the research methods (LC Principle 4.7, LC Principle 4.8) and a clear presentation of the assumptions and objectives of the research conducted (LC Principle 4.4, SP Principle 4.2). A good practice in terms of documentation is to adhere to the

intellectual property of the materials used (LC Principle 4.3) and to clarify specialist terminology (LC Principle 4.9).

Visual presentation should allow the identification of authentic elements of the object (LC Principle 4.10, SP Principle 4.4.2) and incorporate different levels of interpretation hypotheses through visual identification (SP Principle 4.4, SP Principle 4.4.3). Besides, if alternative reconstruction hypotheses arise, the authors should document them accordingly (SP Principle 4.4.1). The presentation of visual materials should also maintain historical rigour, which means that in the case of objects dated to multiple phases, the earlier phases should be presented. The focus on the ideal form of the reconstructed phase is not necessary (SP Principle 4.5.2). The object should always be presented in the context of its surroundings (SP Principle 4.5.3).

Documentation output should be prepared in a structured manner (LC Principle 3, LC Principle 4.1), ensuring complete research transparency (SP Principle 4.7.1) and making it possible to evaluate it in terms of historical or scholarly rigour (LC Principle 4.2). Documentation should be prepared based on relevant standards, ontologies and terminologies adopted in the target communities (LC Principle 4.12) using the most effective data formats (LC Principle 4.11).

Precise requirements are specified for the content of documentation or presentation of visual materials. Only general guidelines apply to documentation output. It is unclear what is meant by 'relevant standards' and whether such standards exist. Some rules can be interpreted subjectively, assuming, for example, that the transparency of the research will be ensured when a list of source materials is given. At the same time, another researcher may understand this as the need to describe the use of particular sources throughout the process. It is also difficult to identify the 'relevant communities' mentioned in LC Principle 4.12. The virtual archaeologists behind the development of the SP constitute one of such communities, but there are undoubtedly many others. The LC principles were intended as a general guide to critical historical visualisation practice. Individual subject communities were encouraged to develop specific guides for good practice in their respective fields. The following considerations should be treated as an interpretation from the perspective of the architectural community of practice to which the authors of this paper belong. Unlike virtual archaeologists, architects have not developed shared rules for conducting 3D reconstructions of architectural heritage. They mainly rely on LC and SP, which leads to the development of individual approaches for documentation.

C.2. … for data sharing

Neither LC nor SP addresses the preservation and publication of 3D data in any way. A 3D digital reconstruction is a collection of digital data and should adhere to the ethical standards of working with digital resources. The challenge lies in the fact that, unlike other digital assets, 3D models can be stored in a wide variety of formats, and a generalized standard for this has not yet been developed. Therefore, it is important to consider the general principles associated with digital data. Preservation involves not only the proper preparation of data but also making it accessible to others. A digital resource can be a valuable information asset, but only if it is properly prepared and published. In this context, publishing does not refer to a written scientific paper, but rather to the public release of a digital resource, which includes a 3D reconstruction along with the necessary documentation that enables its exploration, validation, and use by a specific target audience.

With the concept of publication defined, we can now examine the general principles for sharing digital data. The first is the 5-star Open Data Scheme (5OD) (Berners-Lee, 2012). This document presents five levels that can be achieved by publishing data on the web. Level one specifies only making the data available under an open licence,

while level five specifies full compliance with the Linked Open Data (LOD) concept. The LOD concept combines both the openness of the data and the referencing between them. Each level is linked to a condition concerning the data format and structure. The second document is the FAIR Guiding Principles for Scientific Data Management and Stewardship (FAIR) (Wilkinson et al., 2016). It emphasises findability, accessibility, interoperability, and reuse of published scientific data, focusing on ensuring machine readability of data. Collecting the guidelines of both documents, we can classify their principles into the following main thematic groups:

- **Findability**: principles of the visibility of published data on the web, its indexing, and the importance of metadata;
- **Accessibility**: principles of data access provision, making data easier to read, or using open technology solutions;
- **Interoperability**: principles of formatting data to allow for proper analysis, processing or storage;
- **Reuse**: principles of data preparation for use by independent users and how to describe it to reach potential audiences;
- **Preservation**: principles of ensuring the longevity of published content and preparing data for archiving.

The **findability** emphasises the need to use unique, global, and permanent identifiers for published data (FAIR Principle F1). This identifier is created automatically by most data repositories in the form of a web link called a Uniform Resource Identifier (URI). It is important to emphasise that every link on the Internet is a URI. Although it is expected to refer to any Internet address as a Uniform Resource Locator (URL), the latter is only part of a URI. It refers to the location of the resource for which one is searching. This means that placing a resource anywhere on the internet generates its URI. However, not every website guarantees its URI will be long-term and permanent. It is, therefore, essential to publish the data with services that provide a certain level of stability, such as Zenodo,[26] which guarantees the creation of a URI in the form of a Digital Object Identifier (DOI)[27] for each re-source published. An alternative method is to publish the data in established digital repositories within libraries and archives (SP 4.7.3) that guarantee permanent identifiers for each deposit. However, depositing 3D reconstructions in libraries or archives can be arduous due to the lack of accepted rules for archiving 3D models and the high costs of managing heavy data. Data findability is also affected by the richness of metadata (FAIR Principle 2). Metadata is information (usually textual) that provides context for published resources. Their primary division includes administrative, descriptive, and structural metadata. Administrative metadata for management contains information about the resource type, origin, and granted rights. Descriptive metadata are used for resource identification and contain information about the title, author, keywords, etc. Structural metadata includes information on components of the resource and its structure. Sometimes, administrative metadata are divided into rights management metadata (copyright and licensing information) and preservation metadata (provenance and technical specifications). The more metadata is provided during publication, the greater the chance that the target audience will find the resource. However, the metadata must be connected to the described resource through an identifier (FAIR Principle 3). This is because metadata are often stored in a separate file, so the data storage must provide a link based on the resource

[26] Zenodo is an open repository for research data from all fields, which is built on the rules of the FAIR Principles, available at: https://zenodo.org/ (accessed 23 February 2022).

[27] DOI is a unique number comprising a prefix and a suffix separated by a forward slash. More information is available at: https://www.doi.org/ (accessed 22 February 2022).

identifier. The published resource and its metadata should also be indexed in the search engine (FAIR Principle 4). Indexing involves capturing the essence of the published re-source and creating a record in the search engine database with phrases that act as keywords, enabling quick and efficient searches. No one will find data published in an unknown (not machine-readable) repository. Google's search engine automatically updates new web resources, which may not be sufficient for scholarly data. As in the case of paper-based publications, findability can also be enhanced through referencing other resources, which is crucial (5OD 5). This allows the data to be placed in a broader context by inserting hyperlinks in documentation materials.

The **accessibility** of published data can be understood as access to virtual surrogates of lost or in-accessible cultural heritage (LC Principle 6.1). Therefore, it is good practice to make scientific data that are not perceived as sensitive available under an open license (5OD Principle 1). However, the model can still be locked by the format used. Many 3D files are proprietary formats, meaning the way the data are encoded remains undisclosed and specific to particular software. Opening data stored in proprietary format requires commercial software. Therefore, sharing data in open, non-proprietary data exchange formats increases access to the file's contents (5OD Principle 3). For text files, it is the TXT format; for sheets, it is the CSV (Comma-separated values) format. 3D files do not have a single open format. The Wavefront (OBJ) format is used by 3D graphic designers, Stereo-lithography (STL) is used in 3D printing, and the Industry Foundation Classes (IFC) format is used by engineers and designers. At the same time, Initial Graphics Exchange Specification (IGES) is preferred in the mathematical recording of model geometry. Therefore, using open 3D file formats may not necessarily provide access to the data. Meeting this condition requires providing the open exploration of the 3D model using appropriate viewer technology in a web browser. Accessing data published within the model without the need for their downloading and without specialised software benefits a larger audience (LC Principle 6). Accessibility can also be understood as offering methods for retrieving data (FAIR Principle A1). Although most data are available on the web through publicly available protocols such as HTTP (s),[28] this does not mean the data are open and accessible. However, in the case of protected data, some form of contact (by phone, skype, email, etc.) should be provided to verify the terms of access (FAIR Principle A1.1). It is essential that the communication protocol is standardised, allows user authorisation (if required) (FAIR Principle A1.2) and is included in the metadata. However, due to rapid technological development, published data can quickly become outdated and useless. Preserving metadata can make it possible to locate the relevant contact to obtain information about the outdated resource (FAIR Principle A2). Therefore, it is necessary to ensure the long-term preservation of metadata storage by storing data in official archives or services like Zenodo.

The **interoperability** of the data allows for their interpretation by humans and processing by machines. The first step in this direction is to structure the published resources, for example, by collecting the data as an Excel file sheet (5OD Principle 2). A structure can be applied to the created 3D geometry using layers or grouping. Data and metadata should also be compiled in a shared knowledge representation language with broad applicability (FAIR Principle I1, 5OD Principle 4) using a vocabulary that meets FAIR principles (FAIR Principle I2). A knowledge language can encode information in a formal way in order for it to be readable by a machine. For scientific data, standardised knowledge representations are data models, including Resource Description Framework (RDF), Web Ontology Language (OWL) and JavaScript Object Notation for Linked Data (JSON LD). Each of these languages is a file format containing part or all of the documentation of the published resource (the use of the OWL file in the documentation was described with the knowledge graph method in the previous

[28] http stands for The Hypertext Transfer Protocol and is a fundamental method of fetching data on the Internet. The web page that the user sees in the browser is the result of loading the encoded files on the website server (html, css, etc.).

section). Data models also create terms, concepts, and controlled vocabulary databases. The definitions developed there are fixed; each concept is equipped with its unique identifier (URI), thus meeting FAIR requirements. An example of controlled vocabulary for use by the architectural community might be the Getty Art and Architecture Thesaurus (Getty AAT),[29] which defines concepts and terms related to architecture, art, and culture. Interoperability also means ensuring a broader context for the information provided, which can be achieved by referring to relevant external sources on the web (FAIR Principle I3).

The **reuse** of a published resource requires its appropriate adaptation. The 3D model should be available in an open format suitable for the target audience (FAIR Principle R1.3). If this format is not known, the most appropriate method of publication would be to make the model available to a web viewer, allowing a potential audience to examine the reconstruction (LC Principle 4.2). Although the publication should aim at a specific community, it is not always possible to predict the profile of the potential audience. Therefore, the published resource should be enriched with metadata about the resource and the context in which it was created (FAIR Principle R1). The published 3D model should also be accompanied by documentation showing the underlying inquiry process and technical development documentation transparently and understandably (SP Principle 4.7). This will allow the model to be used for validation purposes. Also, the usage of published data under legal conditions should be specified by stating the adequate license and indicating whether published data could be downloaded, changed, modified, or embedded (LC Principle 6.2, FAIR Principle R1.1). It is also good practice to describe the provenance of the data, the desired method of citation and the acknowledgement (or its lack), and the method of obtaining and processing it (FAIR Principle R1.2).

Preservation of reconstruction models requires ensuring the longevity of the data (LC Principle 5), storing it in appropriate data formats (LC Principle 5.2), and using the most reliable archiving tools (LC Principle 5.1). These questions are still open to interpretation. A significant problem is the rapid development of computer visualization technologies, making 3D formats used a few decades ago unusable. Tools for effectively archiving 3D files have not yet been developed or are not common standardised solutions. This remains a subject of heated discussion among 3D practitioners. However, promising data exchange formats are emerging that use metadata storage along with geometry information, such as IFC and CityGML (Geography Markup Language),[30] which have the potential for 3D file archiving in the CH domain.

An important contribution to best practices in 3D data preservation was made by the previously mentioned CS3DP working group (Moore et al., 2022). They claim that the publication of 3D models on the web requires a specific purpose and should be directed to the relevant audience (Golubiewski-Davis et al., 2021). Suppose those aspects of publication are not clear. In that case, a study of the lifecycle of a digital asset (see Fig. 6) can help with outlining the goals associated with publishing digital assets at five different stages:

1. Creation (about designing, capturing, and tagging)
2. Management (about reviewing, annotating and approving)
3. Distribution (about sharing and delivering)
4. Retrieval (about searching, finding and reusing)
5. Achieving (about preserving and expiring).

[29] https://www.getty.edu/research/tools/vocabularies/aat/ (accessed 05 January 2024).

[30] CityGML is an open standardised data model and exchange format to store digital 3D models of cities and landscapes.

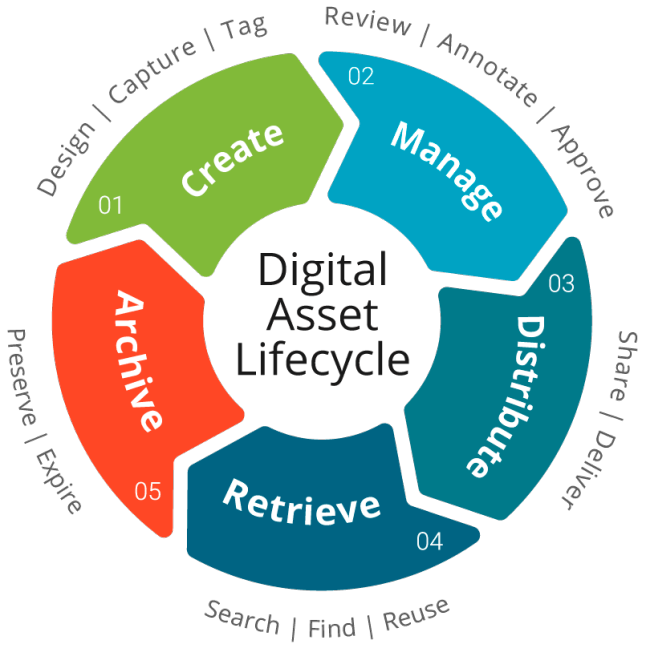

Fig. 6 Digital asset lifecycle chart (Filecamp, 2020).

Each stage can be documented in a different way depending on the type of digital medium involved (Blundell et al., 2021). The first two stages of the cycle are most often carried on local computers. Data is not shared externally, which often implies the lack of even basic documentation. Even if no further use of the models is planned, it is worth considering at **creation** phase (first stage of the cycle) a documentation of basic metadata set. It should contain information regarding the methods used to create the file, specifications in terms of geometry, materials and textures, source data used, as well as administrative data about the project and people involved in the creation of the model. For further **management** of the 3D file (the second stage of the cycle), the prepared documentation should be further enriched with an explanation of legal information, the specifics of the file in terms of its size, format, version, or time of creation, as well as technical information in terms of the scale of representation of the object, the number of vertices and faces. The next stages of the cycle are linked to the release of data to the public, which requires appropriate structuring of information and enrichment of the set with additional information. **Distribution and publication** of the model (the third stage of the cycle) requires the inclusion of a lot of non-3D-oriented metadata, the role of which is to fulfil FAIR's principals to achieve a high level of findability for published content (Wilkinson et al., 2016), as well as clarifying the legal policy on released asset. Often the publication of a digital model on the web is motivated by obtaining a quick and easily accessible visualisation of the created content, keeping metadata at a minimum. Relevant documentation for this stage also includes the available formats of the 3D model, the purpose for which it is created, information about the original file's location and provision of contact data to the creators, or text description that can convey a condensed portion of various information. A very similar documentation package should be included for **accessing and reusing** 3D models (fourth stage of the cycle). Refusing 3D models is often extremely challenging, so the metadata included should clearly express whether a particular resource is suitable for various purposes. This can be achieved by specifying possible derivatives based on presentation technologies (web-viewer, 3D printing, AR or VR, etc.), sharing the original native file format as well as the data exchange formats, and describing the methods of work, including the accuracy and resolution of the model. Additionally, the description of the copyrights should clarify the rules under which a 3D model can be reused. The final stage in the life of 3D models, **archiving**, requires additional effort regarding the metadata record itself. Most of the

information overlaps with the previous stages. The difference here is the need to use standardised solutions and permanent identifiers to ensure data preservation over a long time and the data readability by humans and machines (Golubiewski-Davis et al., 2021). Authority files, controlled vocabularies, and linked open data tools such as resource description framework (RDF) are used to achieve this.

The full lifecycle of a 3D digital resource can only come to a close if the institutions undertaking the reconstruction projects are equipped with the right tools for archiving 3D data. Most research institutions do not have this type of solution. As already mentioned, the responsibility for data archiving lies mainly with digital libraries and archives. However, researchers are not obliged to submit these data for archiving, and the archiving institutions may still be unprepared to accept 3D data. These challenges are being addressed in the German DFG 3D-Viewer project[31], which aims to provide an infrastructure for preserving 3D reconstructions. The author's collected experiences during this collaboration are described in more detail in Chapter IV.

C.3. … for research work

Digital 3D reconstruction must also meet the standards set by the academic community. While the principles of LC and SP are aligned in this direction, it is essential to highlight what characterises academic work, particularly in the context of historical research. Historical research is not an exact science, and it is not uncommon for erroneous hypotheses to emerge. Therefore, it is crucial to present one's reasoning transparently and to reference the materials that inform one's conclusions (UNESCO, 2018). The deliberate misrepresentation of history carries a significant responsibility, which is why research should always be conducted and presented in accordance with scientific ethics. Additionally, it is important to consider international guidelines for best practices in art and architectural history, which emphasise a moral obligation to share findings in a balanced and transparent manner (McClanan et al., 2014).

Working on digital reconstruction also requires the adoption and application of critical analysis methods grounded in a solid foundation of architectural historical knowledge (Kuyper, 1991). Critical analysis plays a pivotal role in evaluating sources, shaping the reconstruction's vision, and ultimately imbuing the 3D model with scientific value. By rigorously assessing the evidence and carefully reconstructing historical objects, researchers can ensure that their digital models serve as accurate, reliable tools for further study and education.

Given the criteria outlined above, any scholarly work related to reconstructions must include a thorough critical analysis, a comprehensive bibliographic list of materials, and a detailed description of the methods employed. These elements are crucial for ensuring transparency, allowing others to evaluate the validity of the work, and facilitating replication or further research. While the methods of presenting this information may sometimes be unconventional (see Chapter III), they must nonetheless adhere to rigorous academic standards. Incorporating these practices not only strengthens the credibility of the reconstruction but also contributes to the broader academic discourse by providing a clear and accessible record of the research process. This approach ensures that the scholarly community can engage with, critique, and build upon the work in meaningful ways.

[31] The project "DFG-Viewer 3D - Infrastructure for digital 3D reconstructions" endeavours to establish an infrastructure facilitating the straightforward publication of 3D models within the expansive realm of digital reconstructions in the context of CH. The project is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation), DFG-LIS, Förderkennzeichen: MU 4040/5-1. See online: https://dfg-viewer.de (accessed 02 September 2024).

C.4. … for creative work

Digital 3D reconstruction is also a creative work. Creators must have skills related to the field of digital arts. Authors who produce such reconstructions have rights to their creations and should be conscious of their ownership. However, institutions that host or publish these works do not always appropriately credit the authors, which can lead to a lack of recognition for their contributions. This makes it essential for creators to understand and assert their rights, especially in licensing, when they choose to share their work with a broader audience.[32]

Any publication of a reconstitution involves a clear statement of the rights of use of the published resource, without whose declination we may consider the resource to have been abandoned by the author. Although this information does not need to be in the documentation of the reconstruction process itself, it must appear every time the files themselves are made publicly available. Licensing defines how others can use, share, and adapt these digital models. Many creators are unaware of the different licenses available, which can lead to unintended uses of their work.

The core licensing package for creative works is set out in Creative Commons (CC)[33]. Creative Commons licenses are standardised tools that help authors of creative works share their creations on their terms. These licenses range from very permissive options that allow users to adapt and share the work freely to more restrictive licenses that limit commercial use or modifications. The six core types of Creative Commons licenses include:

- **CC BY (Attribution)**: Allows users to distribute, remix, and build upon the work, even for commercial purposes, as long as credit is given to the original creator.
- **CC BY-SA (Attribution-ShareAlike)**: Similar to CC BY, but any derivative works must be shared under the same license.
- **CC BY-NC (Attribution-NonCommercial)**: Allows the work to be used and adapted for non-commercial purposes only, with credit given to the original creator.
- **CC BY-NC-SA (Attribution-NonCommercial-ShareAlike)**: Similar to CC BY-NC, but derivative works must be shared under the same license.
- **CC BY-ND (Attribution-NoDerivatives)**: Allows the work to be distributed unchanged, including for commercial purposes, as long as attribution is provided.
- **CC BY-NC-ND (Attribution-NonCommercial-NoDerivatives)**: The most restrictive license, allowing only the sharing of unaltered versions of the work for non-commercial purposes, with credit to the original creator.

In addition to these licenses, Creative Commons also provides a tool called **CC0 (Public Domain Dedication)**. This tool allows creators to dedicate their work to the public domain, relinquishing all copyright claims and permitting unrestricted use of the work without any need for attribution.

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[32] Flynn, T. (2022). *An Introduction to Creative Commons Licenses*. Sketchfab, see online: https://sketchfab.com/blogs/community/an-introduction-to-creative-commons-licenses/ (accessed 04 September 2024).

[33] Creative Commons, see online: https://creativecommons.org/ (accessed 04 September 2024).

The choice of license depends on the creator's goals. For example, if the aim is to maximise exposure while retaining control over how the work is used, a license like *CC BY* might be most suitable. Conversely, if the creator wants to prevent commercial exploitation of the work, they might choose *CC BY-NC*. Importantly, once a Creative Commons license is applied, it cannot be revoked, meaning anyone who receives the work may continue to use it under the original license, even if the creator later stops distributing the work.

This framework has become increasingly important for creators working on digital 3D models, especially within the cultural heritage sector, where the preservation and reuse of cultural assets are central concerns. The European Commission's recent recommendation for a common European data space for cultural heritage highlights the need for digitisation, accessibility, and reuse of cultural assets such as 3D models. The recommendation encourages the use of Creative Commons licenses as a way to standardise the sharing and reuse of cultural heritage across Europe.[34] This move underscores the role of CC licenses in ensuring that 3D reconstructions and other digital works remain accessible while protecting the rights of their creators.

[34] Vézina, B. (2021). *Creative Commons Welcomes EC Recommendation on Common European Data Space for Cultural Heritage*. In: Creative Commons, see online: https://creativecommons.org/2021/11/19/creative-commons-welcomes-ec-recommendation-on-common-european-data-space-for-cultural-heritage/ (accessed 04 September 2024).

II. Documentation of the Scientific-Creative Process

Having established the definition of digital 3D reconstruction and the main challenges in the field, we can now explore the practices used in documentation by the scientific community. Documentation of work is one of the central themes in studied publications (see Chapter I. B.), serving as a record of methodologies and as a critical component in ensuring the transparency, reproducibility, and academic credibility of virtual reconstructions. Reconstruction projects often differ significantly from one another, with varying objectives, datasets, and interpretative approaches, which creates a complex landscape for methodological consistency. The lack of precise classification and standardisation for documentation methods and tools makes researchers hesitant to adopt existing options, often prompting them to develop their own frameworks. This fragmentation can hinder cross-project comparisons, limit the ability to verify results and slow the establishment of best practices across the discipline.

However, the choice of appropriate documentation methods is not merely a technical concern—it has broader implications for how virtual reconstructions are perceived and utilised across multiple fields. Incorrect or inconsistent documentation can distort certain aspects of a model, affecting its credibility, interpretative accuracy, and usability in historical analysis, archaeological reconstructions, and cultural heritage studies (Apollonio et al., 2021). By establishing general criteria for documentation that align with scientific standards, researchers can enhance the interoperability of their projects and strengthen interdisciplinary collaborations.

The impact of structured documentation extends beyond individual reconstructions, supporting communication and methodological consistency among professionals from diverse fields, including art and architectural historians, archaeologists, architects, computer graphics specialists, and IT experts. A well-defined systemisation of working methods can bridge disciplinary gaps by providing a common framework for assessing the validity of reconstructions, integrating different types of data sources, and refining the interpretation of historical artefacts and spaces. Furthermore, standardised documentation practices would improve the long-term accessibility and preservation of digital models, ensuring their usability for future research, educational purposes, and public engagement. By fostering a shared methodological approach, documentation can be crucial in transforming 3D reconstructions from isolated projects into a collectively developed body of knowledge, ultimately enhancing their contribution to the broader scientific and cultural discourse.

A. Framework of digital 3D reconstruction process

The primary factor in choosing a work methodology is accurately identifying the object of interest and the scope of the research. Depending on the project assumptions, the methodology can completely alter and demand a different level of professional expertise. This initial identification should involve defining the scale of the site and its current condition. The scope of the survey should consider which phase or phases of the object are being reconstructed, whether the reconstruction will focus on the exterior, the interior, or both, whether only the geometry of the building or also the finishing materials will be included, and finally, whether the object will be presented within a broader context. Although the LC provides clear guidelines for conducting such studies, not every project can meet these requirements. To differentiate the steps based on the project's initial assumptions, 21 publications describing methodologies of digital reconstruction were selected. These studies were then categorised by attributes such as the scale of the object, the reconstructed phase, and the object's current condition (see Tab. 2).

In terms of object scale, a distinction is made between site, building complex, building, monument, building element, statue, and artefact. The scale type was classified as various if the article did not specify a particular object scale for the methodology presented. The selection of the reconstructed phase was based solely on whether the reconstruction referred to the past, present, or conceptual phase. The classification was marked as various if the methodology addressed at least two of these phases. The most detailed classification was applied to the current state of the site. If the object was well-preserved and the reconstruction primarily served as documentation, it was classified as preserved. If the object was well-preserved but showed significant damage and was no longer in use, leading to progressive degradation, it was classified as damaged. If a significant portion of the structure was destroyed but the remains were uncovered and recognisable without archaeological work, it was classified as ruined. If archaeological work was required to identify the site, the classification was excavated. In cases where the structure had not been preserved and no archaeological work was undertaken, yet rehabilitation occurred, the classification was destroyed. If the reconstruction focused on the conceptual phase of the site, based solely on design drawings, it was classified as unbuilt. When the methodology applied to several of these states, the classification was marked as various.

Tab. 2 Classification of the themes of the digital 3D reconstructions in the selected publications in terms of the scale, current state, and reconstructed phase of the object of interest.

Publication	Object Scale	Reconstructed Phase	Object Condition
Martens et al. (2002)	Building	Past (2nd half of the 19th century)	Destroyed
Grün et al. (2004)	Statue	Past	Destroyed
Hermon (2005)	Site	Past	Excavated site
Murphy et al. (2009)	Building	Present	Preserved
Boeykens et al. (2012)	Building	Past	Destroyed
Apollonio et al. (2013)	Building	Past	Destroyed; Unbuilt
Gomes et al. (2014)	Artefact; Statue	Present	Preserved
Demetrescu (2015)	Site; Building	Past	Excavated site; Ruined
Apollonio (2016)	Building	Past; Concept	Destroyed
Mezzino et al. (2016)	Building	Present	Damaged
Apollonio (2018)	Various	Past; Present	Various
Giovannini (2018)	Monument	Past (roman times)	Excavated site
Schäfer (2018)	Various	Past	Various
Yang et al. (2020)	Building Component	Present	Preserved
Apollonio et al. (2021)	Building	Concept	Unbuilt
Grellert et al. (2021)	Site; Buildings Complex	4 Past Phases	Excavated site
Kuroczynski et al. (2021)	Building	Past (1873)	Destroyed
Pietroni et al. (2021)	Site; Building; Artefact	Past	Excavated site
Apollonio et al. (2023)	Building	Concept; Past	Unbuilt; Destroyed
Garofalo et al. (2023)	Buildings Complex	Past (18th century)	Ruined
Argasinski et al. (2023)	Building	Present	Damaged
Bajena et al. (2023)	Building	Past	Destroyed
Kuroczynski et al. (2023)	Various	Past; Concept	Destroyed; Unbuilt; Excavated Site

Some of the publications present case studies and focus on presenting a general methodology but including them in this compilation allows for a more thorough verification of the necessary steps in scientific reconstruction. In the case of publications that focus on describing methodology, one can see a variation in the focus on other process elements.

Hermon (2005) presents the methodology of virtual reconstitution as integrating knowledge from four different sources. The main one is the documentation of the object's remains, the second one is the comparative study to other studies and data. Only the third in order is historical research and finally, one's own imagination, i.e. filling in the gaps with one's own knowledge and experience (Fig. 7). The most important point of this methodology, however, is the evaluation of the work's reliability level. Hermon provides a mathematical formula which, based on dividing a virtual model into smaller units and assigning them a subjective reliability value, allows the scientific value of a reconstruction to be estimated based on fuzzy logic.

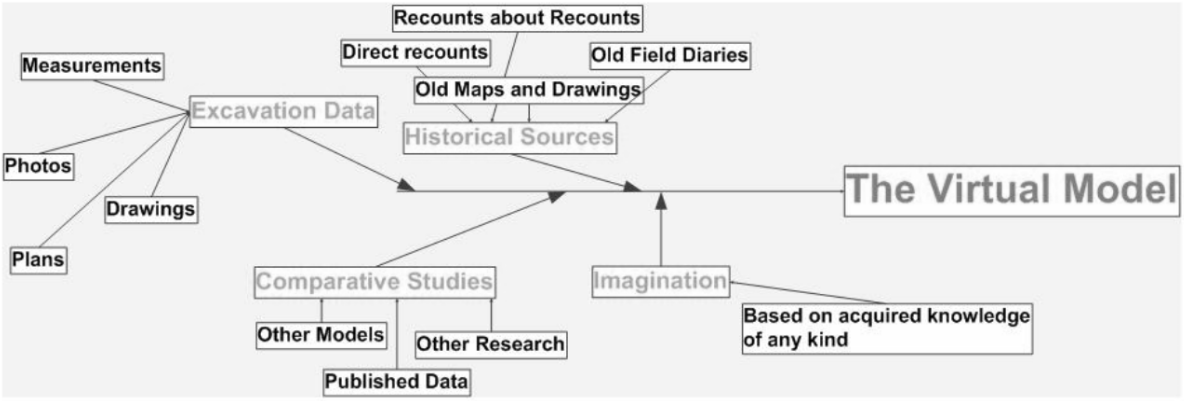


Fig. 7 Diagram illustrating the sequence of steps in creating a virtual 3D model of the reconstruction of the building based on an archaeological site (Hermon, 2005).

Murphy (2009) developed a digital reconstruction method based on Building Information Modelling (BIM) for historic buildings – HBIM (Fig. 8). Although its methodology is adapted to preserved objects and is based on the automatic collection of data in the object by laser scanning or photogrammetry, it presents for the first time the idea of preparing project documentation in the 3D model itself. Murphy suggests creating a library of parametric architectural elements of the object and connecting additional parameters to them, including historical materials. This allows the entire project to be stored and managed from a single file.

Demetrescu (2015) developed the Extended Matrix method, which originated in archaeology. Its core element is adjusting the granularity of the semantic division of the object into Stratigraphic Units, both real and virtual (Fig. 9). Each unit is then assigned an ID (e.g., SU1, SU2, USV/S 100), allowing for machine processing of the data. Sets of properties are assigned to each unit, enabling the identification of the basis for a given reconstruction, as well as the unit's dimension, material, or pose in the object, and its relationship to other units. This is the first methodology that attempts to represent the process in the form of an algorithmic diagram, which, with sufficient effort, can be made machine-readable.

Apollonio (2016) developed a methodology focused on visualising the level of uncertainty in hypothetical reconstructions. He demonstrated that, to create such visualisations, it is essential to segment the object into parts based on the available sources (Fig. 10). This segmentation allows the resulting 3D model to be divided into semantic components, to which uncertainty information can be assigned and visually represented.

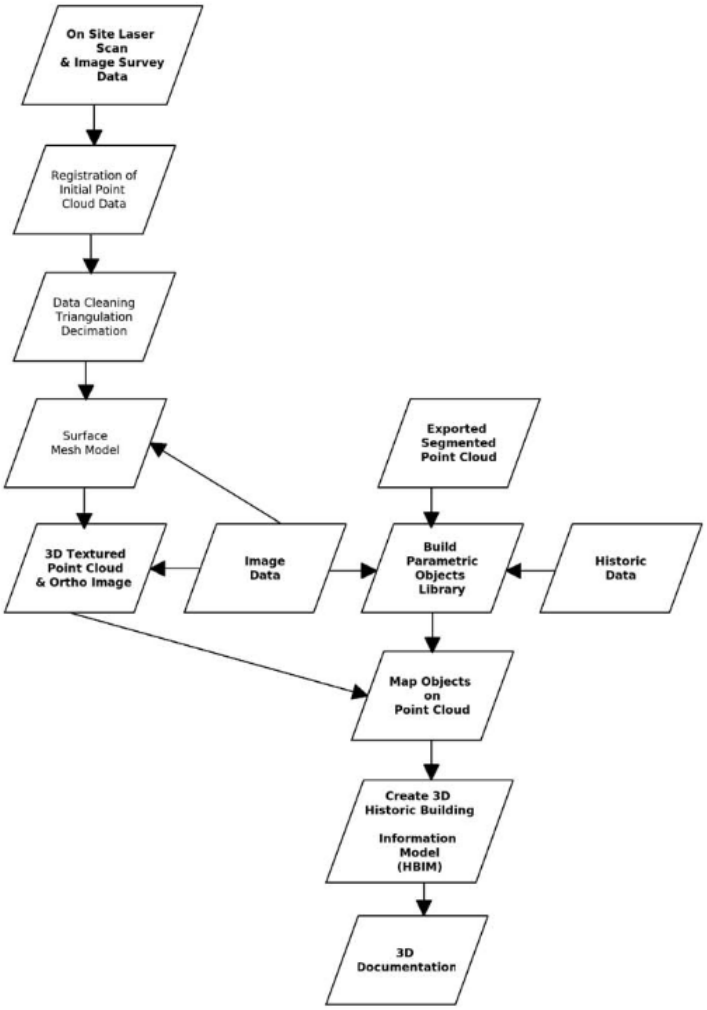


Fig. 8 Diagram of HBIM development from point cloud acquisition to informative 3D model (Murphy, 2009).

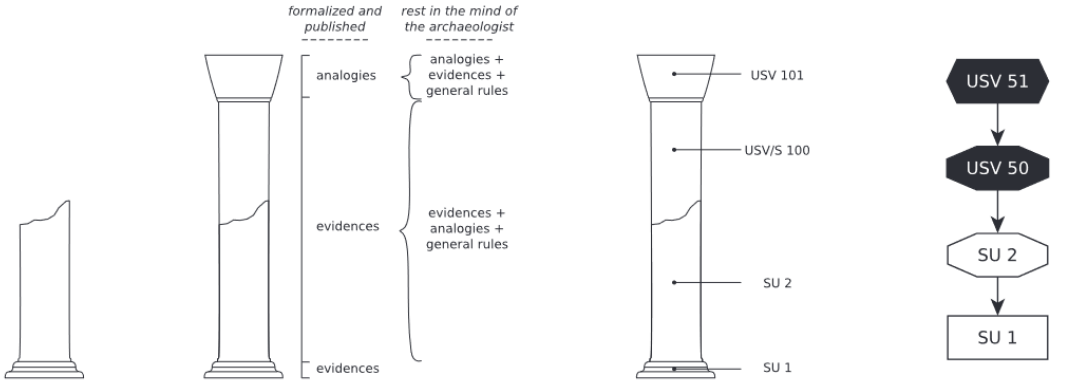


Fig. 9 Diagram showing the steps to determine the granularity of the 3D model in order to obtain the Extended Matrix (Demetrescu, 2015).

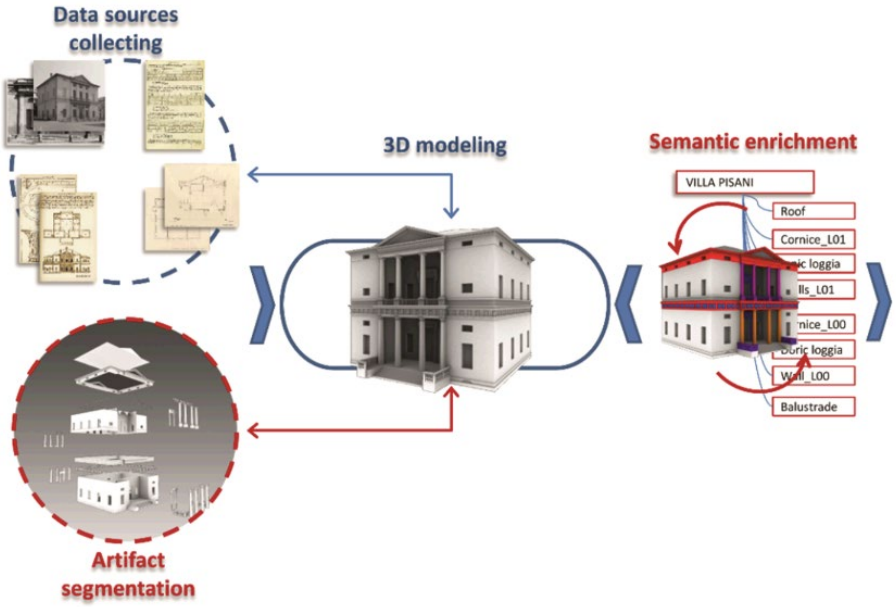


Fig. 10 Diagram showing the operational pipeline for a process of hypothetical digital 3D reconstructions (Apollonio, 2016).

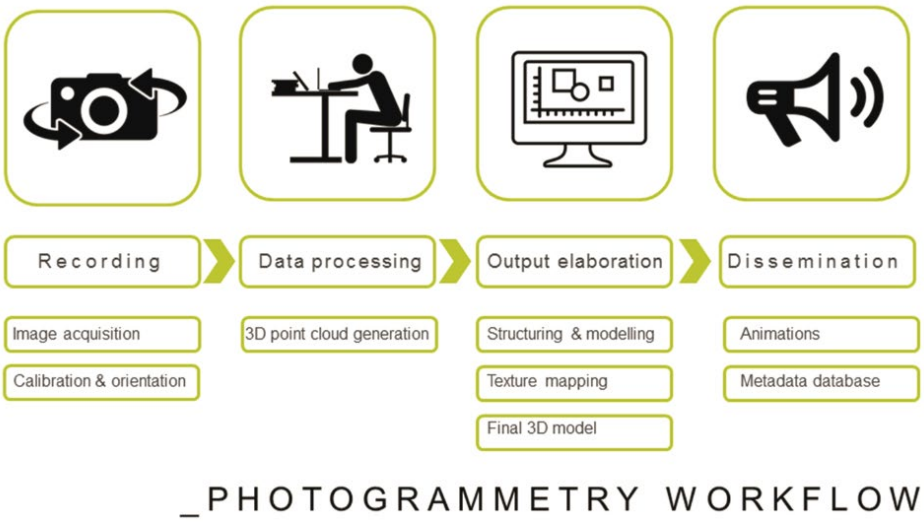


Fig. 11 is a Diagram illustrating the methodology for working with endangered monuments, based on HBIM and photogrammetry, with consideration for future dissemination of results (Mezzino, 2016).

Mezzino (2016) introduced a workflow for endangered monuments, building on an extension of the HBIM methodology (Fig. 11). The process begins with photogrammetry, followed by segmentation and structuring of the object. It culminates in the creation of a 3D model and associated library elements. The key difference from Murphy's methodology is the use of the 3D model for dissemination through various derivatives, such as animations and visualisations, and their application in education.

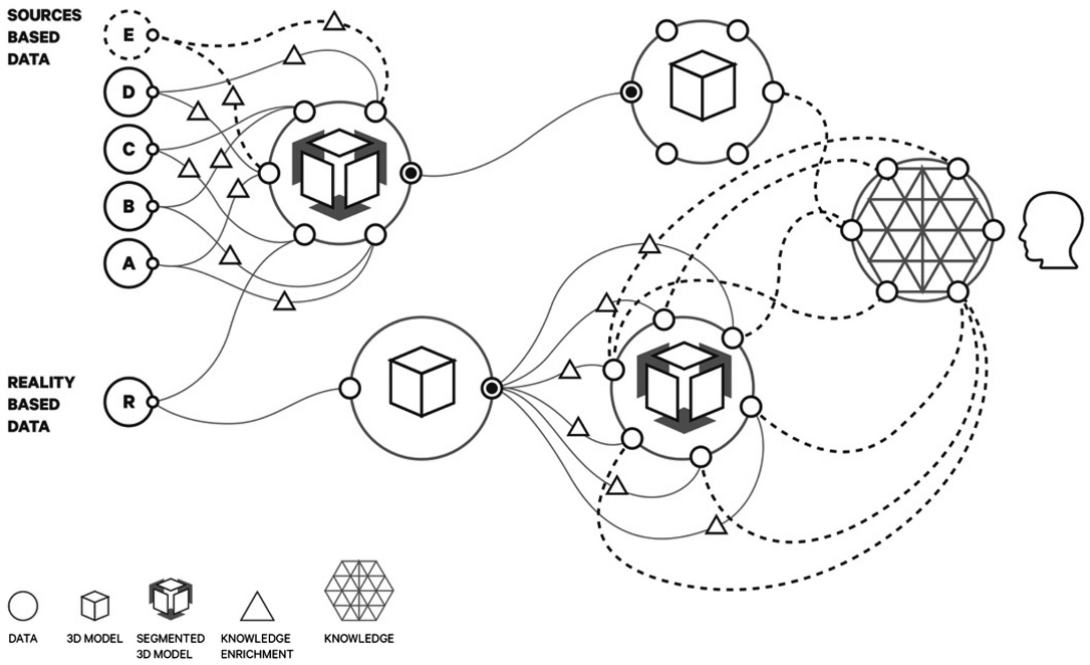


Fig. 12 Diagram illustrating the integrated workflow for the digital 3D reconstruction process (Apollonio et al., 2018).

Apollonio et al. (2018) presented an extended version of their previous methodology, addressing the challenge of archiving 3D models of hypothetical reconstructions (Fig. 12). The proposed workflow for archiving focuses on four key elements: documentation of the working method, the quality and assumed properties of the reconstruction, the semantic structure of the 3D model, and the process of formalisation and knowledge capture. The methodology is designed to equally integrate knowledge from both reality-based and source-based data. It also assumes that reconstruction can convey knowledge only when the model is segmented and enriched with interpretive human input. In this context, the role of the archive is not just to capture a single 3D reconstruction but to document the entire body of knowledge about the object, extending beyond the 3D model itself.

Yang et al. (2020) developed a 3D modelling workflow for cultural heritage sites to support heritage site management (Fig. 12). In the initial phase, the workflow focuses on integrating survey-based data of the object with available documentation to create parametric components. The methodology outlines three stages in creating a 3D model: a geometric model representing the object's structure, a semantic model divided into components based on the documentation, and an information model enriched with additional knowledge assigned to individual components. Although this methodology focuses more on technological solutions, it aligns with the objectives presented in Apollonio et al.'s (2018) methodology.

Apollonio et al. (2021) presented a rather unique methodological approach in the form of the Critical Digital Model (CDM) concept. Its primary application is for never-realised projects. The methodology's key idea is to closely follow the original designer's intent in terms of the object's geometry and the materials used. To achieve this, the methodology suggests using original design drawings to extract textures and apply them to the surface of the 3D model. This way, the source material is automatically integrated with the 3D model. Additionally, the model conveys an abstract vision of the materials, avoiding the issue of misleading visualisations that might suggest anecdotal information about materials and colours (see Fig. 14).

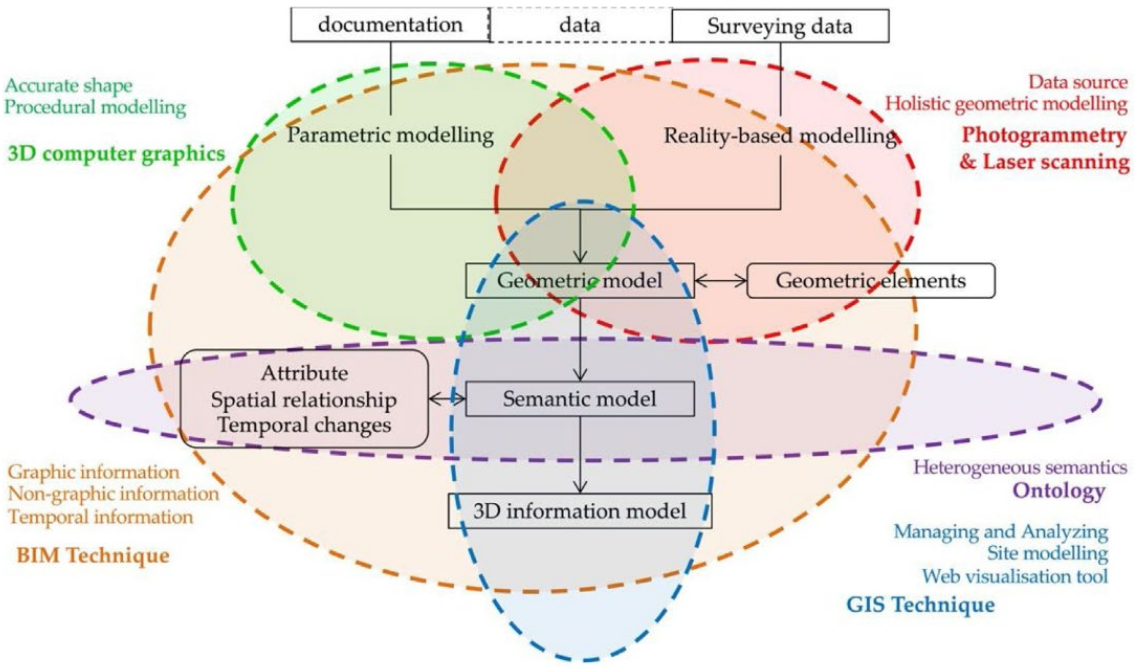


Fig. 13 Diagram illustrating the overall 3D modelling methodology for built heritage with combined techniques (Yang et al., 2020).

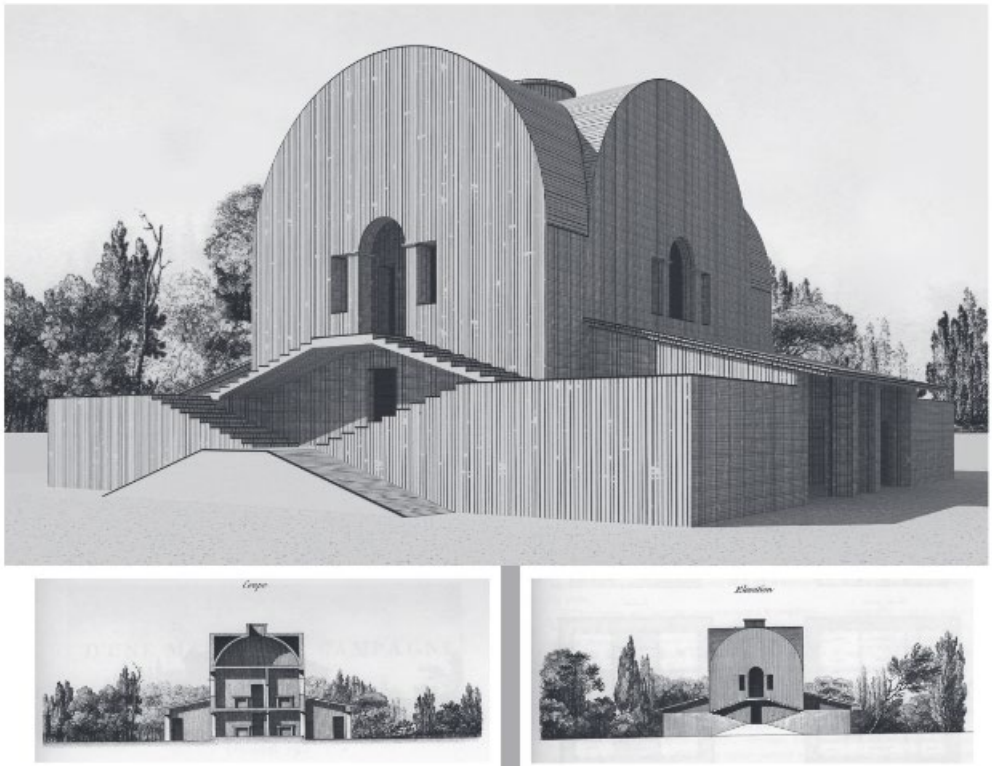


Fig. 14 An example of the application of CDM methodology in practice. The top visualisation shows a CDM reconstruction model with materials and visualisation style corresponding to the design drawings. The lower drawings are the original design materials developed by Claude Nicolas Ledoux for the Maison d'un employè project. Source: Cité idéale de Chaux, Tome 1, Pl. 17 (Apollonio et al., 2021).

Building on the concept of creating knowledge models, a methodology was developed to meet the needs of higher education and study lost architectural heritage based on historical sources. This approach aims to

produce 3D digital reconstruction models that are referable, transparent, and easily accessible.[35] The methodology was developed in collaboration with Prof. Kuroczyński, culminating in the experience with digital reconstructions at the Hochschule Mainz – University of Applied Sciences in Germany. It emphasises the need to structure the work, both in collecting and analysing source material and in the modelling and documentation of reconstructions (Fig. 15). The preparation of documentation and the publication of results and 3D data in an online repository are also listed as separate steps. This last step is most often overlooked in previous methodologies, resulting in a lack of access to the 3D files and consequently preventing verification of the model geometry and the entire reconstruction.

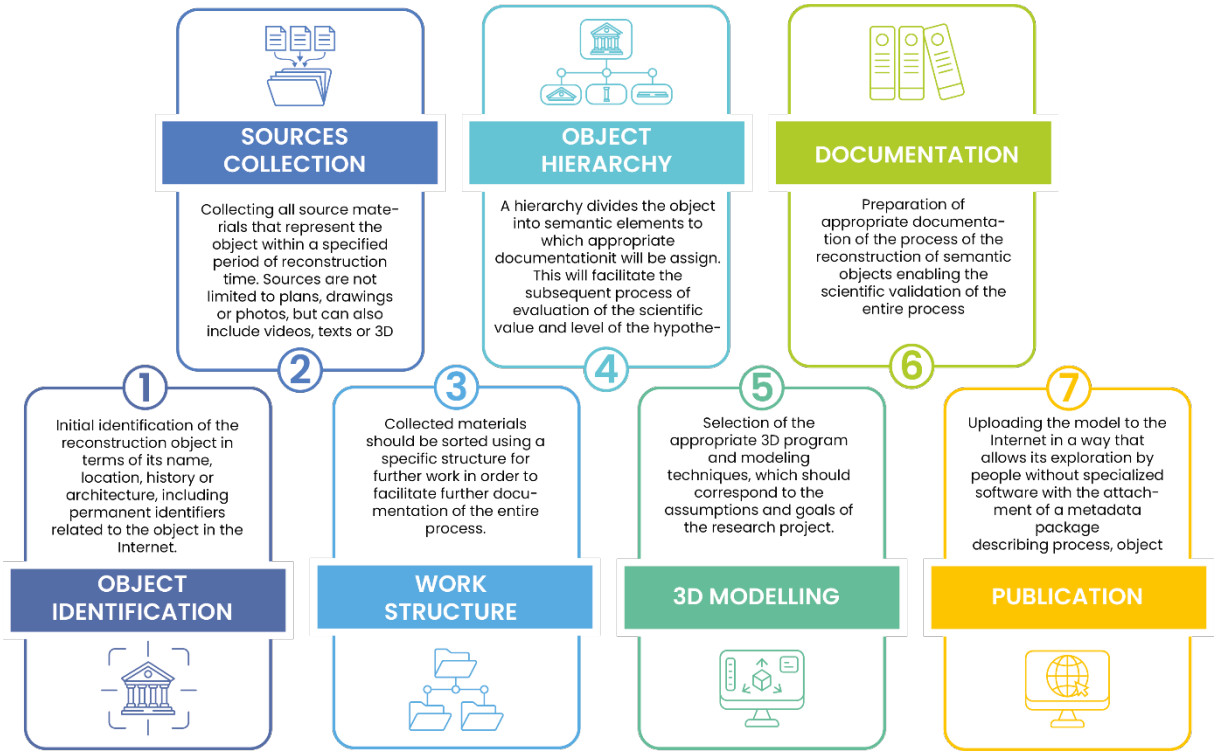


Fig. 15 Visual representation of the methodology for source-based hypothetical digital 3D reconstruction of lost architectural heritage applied in teaching in higher education (© AI MAINZ/Igor Bajena, 2022).

The most recent methodology, which evolved directly from the previous one, is the Scientific Reference Model – SRM (Kuroczyński, Apollonio, et al., 2023). It is the result of a collaboration between Hochschule Mainz - University of Applied Sciences and the University of Bologna, drawing on the research from two doctoral theses—one focused on the documentation and publication of digital reconstruction and the other on evaluating the results of work in terms of uncertainty, prepared by Irene Cazzaro under the joint supervision of Prof.

[35] The methodology was presented at the conference '*(IN)TANGIBLE HERITAGE(S) - A conference on technology, culture and design*' at the University of Kent, Cantebury (UK) on 15-17 June 2022. Details can be read in the paper developed for the conference proceedings: Igor Bajena, Piotr Kuroczyński: Development of the Methodology and Infrastructure for digital 3D Reconstruction, in: Proceedings of *(IN)TANGIBLE HERITAGE(S) A conference on technology, culture and design*, Canterbury 2022, AMPS conference proceedings series, ISSN 2398–9467, 2023, p. 72–83, online: https://amps-research.com/wp-content/uploads/2023/02/Amps-Proceedings-Series_29.2.pdf (accessed 20 September 2024).

Fabrizio Apollonio and Prof. Piotr Kuroczyński.[36] The methodology also references the CDM method as one of the potential development paths for SRM.

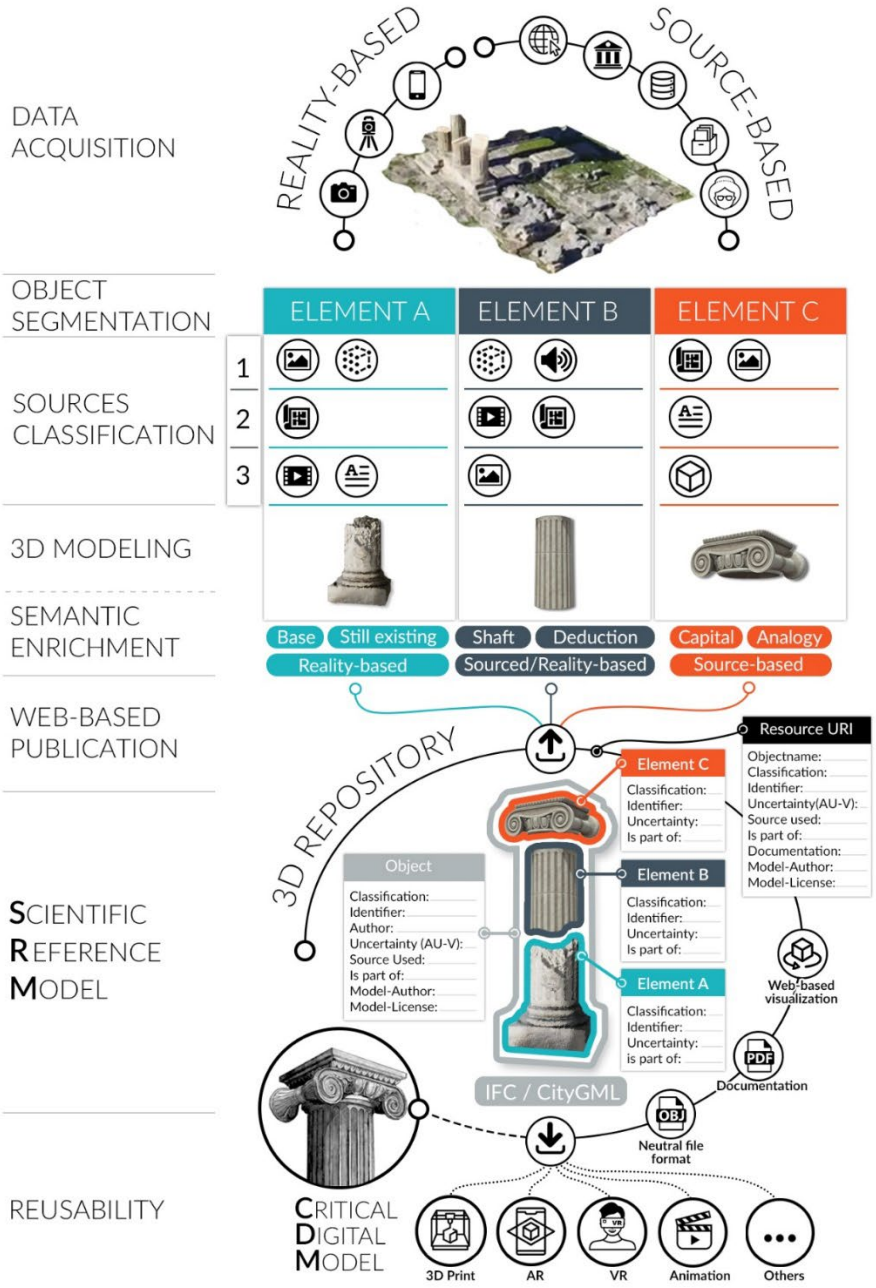


Fig. 16 An overview of the data-driven SRM methodology and its derivatives. (AI MAINZ/Piotr Kuroczyński and Igor Bajena, 2023, CC BY-NC-SA).

[36] The methodology was presented by Prof. Kuroczyński at the 29th CIPA2023 Symposium '*Documenting, Understanding, Preserving Cultural Heritage: Humanities and Digital technologies for Shaping the Future*' in Florence on 25-30 June 2023. For more on the SRM methodology, see the article in the ISPRS: Kuroczyński et al. (2023): SCIENTIFIC REFERENCE MODEL - DEFINING STANDARDS, METHODOLOGY AND IMPLEMENTATION OF SERIOUS 3D MODELS IN ARCHAEOLOGY, ART AND ARCHITECTURAL HISTORY, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLVIII-M-2-2023, 895-902, online: https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-895-2023.

Tab. 3 *Comparing the steps of the universal methodology with the methodologies described in the selected publications (continuation on the next page)*

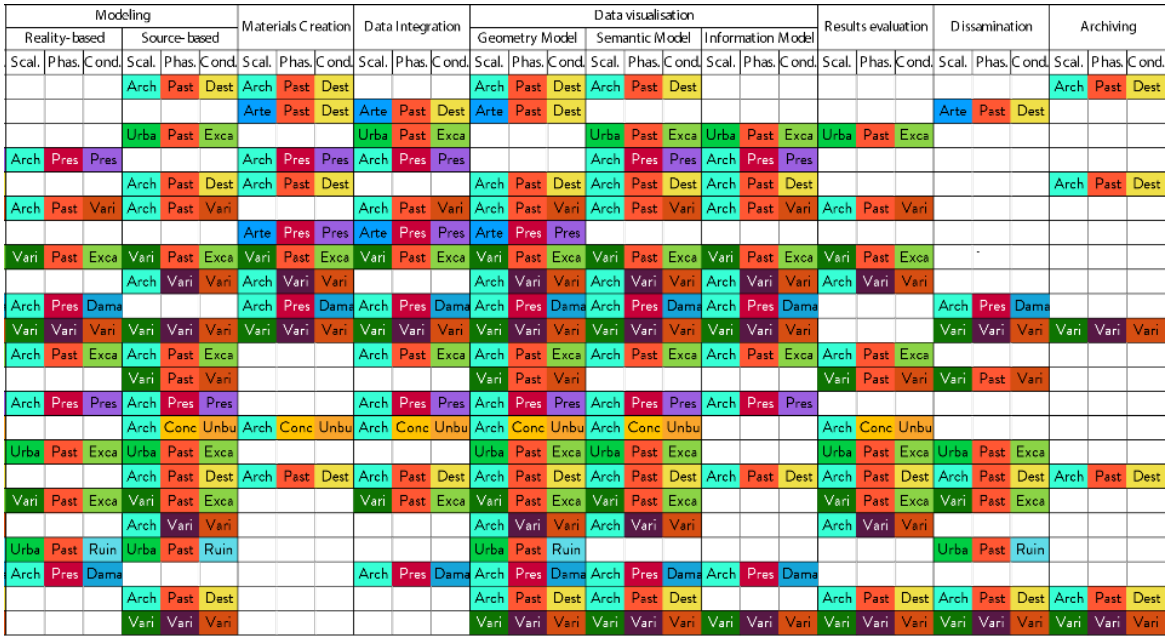
	Data Acquisition			Data Processing			Data Collection			Data Analysis									Data Structuring			Data Interpretation			Documentation		
										Historical Study			Comperative Study			Knowledge Gaps											
	Scal.	Phas.	Cond.	Scal.	Phas.	Cond.	Scal.	Phas.	Cond.	Scal.	Phas.	Cond.	Scal.	Phas.	Cond.	Scal.	Phas.	Cond.	Scal.	Phas.	Cond.	Scal.	Phas.	Cond.	Scal.	Phas.	Cond.
Martens et al. (2002)							Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest						
Grün et al. (2004)				Arte	Past	Dest	Arte	Past	Dest				Arte	Past	Dest	Arte	Past	Dest									
Hermon (2005)	Urba	Past	Exca				Urba	Past	Exca	Urba	Past	Exca	Urba	Past	Exca	Urba	Past	Exca	Urba	Past	Exca	Urba	Past	Exca			
Murphy et al. (2009)	Arch	Pres	Pres	Arch	Pres	Pres													Arch	Pres	Pres				Arch	Pres	Pres
Boeykens et al. (2012)							Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest				Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest
Apollonio et al. (2013)	Arch	Past	Vari	Arch	Past	Vari	Arch	Past	Vari	Arch	Past	Vari	Arch	Past	Vari	Arch	Past	Vari	Arch	Past	Vari	Arch	Past	Vari	Arch	Past	Vari
Gomes et al. (2014)	Arte	Pres	Pres	Arte	Pres	Pres																					
Demetrescu (2015)	Vari	Past	Exca				Vari	Past	Exca							Vari	Past	Exca	Vari	Past	Exca	Vari	Past	Exca	Vari	Past	Exca
Apollonio (2016)	Arch	Vari	Vari				Arch	Vari	Vari	Arch	Vari	Vari	Arch	Vari	Vari	Arch	Vari	Vari	Arch	Vari	Vari	Arch	Vari	Vari			
Mezzino et al. (2016)	Arch	Pres	Dama	Arch	Pres	Dama	Arch	Pres	Dama										Arch	Pres	Dama				Arch	Pres	Dama
Apollonio (2018)	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari
Giovannini (2018)	Arch	Past	Exca				Arch	Past	Exca	Arch	Past	Exca	Arch	Past	Exca	Arch	Past	Exca	Arch	Past	Exca	Arch	Past	Exca	Arch	Past	Exca
Schäfer (2018)	Vari	Past	Vari	Vari	Past	Vari	Vari	Past	Vari							Vari	Past	Vari				Vari	Past	Vari			
Yang et al. (2020)	Arch	Pres	Pres				Arch	Pres	Pres										Arch	Pres	Pres				Arch	Pres	Pres
Apollonio et al. (2021)							Arch	Conc	Unbu	Arch	Conc	Unbu	Arch	Conc	Unbu	Arch	Conc	Unbu	Arch	Conc	Unbu	Arch	Conc	Unbu	Arch	Conc	Unbu
Grellert et al. (2021)	Urba	Past	Exca				Urba	Past	Exca	Urba	Past	Exca	Urba	Past	Exca	Urba	Past	Exca	Urba	Past	Exca	Urba	Past	Exca	Urba	Past	Exca
Kuroczynski et al. (2021)							Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest
Pietroni et al. (2021)	Vari	Past	Exca	Vari	Past	Exca	Vari	Past	Exca	Vari	Past	Exca				Vari	Past	Exca	Vari	Past	Exca	Vari	Past	Exca	Vari	Past	Exca
Apollonio et al. (2023)							Arch	Vari	Vari	Arch	Vari	Vari	Arch	Vari	Vari	Arch	Vari	Vari	Arch	Vari	Vari	Arch	Vari	Vari	Arch	Vari	Vari
Garofalo et al. (2023)	Urba	Past	Ruin	Urba	Past	Ruin	Urba	Past	Ruin	Urba	Past	Ruin				Urba	Past	Ruin				Urba	Past	Ruin	Urba	Past	Ruin
Argasinski et al. (2023)	Arch	Pres	Dama	Arch	Pres	Dama													Arch	Pres	Dama				Arch	Pres	Dama
Bajena et al. (2023)							Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest	Arch	Past	Dest
Kuroczynski et al. (2023)	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari	Vari

SCALE		PHASE		CONDITION			
Artefact	Arte	Concept	Conc	Preserved	Pres	Destroyed	Dest
Architectural	Arch	Past	Past	Damaged	Dama	Unbuilt	Unbu
Urban	Urba	Present	Pres	Ruined	Ruin	Various	Vari
Various	Vari	Various	Vari	Excavated	Exca		

Like the previous methodologies, SRM emphasises the segmentation of an object as the foundation for documenting the reconstruction process. It also encourages using methods applied in heritage management and information assignment to semantic parts of the model. However, its most significant feature is the publication of 3D models in an online repository using open file formats that support model segmentation and metadata storage (see Fig. 16). This ensures documentation of knowledge and the assessment of the cognitive value of a referential 3D model, produced in accordance with the fundamental principles of the scientific and subject-specific methods, as in the case of the CDM. Therefore, SRM constitutes an applicable methodology aimed at offering heritage scholars a potentially useful three-dimensional reference tool.

Although each of the cited methodologies focuses on different aspects, there are evident commonalities. To identify these, a list of steps was compiled based on the methodologies, considering the use of both reality-based and source-based data, and including all possible stages. This resulted in a universal list of steps for digital reconstructions, as follows:

1. Data acquisition (for reality-based data);
2. Data processing (for reality-based data);
3. Data collection (for source-based data);
4. Data analysis (for both data type);
    a. Historical study;
    b. Comparative study;
    c. Knowledge gaps identification;
5. Data structuring (work organisation; sources classification; object segmentation, etc.);
6. Data interpretation;



7. Documentation;
8. Modelling;
    a. Reality-based model;
    b. Source-based model;
9. Materials creation;
10. Data integration (source-based and reality-based);
11. Data visualisation;
    a. Geometry model (pure geometry with or without materials);
    b. Semantic model (model divided on semantic segments/units);
    c. Information model (model with information attached to semantic segments/units);
12. Results evaluation (how uncertain is the model?)
13. Dissemination (how data will be shared with audience?)
14. Archiving (is there any strategy for preservation of data?)

Not all of these steps will be present in every reconstruction. Therefore, selected publications describing the working methodologies were compared against this list of steps. By illustrating the typology of different methods—object scale (Scal.), reconstructed phase (Phas.), and object condition (Cond.)—it becomes clear which steps are common across various types and which are more specific to certain types of reconstruction (see Tab. 3).

The compilation revealed several key points crucial for recognising hypothetical digital reconstructions as scientific. The first is object segmentation. In each of the methodologies related to documentation, segmentation into semantic units appears to be a necessary foundation. This decision has significant consequences and determines the level of detail in the study. Without segmentation, it is impossible to directly attribute sources to the specific part of the model they correspond to—at least not in a suitable way for machine processing.

Self-evaluation of results seems to be an inherent component of hypothetical reconstructions. This can be done by calculating reliability values (Hermon, 2005) or visualising different levels of uncertainty (Fabrizio I. Apollonio, 2016). Regardless of the method, this critical process of assessing the model's reliability is an essential indicator in the scientific community, reflecting the quality of the work.

However, the approach to digital 3D models as knowledge carriers' worth preserving seems to have been neglected. Only one in four publications mention archiving files, and only one in five mentions making archived data publicly available. This is the main issue with 3D models. Despite recognition of their value and the development of methods to evaluate and verify reconstructions, the data itself is often not made accessible to researchers. This trend is slowly changing with increasing investment in infrastructure for the publication and documentation of 3D models, as discussed further in Chapter III.

Before publication, however, it is crucial to collect data on the process to determine the model's value. It is important to remember that 3D digital reconstruction consists of two components. The first is analysing and interpreting sources, identifying gaps in knowledge, and filling them with hypotheses. The second component involves selecting the tools and techniques that enable the creation of a virtual model simulating the past. The following two chapters will focus on documenting these aspects.

B. The process of scientific analysis and interpretation

The greatest value of digital 3D reconstructions lies in the knowledge gathered about an object, identifying gaps in that knowledge, and presenting a research hypothesis to fill those gaps. It is a creative process, sometimes referred to as reverse engineering, as it involves breaking down the object into smaller units to understand its function (De Luca et al., 2007). Scientific analysis and interpretation begin once the object has been segmented into independent units.

This analysis should start with historical sources, which need to be segregated, classified, and dated to ensure they correspond to the site's reconstructed phase. It is also essential to determine which segments of the model are represented in the source. The form, reliability, and quality of the source are crucial considerations. For instance, historical photographs are generally more reliable than hand-drawn plans, and architectural drawings are more dependable than artistic representations, where reality can be distorted. The condition and legibility of the source also matter, as well as its accuracy (Apollonio et al., 2017).

Checking the consistency of sources is important, as plans can sometimes contradict each other. In such cases, a hierarchy of importance must be established, and a primary source selected as the priority for interpretation (Mader-Kratky et al., 2023). Gaps in the sources can be filled using analogies from other buildings related to the one being reconstructed, whether by common architect, location, time of construction, or architectural style. Based on this information, assumptions for modelling should be formulated.

The actual form of buildings, or even hand-drawn architectural drawings, often contains irregularities and imperfections (Dell'Unto et al., 2013). However, in 3D modelling, we often strive for ideal forms, using repeated elements and modules to streamline the work. A lack of information about materials and colours can also be an issue. In large-scale projects like urban reconstructions, details are often reduced or omitted, and the form of buildings within the city structure can be highly symbolic (Kuroczyński et al., 2023). All these elements must be clearly defined in the project documentation to ensure transparency.

Therefore, we can identify three main aspects of documentation at this stage: the classification of sources, the interpretation of the object's form, and the assumptions made for the digital reconstruction modelling. Each of these aspects influences the transparency of the research and should be mandatory in the documentation of digital reconstruction projects.

B.1. Transparency of interpretative decisions

Ensuring research transparency requires that all the factors listed above are documented in an accessible manner, providing modellers with easy access to source analysis and interpretation. In practice, many decisions and interpretations occur during the 3D modelling process, requiring a documentation strategy that evolves alongside the model's development. This can be challenging, so researchers examined the methods to document decisions and classify sources.

The first method involves a simple tabulation of information, for instance, in Excel. This approach is beneficial for evaluating sources and recording their origins (see Fig. 17). It is also adequate for compiling evaluations of reconstructed model segments (see Fig. 18, Fig. 19). At the same time, this method is easy to implement, tables can quickly become very large, making them difficult to manage. Additionally, incorporating images into the table can be problematic, as they often do not fit well into the format and may slow down the document. Internal name coding by introducing identification numbers is often necessary to make working with the table more efficient. However, this can also be a limitation. The documentation may become challenging to understand without additional information explaining the identification system. This method is typically more suitable in the early stages of a project or when the complexity of the object being studied is low.

Filename	Type	Purpose	Location	Floor	Date	Year	Group	Author	Source	Comment
p0001	plan	heating	right side building	1	unknown	unknown	1	unknown	JMAP	
p0002	plan	heating	right side building	1	unknown	unknown	1	unknown	JMAP	
p0003	plan	heating	right side building	1	unknown	unknown	2	Leopold Ehrmann	JMAP	
p0004	plan	heating	right side building	0	unknown	unknown	2	Leopold Ehrmann	JMAP	
p0005	section	heating	side buildings	N/A	unknown	unknown	2	Leopold Ehrmann	JMAP	
p0006	plan	heating	right side building	-1	September	1937	3	Saniterma	JMAP	
p0007	plan	heating	right side building	0	September	1937	3	Saniterma	JMAP	
p0008	plan	heating	right side building	1	September	1937	3	Saniterma	JMAP	
p0009	plan	heating	right side building	2	September	1937	3	Saniterma	JMAP	
p0010	plan	heating	right side building	-1	unknown	unknown	N/A	Saniterma	JMAP	
p0011	plan	heating	center	0	19 January	1896	N/A	unknown	JMAP	
p0012	plan	heating	center	1	18 January	unknown	N/A	Wilhelm Bröckner	JMAP	
p0013	plan	heating	center	0	18 January	unknown	N/A	Wilhelm Bröckner	JMAP	
p0014	plan	heating	center	-1	18 January	unknown	N/A	Wilhelm Bröckner	JMAP	
p0015	plan	unknown	left side building	2	unknown	unknown	4	unknown	JMAP	AB, CD

Fig. 17 Example of an extract from a source classification table in Excel (Boeykens et al., 2012)

Model Part	Level of Certainty	Source Data	Thumbnail
58 French Street	Very High	The building survives.	
Canute's Palace	Medium	The building survives in ruins in places to roof level allowing the creation of a ground plan and partial elevation. Reports suggest it was a house but later converted into a warehouse pre-1454.	

Fig. 18 Example of an extract from the uncertainty assessment table with a preview of the visualisation of the reconstructed segments of the 3D model of a medieval town (Jones, 2012).

Structuring the information to be collected also requires that a concept for organising the data and the factors under investigation be drawn up in advance. Not every project is executed with the same degree of complexity. The initial project assumptions and collected material can be organised as a graph or mind map (Markiewicz, 2024). Mind maps are an effective method of documentation, representing information as a collection of nodes (or bubbles) connected by edges (or lines). These edges indicate the relationships between different entities. Within each node, we can include various types of information such as source materials, analogies, people, visualisations of reconstructions, and many other elements. This is a handy technique to capture the links between sources, especially in the early stages of a project. It also allows all aspects related to the project to be captured beyond the mere reconstruction of the building, such as the historical, cultural, or social context (Fig. 20).

Element	Uncertainty Level					Relev.	Volume
	Geom.	Constr. Syst.	Surf.	Pos.	Average		
Stadera's tower	2	2	2	1	1.75 (≈25%)	1	630 m^3
Other buildings	5.5	5.5	5.5	3.5	5 (≈71%)	0.25	48,926 m^3
Mercanzia residence	2	2	3.5	1	2.125 (≈30%)	1	7558 m^3
Vanini's house	3.5	3.5	5.5	2	3.625 (≈51%)	1	211 m^3
Money changer's lodge	3.5	5.5	5.5	2	4.125 (≈59%)	1	5640 m^3
Fish's stone and chicken coop	3.5	3.5	3.5	3.5	3.5 (≈50%)	1	32 m^3
Domus Bladorum (+Mazzanti house and Region's Palace)	2	2	5.5	1	2.625 (≈37%)	1	41,016 m^3
Gardello's tower	2	2	2	1	1.65 (≈24%)	1	2775 m^3
Capitello	1	1	1	1	1 (≈14%)	1	20 m^3
Madonna Verona's fountain	1	1	1	1	1 (≈14%)	1	45 m^3
Ancient column	1	1	1	3.5	1.625 (≈23%)	1	7 m^3

Fig. 19 Example of a from a table with uncertainty calculations of reconstructed segments of the 3D model of the medieval Piazza delle Erbe (Apollonio et al., 2024).

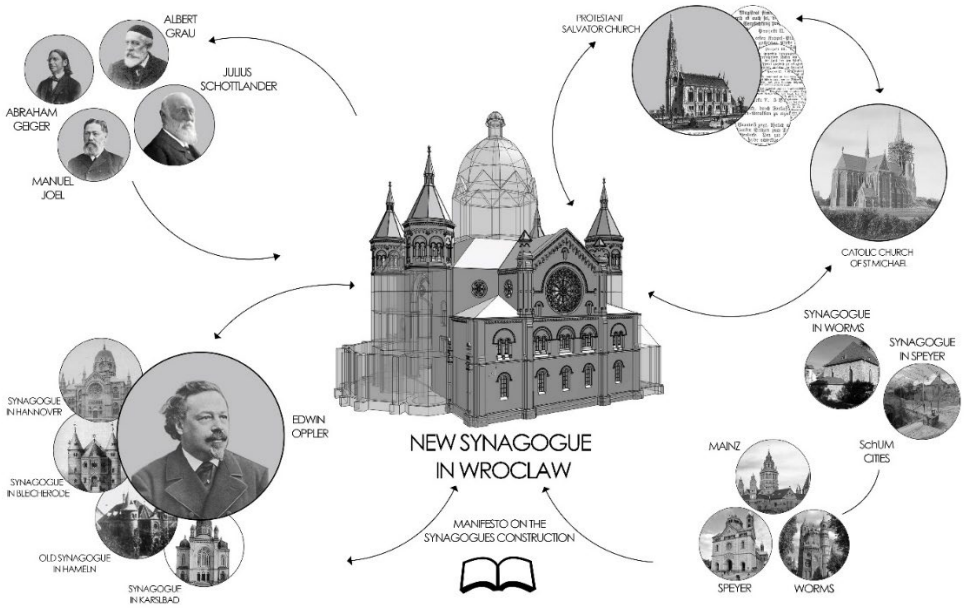


Fig. 20 Map of the project of the New Synagogue Reconstruction in Wroclaw (Poland) with a mind map, showing the main areas of interest in the project (©AI MAINZ, 2018).

A mind map can also evolve into a higher form of documentation called a knowledge graph by specifying the type of relationship each edge represents. The knowledge graph is a structured schema composed of data entities connected to predefined types of interrelationships (Soto-Martin et al., 2020). It requires the creation of a documentation scheme that visualises the information recorded in the reconstruction process. In this way, the documentation reveals relations between the reconstructed object, the iconographic sources, the research activities concerning the object (including the creation of paradata or 3D models), the actors involved in the process and the types of relations between them (Fig. 21). The information documented is grouped into so-called triples. A triple can be understood as a descriptive sentence of human language that consists of three parts: a subject, a predicate, and an object (Kiryakov, 2015). A predicate defines the relationship between a subject and an object; it performs a function like a verb in a sentence. An example of a triple could be the following sentence:

Edwin Opler *was architect of* **New Synagogue in Wroclaw**.

In this case, **Edwin Oppler** represents the subject, the **New Synagogue in Wroclaw** represents the object, and *was architect of* represents the predicate. Creating triples from raw data forms a relational graph, thus providing a context that allows the stored data to be considered a knowledge resource.

Similarly, knowledge can be stored using relational databases (Giovannini, 2018) or virtual research environments (Kuroczyński, 2017). The main difference is that graphs are a visual form of knowledge transfer, easily readable by humans, whereas databases are primarily machine-readable. While humans can read databases, navigating them often requires prior training. A significant challenge lies in creating such environments, which demands expertise in computer techniques for managing scientific data. Currently, there is a lack of ready-made solutions that work out of the box without requiring information technology and programming skills. Even when researchers use these systems, they are often stored locally on computers, and if networked, access is typically restricted, requiring contact with the authors to gain permission.

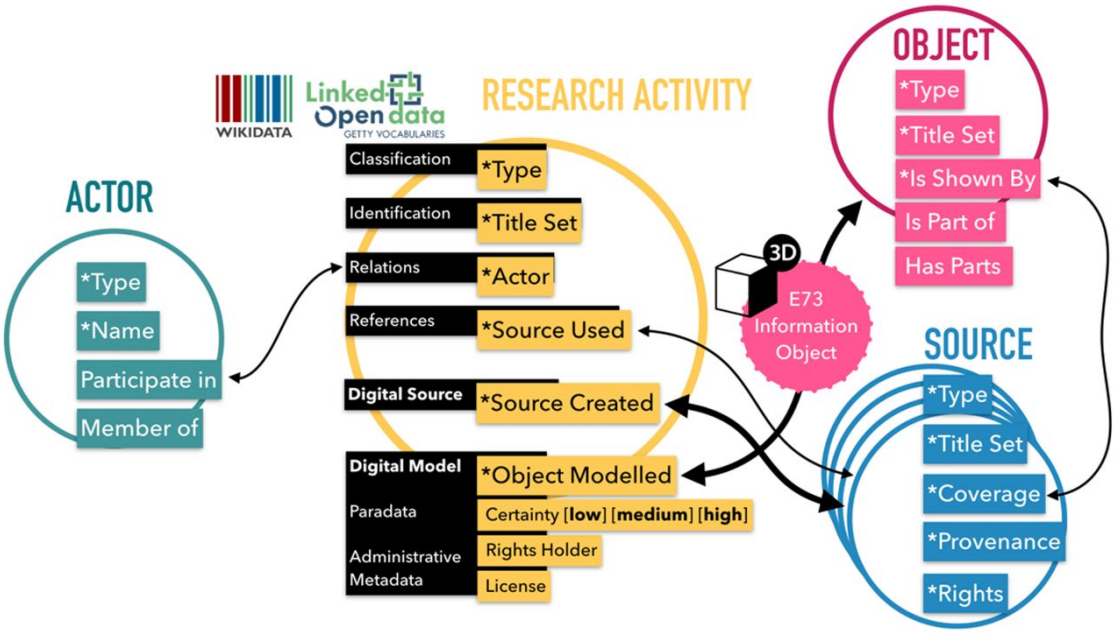


Fig. 21 Scheme of documentation based on a knowledge graph, illustrating possible properties assigned to different kinds of entities in the reconstruction project: actor, research activity, object, and source (Kuroczyński et al., 2021).

The most practical approach to documenting decisions made during reconstruction is through sketches created while interpreting the data. Reconstruction is a creative process that requires visualising a given form to explore

suitable solutions. While the drawing may not always represent reality accurately, it can help the modeller understand the geometry and function of the reconstructed space. This form of documentation seems to be undervalued in the scientific community, and it is rare to find publications that present the thought process through sketches, as the 3D model often takes over the role of visualising solutions. This is particularly interesting, especially among architects trained to create through drawing. The increasing digitisation has led to sketches being sidelined as a research presentation. However, these sketches, with their human touch, can reveal the most about the creative thought process. Interestingly, the form of drawings on paper works best in meetings with specialists overseeing the historical accuracy of the reconstruction, such as archaeologists or art historians. By overlaying a corrective layer, the specialist can visually present his or her objections while at the same time creating documentation that can be passed on to those modelling (see Fig. 22).

Face-to-face meetings with specialists are increasingly replacing online meetings on platforms such as Teams or Zoom.[37] Interestingly, these meetings also rely on graphical methods and quick sketches to communicate reconstruction adjustments (Fig. 23). Although this form of communication may not be meticulously crafted, capturing these adjustments through screenshots provides a simple way to document the history of changes to the model. Though often not shared, this type of raw data can contain a substantial amount of valuable knowledge. This quick and convenient form of documentation is convenient, although it may not necessarily be understood by those not directly involved in the project.

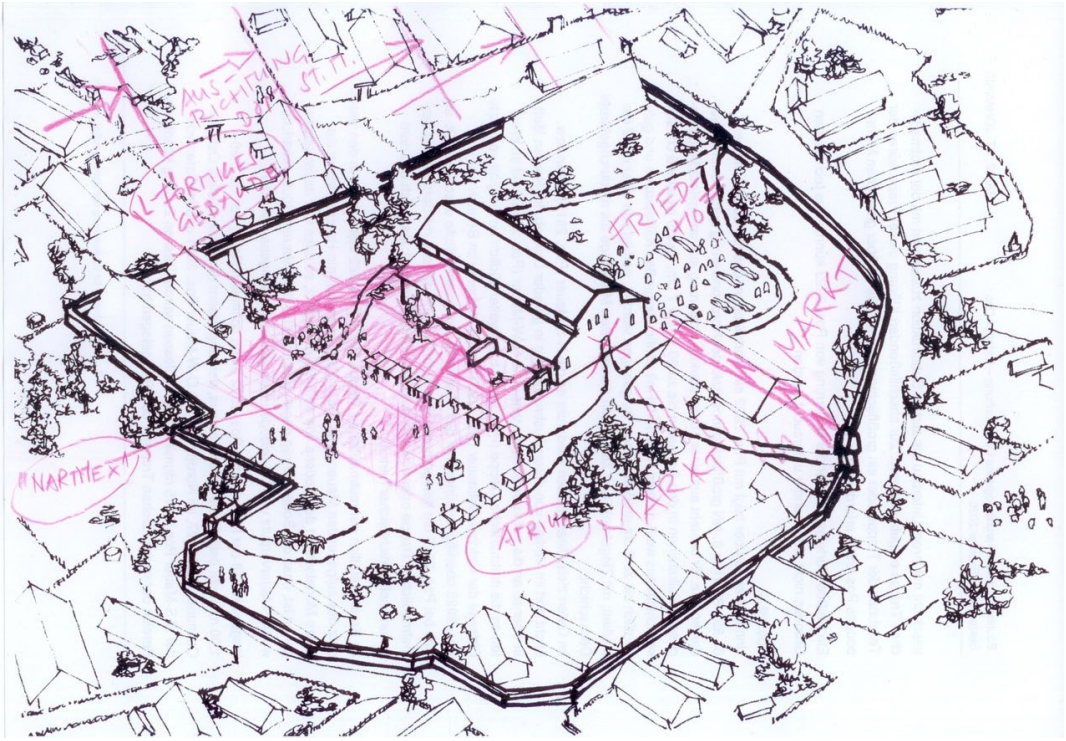


Fig. 22 Handwritten sketch showing the proposed reconstruction of the St. Johannis church in Mainz (black) with corrections by archaeologist Dr. Gudio Faccani (pink) (AI MAINZ, 2020).

[37] According to statistics, since the beginning of the Coronavirus pandemic in 2019, the number of Teams users has increased 16 times and the number of people claiming to use Zoom at work has increased more than four times. See: https://www.demandsage.com/microsoft-teams-statistics/ & https://backlinko.com/zoom-users (accessed 22 September 2024).

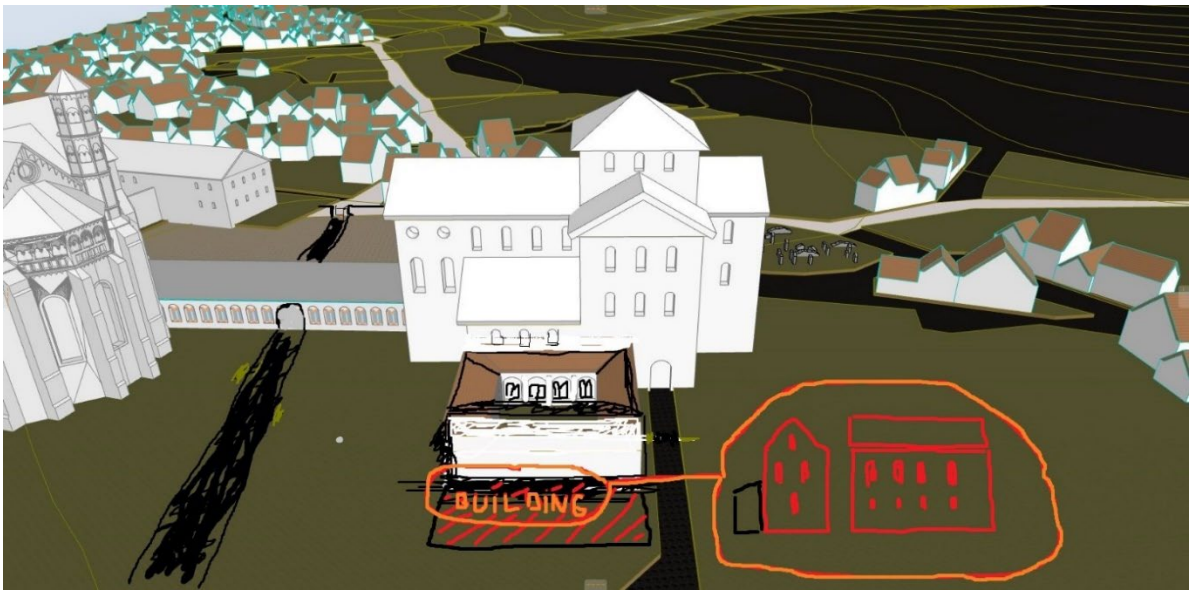


Fig. 23 *Example of online correction for the reconstruction of the area of the church of St. Johannis in the 13th century by Gernot Frankhäuser (AI MAINZ, 2020).*

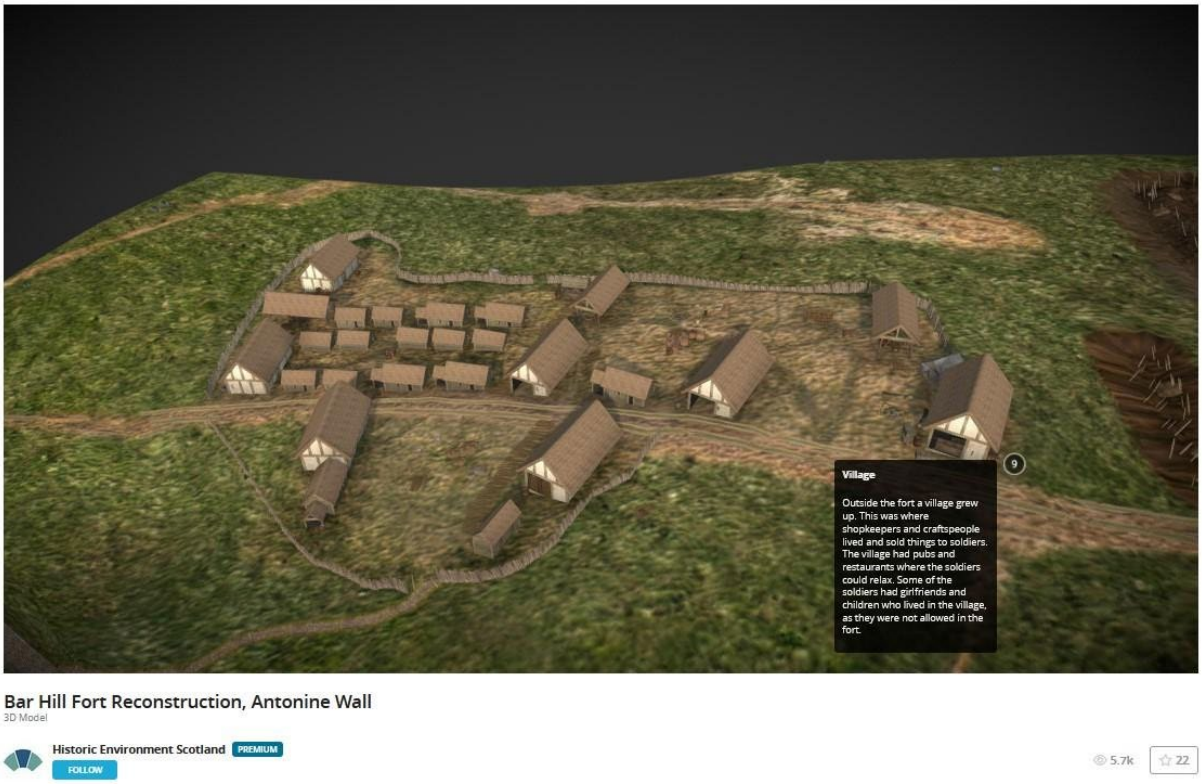


Fig. 24 A screenshot showing an example of 3D model documentation using annotation in the Sketchfab web-viewer virtual space (https://skfb.ly/6BEXW, accessed 03 January 2024).

When conducting reviews with specialists, another method of documentation involves using annotations within the model. However, since some historians or archaeologists may lack expertise in 3D modelling, it is often necessary to present the models in an accessible manner. This can be achieved through free services that allow the publication and visualisation of 3D models, such as Sketchfab (Fig. 24). Publication requires exporting the file into a format suitable for web display (more on formats in Chapter III.B.3.). However, this process risks

altering the model's form or texture mapping. Despite this, it provides a general overview of the current state of the work and enables exploration of the model in a virtual 3D space. Reviewers can create annotations—specific interaction points where they can leave comments for the authors (Ponchio et al., 2019). This method is also commonly used to present final models to a broader audience.

Graphically capturing the stages of work as documentation is effective, which led to the development of a scientific method tailored to the needs of hypothetical digital reconstructions—the Reconstruction-Argumentation Method (R-A-M) at the Digital Design Unit of the Faculty of Architecture at the Technical University of Darmstadt. This method is based on segmenting an object into semantic units, called areas, which are independently documented entities (Grellert et al., 2018). Each area is represented by a visualisation of the digital reconstruction of the corresponding element, combined with the source used as the primary material in the reconstruction, along with textual argumentation. This creates a visual triple that allows a quick evaluation of the presented reconstruction's validity compared to historical sources (see Fig. 25).

Each of the listed documentation methods can support the organisation of work but at different stages. Tabulated data summaries are most effective for evaluating sources or the reconstruction results, but they can be ineffective for documenting ongoing decisions. Graphs and mind maps are handy for planning the project's scope, identifying connections between various elements, or segmenting the site, making them more valuable in the initial phase. Database documentation is the most effective solution for handling large amounts of information and allowing for machine analysis. However, it requires finalised data, and since reconstruction is a creative process, the data may change as the project evolves. Therefore, using this method requires setting milestones, at which point the data can be entered into the database. Leaving all documentation until the end of the project can be too exhausting and time-consuming.

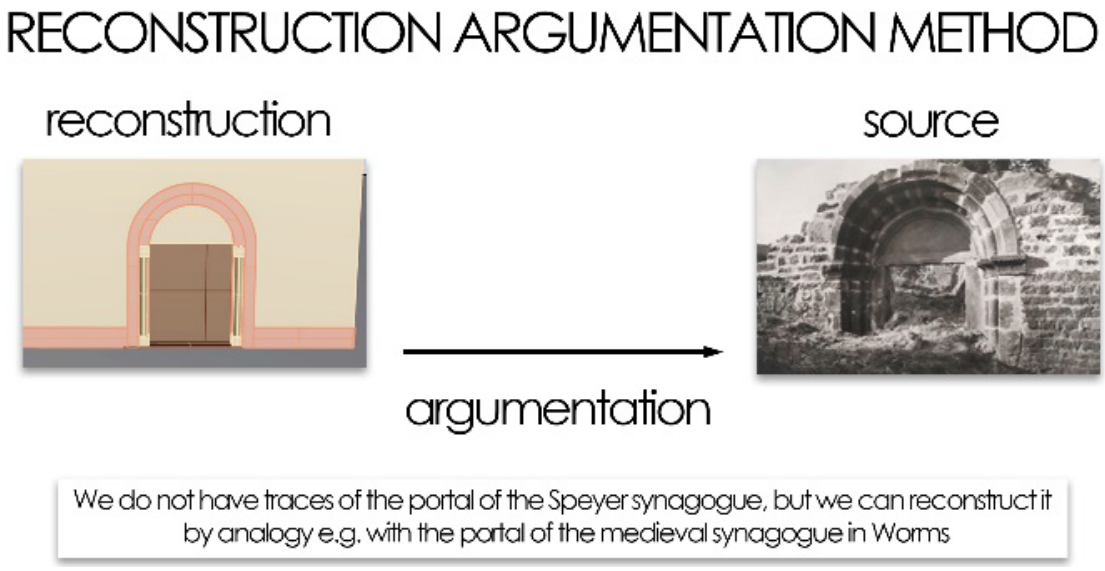


Fig. 25 A triple representation of the Reconstruction Argumentation Method (R-A-M). On the right is a historical source; on the left, a digital reconstruction is presented. Below is the argumentation describing the relationship between source and reconstruction.

The most practical method is applying sketches and corrections directly to flat screenshots of the 3D model, as this allows for quick identification of key issues. These raw data can later form the basis for more detailed documentation, so it is worth collecting and storing them in an organised manner. The R-A-M method represents a compromise between quick sketches and structured documentation. It is an excellent visual

approach that aids in understanding decisions, especially when carried out directly during modelling and source interpretation. Ultimately, well-executed documentation should combine these methods most effectively for the project's specific requirements. The only thing to remember is that the final form of the documentation must be accessible to the intended audience and, therefore, appropriately structured.

The initial phase of the thesis considered how the documentation methods perform in light of the main principles for digital 3D reconstruction (see **Chapter I. C.1.**), namely the London Charter (LC) and the Seville Principles (SP). Three selected documentation methods were included in the study: knowledge graph, R-A-M, and use of annotations. The characteristics of the selected methods are the ability to process the data in a structured way, giving the potential to create a machine-readable data package. The study results are presented in a forthcoming paper of the Proceedings of the 26th International Conference on Cultural Heritage and New Technologies, which is currently being published.[38] A table with an evaluation of documentation methods in the light of the LC and SP is included in Tab. 27 in Appendix 2. A summary of the study is presented below.

The **knowledge graph** documentation method makes it possible to obtain an overview of the entire process and adapt it to the selected digital reconstitution techniques. Adequate preparation is required beforehand. Following the implementation into the system (which requires specialised knowledge), the user can only see the graph using advanced data acquisition and visualisation methods. This, through the complex web of relationships between data, can make the system difficult for new users to navigate. Despite this drawback, the method is flexible and meets documentation principles. The **R-A-M** method provides a visual method of documentation based on a simple diagram, so it is easy to use and read. It also allows immediate comparison of the reconstruction and its source. Although it does not meet all the requirements, it is a practical alternative, facilitating adequate documentation with little effort. The web visualisation method, on the other hand, works best when applied to depict the lost CH. One can feel the space and freely colour the model if it is high-quality. However, documentation is on the back burner with this method. Few models are annotated, which can substitute complicated databases. The need for post-production of the model after uploading to the web-viewer is a barrier. Creating interactive points and descriptions and preparing media files all require mastery of an additional tool and resources. The listed documentation methods differ but have one thing in common – they all use tools that require publishing the resources on the web. As a result, access to the data is open. After all, peer review is key to scholarship. Nevertheless, is documentation sufficient to evaluate the scholarly value of 3D reconstruction work, or is a 3D file necessary?

B.2. Tools for documentation

Each method requires the appropriate tools for its implementation, and the choice of tools can significantly influence the quality of the documentation and the adherence to the principles of working with digital 3D reconstructions. The following section describes which tools can be used for the mentioned documentation methods. However, it should be noted that these are not all possible solutions, and only those tools have been included, making it possible to document the reconstruction in real-time during the project workflow. The tools for documentation after the reconstruction work has been completed are described in Chapter III.B.2.

[38] See preprint: Bajena, I.P. & Kuroczyński P. (2021). "Challenges in the face of documentation and publication of 3D reconstructions of Cultural Heritage. How to capture the process and share the data?" In: *Proceedings of the 26th International Conference on Cultural Heritage and New Technologies*, held in Vienna and online, November 2021. Heidelberg: Propylaeum, online: https://seafile.rlp.net/f/77b14aa27ea945d18d35/ (accessed 04 March 2024).

Proper data management and documentation in the digital 3D reconstruction process requires the use of appropriate tools. The simplest is spreadsheet software, such as Microsoft Office Excel.[39] Microsoft Excel is a widely used spreadsheet application that allows users to organise data in rows and columns, perform complex calculations, and create charts and graphs. Its familiarity and extensive features make it a strong choice for documenting hypothetical digital 3D reconstructions. However, it is paid software, which might not be accessible to everyone. Free alternatives like Google Sheets and LibreOffice Calc offer similar functionalities. Google Sheets is a web-based application that enables real-time collaboration, which can benefit multiple researchers working on the same project. Its cloud-based nature ensures that data is accessible from any device with an internet connection. On the downside, it relies on internet connectivity and may have limitations in handling very large datasets. LibreOffice Calc is a desktop application that is part of the LibreOffice suite. It offers robust features comparable to Excel and does not require an internet connection. Being open source, it is free to use, but it may lack some of the advanced features and support that Excel provides. These tools are handy for evaluating source materials and reconstruction results and performing automatic calculations to assess the work's scientific value.

Software like Miro, Coggle, or Canva can be valuable tools for creating mind maps. Miro is an online collaborative whiteboarding platform that supports real-time teamwork. It offers a range of templates and tools for brainstorming, mapping processes, and visualising ideas. Its strength lies in its collaboration features, but it may require a subscription to access advanced functionalities.[40] Coggle is a web-based application designed to create mind maps and flow charts. It is intuitive and user-friendly, making it suitable for organising thoughts and materials in a hierarchical structure (see Fig. 26). While it offers a free version, some features are limited unless upgraded to a paid plan. Canva, while primarily known as a graphic design tool, also offers features for creating mind maps and diagrams. It provides a vast library of templates and design elements, enabling users to create visually appealing documents. Its drag-and-drop interface is easy to use, but some features like Miro may require a paid subscription. All of that software provides virtual boards where users can place images and texts and visually organise them in clusters. They often have built-in functions for creating links between board elements and simplifying documentation.

Database software like Microsoft Access or its free alternatives can be used to organise data. Microsoft Access is a desktop database management system that combines the relational Microsoft Jet Database Engine with a graphical user interface. It is useful for managing large amounts of data, such as historical sources and archival materials, enabling users to create custom databases to suit their needs. However, it is part of the Microsoft Office suite, which requires a purchase. Free alternatives include LibreOffice Base and Apache OpenOffice Base. These open-source desktop applications offer functionalities similar to those of Access. They allow users to create and manage databases, design forms and reports, and perform SQL (Structured Query Language)

[39] There are now many spreadsheet-related software solutions, a list of which can be checked here: https://en.wikipedia.org/wiki/List_of_spreadsheet_software (accessed 22 September 2024).

[40] The use of MiroBoard as a tool for organising design materials was tested in co-curricular activities with Prof. Kuroczyński in an elective course on the digital reconstruction of wooden synagogues with architecture students at the Technical University of Lodz and the Warsaw University of Technology in Poland in summer semester 2023. The results of selected works can be viewed here: https://miro.com/app/board/uXjVMKxUC24=/?share_link_id=995592197835 & https://miro.com/app/board/uXjVMKxUCC8=/?share_link_id=370896386480 (accessed 22 September 2024).

queries.[41] While they are cost-effective, they may not offer the same level of integration with other applications or the extensive support that comes with Microsoft products. Such database software is beneficial for managing research data in digital 3D reconstruction projects. They enable the organisation of large amounts of information in a structured way, facilitating easy retrieval and analysis. However, these databases are typically stored locally on computers, which can limit accessibility and collaboration unless measures are taken to share the data securely.

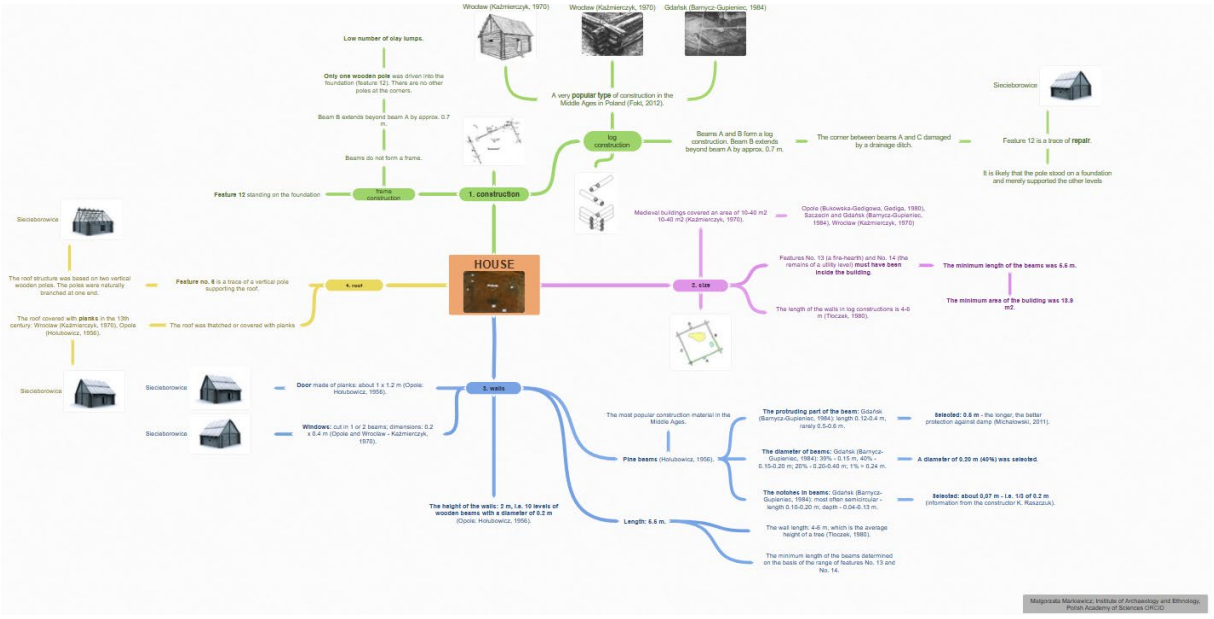


Fig. 26 A mind map created in the form of documentation of the project of the reconstruction of the medieval house from Siecieborowice in Coogle software (Markiewicz, 2024).[42]

Another valuable tool in the digital reconstruction process is a specialised type of database integrated into the 3D model, commonly used in architectural design. These are Heritage Building Information Modelling (HBIM) programmes, such as Archicad[43] and Revit[44], where each 3D object carries a multitude of properties. Thoughtful use of these tools can lead to comprehensive documentation and effective data management within the 3D model itself. In the context of preparing documentation for hypothetical digital 3D reconstructions, these HBIM tools offer significant advantages.

By embedding information directly into the 3D model, researchers can ensure that all relevant data is accessible and linked to specific elements. This facilitates better organisation of historical sources and archival materials.

[41] SQL queries are commands used to interact with databases that support Structured Query Language. They can be used to perform a variety of operations on the data stored in a relational database. SQL queries make it possible to retrieve specific data, insert new records, update existing information, or delete records from the database.

[42] For the full resolution of the graph, see online: https://coggle.it/diagram/ZIn95ulidps3WZ83/t/house-foto (accessed 22 September 2024).

[43] Archicad, developed by Graphisoft, is professional architectural software that allows for the creation of detailed 3D models of buildings. It integrates both geometric and semantic information, enabling architects to design with a holistic approach. Each element in Archicad can be enriched with data about materials, dimensions, and other relevant attributes, making it particularly useful for documenting hypothetical digital 3D reconstructions.

[44] Revit, from Autodesk, is another powerful HBIM software widely adopted in the industry. It supports multidisciplinary collaboration, allowing users to design, simulate, and visualise in a unified environment. Revit's parametric modelling capabilities enable the creation of intelligent 3D models, where changes made to one part of the model automatically update across all related views and documentation.

The effectiveness of using such tools was demonstrated in Elisabetta Giovannini's doctoral thesis.[45] She presented a method for managing data using Revit software, Excel sheets, and Dynamo parametric modelling add-on to create an interactive database connected to the 3D model (see Fig. 27). This approach enhances data management and allows for more efficient collaboration among team members, ultimately improving the quality and transparency of the reconstruction project.

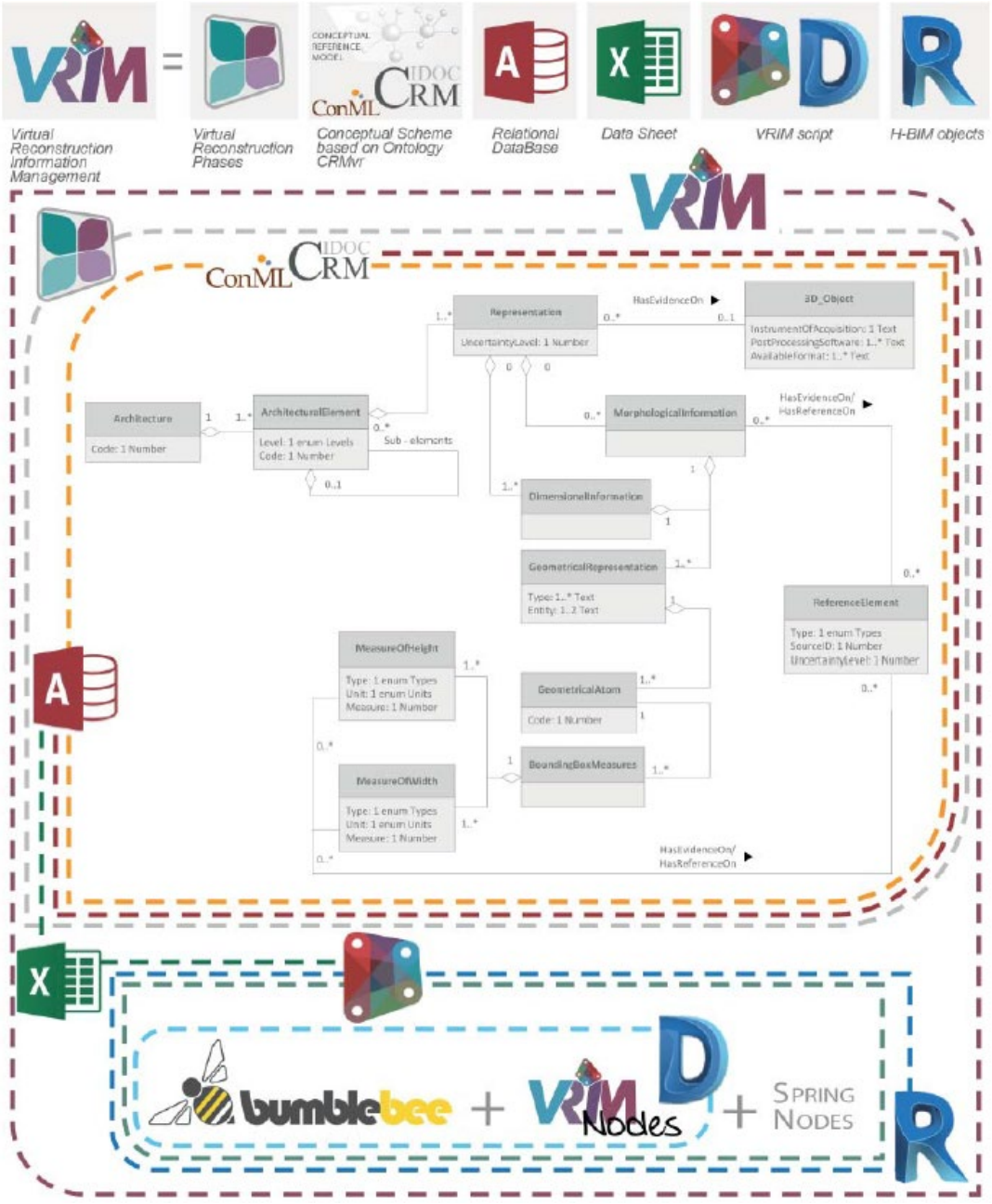


Fig. 27 Scheme of Virtual Reconstruction Information Management (VRIM) workflow (Giovannini, 2018).

[45] See: Giovannini, Elisabetta Caterina (2018) *Virtual Reconstruction Information Management. A scientific method and 3D visualization of Virtual Reconstruction Processes.*, [Dissertation thesis], Alma Mater Studiorum Università di Bologna. Dottorato di ricerca in Architettura, 30 Ciclo. https://doi.org/10.6092/unibo/amsdottorato/8330/.

B.2.1 Virtual Research Environment (VRE)

Some tools enable the creation of an online relational or graph database as an environment for researchers to collaborate on a scientific project. This type of solution is called Virtual Research Environment (VRE). It is a web-based workspace that enables researchers to collaborate and manage their work in a flexible and accessible manner, regardless of their location. Designed to meet the specific needs of research communities, VREs allow researchers to access, share, and organise data, software, and other resources seamlessly across different institutions and platforms. This makes them particularly useful in today's scientific landscape, where projects often span multiple disciplines and require input from geographically dispersed teams (Candela et al., 2013).

One of the key benefits of VREs is their accessibility. Since they operate online, researchers can access vital resources and data from anywhere with an internet connection, greatly facilitating collaboration. This is especially important for large or complex projects where multiple researchers need to work together in real time, sharing tools and data without the delays that come with traditional methods. Another advantage is the ability of VREs to integrate various resources into a single, unified platform. This helps streamline the management of diverse datasets, software tools, and workflows, which is crucial for handling the intricacies of modern scientific research. Moreover, VREs are highly adaptable and can be customised to fit the unique demands of different research fields, offering flexibility that traditional systems often lack.

However, there are also some challenges to consider when using VREs. Setting them up and managing them effectively requires technical expertise, especially in data integration and system interoperability. Ensuring that different systems and tools can work together smoothly can be time-consuming and complex. Additionally, long-term sustainability is a significant concern. Maintaining a VRE over time demands ongoing financial and technical support, which can be challenging to secure. It can be hard to keep the environment functioning properly without sufficient resources. Despite these challenges, VREs are becoming more popular, especially in the digital humanities sector. Solutions based on Linked Open Data (LOD) are exciting and enhance data accessibility and reusability by structuring and enriching it with semantic information (Auer et al., 2014). The Linked Open Data Working Group of NFDI4Culture recently published a list of specifications and a comparison of the various VRE solutions used in digital humanities (Nasarek & Rossenova, 2023). The selected tools covered in their study are:

- **ConedaKor** is a tool often used for image management and cultural heritage projects, designed to facilitate the linking of data through a graph-based structure.[46]
- **LinkedDataHub** is open-source software you can use to manage data, create visualisations and build apps on RDF Knowledge Graphs.[47]
- **Metaphacts** provides a comprehensive platform for publishing research data modelled using the CIDOC-CRM ontology for Cultural Heritage and Digital Humanities in the Galleries, Libraries, Archives, and Museums (GLAM) sector.[48]
- **Omeka S** is a widely used platform, particularly popular for managing and publishing cultural heritage data. It allows users to create rich metadata for their digital collections and provides LOD capabilities,

[46] https://coneda.net/ (accessed 23 September 2024).

[47] https://atomgraph.github.io/LinkedDataHub/ (accessed 23 September 2024).

[48] https://bitbucket.org/metaphacts/metaphacts-community (accessed 23 September 2024).

making it a versatile tool for smaller institutions or projects with a strong focus on web-based digital archives.[49]

- **ResearchSpace** is a more robust solution that enables collaboration on large-scale projects, particularly in the research and cultural heritage sectors. It integrates semantic web technologies, allowing for deeper data linking and analysis.[50]
- **Vitro** was first developed for a research and scholarship portal at Cornell University. It is now a general-purpose web-based ontology and instance editor with customisable public browsing.[51]
- **WikiBase**, originally developed for Wikidata, is another strong player in the field of LOD. It provides a highly adaptable and open platform for managing complex datasets.[52]
- **WissKI** (WissenschaftlicheKommunikationsInfrastruktur) stands out for its focus on integrating LOD with traditional scholarly workflows. This makes it particularly useful for research environments that need to link archival data with semantic web technologies.[53]

The underlying database technology is an important aspect to consider when choosing a platform. Traditional SQL databases (Structured Query Language), like those used in many applications, are relational, meaning they store data in tables with predefined relationships between them. These databases are well-suited for structured data and are highly efficient when handling transactions, updates, and queries involving fixed relationships. However, they can become rigid when handling more complex, unstructured data, which is common in humanities research. On the other hand, SPARQL databases (SPARQL Protocol and RDF Query Language) are explicitly designed to query data stored in Resource Description Framework (RDF) format, which is a standard for encoding Linked Open Data. Unlike SQL, SPARQL queries graph-based data, where relationships between entities are more flexible and can be dynamically defined. This makes SPARQL particularly powerful for LOD applications, as it allows for more complex, semantic queries across interconnected datasets (Nasarek et al., 2024).

The main advantage of SPARQL databases is their ability to handle complex, interconnected data and extract meaningful relationships between seemingly unrelated data points. However, they can be more challenging to set up and manage, requiring higher technical expertise. SQL databases, by contrast, are easier to work with for most users but are not as flexible in handling LOD. Regarding the solutions mentioned earlier, platforms like ConedaKor and WikiBase are built with a focus on graph-based data and use SPARQL for querying, making them highly suitable for LOD applications. On the other hand, platforms like Omeka S and Metaphacts can operate with both SQL and SPARQL databases, offering a hybrid approach that combines the robustness of traditional relational databases with the flexibility of graph-based querying. WissKI is particularly well integrated with SPARQL databases, aligning itself closely with LOD principles, which is beneficial for projects that require deep semantic linking of archival or historical data.

SPARQL databases are generally more beneficial when working with LOD due to their flexibility and ability to query across different datasets meaningfully (Lincoln, 2015). However, SQL databases can still offer a highly efficient solution for projects that do not require such complex interconnections. The choice between SQL and

[49] https://omeka.org/s/ (accessed 23 September 2024).
[50] https://researchspace.org/ (accessed 23 September 2024).
[51] https://vivo.lyrasis.org/vitro/ (accessed 23 September 2024).
[52] https://wikiba.se/ (accessed 23 September 2024).
[53] http://wiss-ki.eu/ (accessed 23 September 2024).

SPARQL, or a hybrid of both, ultimately depends on the project's needs and the complexity required for linking and querying data (Vipin et al., 2011).

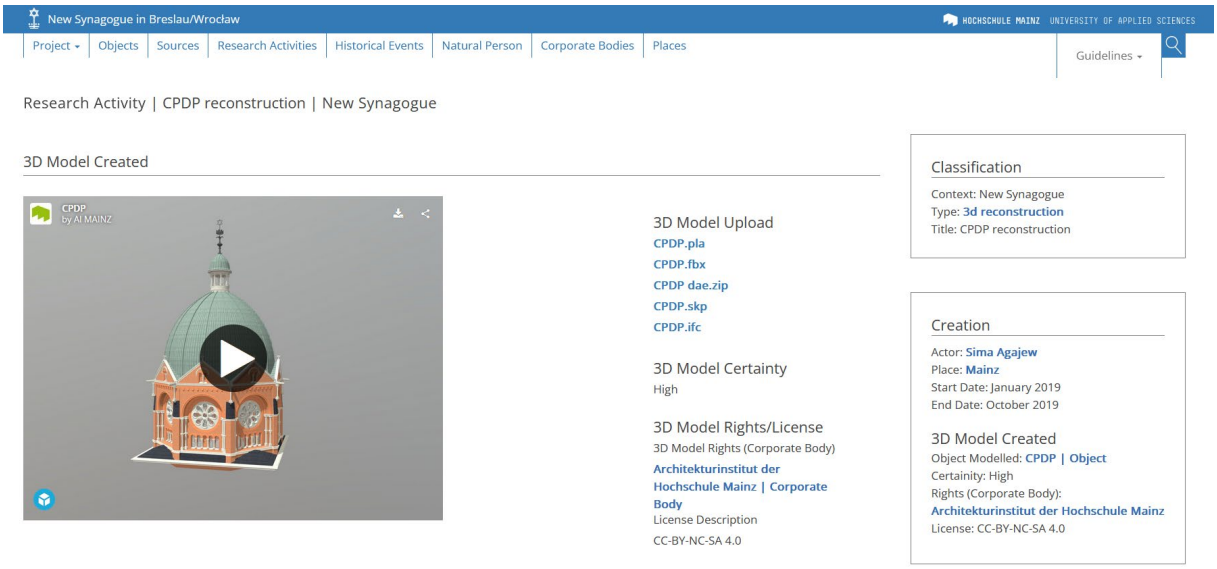


Fig. 28 Sample record from WissKI-based VRE documenting the reconstruction of the dome of the New Synagogue in Wroclaw (AI MAINZ, 2019).

Virtual research environments are just beginning to make their way into the realm of 3D digital reconstructions, and it is still difficult to find projects that directly reference them. While these environments are often used in the humanities, few projects related to 3D models employ this method of documentation. Even among the projects that have adopted this approach with promising results (Kuroczyński et al., 2016), some have not survived over the period and are no longer accessible online.[54] However, it is still possible to find VREs of reconstruction projects documenting 3D models that are in use and have been hosted by host institutions for years. Examples include the projects '*MayaArch3D*'[55] about which the first publications date back to 2009(von Schwerin et al., 2016), '*New Synagogue in Breslau: A Digital Reconstruction*'[56] which WissKI-based (see Fig. 28) opened to the public in 2019 (Kuroczyński et al., 2021) or '*Florence4D*'[57] with use of Omeka S-based VRE published online in 2021 (Nevola et al., 2023).

B.2.2 R-A-M-based tools

Although VREs are comprehensive tools, integrating them into a project often requires building a system nearly from scratch. To address this, researchers have begun developing open repositories that allow users to create documentation for their projects using pre-designed templates within the system. However, there are few solutions that focus on real-time documentation throughout the project's development—most repositories are

[54] An example is the project 'Virtual Reconstructions in Transnational Research Environments - the Portal: Palaces and Parks in Former East Prussia' developed by the Herder Institute for Historical Research on East Central Europe, whose publications can be found dated 2016. The URL of the project's virtual research environment currently redirects to the project website, see: https://patrimonium.net/ (accessed 23 September 2024).

[55] VRE of the MayaArch3D project: https://mayaarch3d.org/en/ (accessed 23 September 2024).

[56] VRE of the New Synagogue in Breslau: A Digital Reconstruction project: https://www.new-synagogue-breslau-3d.hs-mainz.de/ (accessed 23 September 2024).

[57] VRE of the Florence4D project: https://florence4d.org/ (accessed 23 September 2024).

primarily geared towards publishing final results (Champion & Rahaman, 2020). The exception was the platforms developed based on R-A-M. Here, documentation is not done directly on the 3D model but using 2D images created from the model.

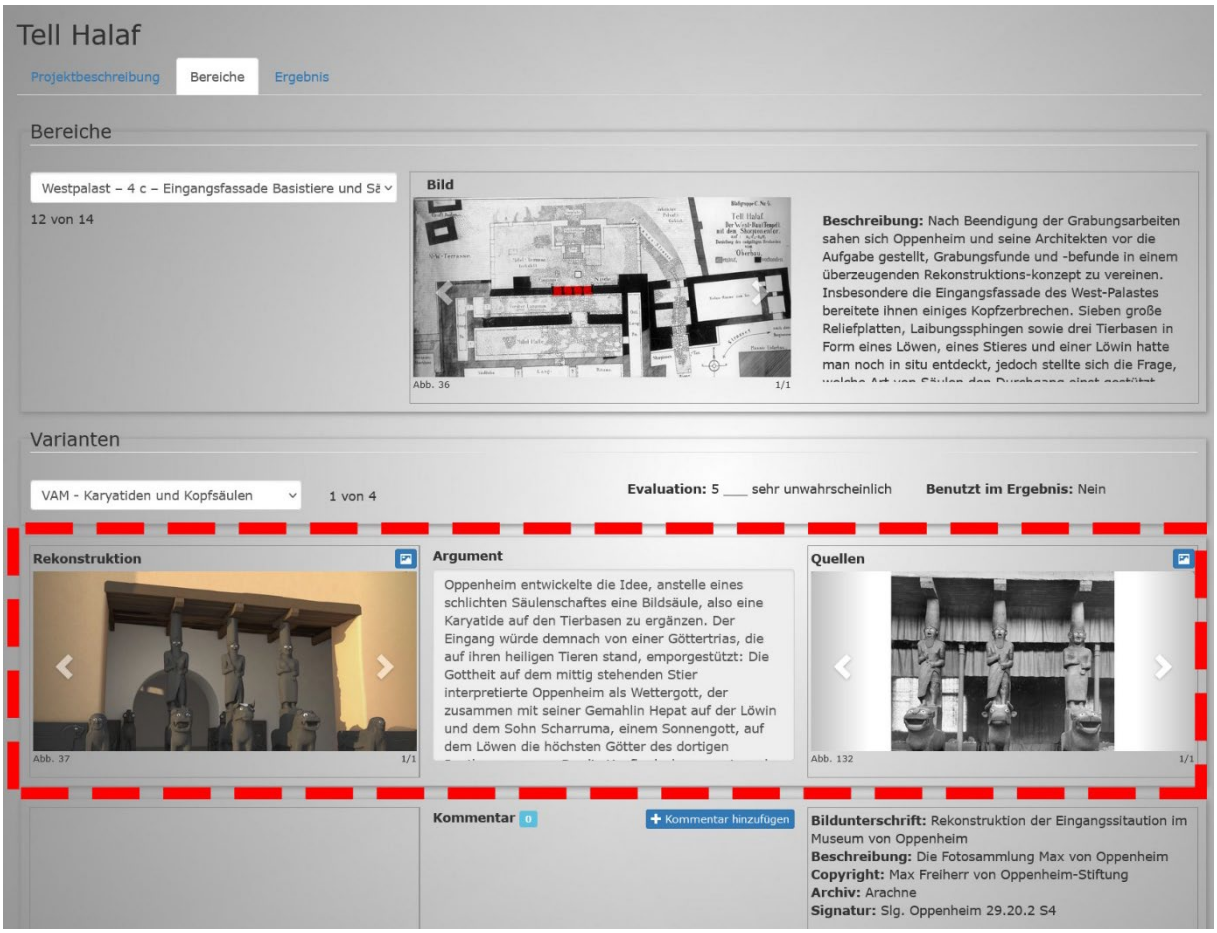


Fig. 29 A screenshot showing the documentation of an area from a sample project from the ScieDoc system. The red dashed line is the triple 'reconstruction (Rekonstruktion) – argument (Argument) – source (Quellen)' that forms the core of R-A-M. (*http://www.sciedoc.org/*, 03 January 2024).

The first tool of this type is **ScieDoc**.[58] It is an online tool developed for the structured documentation of virtual reconstructions, focusing on making the reconstruction process transparent and traceable (Grellert et al., 2017). The system allows users to document every decision made during the reconstruction by linking each reconstructed area of a building to its sources and explaining the rationale behind the choices made. The platform organises data through a structured approach. Each reconstruction project is divided into various 'areas', such as walls, roofs, or windows. Each area can be represented by multiple 'variants', which show different possibilities for reconstruction based on the available evidence. These variants are supported by three core elements: the **Reconstruction** (visual representation, such as a rendering or a 3D model), the **Source** (a historical document, photo, or drawing), and the **Argumentation** (a written explanation detailing how the source material led to the chosen reconstruction). This triple structure—Reconstruction, Source, and Argumentation—ensures that each aspect of the project is well-documented and supported by evidence (see Fig. 29).

[58] ScieDoc Website: https://sciedoc.org/ (accessed 03 January 2024).

Despite its simple functionality, ScieDoc has gained a following of regular users from German-speaking countries, proving the platform's practicality. Therefore, a few years later, the ScieDoc framework was used to develop a new tool, infrastructure for documenting virtual reconstructions—IDOVIR.[59]

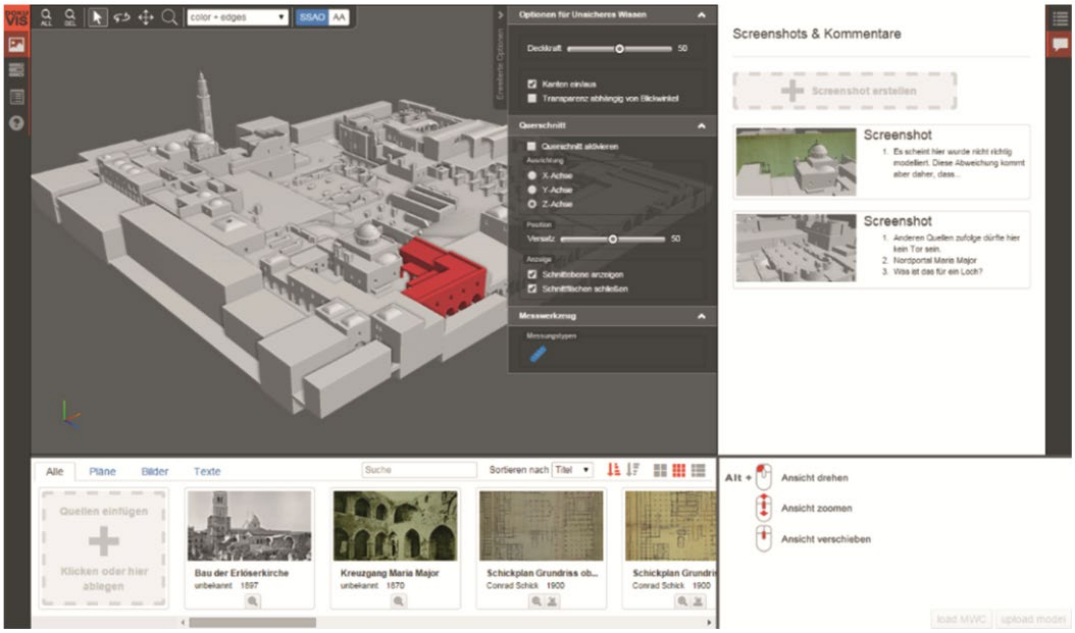


Fig. 30 Graphic interface of the DokuVis tool (Bruschke & Wacker, 2016).

IDOVIR is a platform built on the collective experience gathered from two projects - the aforementioned ScieDoc and the Interactive Documentation System - DokuVis[60]. **DokuVis** serves as a collaborative platform and research environment, supporting project teams in documenting, managing, and verifying their work in a structured manner. A key feature is integrating a 3D model into the system, which allows users to annotate and link historical sources directly within the 3D virtual space (see Fig. 30). However, unlike SciDoc, DokuVis does not make documented projects publicly accessible. Instead, they are only available to registered users assigned explicitly to the project by its creator.

IDOVIR as an online platform developed to document virtual reconstructions, is aimed at providing transparent and structured data. The platform is designed to simplify the process of documenting every step of a reconstruction project, from the sources used to the decisions made during the reconstruction. It ensures that each part of the work can be traced back to its original evidence, following the ScieDoc approach based on R-A-M. The core of the system is division of the reconstructed building or site into different spatial areas and time periods (see Fig. 31). Each area is documented with three key components: the **reconstruction** itself (in the form of a 2D or 3D model), the **source material** (such as historical documents, drawings, or photos), and a detailed **argumentation** that explains how the sources informed the reconstruction (see Fig. 32). The platform also supports the creation of **variants**—different potential versions of a reconstruction—allowing researchers to document and compare multiple interpretations of the same area or building. This feature is particularly useful when dealing with ambiguous or incomplete historical data, as it allows for the recording of alternative

[59] IDOVIR website: https://idovir.com/ (accessed 24 October 2023).
[60] DokuVis website: https://dokuvis.org/#!/home (accessed 23 September 2024).

reconstructions and the reasons why certain versions were favoured or rejected. Each variant is stored in a hierarchical tree structure, making it easy to navigate and update as new information becomes available.

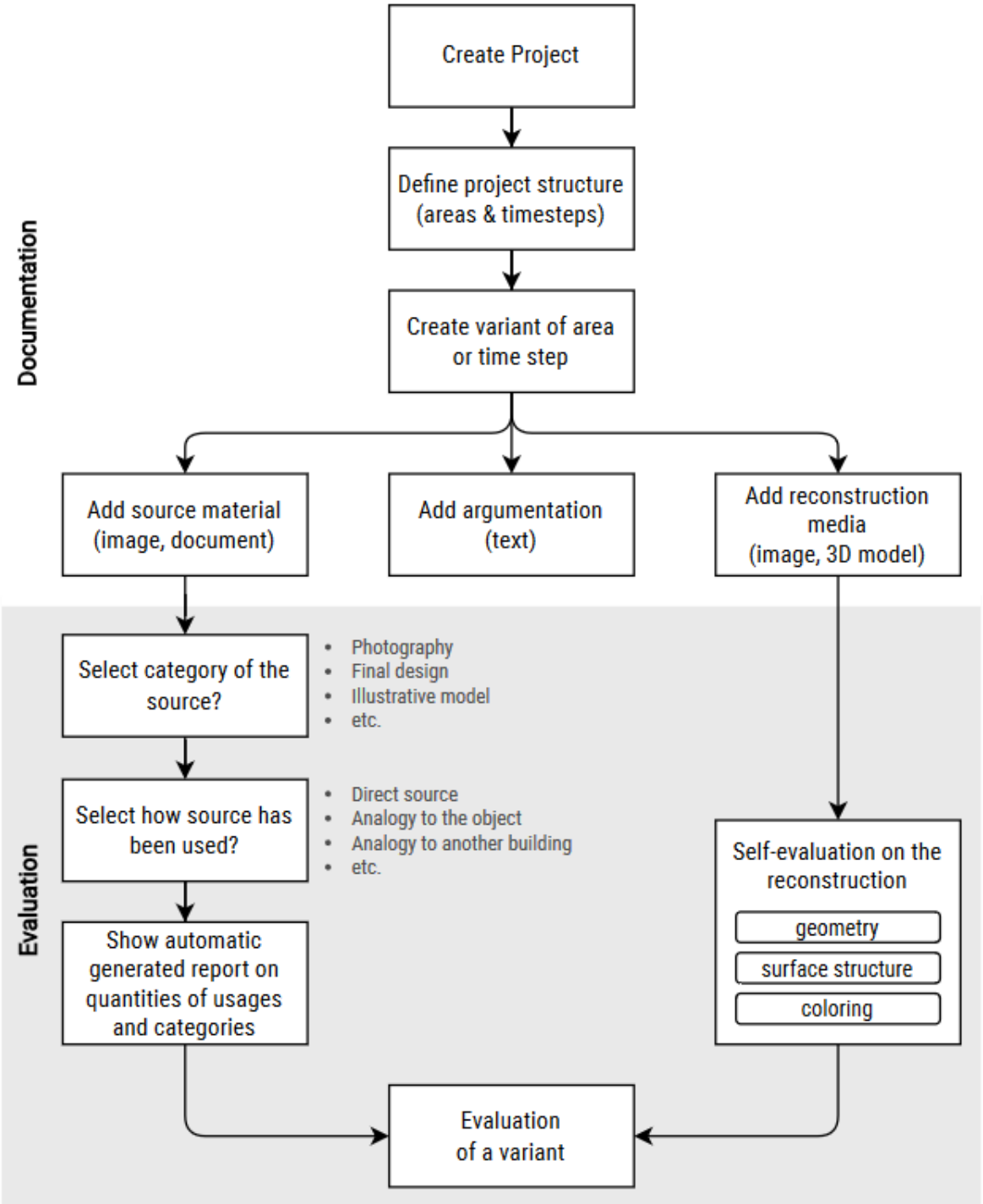


Fig. 31 Workflow of documentation and evaluation in IDOVIR (Grellert et al., 2023).

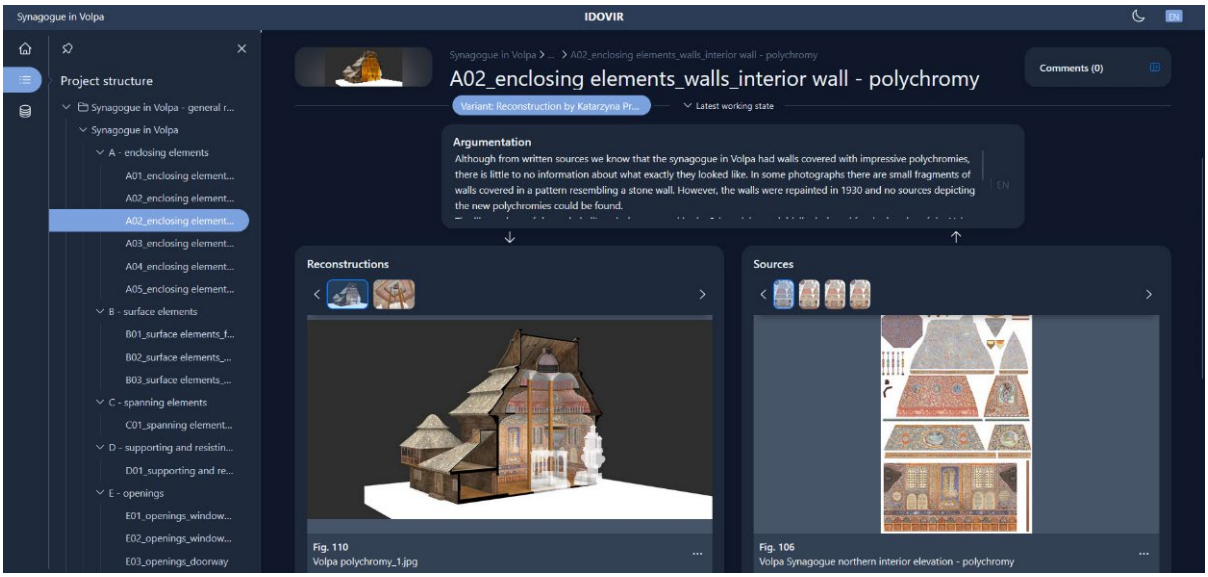


Fig. 32 Use of the RAM method in the documentation of the polychrome reconstruction of the Volpa Synagogue in the IDOVIR system. Entry prepared by Katarzyna Prokopiuk as part of a student reconstruction project at Warsaw University of Technology in 2023.

The platform allows for easy entry of reconstruction data, and sources are stored separately but remain accessible for reference across all project parts. The system is flexible, enabling users to customise the organisational structure of their projects, which can be expanded or adjusted as needed. In terms of evaluation, IDOVIR offers tools for both subjective and objective assessments of the reconstructions. Users can rate the uncertainty of the reconstruction in terms of geometry, surface structure, and colour, and these ratings are visually represented through pie charts, helping to convey the level of certainty behind each reconstruction. To use IDOVIR, all that is needed is access to the platform through account registration, a basic understanding of the RAM documentation process, and 3D models of the reconstructions. The platform has been designed to be intuitive, allowing even those without extensive technical skills to document and evaluate their work effectively.

B.2.3 Annotation-based viewer tools

The documentation methods associated with annotation are strongly linked to the tools for publishing and presenting the 3D model, so the most commonly used tools in this method are web-based 3D viewers that offer annotation as a feature (Camba et al., 2014). Among the most popular is the commercial viewer Sketchfab. It is an open, commercial repository of web viewers and 3D data storage services. It is a world leader among 3D model repositories supporting cultural heritage, which was already mentioned while describing annotations as documentation methods. It allows the creation of text annotations once with a camera setting, which can be combined into a virtual tour.

Alternatives to this solution developed by scientific institutions have also emerged. The first is the 3D Heritage Online Presenter (Potenziani et al., 2015). It is a framework that allows you to create an interactive point or area in a 3D model that can trigger user interaction and display the desired information (Fig. 33). Unlike Sketchfab, however, it is not embedded in a data repository, so its use requires prior setup of the platform hosting the viewer. Another solution with a similar working principle is the Smithsonian Voyager[61] developed as part of *the Smithsonian 3D* Digitisation programme (Fung et al., 2021). The software is an access commodity and has been

[61] https://github.com/smithsonian/dpo-voyager (accessed 10 October 2024).

developed to enable the creation of virtual tours around digitised museum collections. As with 3DHOP, its use requires the program to be embedded in its repository (see Fig. 33). The editing interface, however, appears more advanced and allows for thematic grouping of annotations and the inclusion of images.

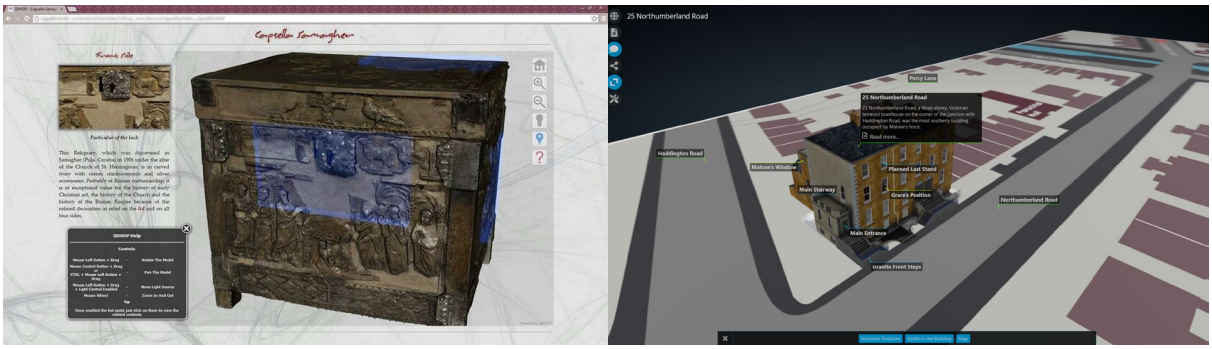


Fig. 33 Examples of the interactive annotations. On the left side interactive area on the model surface using the 3D Heritage Online Presenter (3D HOP) (M'DARHRI et al., 2019). On the right side, groups of annotations with text information within the Smithsonian Voyager viewer—materials from the September 2023 PURE3D Training Session about the Smithsonian Voyager Interface.

The last solution described is the Kompakkt[62] viewer, which is a great alternative to Sketchfab. It is developed by the Institute for Digital Humanities at the University of Cologne (Eide et al., 2019). It offers the same service, but as an institutional product, it is entirely free. The system for annotating and creating virtual tours is intuitive and similar to Sketchfab. Recent development of the platform has led to the Semantic Kompakkt[63] project, which is an extension involving the possibility of linking the viewer to a Wikibase[64], where all annotations can be documented semantically as on Fig. 34 (Rossenova et al., 2022). However, this requires IT skills to create your own Wikibase instance and connect the viewer to it.

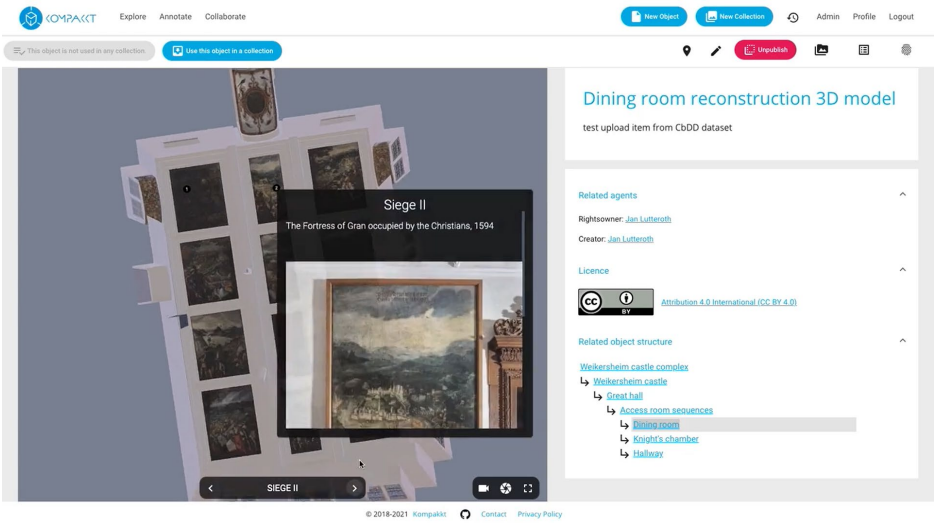


Fig. 34 Example of multimedia annotation using images in Semantic Komapkkt. On the right, you can see the semantic model hierarchy encoded using Wikibase (https://nfdi4culture.de/services/details/semantic-kompakkt.html, accessed 11 October 2024).

[62] https://kompakkt.de (accessed 10 October 2024).

[63] https://semantic-kompakkt.de/ (accessed 10 October 2024).

[64] https://wikiba.se/ (accessed 10 October 2024).

B.2.4 Tools evaluation

As with the documentation methods, the selected tools were evaluated. This time, the decisive factor in the selection was the link between the tool and the possibility of publishing the data. Thus, three tools were distinguished in the form of a VRE (using WissKI as an example), a RAM-based tool (using ScieDoc as an example) and an annotation-based tool (using Sketchfab as an example). The tools were juxtaposed equally with the already discussed principals for digital reconstruction (LC & SP) as well as the principals for data sharing (FAIR Principles & 5-deployment scheme for Linked Open Data) described in Chapters I. C.1. and I. C.2. The results of the study are also part of the forthcoming publication of the Proceedings CHNT26, which is currently in the publication process. A table with an evaluation of documentation tools is included in Tab. 28 in Appendix 2. A summary of the study is presented below.

Research has shown that the more principles a publication method fulfils, the more effort the publisher requires. Although publishing using VRE fulfils almost all the principles, its creation involves computer science, informatics, and data science knowledge. Using ready-made institutional solutions requires a conscious choice of the principles to be followed. The example of SciDoc shows that, although it is an excellent and easy-to-use tool for documenting the reconstruction process, it does not provide an adequate infrastructure to guarantee the publication of the 3D model medium itself and does not provide the possibility to structure and index the published data. The example of Sketchfab, used by many renowned cultural heritage institutions, is fascinating. Despite its clear policy against data preservation, it is still an unrivalled tool for the simple and fast visualisation of 3D models.

B.3. Evaluation of the scientific value of the work

Regardless of the chosen working methodology or documentation tools, the question of determining the scientific value of digital 3D reconstruction projects remains (Pfarr-Harfst, 2018; Stiller & Wintergrün, 2016). It is legitimate to question the value of visualising reconstructions, as we can never be sure whether hypothetical or synthesised elements have been introduced into the model. Niccolucci and Hermon (2004) expressed the need to provide an evaluation of the reliability of the results to consider the digital reconstruction process as scientific, writing as follows:

> *"(…) it is more 'scientific' to state "I believe this reconstruction is valid because I am an expert in this field" than simply presenting the model without any further comment."*

Although this statement has been used in the context of virtual reconstructions, which are always subject to a certain level of hypothesis, it is valid for the entire field of digital models of CH. Especially in the age of artificial intelligence, the provenance of digital data is uncertain, and the authenticity of the 3D models presented should be subjected to appropriate verification.

The London Charter (2012) mentions the need to present the distinction between preserved elements, evidence-based restoration, and hypothetical reconstruction with an indication of the distinction between the levels of uncertainty of the reconstructed elements. The simplest solution is to avoid a realistic representation of objects that do not represent the preserved substance and look for alternative graphic communication methods. Methods for visual representation of uncertainty were the topic of the Irene Cazzaro's PhD thesis and will not

be examined in detail here.[65] However, it is worth addressing how the uncertainty value of digital reconstructions can be estimated. It is also essential to differentiate between the uncertainty and scientific value of 3D models. Projects with high uncertainty can still hold significant scientific value, as the scientific value may lie in the hypothesis itself, even if there is no evidence for its total plausibility. As a result, the ability to self-assess the reliability of the outcomes of digital 3D reconstructions appears to be one of the key elements constituting the basis for the recognition of the 3D model as a scientific (Apollonio, 2016; Beale, 2008; Grellert & Haas, 2017; Hermon et al., 2006; Johnson & Sanderson, 2003; Zuk et al., 2005).

Although many methods have been developed on the subject, there is a lack of a unified approach, which can already be seen in the terminology. The most common determinant of this value in use is the level of uncertainty (Cazzaro, 2023a). The uncertainty level, sometimes called the hypothesis level, indicates how uncertain one is about the proposed solution. A higher value suggests that more caution is needed, as there is less evidence for the presented reconstruction, and several other possible variants could not be included in the studies. On the other hand, some researchers refer to the opposite value of the level of certainty (Kuroczyński et al., 2021), which is often described using terms like credibility (Bakker et al., 2003), knowledge (Ortiz-Cordero et al., 2018), plausibility (Blaise et al., 2023), or reliability (Pietroni & Ferdani, 2021). These two values (certainty and uncertainty) should complement each other. Despite the lack of standardised terminology, it is crucial to recognise that both certainty and uncertainty are in use to describe the same issue, but in an opposite way, and that uncertainty tends to dominate in the literature (Fallavollita et al., 2024).

Level of evidence	Colour Byzantium 1200	Definition Byzantium 1200	Colour Aparicio and Figueiredo (2017)	Definition Aparicio and Figueiredo (2017)	Colour Ortiz et al. (2018)	Definition Ortiz et al. (2018)
1		Exists in its original form		Imagination		Still existing in its original form
2		Partially or with modifications		Conjecture based on similar structures		Still existing with modifications
3		Photographs or plans available		Basic textual reference		Detailed graphical evidence
4		Archaeological information		Descriptive textual reference		Slight graphical evidence
5		Detailed graphical evidence		Simple graphical reference		Archaeological hypothesis
6		Simple graphical evidence		Detailed graphical reference		Textual evidence
7		Textual and comparative evidence		Basic archaeological information or simple base plans		Based on similar structures
8		Textual evidence		Strong archaeological and documental evidence in photographs and detailed plans		Based on historical context, nature and culture
9		Based on similar structures		Still existing (or partially existing) with modifications		
10		Imagination		Still existing in its original form		

Fig. 35 Representation of selected uncertainty scales with the level number (level of evidence), colour code and case definition for using the level (Cáceres-Criado et al., 2022).

[65] See Chapter 2 "Uncertainty classification and visualisation" (p. 56-136) in: Irene Cazzaro, "Digital 3D Reconstruction as a Research Environment in Art and Architecture History: Uncertainty Classification and Visualisation", Bologna: Alma Mater Studiorum - Università di Bologna, 2023, online: https://doi.org/10.48676/unibo/amsdottorato/10817.

The level of uncertainty or certainty can be expressed in various ways. The most common method is to create a multi-level scale, with specific criteria assigned based on the origin of the information used to reconstruct the object. Depending on the complexity of the scale, it can range from a few levels to a dozen or more. Each level is often given a distinct colour code for visual identification. The choice of colours for the uncertainty scale is an area of ongoing research (Apollonio, 2016; Cazzaro, 2023b; Lengyel & Toulouse, 2017; Schäfer, 2018), as colours are often associated with particular meanings in society (e.g., green for correct, red for incorrect). Along with the colour, each level can have an assigned number (ranging from 1 to the total number of levels) and a label indicating its meaning (see Fig. 35).

The problem with these solutions lies in the wide range of possible interpretations for the scales. There is no standardised approach, and the number of levels in the scales can vary significantly. Ultimately, this value is always a variable from a specific range with a clearly defined beginning (completely uncertain) and end (completely certain). The most straightforward, uniform solution is to express uncertainty as a unified numerical value. One of the first approaches to calculating the reliability of reconstructions was developed as a probability degree calculation (Niccolucci & Hermon, 2004). The researchers considered archaeological excavations as the basis for the study. The 3D model of the remains was the first model in the reconstruction (M_1), for which a subjective probability value was assigned, operating with an interval of [0,1] (completely improbable) and 1 (entirely probable). Each interpretive step in the reconstruction was then recorded as another model with a specific probability value P(M). For example, the remains of the foundations are the premise for a wall reconstruction model (M_2), but without height information, which lowers the probability level of the element. Adding detail, e.g. a window to a wall is another model (M_3) with yet another probability level (e.g. based on the characteristics of objects from the reconstructed period). Each model mentioned is linked to the previous one by its position in space, which is also the subject of a specific probability. To test the method, a fitness probability index was used to calculate the relational position of the models as well as the order in which further attributes were added to the model (such as the height of the walls or the addition of a window). According to the traditional probability formula, in order to calculate the value for a model, one would have to calculate the multiplication of all models involved:

$$P(M_1, M_2, M_3) = P(M_1) \times P(M_2) \times P(M_3)$$

Assuming subjectively that the probability for the excavation model M_1= 1, for the wall height M_2=0.7 and for the occurrence of windows M_3=0.5, the product of the total probability for the reconstruction is only 0.35. However, the researchers presented that the law of multiplication is not the best method for assessing the reliability of reconstruction due to its normalisation. The results do not reflect the true value, as other factors also influence it. They, therefore, presented an alternative solution following fuzzy logic. According to this method, each reconstruction decision is presented as a variety of options with varying degrees of probability estimated subjectively by the researcher. The final probability value for the entire model is no longer a product, al takes the minimum value from all components of the 3D model, according to the formula:

$$f(M_1, M_2, M_3) = \min\left(f(M_1), f(M_2), f(M_3)\right)$$

In this way, the probability for the example calculated with three models (excavated foundations, walls and windows) has already reached 0.5 (for M_1= 1, M_2=0.7, and M_3=0.5). While this is a much more appropriate value, it can be questioned whether simplifying to a minimum value is the most accurate solution. In addition, the method does not present criteria for selecting values, leaving them entirely to the subjective choice of the recipient.

A different approach was presented in the calculation method of the Average Uncertainty Weighted on the Volume (AU_V) (Foschi et al., 2024). As in the fuzzy logic method, its basis is dividing the object into smaller, separate models. In this case, however, the order of their deduction does not matter, and the method can also be used in the absence of information about the remains of the object. Each semantic part has been assigned with value uncertainty based on the flowchart (see Fig. 36). Depending on the desired level of complexity, the scale can be adjusted to 3, 5 or 7 levels. Most significantly, however, each level has a specific percentage of the degree of uncertainty through the upper and lower values. This approach aligns with fuzzy logic, designating a value not as definite but as an interval between upper and lower limits. The percentage expression of the value is also universal, unambiguous and of no concern regarding interpretation.

The assigned values serve as the basis for calculating uncertainty, and the impact of individual parts depends on the percentage of the volume of a given element to the sum of the total volume of all model segments, as expressed by the following formula:

$$AU_V = \frac{\sum_{i=1}^{n}(Vol_i \times Uncert_i)}{\sum_{i=1}^{n} Vol_i}\%$$

where

- AU_V is the average uncertainty weighted with the volume of the individual elements;
- n is the total number of elements;
- i is the index of the considered element;
- Vol is the volume of the considered element;
- $Uncert$ is the uncertainty value of the considered element (Foschi et al., 2024).

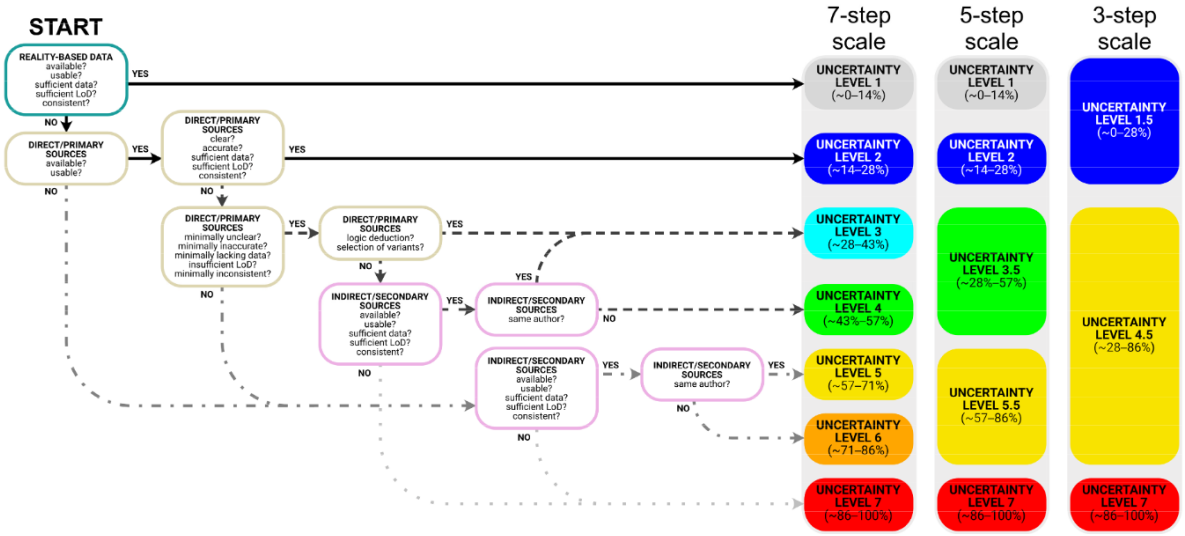


Fig. 36 Yes/no flowchart that aids in applying the uncertainty scale (Foschi et al., 2024).

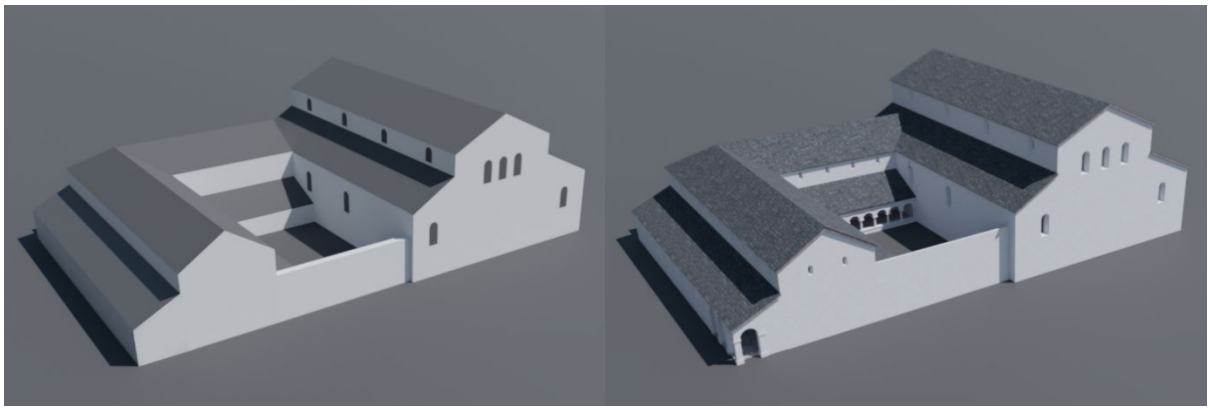


Fig. 37 Comparison of two visualisations of reconstructions prepared using the same sources and with the same level of uncertainty, calculated based on the volume of the elements. The reconstruction on the left was created with the assumption of simplified forms, and only colours were used to distinguish between different materials of surfaces. In contrast, the reconstruction on the right was developed in greater detail, incorporating detailed material textures.

The authors highlighted the risk of uncertainty values being disproportionately influenced by elements with simple forms but relatively large volumes, such as floors or walls. They introduced an extended formula version incorporating a relevance index to address this. Relevance is a subjective value, ranging from 0 to 1, assigned based on critical evaluation. This method, called Average Uncertainty Weighted on the Volume and Relevance (AU_VR), is expressed by the following formula:

$$AU_VR = \frac{\sum_{i=1}^{n}(Vol_i \times Uncert_i \times Relev_i)}{\sum_{i=1}^{n}(Vol_i \times Relev_i)}\%$$

where *Relev* is the relevance factor (which can be larger or smaller than 1 but never equal or smaller than 0). (Foschi et al., 2024). Although the value obtained in this method is more user-dependent and, therefore, more subjective, it can provide more meaningful results for objects with substantially large volumes of less significant elements for reconstruction. The researchers also tested calculations using other parameters, such as surface area, the number of vertices, and the mean curvature. However, none of these alternatives produced results as accurate as those based on volume (Foschi et al., 2024).

The introduction of the relevance factor introduces, however, the question of whether it is the only possible factor influencing the scientific value, other than agreeing on the element's uncertainty based on the classification of the knowledge source. This can be easily illustrated with a simple example (see Fig. 37). Below are two reconstructions of the same object based on the same sources, and their calculated uncertainty value is about 65%. However, when comparing the two visualisations, we can see significant differences that stem from the initial reconstruction assumptions regarding the level of detail and interpretation of materials. The surface finishes and their colouring issues were not considered in AU_V or AU_VR, as both methods assumed false colours from the scale to visualise uncertainty.

CityGML LoD Levels	Description
LoD 0	Only the 2D footprint (or projection of roofs) of the buildings is available, useful for regional landscapes
LoD 1	3D coarse prismatic models, usually obtained by extruding LoD0 data along the Z axis (e.g., known number of floors, heights), useful for cities and regions
LoD 2	3D simple models that approximate roof shapes, useful for city districts
LoD 3	3D refined models with architecturally detailed outdoor aspects (with doors, chimneys, windows, etc.), useful for landmarks
LoD 4	3D refined models that also present indoor features, useful for architectonic scale

LoD for Surface Appearance	Description
LoD 0	The surface appearance is not defined, and only a flat generic base colour (e.g., flat grey, white, brown, etc.) is applied without defining details at any scale
LoD 1	The surface appearance is drafted up to large-scale details (overall colours of the various parts, arrangement and layouts of patterns and constructive elements at surface level, no small-scale details)
LoD 2	The surface appearance is defined up to small-scale details (bumps, crevices, dirt particles, roughness, etc.)

LoD of Constructive System	Description
LoD 0	The constructive system is not defined.
LoD 1	Only the general type of constructive system is defined (e.g., wooden beams and pillars with brick infill, load-bearing concrete walls, brick masonry walls, etc.).
LoD 2	The constructive system is defined in detail (e.g., stratigraphy, type, materials, variety, arrangement of the blocks/elements/bricks, etc.).

Fig. 38 Scales of the level of detail for geometry (based on CityGML standard), surface appearance and constructive system used in case study of Piazza delle Erbe (Apollonio et al., 2024).

Colour Code	Uncertainty	Description
1	Lowest uncertainty (~0 to 14% uncertain)	The analysed feature of the 3D model is derived mainly from good-quality, REALITY-BASED DATA which reach the target LoD.
2	Low uncertainty (~14 to 28% uncertain)	Reliable conjecture based mainly on clear and accurate DIRECT/PRIMARY sources which reach the target LoD. When REALITY-BASED DATA are not available, available but unusable, or do not reach the target LoD.
3,5	Average uncertainty (~28 to 57% uncertain)	Conjecture based mainly on INDIRECT/SECONDARY SOURCES, which reach a sufficient LoD, or logical deduction/selection of variants. When DIRECT/PRIMARY SOURCES ARE AVAILABLE, but minimally unclear, damaged, inconsistent, inaccurate, or do not reach the target LoD.
5,5	High uncertainty (~57 to 86% uncertain)	Conjecture based mainly on INDIRECT/SECONDARY sources which reach the target LoD. When DIRECT/PRIMARY SOURCES ARE NOT AVAILABLE or unusable.
7	Highest uncertainty (~86 to 100% uncertain)	Conjecture based mainly on personal knowledge due to missing or UNREFERENCED SOURCES.
\	Abstention	Not relevant, not considered, left unsolved, missing data, and missing conjecture (does not count for the calculation of the average uncertainty).

Fig. 39 The scale of uncertainty with 5 (+1) levels, which does not consider authorship (Apollonio et al., 2024).

It can therefore be easily concluded that the methods mentioned above only describe uncertainty in the geometric form of objects. While this is likely the most significant factor, it is not the only one. In another publication, Apollonio et al. discuss the reconstruction of the urban space of Piazza delle Erbe in Verona. Several factors were considered when estimating uncertainty: Geometry (relating to dimensions and formal features of the object), Constructive System (including construction technology, stratigraphy, manufacturing systems, etc.), Surface Appearance (covering visible material features such as colour, roughness, and reflectivity), and Position (referring to the location of the building or architectural element in relation to its context). Additionally, an initial assumption was made regarding the Level of Detail (LoD) indicator in each area (Apollonio et al., 2024).

Level of Hypothesis (LoH = LoD - LoI)		Level of Information (LoI)		Traditional Scale	Level of Detail (LoD)	
Compliant to source (Also if LoH is negative)	0	Known existence	1	N.A.	Symbolic geometry	1
Feasible assumptions	1	Locatable	2	1:5000	Emblematic geometry	2
	2	General information about appearance	3	1:500	Diagrammatic geometry	3
	3	Freehand drawings, paintings, photographs	4	1:200	Reduced geometry	4
	4	Survey drawings, close-up photographs	5	1:100	Simplified geometry	5
	5	Detailed drawings, photogrammetry	6	1:50	Detailed geometry	6
	6	Detailed drawings, photogrammetry	7	1:10	Highly detailed geometry	7
	7	Highly detailed drawings	8	1:5	Compliant to building parts	8
Completely speculative	8	Point clouds from 3D scan	9	1:1	Geometry with all distortions	9

Fig. 40 Matrix of levels for hypothesis estimation in hypothetical CHML reconstructions (Hauck & Kuroczyński, 2014).

LoD is a concept rooted in computer graphics, which refers the to the different levels of complexity and precision used in models. LoD is used to improve performance by adjusting the detail of a 3D model depending on how close the viewer is or the resources available. When something is viewed up close, a higher level of detail is required, but when it is far away, the detail is reduced to conserve processing power. The LoD concept is also used in architecture design, but with slightly different meanings and in the Building Information Modelling (BIM) context. In architecture, LoD helps convey the various stages of a project, ranging from rough conceptual designs (LoD 100) to highly detailed, construction-ready plans (LoD 400), and eventually as-built representations (LoD 500) that reflect the final structure (Abualdenien & Borrmann, 2022). In digital reconstructions, both definitions can be assumed to be correct. In the case of the aforementioned case study of Piazza delle Erbe, this factor was used in three categories (geometry, surface appearance and constructive system) to represent the individual definitions of each LoD level shown in Fig. 38. LoD is not applicable in the estimation of object positions.

For the LoD for object geometry, the researchers used the existing CityGML standard, which describes varying degrees of visualisation of buildings in the context of urban modelling, ranging from a flat projection on a map (LoD 0), simple solids with defined height and roof form (LoD 2) to detailed models with interior elements (LoD 4). The LoD does not affect the value of the uncertainty itself, but its knowledge is important in interpreting the visualisation of the reconstruction. The uncertainty for the objects in this case study was calculated as the arithmetic sum of the uncertainty estimated for each category (see Fig. 19), but using 5(+1) levels on the uncertainty scale (see Fig. 39).

While the method itself can be replicated, the overall workflow requires more attention, particularly in relation to the criteria set at the start of the project, which should be considered during the reconstruction process. Another important observation is that models with the same uncertainty value can hold different levels of scientific significance. From the perspective of the knowledge represented in the model, reconstructions with a higher level of detail convey a greater amount of information. The uncertainty index helps assess the reliability of the underlying hypotheses. One final factor that has been overlooked is the ratio between the knowledge contained in the source material and its interpreted form in the reconstruction. It is possible that the sources provide a significantly higher level of detail than what is needed for the reconstruction, meaning simplifications must be made. This concept was described within Cultural Heritage Markup Language (CHML) using three variables: Level of Hypothesis (LoH), Level of Detail (LoD), and Level of Information (LoI) (Hauck & Kuroczyński, 2014). LoI refers to the knowledge available from the sources, while LoD relates to the geometric assumptions in the reconstruction. The difference between the two gives the LoH value, indicating the degree of compliance between the reconstruction and the sources (see Fig. 40). This indicator can give a much better indication of the scientific value of a project, where a value of LoH = 0 means maximum use of knowledge from the source, positive values mean greater ingenuity in hypothetical solutions and negative values mean the omission of details contained in the sources.

C. Creative 3D modelling and visualisation of findings

The classification and documentation of source interpretation are central to the process of recording digital reconstructions. However, from a scientific perspective, the modelling process and visualisation methods should also be given significant attention. 3D modelling is a creative process that can involve a range of techniques and software tools. The reasoning behind the choices made regarding these technical aspects can be a valuable topic for documentation. Unfortunately, this area is often either overlooked or limited to a simple mention of the software used, especially in database records (Münster & Prechtel, 2014). The scientific community also seems to be just beginning the process of investigating the research methods used in terms of creative 3D modelling (*Glossary – CS3DP*, n.d.; Münster et al., 2024a), as a shared thesaurus is lacking (Fallavollita et al., 2024). It is also not entirely clear whether the choice of 3D modelling techniques and software can have a direct impact on the quality of the 3D model and the choice of documentation methods.

C.1. Techniques and representation methods

The programme choice alone does not determine how the reconstruction will be performed. The further model performance indicators are its representation in 3D space, as well as used modelling techniques. The representation of the model depends largely on the export format used to present the model and the 3D viewer used. In turn, the modelling techniques and the choice of 3D software itself influence the methods used to create and store geometry information (Münster et al., 2018a).

Model representation methods can be classified into different categories, such as the type of topology or connectivity of vertices. This includes vertices in space as a point cloud, vertices connected by lines as a wireframe, lines forming polygons as boundary representation (B-REP), and polygons connected into solids as volume representation (V-REP). Another category is the type of geometry representation, such as NURBS, mesh, or point cloud. Choosing the right technique can greatly simplify (or complicate) the process of achieving accurate results. Since creating a 3D model often involves using more than one technique, the second-level classification field may contain multiple values:

- Polygonal modelling:
  This type of modelling builds 3D objects out of smaller components called "tris" (triangles) or "polys" (polygons). Each poly or tri is a completely flat shape that is defined by the position of its vertices (or points) and its connecting edges (Spatial Team, 2019).
- NURBS and curve modelling
  NURBS is shorthand for non-uniform relational B-spline. It's a mathematical model that uses basis splines (B-splines) to represent curves and surfaces. It's suited for models where a high degree of accuracy is required (Cherie Tan, 2021).
- Object oriented modelling
  A technique based on the manipulation of ready-made components (e.g. walls, roofs, windows, but also cube, sphere, etc..) that are then modified via built-in editing parameters (Own studies).
- Boolean modelling
  In this approach the geometry of an object is created by taking two objects and making them a new one; either by cutting one out of the other, combining the two, or using the negative space of the intersection as the new object (Arash Naghdi & Payam Adib, 2021).
- Laser scanning
  In this technique, a real object is laser-scanned to create a digital representation of it. The scanning process is usually quick and easy, but the geometry created needs to be cleaned up before use (Arash Naghdi & Payam Adib, 2021).
- Photogrammetry
  With this technique we use a camera and photograph an object multiple times from all angles in a lighting condition that is as even as possible. Then we feed these images into a program that interprets them and generates a 3D representation of the object (Selin, 2020).
- Digital sculpting
  Sculpting uses vertices, faces and edges to separate the shaping process from the more technical details of worrying about the individual elements. Instead of manipulating based on selection we have brushes. The brush has an influence area and more organically reshapes the geometry based on the brush type and settings (Arash Naghdi & Payam Adib, 2021).
- Procedural modelling
  Procedural techniques are code segments or algorithms that specify some characteristic of a computer-generated model or effect. For example, a procedural texture for a marble surface does not use a scanned-in image to define the colour values. Instead, it uses algorithms and mathematical functions to determine the colour (Ebert et al., 2002).

After completing this classification, a research group from the University of Bologna introduced their own classification of methods (see Fig. 41), which clearly distinguishes between representation methods and modelling techniques (Fallavollita et al., 2024). The criterion used to divide these two categories is also relevant. In terms of modelling techniques, the basic classification considers the factor that drives geometry creation, separating techniques into designer-driven, constraint-driven, and algorithm-driven approaches. The techniques mentioned in the author's earlier classification have been assigned to the corresponding subgroups. Alternative classifications, which include modifications to modelling history or output prediction, are also presented.

For representation methods, there is no single main classification but rather three equivalent systems (see Fig. 41). These correspond to the criteria of geometry continuity (discrete or numerical), mathematical formulation (implicit or explicit), and morphology (solid, surface, wireframe, or volume). These classifications provide insight into the possible analytical methods that can be applied to the model. For instance, a discrete (numerical) model allows for in-depth analysis of graphical construction methods, whereas a numerical representation may only provide approximate results. In the case of morphological classification, the representation helps us understand how the software displays geometrical shapes. If, for example, the morphological representation includes solids, it becomes possible to evaluate whether the shapes shown are correct and represent closed, solid elements.

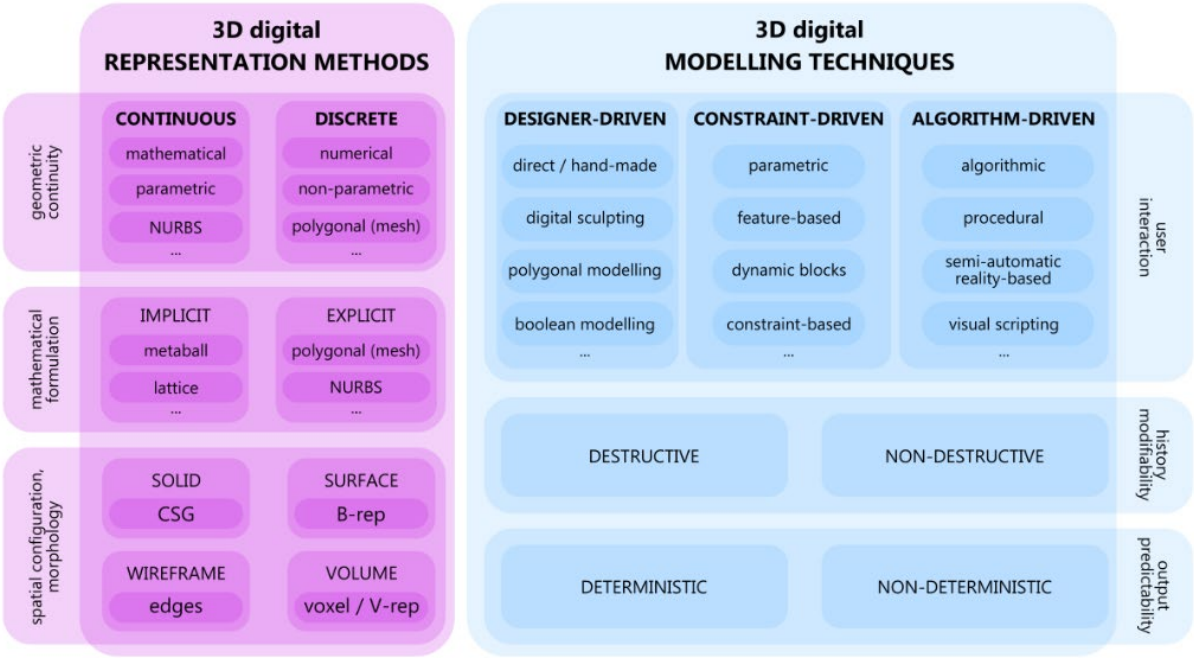


Fig. 41 A simplified taxonomic scheme of the 3D Digital Representation Methods and 3D Digital Modelling Techniques (Fallavollita et al., 2024).

C.2. 3D Software

3D modelling software can impose limitations on the possible modelling techniques and documentation methods. The choice of programme for a reconstruction project should be aware of the implications. On the other hand, technological development is advancing much faster than it once did (Kirpes et al., 2022). New versions of the software are released almost every year, and new 3D modelling tools are constantly emerging on the market. Additionally, the number of scientific issues related to 3D modelling is growing, with a shift towards making 3D data more accessible to the general public (see Fig. 42). This is why it's crucial to understand the project's objectives from the outset and select tools with appropriate features for the task.

S. No	3D Product Model Research Themes	1940s–1960s	1970s	1980s	1990s	2000s	2010s	2020s
1	Product Design	3	4	12	15	3		
2	Design for Assembly	3			2	15	1	
3	Data Processing		2	6	1	2	11	
4	Geometric Dimensioning and Tolerancing		1	3	1	11	15	3
5	Assembly Sequence Planning			1	2	9	21	1
6	Virtual Assembly/Virtual Reality				6	11	10	
7	Assembly line/station layout planning				7	6	8	3
8	Interpolation between 2D and 3D Models				2	4	3	1
9	Reverse Engineering/Scanning Technology				2	1	3	1
10	Assembly Feasibility				1	2	1	
11	Web-Based Applications					9	4	1
12	Virtual Training/Work Instructions					2	9	2
13	Augmented Reality					2	12	7
14	3D Model Library					1	11	1
15	Disassembly						3	
16	Artificial Intelligence and Digital Twin						1	7

Fig. 42 Three-dimensional (3D) product model research themes evolution with journal article count according to the study of Kirpes et al. from 2022.

Digital 3D reconstructions demand a high level of organisation and thorough documentation of each step, as different programmes may handle the process in various ways. To explore this, the use of different software in the field of 3D cultural heritage was studied to highlight the prevailing trends.

One of the first studies that captured the subject was "Sketchfab Cultural Heritage User Survey 2019 Results" [66] (Flynn, 2019). The survey was conducted by 3D model publication and visualisation service, Sketchfab.[67] It is a platform that is one of the most successful services in the 3D web-visualisation sector in the world. According to the report, nearly 97,000 digital heritage files have been uploaded to Sketchfab by the time of the study. The questions were addressed solely to users associated with 3D models of cultural heritage. The survey was conducted under the assumption of a significant predominance of users digitising monuments, so the questions about 3D programmes were spread between photogrammetry programmes and editing programmes. As the digitisation of objects is not the main focus of this study, only the results for 3D editing software were analysed.

38 out of 239 responses declared no use of 3D model editing software (indicating the uploading of models automatically acquired by photogrammetry or laser scanning). Besides, many software names specify software that does not specialise in traditional modelling but is more in visualisation, point cloud processing, model mesh editing, or digital sculpting. The most popular program has been proven to be the free 3D graphics software Blender, mainly based on a polygonal modelling approach.[68] The programme's code is open and can be customised by users themselves. A robust community has grown around Blender, enabling the programme to evolve to combine art and technology (Şengünalp & Sarıhan, 2024). The software possibilities also encourage researchers to create custom plug-ins that apply to the cultural heritage sector (Bossema et al., 2023; Demetrescu et al., 2023). The following two items in the survey included commercial software: Z-brush, an affectionate tool for digitally sculpting 3D solids produced by Maxon,[69] and Max (also called 3DS Max), a commercial alternative to Blender produced by Autodesk.[70]

[66] The survey results were available online: https://docs.google.com/presentation/d/1avExQtbfl6vDCFyo5VgSyBy638BjdDTAIhw79ClHT5A (accessed 19 October 2022). Unfortunately, due to changes with regard to platform owners and policies, as of today (05 October 2024) the survey results are no longer public.

[67] https://sketchfab.com/ (accessed 23 September 2024).

[68] https://www.blender.org/ (last accessed 05 October 2024).

[69] https://www.maxon.net/en/zbrush (last accessed 05 October 2024).

[70] https://www.autodesk.com/products/3ds-max/ (last accessed 05 October 2024).

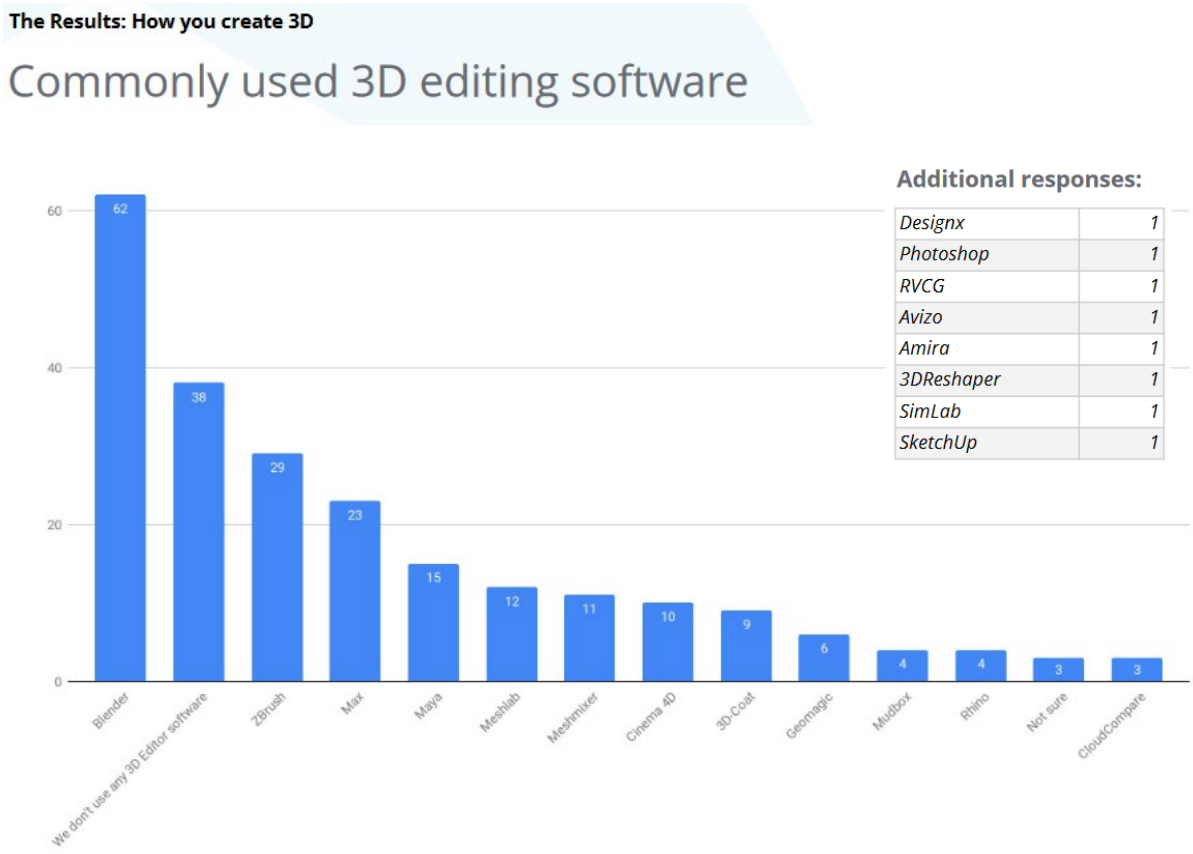


Fig. 43 Results of the Sketchfab Cultural Heritage User Survey (2019) on the question about the 3D modelling software used by the users.

The next step involved conducting a practical study in this area. To achieve this, the 3D repository for cultural heritage models, developed as an initial attempt to create an infrastructure platform for publishing 3D digital reconstructions, was utilised (see Chapter IV. A.). In collaboration with the DFG 3D-Viewer project, the repository collected 266 records of 3D models, which contain a total number of the 301 3D software used (one entry could contain multiple 3D software assigned). The repository was open to all, but its primary users during the two years of operation were project partners of the DFG 3D-Viewer. These included LMU Munich, providing models in the field of art history; BTU Cottbus-Senftenberg, contributing models from architecture; the University of Cologne, offering archaeological models; and the Deutsches Museum Munich, focusing on models from the history of technology. Additionally, students from digital reconstruction courses at Hochschule Mainz, Warsaw University of Technology, Technical University of Lodz, the University of Bologna, Porto School of Architecture, and Universitat Autònoma de Barcelona also used the repository. Researchers from Hochschule Mainz and Friedrich Schiller University Jena also contributed, publishing scientific reconstruction projects.

The final step involved examining set of 595 scientific articles to identify occurrences of the names of specific 3D modelling software mentioned in the text. The method followed the same procedure outlined in Chapters I.A.1. and I.A.2.. However, the pool of articles was expanded to include additional references used in this study, provided that a digital file was available for automatic analysis. The names of the programs that were analysed were identified based on the two previous studies and enriched by items identified during the manual reading of the source materials, resulting in a list of 38 programs used for digital 3D reconstruction. The study revealed 3DS Max as a leader among 3D software used in the cultural heritage field, with occurrence in 98 out of the 595

publications surveyed. The next spot is held by another Autodesk programme AutoCAD[71]. However, AutoCAD is primarily a computer-aided design (CAD) tool, more commonly used for creating technical drawings than 3D models, which may render its ranking somewhat misleading. Third on the list was Sketchfab's survey leader, Blender, which appeared in 68 of the publications surveyed. It is important to highlight that this study covers usage over an extended period, starting as early as the 1990s. As a result, software that entered the market earlier, such as AutoCAD (released in 1988) or 3DS Max (originally known as 3D Studio and released in 1990), naturally has an advantage over newer software like Rhinoceros (1998) or Blender (released as an open-source programme by the Blender Foundation in 2002).

To observe a general trend, incorporating both current and historical data, the results of the three studies were compiled into a table (see Fig. 44). The table displays the total number of occurrences for each programme and their percentage share of the overall sample studied. The rows with programmes that are used for manual 3D modelling are marked with a darker background colour, as it is the manual modelling techniques that are the main focus of this work.

Additionally, a vertical column graph illustrates the total occurrences, visually representing the most and least frequently used programmes in digital 3D reconstructions. This led to the following list of the most frequently used programmes:

1)	Blender	176	12,97 %
2)	3DS Max	132	9,73 %
3)	AutoCAD	105	7,74 %
4)	ArchiCAD	97	7,15%
5)	SketchUp	82	6,04 %
6)	Rhino	77	5,67 %
7)	Maya	73	5,38 %
8)	Unity	57	4,20 %
9)	Z-brush	55	4,05 %
10)	Cinema4D	53	3,91 %
11)	Metashape	50	3,68 %
12)	Meshlab	47	3,46 %
13)	Revit	43	3,17 %

[71] https://www.autodesk.com/campaigns/autocad-family (last accessed 06 October 2024).

Software	Software Type	Sketchfab Survey	WissKI 3D Repository	Literature Review	Summary	
3D-Coat	3D Sculpting	9	0	5	**14**	**1,03%**
3DReshaper	3D Point Cloud	1	0	3	**4**	0,29%
3DS Max	3D Modelling	23	11	98	**132**	**9,73%**
Amira	Visualization	1	0	19	**20**	1,47%
ArcGIS	3D GIS	0	0	28	**26**	1,92%
ArchiCAD	BIM	0	57	40	**97**	**7,15%**
Artec Studio	3D Scans	0	6	1	**7**	0,52%
AutoCAD	CAD	34	0	71	**105**	**7,74%**
Avizo	Visualization	1	0	4	**5**	0,37%
Blender	3D Modelling	62	46	68	**176**	**12,97%**
BodyPaint3D	3D Painting	0	0	1	**1**	0,07%
Cinema4D	3D Modelling	10	12	31	**53**	**3,91%**
Cloud Compare	3D Point Cloud	3	2	23	**28**	2,06%
Faro Focus 3D	3D Scans	0	0	15	**15**	1,11%
Geomagic	Organic 3D Design	6	0	28	**34**	2,51%
Geomagic Designx	3D Scans	1	0	5	**6**	0,44%
Grasshopper	Algorithm 3D Modelling	0	1	21	**22**	1,62%
Laser Control	3D Scans	0	6	3	**9**	0,66%
Light Form Modeller	3D Scans	0	0	1	**1**	0,07%
Maya	3D Modelling	15	0	58	**73**	**5,38%**
MayaArch3D	3D GIS	0	0	15	**15**	1,11%
Meshlab	3D Meshes Editing	12	0	35	**47**	3,46%
Meshmixer	3D Meshes Editing	11	0	4	**15**	1,11%
Metashape	Photogrammetry	0	16	34	**50**	3,68%
Mudbox	3D Sculpting	4	0	5	**9**	**0,66%**
Polycam	3D Scans	0	1	0	**1**	0,07%
Reality Capture	Photogrammetry	0	10	14	**24**	1,77%
Recap	3D Scans	0	0	14	**14**	1,03%
Revit	BIM	0	3	40	**43**	**3,17%**
Rhino	NURB 3D Modeling	4	21	52	**77**	**5,67%**
Simlab	Visualization	1	0	4	**5**	0,37%
SketchUP	3D Modelling	1	31	50	**82**	**6,04%**
Unity	Game Engine	0	0	57	**57**	4,20%
Unreal Engine	Game Engine	0	1	24	**25**	1,84%
VG Studio	CT Scans	0	2	4	**6**	0,44%
XYZscan Handy	3D Scans	0	1	0	**1**	0,07%
Z-brush	3D Sculpting	29	4	22	**55**	**4,05%**
Zeiss RealScan	3D Scans	0	3	0	**3**	0,22%
	Number of studied elements:	228	234	595	**1057**	

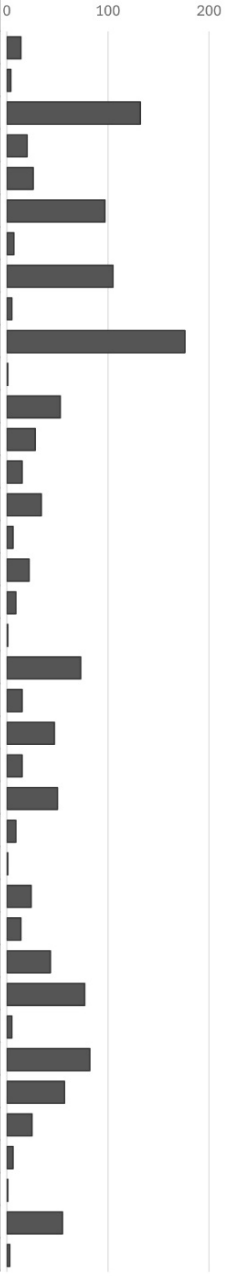


Fig. 44 The table presents the total number of occurrences of 3D programs in each study and the overall total and percentage of the entire study. On the right-hand side, a column graph displays the number of occurrences for each program. Rows with a dark background highlight the 3D programs used for manual 3D modelling, while the other programs focus on automatic or semi-automatic modelling or visualisation.

The programs were also classified based on their modelling method. Those primarily relying on manual 3D modelling were highlighted with a dark background in the table rows. These programs were then selected for further research using the documentation methods discussed in the next chapter. But before that, it was also decided to look at the distribution of BIM programmes, which have great potential for internal documentation.

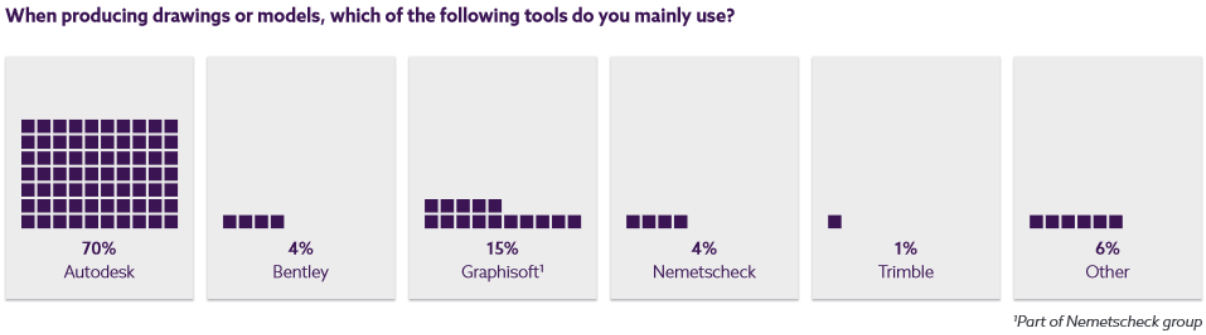


Fig. 45 Graph illustrating the distribution of users of the various BIM programmes between the different software producers according to the 2019 National BIM Report by NBS.

Especially HBIM technology has the great potential of in the documentation of digital reconstructions (Bruno & Roncella, 2019; Kuroczyński et al., 2019; Murphy, 2012). Unfortunately, no documents or reports were found for HBIM, so a general national report on BIM software on global scale prepared by the NBS was chosen for further analysis (Richard Waterhouse et al., 2019). The report collected responses from nearly 1,000 respondents. According to the report, the BIM market is entirely dominated by Autodesk solutions (70%), which illustrates. From Autodesk products in BIM industry, the most popular is Revit[72] (46%). Revit was developed to enable architects and building professionals to design and document buildings using a parametric 3D model. This model incorporates both geometric and non-geometric details related to design and construction, a process commonly referred to as Building Information Modelling (BIM). In second place is Graphisoft Archicad[73] with a score of 15%. Archicad is a software tool for architects working in the architecture-engineering-construction (AEC) industry who design buildings from the conceptual phase to the construction phase. This is followed by various Autodesk software products, AutoCAD[74] (14%) and AutoCAD LT[75] (10%), which are used for the adoption of BIM technology, although their main purpose is the production of 3D drawings. Further positions in the ranking have not been considered because BIM technology is not very popular in digital reconstruction, so the chances of models from less popular software are very low. AutoCAD and AutoCAD LT were also not considered further, as they are not typical 3D modelling software.

The use of 3D programmes for digital reconstruction is distributed quite unevenly. As previously mentioned, each programme is characterised by different methods of representing geometry and creating 3D models. It is suspected that the choice of software can significantly influence the reconstruction process and the documentation itself. In particular, technological advancements are raising community expectations for the introduction of automatic documentation methods that streamline and accelerate the workflow. There is also a growing demand for the integration of these tools directly into 3D software (Demetrescu et al., 2023; Felicetti & Lorenzini, 2011; Siddique et al., 2023). However, without complex workflow and additional 3D software tools, can they not cope with model documentation to any degree? Of course, I also have programmes that have been developed precisely for the documentation of objects and design decisions, such as BIM programmes, but in this case, can the same workflow be used for historical research and reverse engineering?

[72] https://www.autodesk.com/products/revit/ (last accessed 05 October 2024).
[73] https://graphisoft.com/solutions/archicad/ (last accessed 05 October 2024).
[74] https://www.autodesk.com/products/autocad/ (last accessed 05 October 2024).
[75] https://www.autodesk.com/products/autocad-lt/ (last accessed 05 October 2024).

C.3. Impact of the 3D modelling tool on documentation method

Each 3D software carries specific implications. For instance, programmes in the BIM category allow for storing object properties within the internal model, while those based on NURBS geometry enable mathematical analyses of geometric accuracy. However, as the study revealed, manual polygon modelling tools are the most common software used for reconstructions, and they are not typically designed for performing analyses or preparing documentation. Consequently, the decision was made to test the capabilities of selected 3D modelling software in these areas. The study is based on selecting people specialising in different 3D software to perform a 3D reconstruction of a simple object. Steps related to collecting sources, their preliminary analysis and classification will be carried out before the materials are handed over to the modelling soba. In this way, it will be possible to see whether the very documentation of the sources can be valuable material for the presentation of reconstruction knowledge. The analysis included software for manual 3D modelling from the top 13 programmes selected in the previous study. Due to the limited possibilities in terms of finding willing modellers to take part in the case study, the final list of programmes examined included:

1. Blender (2 modellers);
2. Archicad (1 modellers);
3. SketchUp (2 modellers);
4. Rhinoceros 3D (1 modellers);
5. Cinema4D (1 modeller).

The study was prepared in collaboration with Irene Cazzaro, who developed the method for estimating and visualising reconstruction uncertainty[76] and participated in the study as one of the modellers.

C.3.1. Object of interest

The site chosen for the Case Study was the former Synagogue in Speyer.[77] The building was consecrated in 1104, initially consisting only of a men's section. A women's building was added in the mid-13th century. The synagogue survived until the second half of the 17th century when it was destroyed during the Palatinate War of Succession. Currently, the building is preserved as ruins, and it is a part of Museum SchPIRA (Fig. 46). The phase to be reconstructed was set to the 13th century, as reconstructions of the building in this phase (Late Romanesque) had already been developed by AI MAINZ (Kuroczyński et al., 2023), or Architectura Virtualis.[78] It allows us to conclude the collection phase and process the sources faster, although it was not the main topic of study. Including previous reconstruction could also serve as a reference material for modellers.

The collection of written sources included articles, books, an archaeological report, leaflets, and photographs from the site's information boards. Three drawings were gathered to document the site and illustrate possible reconstructions. Additionally, several potential analogies were included, showing examples of solutions for the entrance portal, the columns and their capitals, and the geometry of the roof. The collection also includes a package of site photographs and visualisations from previous reconstruction projects. For the reconstruction conducted by AI MAINZ, a 3D model was also available. A complete list of the materials provided to the modellers can be found in APPENDIX 3. In addition to the source materials, the modellers were given a

[76] See Chapter 3 "Case study: an uncertainty scale to be used in the DFG 3D Viewer" (p. 137-179) in: Cazzaro, Irene (2023) Digital 3D reconstruction as a research environment in art and architecture history: uncertainty classification and visualisation, [Dissertation thesis], Alma Mater Studiorum Università di Bologna. Dottorato di ricerca in Architettura e culture del progetto, 35 Ciclo.

[77] Wikidata record of former Synagogue in Speyer: https://www.wikidata.org/wiki/Q64825449, last accessed 09 October 2022.

[78] http://www.architectura-virtualis.de/rekonstruktion/synagogespeyer.php?lang=de&img=6&file=0, last accessed 09 October 2022.

handbook outlining how to utilise the provided resources, carry out the reconstruction, and complete the required tasks related to documentation and the submission of the 3D model (Bajena et al., 2022).

Fig. 46 The current state of the Speyer Synagogue. Author's photo from February 2024.

C.3.2. Premises of the study

As demonstrated in the study of the methodological steps in the reconstruction process (see p. 38), the initial step always includes object segmentation into semantic elements. This segmentation was also conducted before the materials were handed over. The segmented elements were visualised using the accompanying sources. The external visualisation of the reconstruction, carried out by Architecture Virtualis, was used to identify elements such as walls, roofs, doorways, windows, beams, and plinths. The internal visualisation further helped to identify features such as the floor, ceiling, cornice, and Aron Hakodesh. Additionally, a drawing from an archaeological report showing the current state was used to extract details of the foundations. It was also decided that some elements would not be required in the reconstruction, such as the elements of the interior design, the lighting in the form of chandeliers or candles, as well as the central element of the synagogue - the bimah.

Fig. 47 Identification of the structural elements of the building.

The extracted elements were classified hierarchically. This was done using Getty Art & Architecture Thesarurus Online (Getty AAT)[79]. It is a structured vocabulary, including terms, descriptions, and other metadata for generic concepts related to art, architecture, conservation, archaeology, and other cultural heritage. Included are work types, styles, materials, techniques, and others. Each term has its own identifier, so creating a classification on this basis can allow the data to be indexed. Without the hierarchical structure provided by Getty AAT, six groups were established to classify the distinguished elements: Surrounding Elements, Surface Elements, Span Elements, Load-bearing and Resistant Elements, Openings, and Religious Building Features. Individual elements from each type, identified by their unique characteristics (see Fig. 48), were placed at the base of the hierarchy:

- Wall types: wall a (other walls), wall b (deductively reconstructed walls),
- Roof types: roof a (hipped roof), roof b (gabled roof),
- Beam types: beam a (hipped roof truss), beam b (gabled roof truss), beam c (ceiling structure),
- Window types: window a (bifora), window b (round window).

[79] https://www.getty.edu/research/tools/vocabularies/aat/ (accessed 24 March 2022).

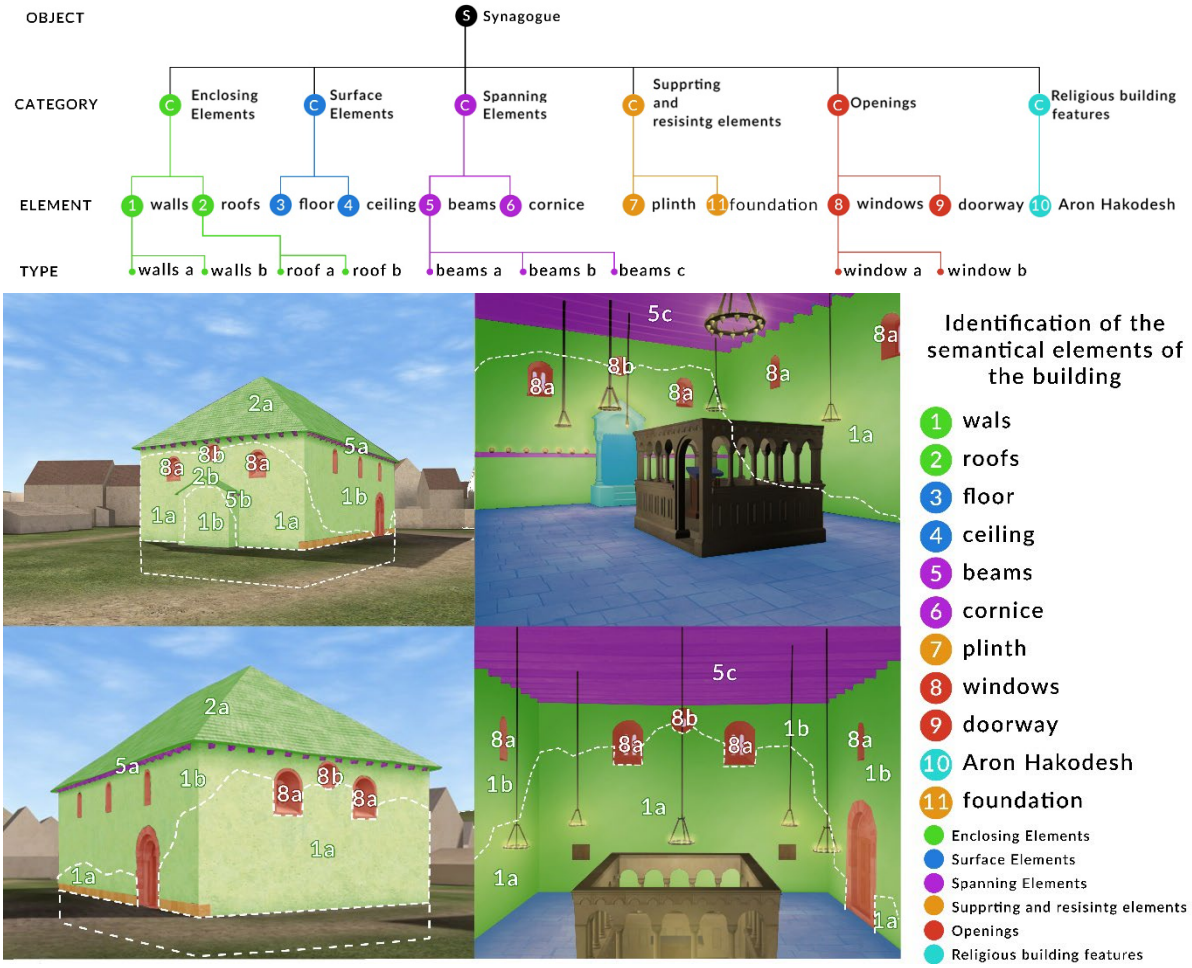


Fig. 48 Scheme of the created hierarchy of structural elements of the building based on Getty ATT with identification of structural elements on the visualisation of the object of study.

A breakdown of the damaged elements (including the buttress of the walls) into those parts that survived and those that did not was also carried out. This subdivision facilitates subsequent documentation and uncertainty assessment and follows the methodology of the Extended Matrix work, which introduced the Stratigraphic Unit (SU) concept for preserved elements and the Virtual Stratigraphic Unit (USV/S) for the hypothetical complement of an element based on deduction (Demetrescu, 2015).

Regarding the model itself, the guidelines indicated that the building would be placed on a platform with dimensions of 25 x 25 m and a depth of 3.0 m. The depth of the foundations should be about 1.5 m. All reconstructed elements should be modelled as an ideal one – based on the right angle and without any curves, which would imitate a more natural form. All elements of the facility were to be textured. The initial package contained five textures, which were to be applied as follows:

- texture_01 - walls, columns in portal, framing and columns of windows, Aron Hakodesh;
- texture_02 - door portal, plinth, cornice, casings of windows;
- texture_03 - floor, stairs in Aron Hakodesh;
- texture_04 - door, ceiling, beams;
- texture_05 – roofs.

In addition, if the programme supported the use of colours to mark surfaces, the colours had to be used according to the following scheme:

- texture01 - R=193 G=174 B= 141, #c1ae8d
- texture02 - R=186 G=121 B=103, #ba7967
- texture03 - R=132 G= 89 B= 72 , #845948
- texture04 - R=90 G= 55 B= 32 , #5a3720
- texture05 - R=119 G=105 B= 96 , #776960

In addition to reconstructing the object's geometry and texturing the model, the modellers were required to implement hierarchical semantics and partitioning in accordance with the provided guidelines. This had to be done using only the built-in tools within the programme. Careful attention also needed to be given to identifying solutions that could potentially be preserved when exporting the file to other formats. The steps taken during the modelling exercise were also to be documented to comparison of the methods and techniques used in the various programs. To facilitate this, the modellers were provided with a templated workflow document (see Tab. 4). In the left column the modeler should describe each step of the process, and the tools used. On the righthand side the modeller should include a screenshot of the step. Modellers are allowed to divide the process in how many steps they need, but it is recommended to fit in the 15 steps. Modellers should keep in mind that the workflow should describe characteristic elements for the used software, not the detailed instructions about basics of the software, while one of the goals of the project is to capture differences between programs.

Tab. 4 Template for the documentation of the workflow

Workflow in "*Name of the software*"	
Description of step 1	Screenshot of step 1
Description of step 2	Screenshot of step 2
Description of step 3	Screenshot of step 3
Description of step 4	Screenshot of step 4

The second task was to evaluate the results obtained according to the uncertainty assessment guidelines given. The evaluation method was developed by Irene Cazzaro, who adopted scale levels based on the classification of sources. The scale defines the hypothesis level of the reconstruction element based on the source materials used. It was expressed in three ways: by colour, numerical value and verbal name (see Fig. 49). Uncertainty visualisation also depends on the level of development of the model: in the case of the Speyer synagogue, a level of uncertainty should be assigned to each element proposed by the structure of the model. As far as the perimeter wall is concerned, it is proposed to divide the still-existing part from the digitally reconstructed one: the former is based on observation and survey, the latter on deduction.

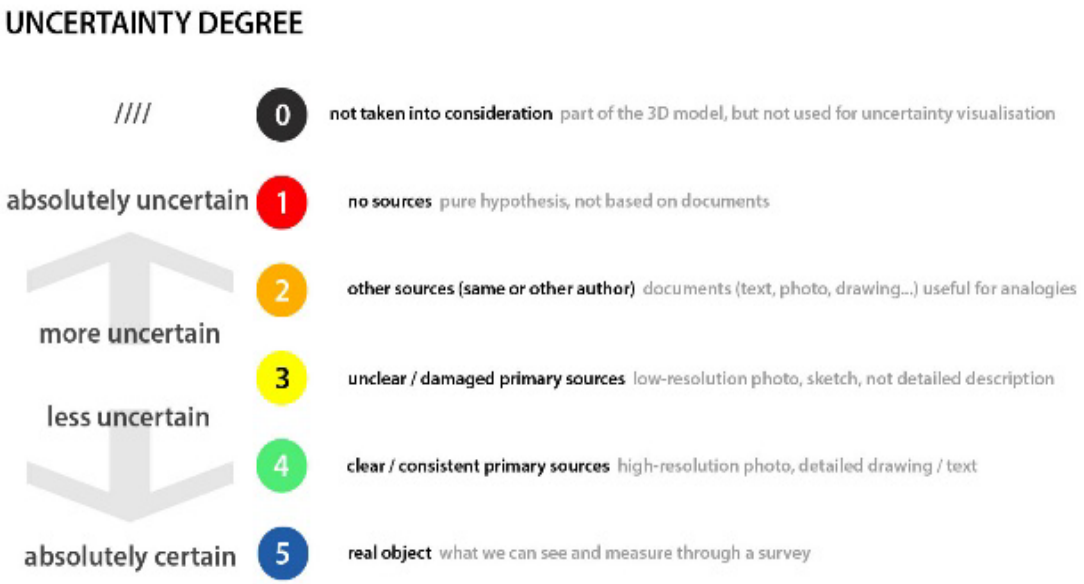


Fig. 49 General uncertainty scale according to the physical or mental operations on the sources used to digital 3D reconstruction (Cazzaro, 2022).

The modellers were asked to try to find a way to implement the uncertainty level to the structural elements of the objects (e.g. create a new parameter to each object) in 3D models. The modellers had free choice in deciding how to include information about the hierarchy, semantics, and uncertainty level of the model.

The final task was to document the reconstruction outside the 3D model as well. A simple documentation form based on the R-A-M method was prepared for this purpose. The form layout provided corresponded to the documentation of the semantic unit of the model. In addition to the fields required by R-A-M (screenshot of the source, reconstruction and verbal argumentation), the form was equipped with fields for the name of the object and a space for uncertainty assessment (see Tab. 5). The form provided was intended to serve as a quick documentation method with a low difficulty threshold that anyone could use as a necessary minimum to document digital reconstructions. Minimal documentation is an essential point in developing digital reconstruction as a scientific tool, even if the scientific community may criticise it. Simple documentation solutions have already been shown to result in at least minimal data on the reconstruction process.(Grellert & Pfarr-Harfst, 2019). This template has been prepared to simplify the documentation process while maintaining the possibility of scientific validation of the reconstitution. It should be mentioned, however, that it was prepared to function as an appendix to the main project documentation, which would at least contain basic information about the project, e.g., in an online repository.

Tab. 5 Template for the documentation of the reconstruction process.

Name of the element with type, *eg. Window type 2*		
Reconstruction	*Image of reconstructed element*	
Used sources	Name of the source, *eg. Photo_location_01*	*Screenshot of the source*
	Name of the source, *eg. Photo_location_02*	*Screenshot of the source*
Uncertainty	Argumentation	Level of uncertainty
Argumentation	Short description of the process of reconstruction with enlightening the challenging part of reconstruction of element	

C.3.3. Obtained results

Each modeller was able to carry out the reconstruction, document the process and include information on the level of uncertainty of at least part of the required hierarchy in the 3D model. The exact reports of the modellers are included in Appendix 4. The results for each modeller are summarised below.

C.3.3.1. Blender

Two modellers prepared a model in Blender, a free 3D program widely used in digital reconstruction projects. Blender is characterised by its use of polygon-based modelling techniques, where mesh elements consist of at least three vertices connected by three edges. The modelling process is object-oriented, allowing for free modification of the polygon mesh. The foundation of the workflow lies in the scene collection system, which organise all geometrical objects, cameras, and lights in the scene. These elements can be grouped into collections, and their visibility can be easily managed by the collection manager.

The first model was prepared by Stefan Wetherington, an archaeologist and computer scientist, during his student internship at the Hochschule Mainz—University of Applied Sciences (see Fig. 50 & Appendix 4 - Blender). He used Blender version 3.0.0. Modelling part took around 20 hours. The model was segmented according to the hierarchy using Blender's built-in sub-collection system. Some of the source material was imported into 3D space and scaled to actual size. Each element was created by adding a geometric object (cantilever, box, cube or cylinder) and then modifying it with operations such as extrusion, scale, copy or merge. For some objects, special attributes called modifiers were used to perform specific actions in a detachable, modifiable and non-destructive manner on the model geometry.

The modifiers used are mirror (allowing the creation of a mirror image of an object), boolean (allowing the geometry of two solids to be joined or subtracted), or array (allowing the creation of a number of copies relative to two axes). Add-ons, which are extensions that enhance the programme's basic functionality, have also been incorporated for more detailed elements. The Archimesh add-on (allowing the import of pre-defined architectural elements) was implemented to create elements such as gables, column capitals and bases, or arches. Material textures were applied to the finished geometry using the UV unwrapping technique. This method involves laying the entire surface of the geometry onto a two-dimensional plane (using the U and V axes), after

which the texture tiles are positioned onto the surface mesh. Documentation was carried out in the collection panel. Each seminal element was given an ID in the element name according to the project guidelines. An uncertainty level was also assigned to the element name following the documentation shown in Tab. 37 in Appendix 4. The documentation in the table took about four hours. The step-by-step workflow is described in Tab. 36 in Appendix 4.

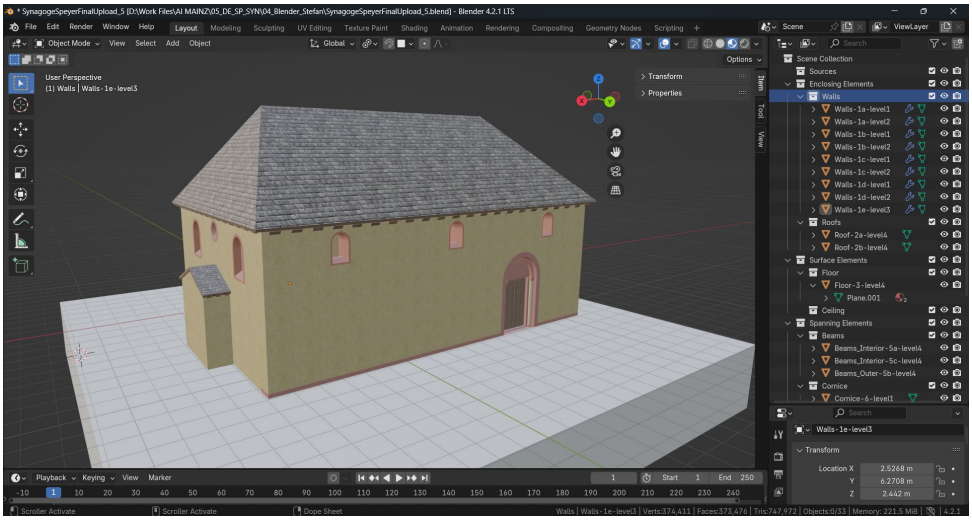


Fig. 50 Screenshot of the model prepared by Stefan Wetherington in Blender. On the right you can see the organisation of objects and collections in the model.

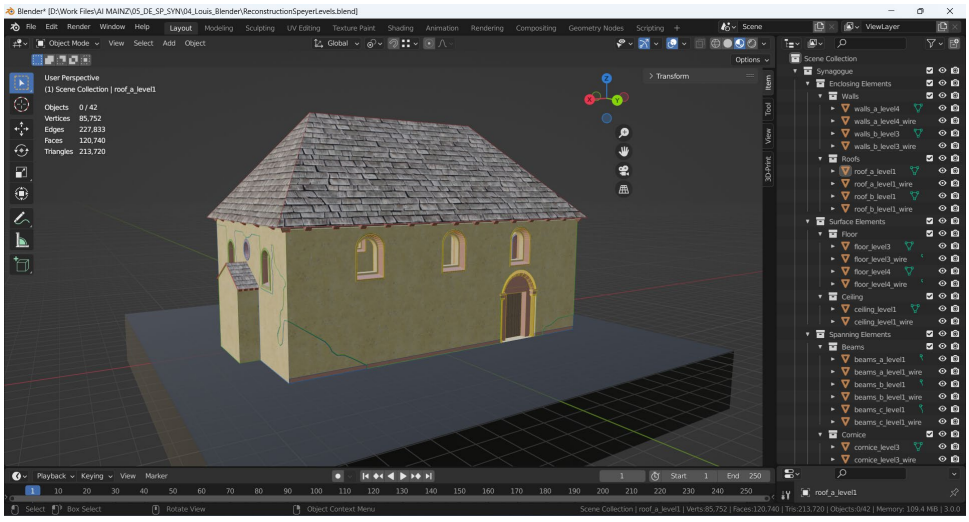


Fig. 51 Screenshot of the model prepared by Louise Tharandt in Blender. On the right you can see the organisation of objects and collections in the model.

The second model in Blender was prepared by Louise Tharandt, a student in the master programme in Archaeology at the University of Cologne, in partnership with the DFG 3D-Viewer project (see Fig. 51 & Appendix 4 - Blender). She used Blender 3.0.3. The modelling part took around 26 hours. The modelling workflow is described in fewer steps, focusing more on the sequence of activities. The file organisation was carried out in the same way as in the previous case. The same object and modifier operations were used; however, the modeller did not use any additional plug-ins this time. One notable difference was the use of the Knife tool to separate the wall geometry into existing and deduced sections. Parts of the floor were also separated similarly. Uncertainty values were assigned in the object names within the collection manager. The key difference was that

naming was introduced not only at the level of object hierarchy but also in the data properties of the internal object group. This distinction is specific to Blender, where object mode affects all objects in the scene, while edit mode allows for manipulation of the geometrical data of a selected object. The exact steps of the workflow process, as well as the documentation of the assigned uncertainty values, can be found in Tab. 38 & Tab. 39 in Appendix 4.

C.3.3.2. | Graphisoft Archicad

The second programme is Graphisoft Archicad, which is BIM (Building Information Modelling) software designed for architects and engineers. Like Blender, Archicad is object-oriented with a polygonal representation in 3D. However, in Archicad, the objects are not basic geometric solids but architectural components such as walls, ceilings, and roofs. Most modifications are made through parameters assigned to the objects, classifying this method as parametric modelling. The organisation of work in Archicad is more complex than in Blender. Since the programme is used for architectural design, the arrangement of reference floor levels is fundamental. These storey levels serve as a basis for positioning objects in relation to height. Another component of organisation is layers, which are similar to collections in Blender, though they do not allow for the creation of hierarchical structures[80]. From the layer level, the visibility of elements can be managed. Additionally, the use of object properties plays a key role in organisation. Each element in the 3D space is assigned several properties that assist in grouping modifications, managing the display of elements with certain properties, and streamlining workflow.

The model was made personally by the author of this work, architect by profession (see Appendix 4 – Graphisoft Archicad & Fig. 52, Fig. 53). The used software version was Archicad 25 International. The modelling part took around 24 hours. The initial workflow began with the preparation of the working environment. As Archicad is based on object-oriented parametric modelling, custom parameters were developed from the outset. These included the assignment of uncertainty properties and object types. A custom classifier was also created, replicating the exact hierarchy from the guidelines and assigning a link that referred to the definition of each term used in the Getty AAT. Most objects were generated using default library options, such as wall, roof, beam, and floor. For windows, doors, and the Aron Hakodesh, custom objects were created using the built-in library tools, and once the desired geometry was finalised, the results were saved as library objects.

In the case of more complex geometries, the morph tool was employed, allowing for free manipulation of the vertices of the solid. Some elements required the use of solid element operations, a feature that acts as a boolean modifier, enabling the subtraction or combination of solid forms. Each component of the model had an associated filler material, one of whose parameters included an attached texture from the guidelines. The textures were automatically mapped by the software, using repetitive tiling at a specific scale. Finally, after all model components were converted into library objects, they were assigned the appropriate classification and uncertainty level. The entire workflow is recorded at Tab. 40 in in Appendix 4.

[80] The study was done in Archicad 25, which doesn't have hierarchical structure in Layers. Later version support organisation of layer into folders.

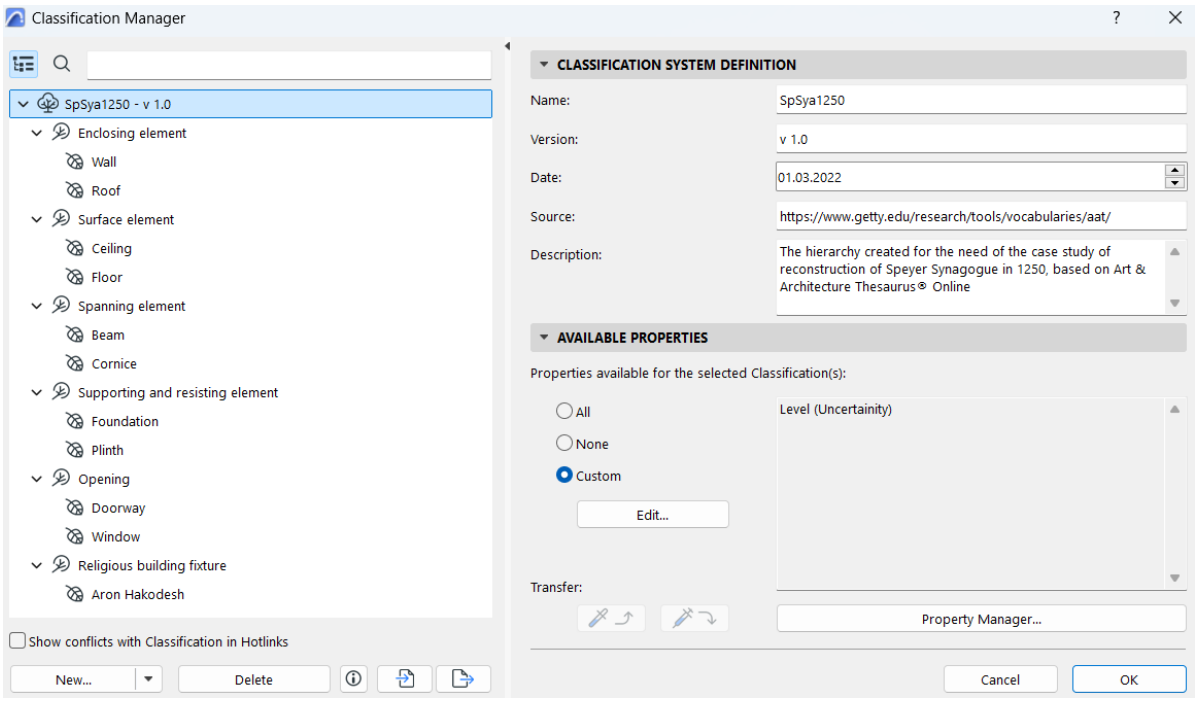


Fig. 52 Hierarchical organisation of building elements based on selected elements from the Getty Art&Architecture Thesaurus in the classification manager of the Graphisoft Archicad software.

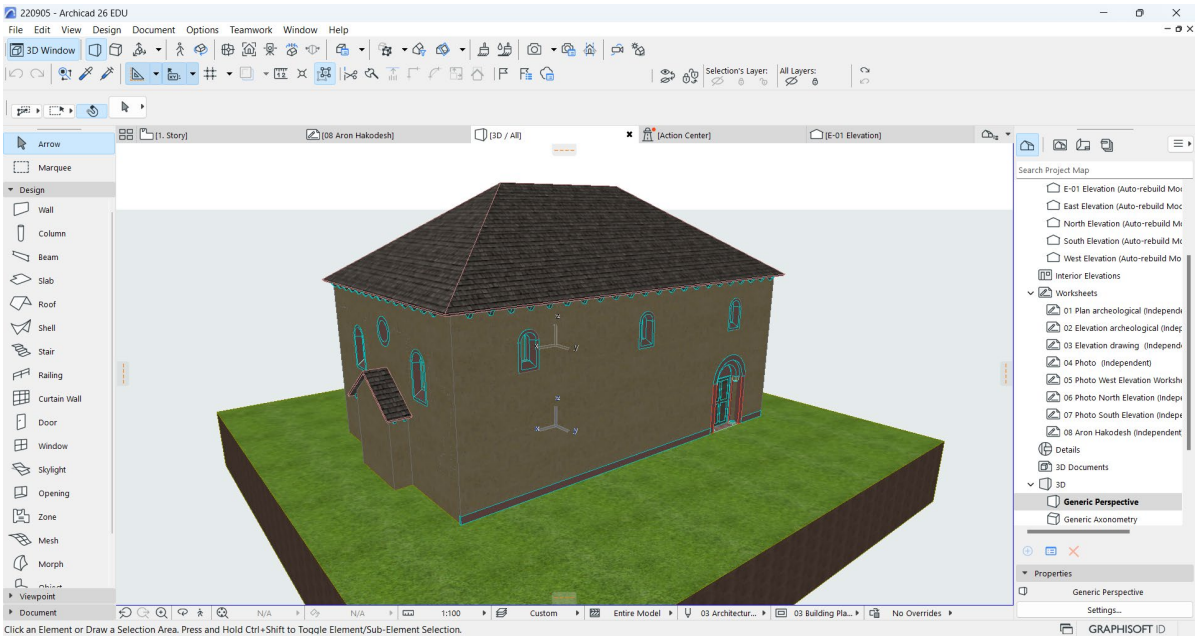


Fig. 53 Screenshot of the model prepared by Igor Bajena in Graphisoft Archicad. Above, the custom classification reflects the hierarchical structure from the guidelines.

C.3.3.3. | SketchUp

SketchUp is a program for fast and sketch-based 3D modelling based on polygons. The basis of modelling here is the handling of lines. The programme is often used in architecture for conceptual design modelling and is intuitive compared to other solutions. The work organisation is centred around a system of tags, which act as layers whose visibility can be manipulated. In addition, SketchUp allows components to be created and stored

in an internal library for reuse within the program. Changes to one component element automatically update all elements of that type in the project. Due to the simplicity of the interface and the ability to efficiently manage many simple objects, the program has also found its way into urban design and has become one of the main programs adapted to the CityGML format documentation standard (Preka & Doulamis, 2016). CityGML is the international standard of the Open Geospatial Consortium (OGC) for the representation and exchange of 3D city models (Groger et al., 2008). It is based on the Geography Markup Language (GML) an introduces the concept of Level of Detail (LoD) of different complexity of object representation in the cities, as well as taxonomies and semantics of data for city 3D models (Costamagna & Spanò, 2013). Therefore, in the case of SketchUp, using a plug-in for the CityGML documentation was exceptionally permitted to analyse the workflow using this documentation standard in a hypothetical digital 3D reconstruction.

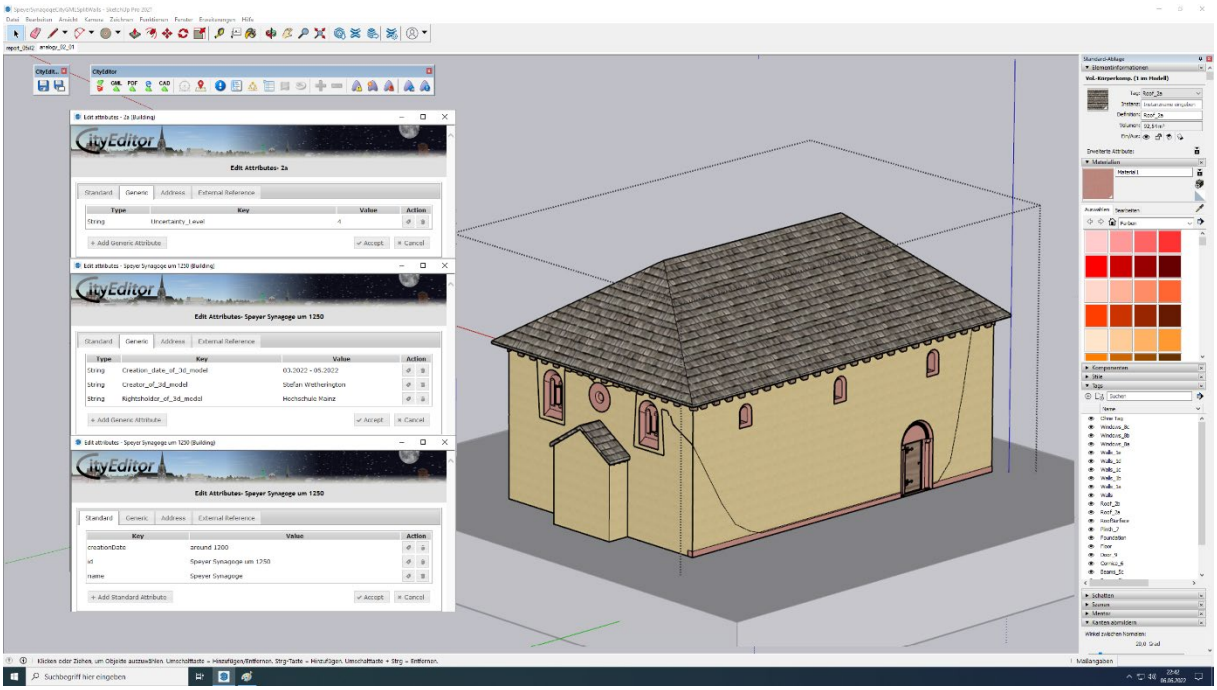


Fig. 54 Screenshot of the model prepared by Stefan Wetherington in SketchUp. On the right, you can see that the tags for each element are organised. On the right, properties are added to grouped geometry with the City Editor add-on.

The SketchUp model was the second contribution to the study of Stefan Wetherington (see Appendix 4 – SketchUp & Fig. 54). The used software version was SketchUp Pro 2021. The modelling part took around 15 hours. This is the first model not based on an object-oriented approach. Each element is created from grouped lines of planes—without grouping, all elements in a scene sharing a standard part (e.g. a vertex or an edge) would form one element. Grouping is crucial in this model, as properties are assigned to groups via the City Editor add-on, which generates a file in CityGML format. In the modelling process, in addition to using lines, tools like the circle tool, push-pull tools, and element copying were utilised. Some repetitive elements were saved as components—grouped elements stored in the programme's library. When one component is edited, changes apply to all instances. The object hierarchy was represented by creating a hierarchy of groups: the entire object was the leading group, within which groups of elements could be accessed, and individual elements could be opened from these groups. Each element was also given a tag or variance. Uncertainty was added as a custom parameter in the City Editor. Materials were applied using the traditional paint bucket method, possibly rescaling texture sizes. Since each geometry plane is treated as a separate element, the programme does not offer the option of automatically decomposing geometry using UV unwrap. Instead, textures can be individually

adjusted on each plane, with options to manipulate their position, rotation, or size. By default, textures are applied using plane mapping and tiling. The workflow and documentation are recorded at Tab. 41 & Tab. 42 in Appendix 4.

C.3.3.4. | Rhinoceros 3D

Rhinoceros 3D (also known as Rhino) is the only 3D programme in the analysis where geometry is created using mathematically determined curves rather than polygons. This modelling method, known as Non-Uniform Rational B-Splines (NURBS), allows for exact geometry, particularly for curves, which in polygonal programmes must consist of polygons and undergo segmentation. As a result, attempts to model specific geometries in polygon-based programmes may fail. NURBS-based programmes are ideal for projects requiring high precision and adherence to specific modules, proportions, and architectural shapes (Di Marco, 2018). The foundation of Rhino's workflow is using layers, where additional attributes such as surface colour, line thickness, or style can be assigned to elements. The modelling process begins with a curve, suggesting a similar workflow to SketchUp. However, while SketchUp operates only with straight lines and merges all intersecting elements into a single object, Rhino treats each newly introduced element as a separate object by default. Modelling can also start by inserting predefined basic shapes or solids, which can be freely modified. Users can unite multiple elements into one or explode complex geometry into smaller parts at any point. Rhino also offers an advantage over other programmes in terms of its ability to quickly analyse models for issues such as cuts or the closure of solids, ensuring the correctness of the created model (Di Marco, 2018).

The Rhino model was prepared by Irene Cazzaro, an architect who has completed the PhD in Architecture and Design Cultures programme in Cycle 35 at the University of Bologna. (see Appendix 4 – Rhinoceros 3D & Fig. 55). The used version of the software was Rhinoceros 5. The modelling part took around 25 hours. In the first instance, the layer structure was organised. This marks the first occasion where layers (or their equivalent functions in other programmes) were not organised by object names but rather by levels of uncertainty. This approach allowed the assignment of a colour code to the layers based on the uncertainty scale provided in the accompanying initial material collection.

In most cases, modelling was limited to creating and extruding a plane for one of the elements' faces. For the roof structure's rafters (beams), elements were copied to the required number, with the edge rafters being rotated. Rounded elements were modelled using circular edge extrusion—a function similar to 'Follow Me' in SketchUp. Holes in the geometry were created using boolean operations. Once the geometry was complete, all components were selected and combined into a single object. Each object had a default set of properties, such as its name, which could be customised. Unfortunately, no method was found to introduce a hierarchical structure for the entire synagogue; instead, only the names of the individual elements were assigned. Dedicated materials were created for all elements of the synagogue using the existing textures from the initial package. The material names reflected their function (e.g. the material for the stone floor tile texture was named 'floor'). Notably, two visualisation methods were introduced: one showing uncertainties based on the attached scale and another displaying the actual materials. Having these two methods within a single model is beneficial for the model itself and subsequent scientific verification of its accuracy.

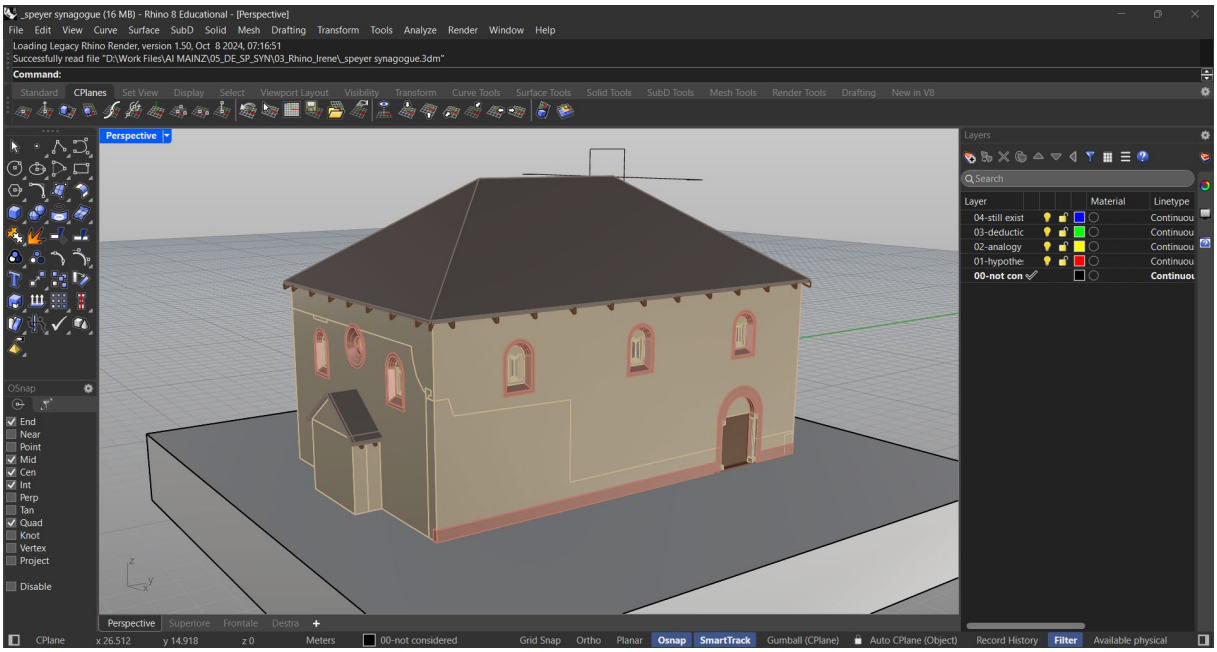


Fig. 55 Screenshot of the model prepared by Irene Cazzaro in Rhino. On the right, you can see the organisation of layers with attributes of surface material and type of lines assigned to each layer.

C.3.3.5. | Cinema4D

Cinema 4D is a commercial software developed by Maxon, offering an alternative to Blender or 3DS Max. Like these programs, it is based on polygonal modelling and uses an object-oriented approach, like Blender. The modelling process typically begins by adding one of the predefined shapes, such as a cube or sphere, which can then be modified in various modes: vertices, edges, or polygons. All objects are organised in a dedicated Object Manager tab, where the modeller can assign different tags. Tags in Cinema 4D function similarly to modifiers in Blender — they apply special visual effects to an object but can be turned off at any time without making permanent changes.

The Cinema4D model was prepared by Maryam Jäger, an archaeologist, as a part of a partnership with the DFG 3D-Viewer project (see Fig. 56 & Appendix 4 – Cinema4D). The software version and modelling time were not reported. The workflow began with organising the object hierarchy in the object manager. Grouping levels were created using 'null objects,' which do not contain geometry. The process of creating building elements was similar to that in Blender. Each object was modelled by placing a solid or shape, which was then modified using various operations to achieve the desired form. Shapes such as boxes, cylinders, cones, and splines were employed. Extrusion and boolean operations were used to modify the shapes. The knife tool was applied to cut holes and divide objects into parts, while the sweep tool was used to create curved elements, allowing the object to be drawn along a specific spline. Materials were assigned to objects as tags. Each object has also been assigned an additional tag specifying the unwrapping of the object planes under the material mapping. Information about the level of uncertainty has been added to the name of each element in the object manager.

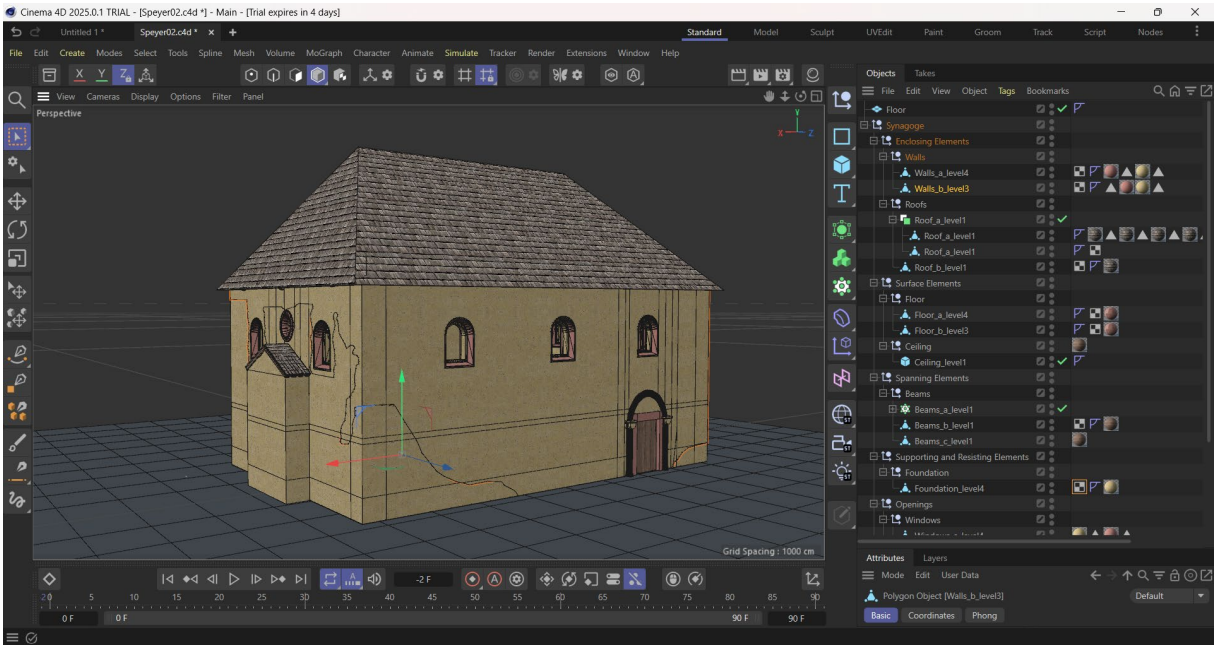


Fig. 56 Screenshot of the model prepared by Maryam Jäger in Cinema4D. On the right, you can see the hierarchical organisation of objects in the object manager.

C.3.4. Comparative analysis of outcomes

The collected digital reconstructions were compared in several aspects. The first objective was to examine how the 3D models differed and assess the influence of human interpretation. If similar results were achieved, it would suggest that developing classified sources could play a role in preserving the outcomes of hypothesised digital reconstructions. To facilitate this comparison, renderings of each model were generated using the same camera settings. The survey revealed significant differences in the proportions, sizes, and positioning of individual model segments that are easily noticeable to the bare eye (see Fig. 57). While it is important to consider that much of the original substance of the building has not survived, and that features like the windows on the longitudinal walls, the entrance portal, and the roof with its trusses are largely hypothetical, the variations in the interpretation of the sources are still substantial. These differences highlight the crucial role that human factor plays in the reconstruction process, even when working with identical source materials, the classification of sources and indication of level of development of the details. Differences were also observed in the materials. Despite using the same textures package, the sizes of the roof tiles varied significantly. This suggests that, to maintain complete information for the reconstruction of a 3D model, it would be necessary to document not only the shape of each object but also the parameters related to the materials used.

The second aspect was to test the potential for organising objects in a file and storing custom information in text form. Most of the modellers used only the element name to implement the reconstruction uncertainty information. Therefore, a check was carried out on the specifications of the programmes regarding work organisation and the availability of tools such as layers, the ability to group elements, the creation of object hierarchies, the introduction of semantic meaning to elements, and the addition of metadata, i.e. textual information, as additional properties to the objects. The results are presented in Tab. 6.

It appears that not every modeller fully utilised the software's capabilities available for the task. This may be due to the tendency to overlook complex file organisation instead of seemingly speeding up the workflow. For

instance, hierarchical organisation in Rhino could have been achieved through sub-layers, while in Cinema4D, the layer system was entirely omitted. Surprisingly, only Archicad included uncertainty information as a custom property, even though nearly every program (except SketchUp) offers this functionality as a built-in feature.

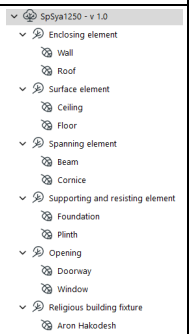
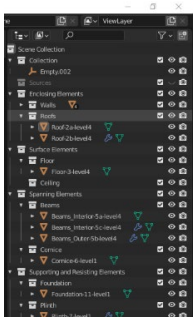
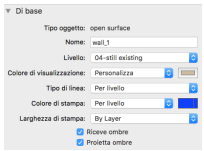
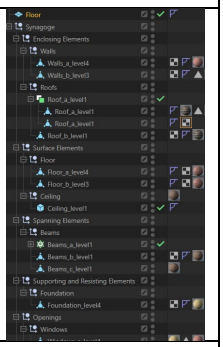
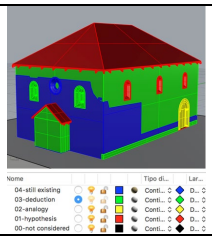
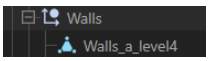
Fig. 57 Comparison of 3D modelling of a hypothetical digital reconstruction created in different 3D modelling software by different modellers based on the same set of sources, their classification and given level of development.

A list of the tasks assigned to the modellers has been compiled, along with the solutions they implemented in the various programs, as shown in Tab. 7. Comments in red highlight where the full potential of the software was not utilised. In conclusion, it can be stated that the 3D programs are equipped with tools that enable the documentation of digital 3D reconstruction based on semantic partitioning. Unfortunately, these functions are not often used, which suggests that even the modellers themselves may not be fully aware of the software's capabilities.

Tab. 6 Characteristics of chosen 3D software with special emphasis on the possible ways of implementation of the model hierarchy and uncertainty level.

	Archicad	Blender	Rhino	SketchUp	Cinema4D
Geometry Representation	Polygons	Polygons	NURBS	Polygons	Polygons
Hierarchy System	As classification manager	As scene collection	As sub-layers	Grouping of groups	Object manager
Semantic	As classification manager	No	No	Provided by CityGML add-on	No
Layers	Yes	No	Yes	As Tags	Yes
Grouping	Yes	Yes	Yes	Yes	Yes
Metadata	As properties manager	As custom properties	As user text attribute	No	As User Data

Tab. 7 Summary of implementation hierarchy and uncertainty level in different 3D software. In red, modellers did not use potential functionalities. The red colour is used to comment on the unused potential of the programme in relation to the task in question.

Software:	Archicad	Blender	Rhino	SketchUp	Cinema4D
Hierarchy: Category	Class in classification manager	Collection	Not implemented, but sub-layers can be used	Group with CityGML name property	As null object in object manager
Hierarchy: Element	Class in classification manager	Sub-collection	Group of surfaces (without naming). Sub-layers could be used for naming	Group with CityGML name property	As null object in object manager
Hierarchy: Element Type	Library object	Object	Object	Group/Component with CityGML name property	Polygon object
Hierarchy: Preview					
Uncertainty Level	New property as integer value	Number and verbal expression in the name of the object and in the data properties, but could be also added as custom property	Layer system with number and verbal expression in the new and colour representation, but could be also added as user attribute	As CityGML custom property assigned to the group, expressed as number	As numerical values expressed in the name of the object, but objects could be sorted on layers assigned to different uncertainty values and value itself could be added as user data
Uncertainty Preview					

C.3.5. Knowledge transfer

Completing the documentation tasks within the 3D program accounted for only half of the overall survey. As most of the programs used are commercial offerings that require an active licence to open, it was also important to examine how the knowledge embedded in the models could be transferred. Data exchange formats are used to facilitate the exchange of information about the 3D models. These file formats are independent of the software they were created and can be loaded into most 3D programs. However, generating such a file involves data processing, compression, and information conversion during export, which carries a degree of risk. Due to the automatic translation of information, parts of the model may become deformed or contain errors. Additionally, much information not directly related to the model's geometry is lost to reduce the file size. Therefore, this part of the study examines whether information such as hierarchy, element naming, and uncertainty levels can be preserved when exchanging files between users.

The tool chosen for this part of the study is the 3D viewer developed in the first phase of the DFG 3D-Viewer project.[81] The solution is based on the three.js framework.[82] This viewer can display up to 11 different data exchange formats. The formats supported by the viewer are listed alongside the export possibilities of the formats from the 3D programs analysed in Tab. 8. Based on the table, six file formats were selected to be tested: .3ds, .dae, .obj, .stl, .fbx and .ifc.

An additional advantage of the chosen 3D viewer is the possibility to view the file's hierarchy, which would allow one to check whether the hierarchical structure of the objects and the information about the uncertainty of the reconstructions (which was most often included by the modellers in the name of the hierarchical element) were maintained.

Tab. 8 Overview of programmes used in the field of digital heritage with possible DFG 3D-Viewer upload formats.

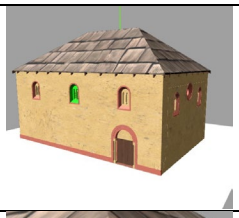
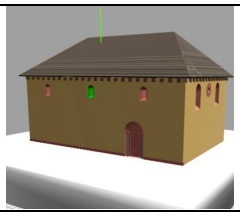
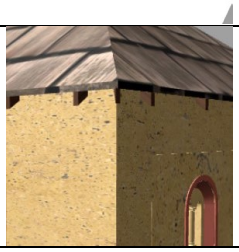
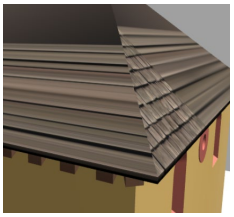
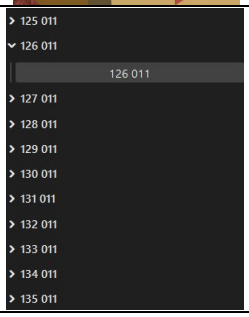
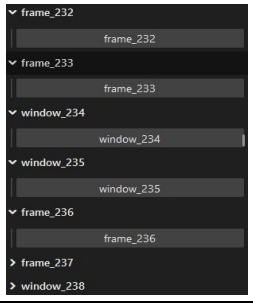
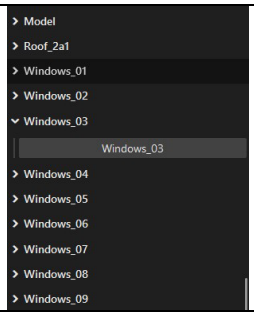
	PROGRAMS				
FORMATS	**Blender**	**Cinema4D**	**Rhino**	**SketchUp**	**Archicad**
OBJ	x	x	x	x	x
DAE	x	x	x	x	x
FBX	x	x	x	x	x
PLY	x	-	x	-	-
IFC	-	-	-	x	x
STL	x	x	x	x	x
XYZ	-	-	-	-	-
JSON	-	-	-	-	-
3DS	-	x	x	x	x
X3D	-	-	-	-	-
glTF	x	x	-	-	-

[81] https://github.com/thedworak/dfg_3dviewer (accessed 20 October 2022).

[82] https://threejs.org/ (accessed 16 October 2024).

The first export format analysed was the 3DS binary data format, developed by Autodesk and compatible with programmes such as Autodesk 3ds Max, MeshLab, and Cheetah3D. Exporting to this format is not supported in Blender. In the other programmes, the geometry appeared to be exported correctly, but there were issues with texture mapping. Textures were overscaled in the Rhino export. In the SketchUp export, materials were stretched in an unusual way. Similarly, the 3DS model from Archicad had severely stretched and deformed textures, making it the worst export in this comparison. The model hierarchy elements displayed by the viewer also performed poorly in the Archicad export. The names of the hierarchy elements appeared as random strings of numbers. In the Rhino export, the hierarchy was flattened to one level, and some of the exported element names did not correspond to the parts of the model specified in the task (e.g. "frame" as part of the window element). The best-performing export in terms of hierarchy was from SketchUp, where, despite the flattening of the hierarchy, the names of the individual elements aligned with those presented in the task (see Tab. 9). However, it should be noted that, in all cases, the hierarchy did not fully adhere to the task guidelines. Sometimes, the exported hierarchy contained divisions into smaller elements than those specified (Archicad, Rhino), and elements repeated in the model were recognised in the hierarchy as distinct, with different names (SketchUp).

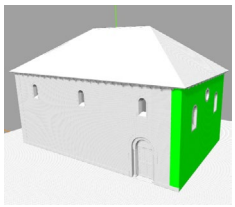
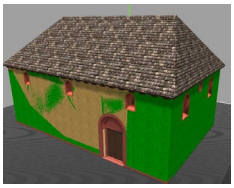
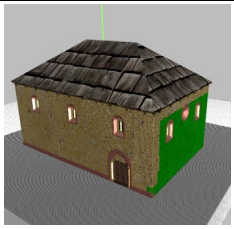
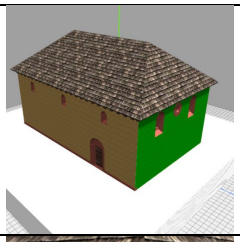
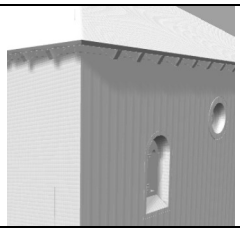
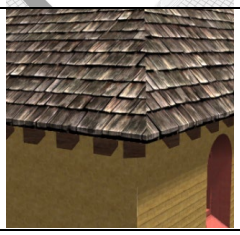
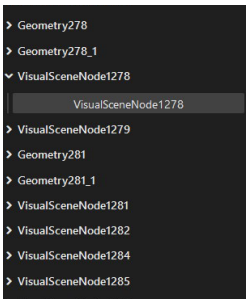
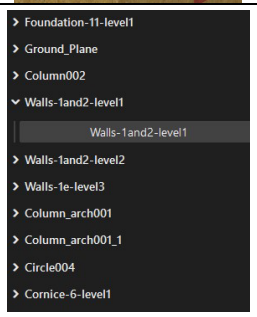
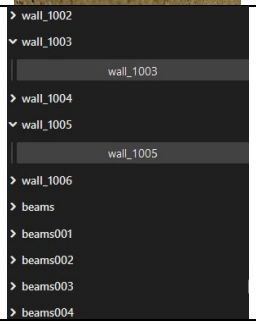
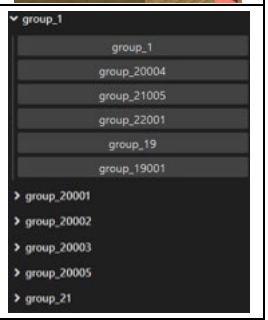
Tab. 9 Results of the upload 3DS format exports to the 3D viewer.

	Archicad	Blender	Rhino	SketchUp
Geometry				
Textures				
Hierarchy				

The next file format was Collada (.dae). It is a protocol that allows data to be exchanged across interactive 3D software programs, owned by the Khronos Group. It was designed to become a standard among 3D file formats and every major 3D software application now supports it. (Mahajan, 2022). Export of this format was available in all four software packages. The geometry itself was transferred correctly to the viewer canvas in all cases. However, visual defects appeared again with the texture mapping. In Archicad, the materials were not loaded at all. In the Rhino export, the textures were overscaled. The SketchUp model exhibited shading issues, with some surfaces showing longitudinal shadow stripes that distorted the final perception of the object. The Blender export, on the other hand, appeared free from such disadvantages.

The transfer of the hierarchy was not so successful. In export from Archicad, the hierarchy was limited to a single level, and the element names were changed to labels such as "Geometry" or "VisualSceneNode." However, it was possible to identify that the grouped elements accurately reflected their equivalents in the model. For Blender export, several additional hierarchy items were outside the initial structure, such as "circle" and "column." Despite this, the remaining elements had the correct semantic names and corresponded to proper geometry in the model. Additionally, the names of hierarchy items included information about the uncertainty level (e.g., "walls-1e-level-3"). The number of elements exported from Rhino was too high compared to the original hierarchy. While the names corresponded with those given in the semantic segmentation, the geometry in the model was subdivided into smaller pieces. In the SketchUp export, the hierarchy names completely lost their semantics and were displayed as "Groups" with different numerical indexes at the end. However, this was the first case of a two-tier hierarchy, where under one group tab, several interactive elements could be selected (see Tab. 10).

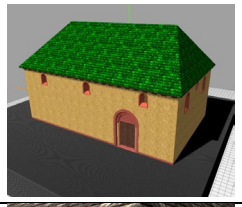
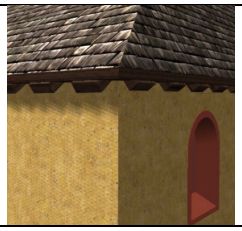
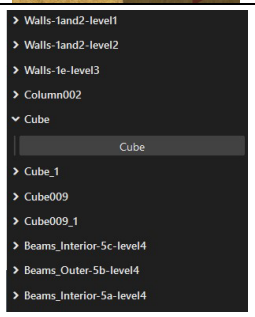
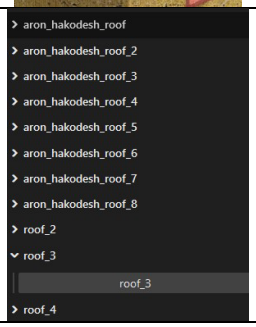
Tab. 10 Results of the upload DAE format exports to the 3D viewer.

	Archicad	Blender	Rhino	SketchUp
Geometry				
Textures				
Hierarchy				

The following test was prepared for FilmBox format (.fbx). FBX is a common 3D file format owned by Autodesk. It was intended to connect diverse file formats in the same pipeline, and it is widely used in the animation industry (Mahajan, 2022). Exporting to this format was not possible in Archicad. The file was not displayed in the 3D canvas for export from SketchUp. However, it is unclear whether this was due to an issue with the export file itself or a bug in the viewer, which was still under development. The geometry in the other two software (Rhino and Blender) was exported without display problems. The texture mapping in Blender appeared with no issues, whereas in Rhino, the overscaled textures recurred. The export of hierarchies from Blender and Rhino was quite similar to the previous case with the Collada format. For Rhino export, the names of the elements displayed in the hierarchy were correct. However, they did not correspond accurately to the correct parts of the

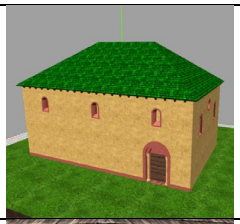
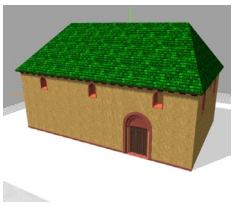
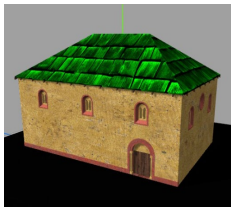
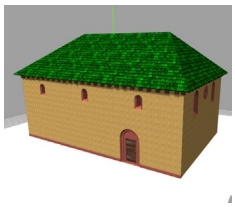
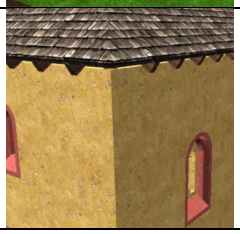
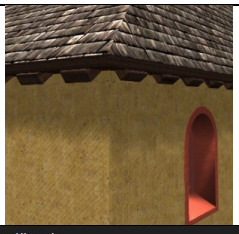
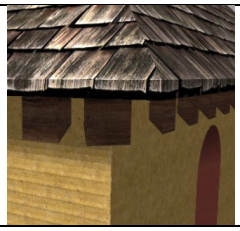
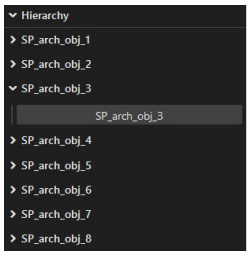
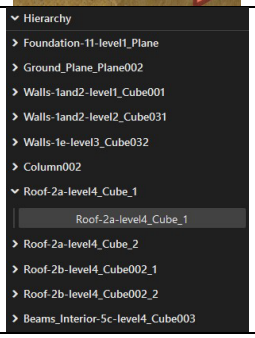
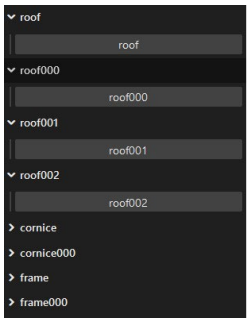
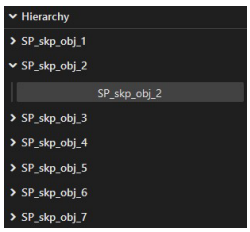
model, being fragmented into smaller pieces. In Blender, additional hierarchy elements labelled as “cube" reappeared. However, the other elements had the correct names, which matched the initial hierarchy and corresponded to the relevant parts of the model. Once again, information about the level of hypothesis (uncertainty) was retained in the names of these elements, such as "*Beams_Interior-5c-level4*" (see Tab. 11).

Tab. 11 Results of the upload FBX format exports to the 3D viewer.

	Archicad	Blender	Rhino	SketchUp
Geometry				
Textures				
Hierarchy				

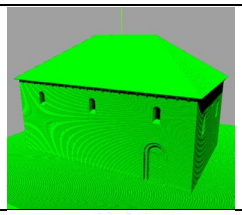
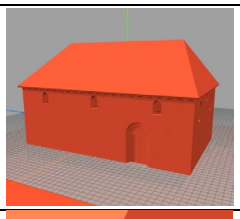
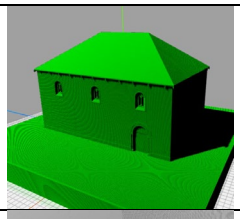
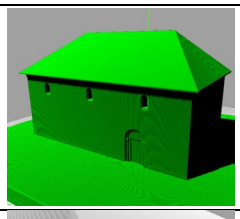
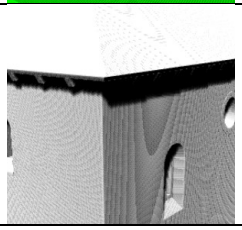
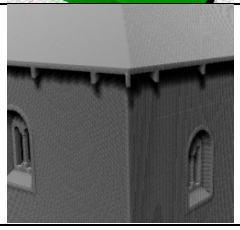
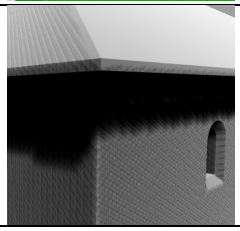
The next one was the Wavefront 3D (.obj) file format. This format is simple and preserves only information about three-dimensional objects, including 3D coordinates, texture maps, polygonal faces, and other objects. OBJ requires an MTL file to map textures on the 3D surfaces, which stores information about materials. (Christensson, 2022)With this format, data from all four software programs could be exported. Geometry is displayed correctly in all cases. However, textures were rescaled during export from Rhino, and an unusual horizontal shadow segmentation appeared on the wall surface in the export from SketchUp. In models exported from Archicad and Blender, the textures are displayed correctly. The export of the hierarchy, however, differed slightly. The hierarchies from SketchUp and Archicad were very similar, but both were linked to the .mtl file attached to the .obj file. Precisely, each element in the hierarchy corresponded to a different texture mapped to the model and was no longer connected to the semantic division. In Blender, the hierarchy division concerning individual objects was preserved, like in previous cases. Again, it also included names and elements corresponding to the initial hierarchical division. The element names also contained uncertainty information. In the case of Rhino, the model hierarchy was once again excessively subdivided. It was observed that four separate elements had to be selected from the list in the viewer to select the entire roof object. This indicated that the hierarchical division in the Rhino export created a new element for each polygon (see Tab. 12).

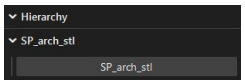
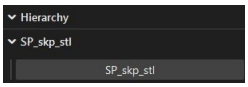
Tab. 12 Results of the upload OBJ format exports to the 3D viewer.

	Archicad	Blender	Rhino	SketchUp
Geometry				
Textures				
Hierarchy				

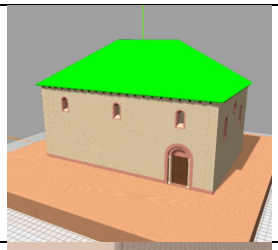
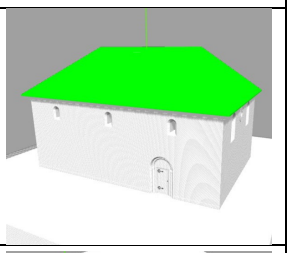
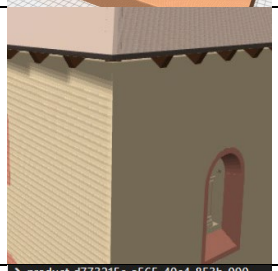
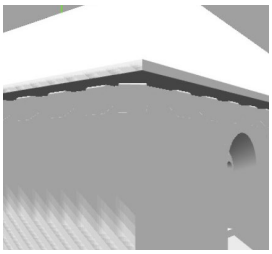
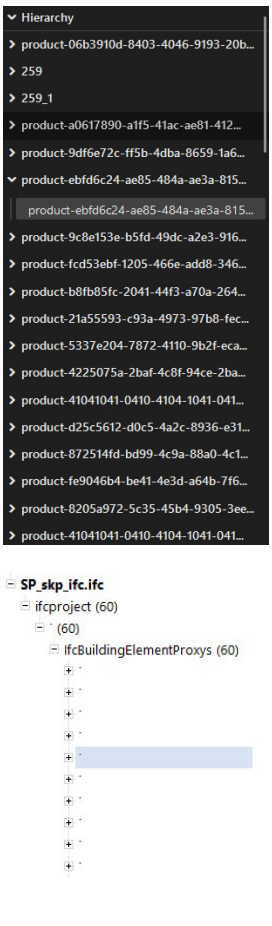
The following was the Stereolithography (.stl) format, which is commonly used for 3D printing. It doesn't preserve information about colour, textures, or any other common model attribute.(All3DP, 2021). All the tested programs support export to STL format. The geometry was exported correctly in all cases. Since the STL format does not support textures, these were not considered in the analysis. However, for SketchUp, Archicad, and Rhino exports, the model shading exhibited unusual segmentation that was not present in the export from Blender (see Tab. 13). This is the first format that does not retain a file hierarchy. The export is treated as a single entity in Archicad, Rhino, and SketchUp, or has no hierarchy at all in Blender.

Tab. 13 Results of the upload STL format exports to the 3D viewer.

	Archicad	Blender	Rhino	SketchUp
Geometry				
Textures				

Hierarchy				

Tab. 14 Results of the upload IFC format exports to the 3D viewer.

	Archicad	Blender	Rhino	SketchUp
Geometry				
Textures				
Hierarchy				

The study revealed that in most cases, the model hierarchy and assigned semantics of objects were either not preserved or the selected tool could not extract this information from the file. Particularly in the case of the IFC format, we know that the information was preserved within the file, but the viewer was not equipped to interpret this encoding correctly. The variations observed in material mapping were also surprising, indicating that some programs use internal mapping methods incompatible with export formats. A positive finding, however, was the retention of uncertainty-level information in some instances, such as in the OBJ format. This suggests that, with further testing, even simple formats can facilitate informed knowledge transfer in models. The study also highlighted that transferring contextual information, such as textual properties, and preserving relevant geometries and materials remain separate challenges. Currently, no single data format can store both aspects in a readable and accessible way. Therefore, it is recommended to use standardised and widely adopted formats by the community. For preserving geometry and materials, the popular Graphics Library Transmission Format (glTF, ISO/IEC 12113:2022) is recommended, while for storing knowledge as model properties, formats like IFC (ISO 16739-1:2024) or CityGML (ISO TC211) should be used. This approach should be followed until a standardised format tailored to the specific needs of digital reconstructions is developed.

III. Publication of 3D datasets in semantic web

One of the main challenges in evaluating the scientific value of 3D digital reconstructions is ensuring access to the underlying 3D files. Traditionally, the primary method of disseminating research findings has been through printed journal articles and books, which often rely on static images or descriptions to convey the results of digital reconstruction projects. However, the advent of the World Wide Web and digital publishing techniques has introduced new possibilities, including the direct publication of digital datasets. This shift presents a significant opportunity to enhance transparency, reproducibility, and collaborative engagement in virtual reconstruction research. Making 3D models accessible allows researchers to examine, verify, and critique the methodologies used in their creation, ensuring that reconstructions adhere to established scientific principles and best practices.

A critical aspect of publishing 3D datasets is the need for standardised documentation and quality control measures, ensuring that shared models are scientifically rigorous and methodologically sound. The availability of 3D reconstructions enables scholars to assess whether the models are constructed according to established rules, theoretical assumptions, and data sources. However, to make these datasets truly valuable, they must be structured according to FAIR (Findable, Accessible, Interoperable, and Reusable) principles. FAIR data preparation ensures that 3D models are not only accessible but also properly documented, machine-readable, and compatible with various analytical tools. This approach fosters broader interdisciplinary collaboration by allowing experts from different fields to interact with the data meaningfully.

Beyond the core disciplines of architectural history, archaeology, and computer graphics, the publication of 3D models has wide-ranging implications for related fields. Digital humanists can integrate these reconstructions into computational historical and cultural data analyses, while museologists can use them for curatorial work, digital exhibitions, and heritage preservation. Architects and urban planners can employ historical 3D models to analyse spatial transformations and inform contemporary design projects. Additionally, art historians can study reconstructions to better understand lost or damaged artefacts, while conservation specialists can use them to simulate restoration processes. By ensuring that 3D datasets are openly available and published with clear methodological documentation, researchers can create a shared digital environment that supports ongoing scholarship, interdisciplinary cooperation, and public engagement with cultural heritage.

This chapter will explore the current methods and platforms for publishing 3D datasets, assessing their alignment with academic standards and prevailing trends within the research community. By establishing guidelines for the structured dissemination of 3D models, the field can move towards greater transparency, academic integrity, and interdisciplinary usability, reinforcing the role of digital reconstructions as scientifically valuable resources rather than isolated, project-specific outputs.

A. Definitions

Digital data publishing, like any other field, has developed a range of specialised terms related to data documentation and existing technological solutions to support data preservation and sharing. Without knowledge of these definitions, the further chapters of this thesis may be incomprehensible, so the following is a definition of the most important terms.

3D viewer – a software application or tool that allows users to view and interact with 3D models in a digital environment. These viewers provide the ability to rotate, zoom, pan, and inspect 3D objects from various angles, offering an immersive experience. A 3D viewer can be used to view models created in various formats, such as STL, OBJ, FBX, and more, depending on the tool's compatibility. In addition to viewing the geometry of 3D models, some 3D viewers may also support features like texture rendering, lighting effects, and animations. They are often used in fields like architecture, cultural heritage, engineering, gaming, and design to display complex 3D data, making it more accessible for both professionals and the general public. 3D viewers are available as standalone software applications, browser-based tools, or integrated into other platforms, such as web-based repositories. Examples include Sketchfab, Autodesk's Viewer, and Blender's internal viewer, which offer interactive experiences without requiring specialised software installations. They can be crucial for education, presentations, and the dissemination of 3D models, particularly in collaborative and academic environments.

authority files - structured and standardised lists or databases that contain authoritative information about names, terms, or other data used in cataloguing and information retrieval systems. They ensure consistency and accuracy by providing a controlled vocabulary for identifying and referencing entities such as people, organisations, subjects, or geographic locations. Authority files are widely used in libraries, archives, museums, and other institutions to maintain uniformity in the description and classification of information. By referring to authority files, cataloguers and researchers can avoid discrepancies caused by variant spellings, name changes, or different formats for the same entity.

controlled vocabulary - organised set of predefined terms or phrases used to ensure consistency and standardisation in the way information is described or categorised. It is a structured way to label and classify content, ensuring that users, researchers, or systems use the same terminology when referencing the same concepts or entities. Controlled vocabularies are typically used in databases, search engines, libraries, and archives to improve the accuracy and efficiency of information retrieval.

data - facts, figures, or information collected and recorded for reference, analysis, or decision-making. It can take many forms, including numbers, text, images, audio, and video. Data is the raw material from which meaningful insights, knowledge, or information are derived through analysis or processing. In its most basic form, data is unprocessed and lacks context. For example, a list of temperatures recorded over several days or the number of people visiting a website in a day are examples of raw data. When data is organised, analysed, and interpreted, it becomes information, which can then be used to make decisions, solve problems, or communicate findings.

file format - standardised way of encoding and storing data in a digital file, determining how the information within the file is structured, represented, and accessed by software. File formats define how the bits of data are organised, allowing a computer to interpret the contents correctly. Each file format is typically associated with a specific type of content or data, such as text, images, audio, video, or 3D models.

infrastructure - technology-based systems, tools, and platforms that support the operation, communication, and services in a digital environment. It is the foundation that enables the functioning of everything from internet connectivity and data storage to cloud computing, cybersecurity, and digital applications.

metadata - data that provides information about other data. In other words, it is descriptive data that helps to identify, organise, interpret, and manage a particular set of information. Metadata serves as a tool for describing

the essential details about data, such as its content, context, quality, and structure. It is commonly used to make information easier to locate, understand, and use.

metadata schema - structured framework or set of rules that defines how metadata should be formatted, organized, and stored to ensure consistency, clarity, and interoperability across systems. Essentially, it provides guidelines for describing data and information resources (such as books, digital files, 3D models, etc.) using standardised terms and formats. A metadata schema usually specifies:

- *Elements* (fields): These are the attributes or properties that need to be described, such as "title," "author," "date," "format," or "location."
- *Definitions*: Clear explanations of what each element represents and how it should be used.
- *Data types and formats*: Guidelines on what kind of data should be used (e.g., text, number, date) and how it should be formatted (e.g., YYYY-MM-DD for dates).
- *Controlled vocabulary*: If applicable, a set of predefined terms or keywords that should be used for specific elements, ensuring consistency.

ontology - formal description of knowledge as the concepts, relationships, and categories within a particular domain of knowledge. In simpler terms, it is a formal representation of knowledge, which helps to organise and model how different elements within a domain relate to one another. Ontologies are widely used in computer science, artificial intelligence, and information science to enable machines and systems to understand, interpret, and reason about data. By providing a shared vocabulary and clearly defined relationships, ontologies ensure that data can be understood consistently across different systems and applications. Ontologies are crucial for **semantic web technologies** because they enable the sharing and integration of data across different systems by providing a common understanding of concepts and their relationships. Examples of widely used ontologies include **CIDOC CRM** for cultural heritage and **FOAF** (Friend of a Friend) for representing social networks.

paradata - additional information or metadata that documents the process, decisions, and context behind the creation or collection of data. It provides insights into the "how" and "why" behind the data, including the methods, tools, and decisions involved in the process. Paradata helps to understand the background, reliability, and interpretation of the data In the context of digital humanities or cultural heritage projects, paradata is especially important when dealing with **digital reconstructions** or **3D models**, as it provides detailed explanations of how the model was created, what assumptions were made, which tools were used, and what challenges or uncertainties arose during the reconstruction.

repository - storage location where data, digital files, or other types of content are systematically stored, managed, and accessed. Repositories are used in a wide variety of contexts, from software development to digital libraries, to academic and research settings. In the context of digital and research environments, a repository typically refers to a system where digital assets such as documents, datasets, 3D models, or multimedia files are stored, preserved, and made accessible to users. Repositories can be open (publicly accessible) or closed (restricted to certain users), and they often support features like version control, metadata tagging, and search functionality.

taxonomy - system of classification used to organise concepts, objects, or data into hierarchical categories based on shared characteristics. The purpose of a taxonomy is to provide a structured framework that allows for the grouping and differentiation of items in a logical, consistent, and clear manner. In digital environments,

taxonomies are often used alongside **controlled vocabularies** and **ontologies** to create more structured and interconnected systems of information.

thesaurus - structured collection of words and phrases (often referred to as terms) that provides synonyms, related concepts, and sometimes antonyms for each term. It helps users find the most appropriate or alternative words to express a concept or idea. In a more specialised context, particularly in information science and knowledge management, a thesaurus is used to provide a controlled vocabulary of terms that are structured to show relationships between concepts, aiding in the consistent indexing and retrieval of information.

B. Web publication

Sharing data online not only benefits the scientific community but also society, as it fosters the dissemination of knowledge about architecture and art history. Published 3D models can be repurposed as assets for the film and gaming industries or used for 3D printing and educational tools in museums. Additionally, such data contributes to the preservation of cultural heritage and promotes the development of new technologies for managing digital cultural resources. Given these benefits, it is crucial to make the 3D data openly accessible once a reconstruction project is complete. Keeping valuable data confined limits the potential for further advancements and deprives others of the insights that have been gained.

However, publication requires a number of factors to be considered, such as the platform for publication and the file format. Each platform may have different requirements for preparing data, influenced by factors such as the target audience. The wide range of available solutions can make it challenging to select the most suitable platform for publishing digital reconstructions in line with the principles outlined earlier in Chapter I.C. To address this, the initial step involved conducting an analysis of the 3D model publication platforms currently on the market and later investigating possible file formats for 3D data in order to distinguish the most effective way to share digital 3D reconstruction projects.

B.1. Requirements for publication platforms

Platform for publishing 3D models of cultural heritage requires a combination of several essential elements that work together to ensure the models are presented, stored, and accessed effectively. At the heart of this is reliable **data storage**, which needs to accommodate large files, including not just the 3D models themselves but also related materials like textures, annotations, and contextual data. This is important for keeping the models secure and easy to retrieve over time. Equally important is a well-organised **metadata structure**. This provides essential details about the model, such as its historical background, how it was created, and its technical specifications. Having comprehensive metadata allows the models to be searchable and understandable, while also making it possible to integrate them with other systems and repositories.

A **3D viewer** is another key feature, allowing users to interact with the models directly on the platform. Although not a necessary component for a 3D model repository, it is definitely desirable. This viewer should be compatible with various file types and allow users to zoom in, rotate the model, and view details like layers or textures, with added annotations to explain specific parts of the reconstruction. Supporting multiple 3D file formats like OBJ, STL, and glTF is crucial, as it ensures models created in different software can still be viewed and used on the platform. In addition to viewing the models, it's important that the platform includes features for adding annotations and explanations, which help users understand the decisions behind the reconstruction and its accuracy.

The platform also needs to be **user-friendly**, with an intuitive interface that caters to both experts and the general public. It should support features like multi-language options and accessible design to ensure it's easy to use for a wide audience. Managing copyright and licensing is another essential aspect, enabling creators to specify how their work can be shared or reused, and providing legal protection through options like Creative Commons licenses. Finally, to maximise the impact of the platform, it should allow for integration with other repositories and databases, making it easier for the models to be reused in different contexts, whether for academic research or public exhibitions. All these components together create a platform that supports the preservation, accessibility, and sharing of 3D cultural heritage models.

B.2. Repositories for 3D data

In defining the criteria for selecting platforms for the study, it was essential to focus on repositories that could be hosted on their own servers without the need for third-party adaptation. The goal was to find platforms that were fully operational and open for immediate use by potential users, without the need for extensive installation or customisation. As a result, typical solutions designed for virtual research environments, which often require individual components to be installed and tailored, were excluded from consideration. Research already conducted on 3D repositories provided valuable insights into possible candidates (Champion & Rahaman, 2020; Community Standards for 3D Data Preservation (CS3DP), 2020; Hardesty et al., 2020). However, due to the limited scientific exploration of publishing platforms in this area, informal sources, such as hobbyist blogs were also consulted to gather additional perspectives (Aniwaa Team, 2022; Hailey, 2022; i.materialise Team, 2018). Previous own experience with the publication of 3D models was also used.

On this basis, nearly 50 repositories were distinguished. Repositories were classified between commercial and institutional offerings. An estimate of the number of deposits in the repositories was also carried out, based on which only the top 15 repositories in each of the two categories were selected (see Tab. 15). Their ranking was based on the number of available models, the quantities of which were taken from information published by the repositories themselves, external sources providing an approximate number, or through the author's analysis of available resources in repository. In addition to the number of models, three other aspects were examined.

Tab. 15 Summary of specifics of selected repositories from the institutional offer.

Repository	Num. of models	Content type				Complexity	Aims					
		M	P	I	H		V	O	R	D	A	S
Institutional												
Morphosource	71 400+	■				advanced	■	■		■		
Shape Net Core	51 200+				■	basic	■				■	
NIH 3D	12 600+				■	advanced	■	■	■	■		
Europeana	5 900+	■	■		■	professional	■	■			■	
3D-ICONS	4 200+	■				basic		■			■	
Smithsonian3D	2 600+	■				basic	■	■		■		■
Conservatoire National des Données 3D	1 200+	■	■		■	professional	■	■				
STARC	700+	■				advanced	■	■	■			
UMORF	600+	■				professional	■	■				
OpenHeritage3D	390+		■			professional	■		■	■		
NASA 3D Resources Site	380+		■			basic				■		

Kompakkt	240+	■			■	basic	■					■
tDAR	160+	■				professional			■	■		
Three D Scans	120+					basic				■		
3D Repository	110+	■		■	■	advanced	■	■	■	■		
CyArk	100+	■	■		■	basic	■					■
Commercial												
GrabCAD	5 690 000+	■		■	■	basic				■		
Sketchfab	5 000 000+	■	■		■	basic	■			■		■
Thingiverse	2 500 000+	■			■	basic	■			■		
CG Trader	1 640 000+	■		■	■	basic				■		
Turbosquid	1 215 000+	■		■	■	basic				■		
Free3D	1 162 000+				■	basic				■		
Cults 3D	998 000+	■			■	basic				■		
3D Export	418 000+	■		■	■	basic				■		
Printables	394 000+	■			■	basic	■			■		
3D Warehouse	190 000+				■	basic	■			■		
MyMiniFactory	154 000+	■			■	basic	■			■		
Unity Asset Store	47 000+	■			■	basic				■		
Hum3D	25 000+				■	basic				■		
BlendSwap	25 000+				■	basic				■		
Pinshape	13 000+				■	basic				■		

The first was the type of models available in the repository, distinguishing between four different types: the models of digitization of reality-based of a mesh (M) and in the form of a reality-based point cloud (P), HBIM information models (I) and 3D models made by hand (H).

Consideration was also given to the complexity of the metadata schema in the repository. As in the CS3DP study, three levels of complexity were considered, based on the target groups:

- **basic** group covering documentation prepared for general users, educators, and students, where the available metadata contain only the necessary information (provided by publisher) and technical specification of 3D model (which could be automatically acquired). It requires low effort from the user uploading the data;
- **professional** group including groups like museums, professionals, NGOs, and public outreach, where metadata are based on existing standards and persistent identifiers;
- **advanced** group covering group of scholars and researchers, where metadata is supported by paradata and specification of methods, techniques, and source materials.

The last criteria considered was the purpose for which the repositories exist. The classifications in this regard were based on the possible purposes of the model's publication on the web, VORDAS, outlined at the beginning of the chapter: V – visualization, O – object record, R – research documentation, D – data reuse, A – data aggregation, S – storytelling.

The classification of repositories by specification shows the relationship between metadata, their complexity, and the purpose the repository serves. It also shows focus of commercial repositories mostly on data reusability. Their metadata schema can be useful in terms of developing the necessary set of technical specifications for a file with a focus on reuse for a specific purpose. These repositories emphasize distinguishing possible uses of a 3D file, differentiating between 3D printing (sometimes with a description of specific printers and techniques to

which the file may correspond), AR/VR applications (distinguishing low-complexity files called "low poly"), use in art (ready-made components for use in commercial programs) or game development (ready-made assets for use in game engines). This issue that is not recognized by many institutional repositories. Even after making a 3D model available for download and describing its specifications, institutional repositories do not provide information on how the model can be used. In turn, the wide variety of repositories of institutional offerings gives the opportunity to consider description of the model from other perspectives. They provide some contributions regarding heritage records in museum collections, scientific documentation related to architectural, historical, and archaeological research, storytelling about objects guided by hotspots and annotation or data aggregation to established digital resources collections.

B.3. File formats

Once a publication platform has been selected in line with the chosen objective and target audience, the form of 3D file format must be decided upon. The choice of format can significantly impact the usability of your reconstruction data, as 3D models can be stored in various formats, each serving different purposes. This principle applies to other types of digital files as well. For example, when dealing with photos, there are numerous formats, each with its specific function—RAW formats preserve unprocessed data from the camera, PSD stores changes made during editing, while formats like JPEG and PNG are used for data exchange, and TIFF is commonly used for archiving (see Tab. 16).

The range of possible file formats for 3D models is even broader, and systematising them is more complex due to the variety of applications, modelling techniques, and software available (McHenry & Bajcsy, 2008). To classify these formats, we can start by distinguishing between closed (**proprietary**) and open (**non-proprietary**) formats (see Fig. 58). Closed formats, such as PLN, MAX, RVT, BLEND, and SKP, are often patented by companies, limiting their use to specific software. In contrast, open formats, such as GLB/GLTF, DAE, OBJ, STL, IFC, and GML, are system-independent, promoting greater accessibility and facilitating file reuse.

Tab. 16 Overview of the different formats for image files in terms of their specifications and use.

Format	Colours	Compression	File Size	Recommendations
RAW	> 68 billion	variable	very large ~10MB	Unprocessed data, editing
PSD	variable	variable	large ~ 8MB	Design and editing
JPG/JPEG	>16 million	lossy	small 0,5-8MB	Websites and storage
GIF	max 256	lossless	small ~1MB	Animation and web
TIFF	variable	lossless	large ~ 8MB	Editing, printing, archiving
PNG	>16 million	lossless	large ~ 8MB	Web, storage, graphic design, editing

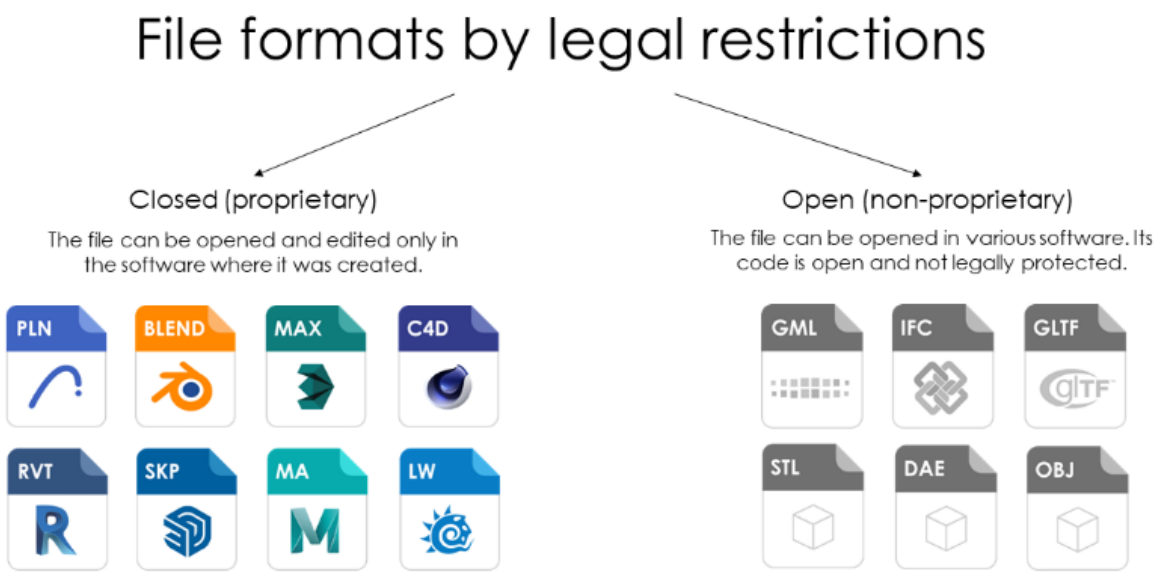


Fig. 58 Classification of 3D file formats according to legal restrictions.

Another classification considers the file's origin, differentiating between native and export formats. Native formats are the original file types used in the software where the model was created, while export formats are those converted to enable compatibility with other software. Export formats, also known as data exchange formats, are designed for transferring data between different programs. Neutral formats, such as IFC, 3DM, and OBJ, are open formats that can be easily integrated into various 3D modelling software.

Choosing the right format is not always straightforward, particularly when the potential audience is difficult to define. In such cases, it is recommended to select a format that allows the audience to fully utilise the 3D model. The data should be easily accessible, modifiable, and capable of being integrated with other datasets. A useful framework for assessing data integrability in these categories was introduced by Tim Berners-Lee in his 5-star deployment scheme for Linked Open Data (2006, see Fig. 59). It is a system that encourages the gradual improvement of data publication on the web, enhancing accessibility and interoperability. At its core, the scheme starts with simply making data available online in any format, such as a PDF, which can be accessed by others. Moving up the scale, data should be provided in a structured format, like Excel, which makes it easier to use. A further step is ensuring the data is in a non-proprietary format, such as CSV, allowing for broader accessibility without relying on specific software. The next level is where data is published using standardised formats, such as RDF or JSON, which link the data to relevant concepts and other datasets, creating meaningful connections. Finally, the highest level involves linking your data to other datasets, enriching the context and making it part of a broader, interconnected web of knowledge. This progressive approach encourages data publishers to enhance the usability and connectivity of their data, making it more valuable for the global community.

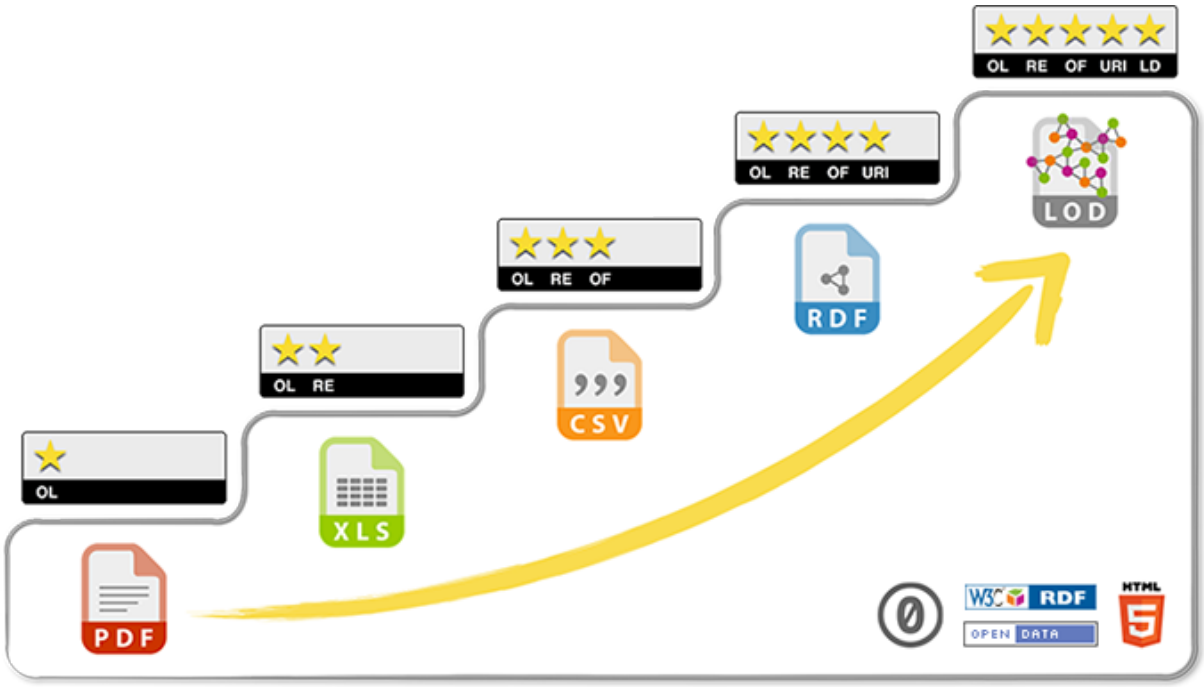


Fig. 59 5-star deployment scheme for Linked Open Data by Tim Berners-Lee. ★ make your stuff available on the web (whatever format); ★★ make it available as structured data (e.g. excel instead of image scan of a table); ★★★ non-proprietary format (e.g. csv instead of excel); ★★★★ use URLs to identify things, so that people can point at your stuff; ★★★★★ link your data to other people's data to provide context (https://5stardata.info/en/).

By treating the 3D model as a digital resource, it is possible to apply this scale to digital reconstruction documentation (Münster et al., 2024b). The basic level involves making the 3D model available online under an open licence. The second level requires introducing structure to the model. As demonstrated in Chapter II.B.1, the segmentation and structuring of the 3D model forms the foundation of its semantic meaning, making this step essential for achieving higher levels of 3D data integration. At the third level, the file should be made available not only under an open licence but also in a non-proprietary file format, allowing it to be used in any 3D software. At level four, the semantic capabilities of the 3D software should be utilised to assign meaning to different segments of the model, whether through properties or other tools provided by the software. The final, fifth step involves integrating the 3D model into a Linked Open Data (LOD) structure by assigning permanent identifiers to the model and its semantic parts, embedding the data into a wider contextual network. This creates a Linked Open Model (LOM)– a 3D model that is open, accessible, and interconnected with contextualised data. The definitions of the levels can be described as follows:

★ Provide your 3D model and the associated metadata on the web under an Open License (OL);

★★ Provide your 3D model in a format supporting Model Structure (MS) and the associated metadata on the web in a structured format (SF);

★★★ Provide your 3D model in Neutral Format (NF) and use open, non-proprietary formats for metadata (OF);

★★★★ Provide your 3D model with Structural Elements Properties (SEP) and use URIs to label things (URI);

★★★★★ Provide your 3D model as Linked Open Model (LOM) and link your data with other data to create contexts (Linked Open Data-LOD).

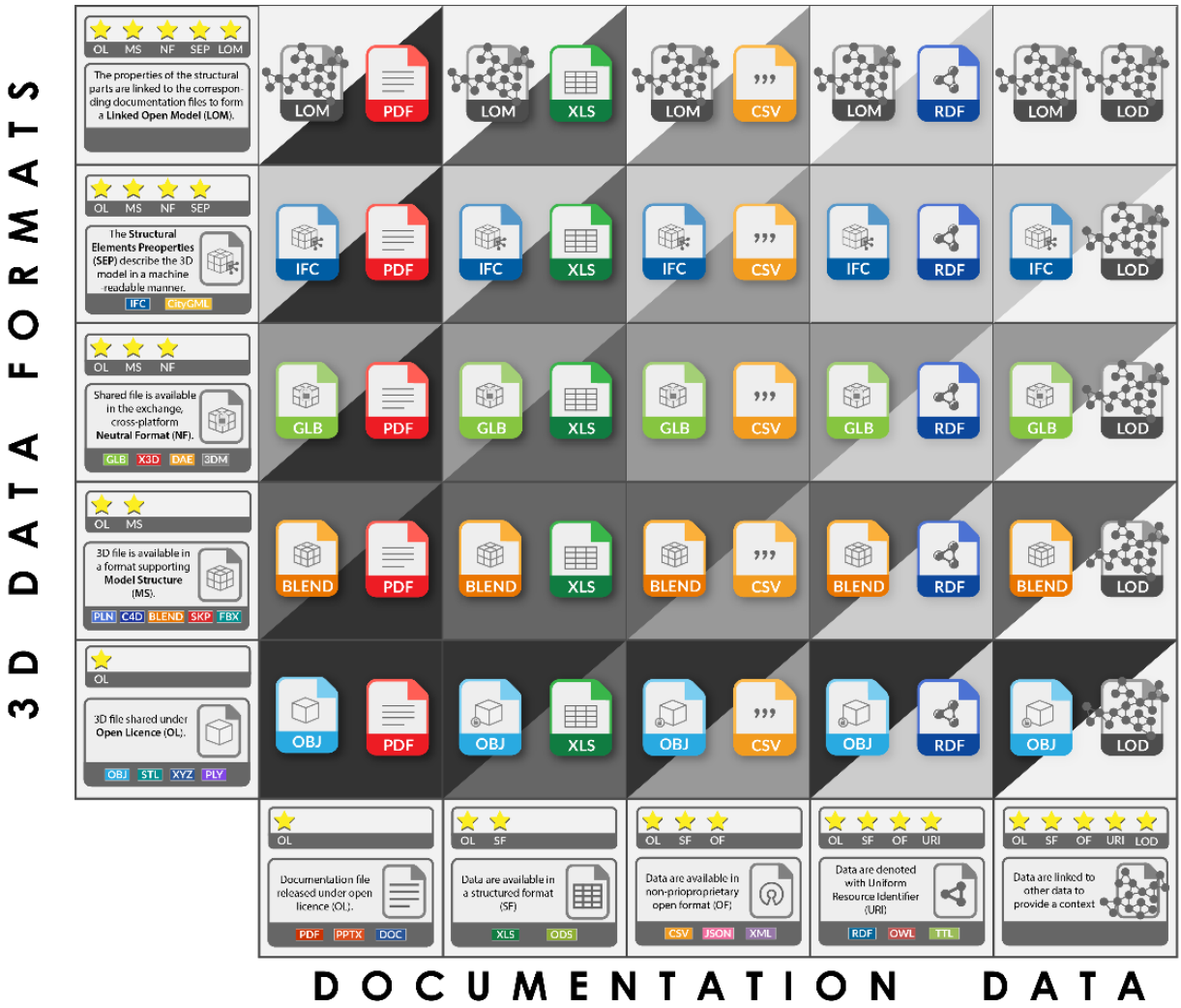


Fig. 60 Summary of criteria for the 5-star data sharing scheme (horizontal axis) and 3D models (vertical axis) in the network.

When documenting digital reconstructions, it is important to consider that comprehensive documentation should not rely solely on the LOM. The model must also be linked to paradata, sources used, and other relevant materials, as outlined in Chapter II.A. These elements should be stored in LOD format to ensure full integration and contextualisation, providing a robust framework for transparency and accessibility in the documentation of the reconstruction process. Therefore, a matrix for evaluating the documentation of published digital 3D reconstruction projects was developed. This matrix is based on a two-component evaluation: the format of the 3D model publication and the accompanying paradata (see Fig. 60). Only by considering both criteria can a proper assessment of the integration level of the entire reconstruction be made in relation to Linked Open Data (LOD). This comprehensive approach ensures that the documentation meets the necessary standards for transparency, accessibility, and integrability within the broader LOD framework.

Most digital 3D reconstruction projects tend to prioritise documentation aimed at the scientific community, often overlooking the issue of sustainable file sharing. To address this gap, the findings from this work have led to a collaboration between AI MAINZ and the University of Bologna to develop a methodology that maximises the potential of 3D models through appropriate publication methods (Kuroczyński et al., 2024). This concept, termed the Scientific Reference Model (SRM), promotes sharing results under an open licence and using non-proprietary file formats. The goal is to enable referencing, further development, and scientific evaluation by third

parties. The SRM is achieved by using standardised formats that store geometry data while allowing models to be structured and divided into elements with metadata embedded directly within the 3D file. Formats that support these requirements include Industry Foundation Classes (IFC), widely used in architecture and construction, and City Geography Markup Language (CityGML), which integrates urban geodata for Smart City and Urban Digital Twin applications.

The SRM methodology utilises standardised formats, which are highly effective for documentation in fields such as urban design and building engineering. However, the number of software programmes that offer the capability to export data to these formats remains limited. In recent years, though, there has been a growing development of plug-in solutions designed to harness the documentation potential of BIM within graphics-oriented programmes. For instance, special plug-ins are now available for IFC in Blender,[83] Rhino,[84] and SketchUp via the CityGML plug-in.[85]

The formats recommended by SRM, while useful, are not ideal for conveying complete reconstruction information. CityGML and IFC, for instance, do not support the storage of material details. Although they can contain surface colour data, they fail to retain texture information, texture mapping, or other material properties. For this reason, multiple file formats need to be considered when publishing 3D reconstructions. The first should be the standardised documentation format mentioned in SRM. The second must be an open data exchange format that can accurately convey both geometry and material details while being compatible with a wide range of 3D software. However, the only format that can hold full information about the reconstruction model is the native file itself. Any export or file conversion carries the risk of data loss. Therefore, to fully document a 3D reconstruction, three file formats should be published: the native format, a format supported by SRM, and a chosen data exchange format. This combination of formats provides a robust foundation for others to reuse, modify, or further develop the reconstruction, helping to preserve and spread knowledge about lost cultural heritage.

It is worth noting that not every program supports export to the same formats, and different formats have different specifications, meaning they should be used for distinct purposes. A table has been prepared to illustrate the available export formats in different programs (see Tab. 17), along with specifications and recommendations for the use of specific file formats (see Tab. 18) to address this issue. Combining this knowledge with the SRM method and publishing a comprehensive file package should provide a solid foundation for the proper preservation and archiving of 3D models.

Tab. 17 Summary of selected 3D modelling software and its ability to import 3D file formats.

Format	Archicad	Rhino	Blender	Cinema4D	Revit	SketchUp	Maya	3DS Max
OBJ	✓	✓	✓	✓	✗	✓	✓	✓
DAE	✓	✗	✓	✓	✗	✓	✓	✓
STL	✓	✓	✓	✓	✗	✓	✓	✓
FBX	✓	✓	✓	✓	✗	✓	✓	✓
GLB	✗	✓	✓	✓	✗	✓	✗	✗
PLY	✗	✓	✗	✗	✗	✗	✗	✗
3DM	✓	✓	✗	✗	✓	✗	✗	✗
IFC	✓	✗	✗	✗	✓	✓	✗	✗

[83] https://bonsaibim.org/ (accessed 22 October 2024).

[84] https://www.visualarq.com/ (accessed 22 October 2024).

[85] https://www.3dis.de/cityeditor/ (accessed 22 October 2024).

BLEND	✗	✗	✓	✗	✗	✗	✗	✗
SKP	✓	✓	✗	✓	✓	✓	✗	✓
RVT	✗	✗	✗	✗	✓	✗	✗	✓
MA	✗	✗	✗	✗	✗	✗	✓	✗
PLN	✓	✗	✗	✗	✗	✗	✗	✗
X3D	✗	✗	✓	✗	✗	✗	✗	✗
C4D	✓	✗	✗	✓	✗	✗	✗	✗
3DS	✓	✓	✗	✓	✗	✓	✗	✓
MAX	✗	✗	✗	✗	✗	✗	✗	✓
IGES	✗	✓	✗	✓	✗	✗	✓	✓

Tab. 18 List of specifications of selected 3D file formats.

Format	Type	Textures	NURBS	Hierarchy	Grouping	Metadata Properties	Recommendations
OBJ	Neutral, Export	✓	✗	✗	✓	✗	3D printing, graphics, 3D scanning, data exchange, web, AR and VR
DAE	Neutral, Export	✓	✗	✓	✓	✗	Graphics, animation, data exchange
STL	Neutral, Export	✗	✗	✗	✗	✗	3D printing, data exchange
FBX	Closed, Export	✓	✗	✓	✓	✗	data exchange, graphics, animation, games development
GLB	Neutral, Export	✓	✗	✓	✓	✗	3D printing, graphics, data exchange, games development, web, AR and VR
PLY	Open, Export	✗	✗	✗	✗	✗	3D scanning, point clouds
3DM	Open, Native	✓	✓	✗	✓	✗	NURBS modelling, graphics, analysis of geometry
IFC	Neutral, Export	✗	✓	✓	✓	✓	BIM, data exchange, SRM
GML	Neutral, Export	✗	✗	✓	✓	✓	Geodata, smart cities, data exchange, SRM
BLEND	Closed, Native	✓	✗	✓	✓	✓	Graphics, animation, polygonal modelling, sculpturing
SKP	Closed, Native	✓	✗	✓	✓	✗	Graphics, polygonal modelling
RVT	Closed, Native	✓	✗	✓	✓	✓	BIM, CAD, object-oriented modelling
PLN	Closed, Native	✓	✗	✓	✓	✓	BM, CAD, object-oriented modelling
X3D	Neutral, Export	✓	✓	✗	✓	✗	Interactive 3D, coloured 3D printing, CAD, data exchange format, animation
XYZ	Open, Export	✗	✗	✗	✗	✗	Data exchange, point clouds
C4D	Closed, Native	✓	✓	✓	✓	✗	Graphics, animation, polygonal modelling
3DS	Closed, Export	✓	✓	✓	✓	✗	Graphics, animation, polygonal modelling, exchange format

MAX	Closed, Native	✓	✓	✓	✓	✗	Graphics, animation, polygonal modelling
IGES	Neutral, Export	✗	✓	✓	✓	✗	CAD, analysis of geometry, exchange format

C. Metadata schema for 3D data

Publishing data on the web necessitates describing it in a way that not only identifies its content but also ensures proper credit is given to its creators through metadata. Metadata serves as the essential set of information about a resource, and its scope can vary significantly depending on the type of resource. In the case of 3D data, a fully standardised approach for describing 3D files on the web has yet to emerge. However, there have been several attempts to develop proposals that aim to prompt further discussion within the community. Constantly emerging data repositories have produced many documentation schemes based on experience with other digital resources and dedicated to the specific application cases. In result, it is easy to see a large difference in the metadata documented, based on the two main factors: the audience or the purpose of publication.

C.1. Existing solutions

The first step in critically analysing the documentation schema was to review the metadata used in existing repositories for 3D models. For this purpose, repositories were selected that are already of interest to researchers of 3D models of cultural heritage (Champion & Rahaman, 2020). However, the number of repositories in the study was limited due to the lack of access or low popularity of some of them. Several items were selected from both commercial and institutional repository offerings available on the market. Sketchfab,[86] Turbo Squid,[87] Blend Swap[88] and 3D Warehouse[89] repositories were selected from the commercial offering, while Kompakkt,[90] 3D Smithsonian[91] and Europeana[92] were selected from the institutional offering. The list of analysed metadata was compiled not only from the repositories mentioned but also from the experience gained during work in the virtual research environment of the New Synagogue reconstruction project in Wroclaw, in collaboration with AI MAINZ.[93] As a rule, the virtual research environment allows for a much more detailed description of published resources than in repositories, it was decided to include a more comprehensive documentation scheme in the study. The complete list of analysed metadata, along with an indication of the repositories in which they are included, is provided in Tab. 19.

[86] https://sketchfab.com/ (accessed 15 October 2024).
[87] https://www.turbosquid.com/ (accessed 30 June 2022).
[88] https://www.blendswap.com/ (accessed 30 June 2022).
[89] https://3dwarehouse.sketchup.com/ (accessed 30 June 2022).
[90] https://kompakkt.de/ (accessed 05 July 2022).
[91] https://3d.si.edu/ (accessed 05 July 2022).
[92] https://www.europeana.eu/ (accessed 05 July 2022).
[93] See documentation of research activities at https://www.new-synagogue-breslau-3d.hs-mainz.de/ (accessed 05 July 2022).

Tab. 19 Analysis of the metadata used by the most popular 3D repositories from commercial and institutional offerings. List of repositories based on the "Survey of 3D digital heritage repositories and platforms" by Champion and Rahaman (2020). List of the metadata field is based on the experience gained during the work with VRE created for the documentation of the reconstruction project of the New Synagogue in Wroclaw.

Metadata			3D Warehouse	europeana	Kompakkt	Sketchfab	Smithsonian	Turdbosquid	Blend Swap
Reconstruction data	Name		x	x	x	x	x	x	x
	Description		x	x	x	x	x	x	x
	Type		-	x	x	x	-	-	-
	Categories		-	x	-	x	-	x	x
	Version of model		-	-	-	-	-	-	-
	Creators	Name	-	-	-	-	-	-	x
		Institution	x	x	x	x	-	x	-
		Role	-	-	x	-	-	-	-
	Date	of publication	-	x	-	x	-	x	x
		of last update	x	x	-	-	-	-	-
	Tags		-	-	-	x	-	x	x
	Made in project	Name	-	-	-	-	-	-	-
		Duration	-	-	x	-	-	-	-
		Cooperation	-	-	-	-	-	-	-
		Fundators	-	-	-	-	-	-	-
		Website	-	x	-	-	-	-	-
	Level of certainty		-	-	-	-	-	-	-
	Used sources		-	x	-	-	x	-	-
	Identifier		-	x	-	-	-	x	-
Object data	Identifier		-	-	-	-	x	-	-
	Name		-	x	x	-	x	-	-
	Producer	Name	-	-	-	-	x	-	-
		Institution	-	-	-	-	x	-	-
	Location	of creation	-	x	x	-	x	-	-
		current	-	x	x	-	x	-	-
	Date	of creation	-	x	-	-	-	-	-
		of destruction	-	-	-	-	-	-	-
		others	-	-	-	-	-	-	-
	Condition (existing, demolished etc.)		-	-	-	-	x	-	-
	Materials		-	-	-	-	x	-	-

Metadata			3D Warehouse	europeana	Kompakkt	Sketchfab	Smithsonian	Turdbosquid	Blend Swap
	Dimensions		-	-	-	-	x	-	-
Reuse data	Licence		-	x	x	x	x	x	x
	Rights	Information	-	x	x	x	x	x	-
		Owner	-	x	x	-	-	-	-
	Contact	Creators	-	-	x	-	-	-	-
		Institution	-	-	x	-	x	x	-
		Right Owner	-	-	x	-	-	-	-
	Available file formats		-	-	-	x	x	x	x
	Related models		-	x	-	-	x	x	-
Technical data	Origin format		-	-	-	x	-	x	x
	Used software		x	-	-	-	-	x	x
	Version of software		-	-	-	-	-	x	x
	Possible formats		-	-		x	x	x	-
	Type of model (points cloud, polygonal, etc.)		-	-	-	-	-	-	-
	Geometry type		-	-	-	-	-	-	-
	Number of	Polygons	x	-	-	x	-	x	-
		Vertices	-	-	-	x	-	x	-
		Layers	x	-	-	-	-	-	-
		Textures	x	-	-	x	-	x	-
	Size		x	-	-	x	-	-	-
	Units		x	-	-	-	-	-	-
	PBR		-	-	-	x	-	-	-
	Rigged geometries		-	-	-	x	-	x	-
	Morph geometries		-	-	-	x	-	-	-
	Scale regulations		-	-	-	x	-	-	-
	Vertex colour		-	-	-	x	-	-	-
	Animation		-	-	-	x	-	-	-
	Bounds		x	-	-	-	-	-	-
Relations	Similar items		-	x	-	x	-	x	-
	Models created by author		x	-	-	-	-	x	-
	External relations		-	x	-	x	x	-	-

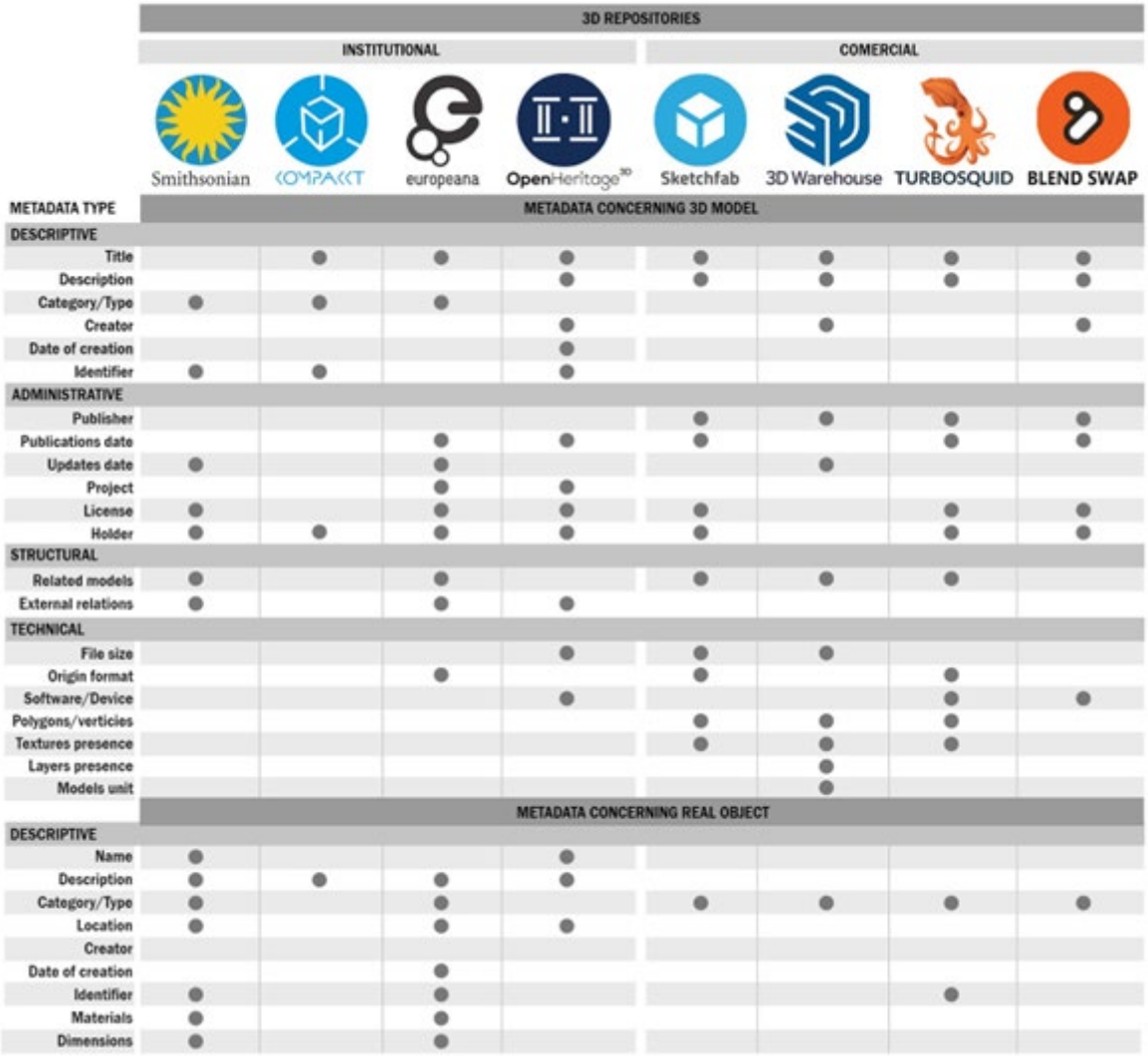


Fig. 61 The synthetic comparison of metadata sets in chosen institutional and commercial web-based 3D repositories.

The survey revealed a lack of consistency in the metadata sets across the repositories. Metadata were documented in varying ways depending on the specific repository. An additional challenge in the analysis was the diverse terminology used. Some fields, despite having different names, referred to the same type of information. The metadata in the table above attempts to unify the vocabulary, aligning fields with the same meaning but different names under a single category. There were also notable differences in the 3D model documentation schemes between commercial and institutional repositories. Commercial repositories tended to focus on the technical specifications of the model and a clear representation of copyright, while institutional repositories placed greater emphasis on accurately describing the object represented in the model. This suggests that the ideal scientific 3D model repository should merge both approaches. The metadata schema should provide information about the reconstructed object that supports further scientific research, while also presenting details about the 3D model itself to enable its reuse in line with FAIR principles.

The next step was to proceed with the preparation of a synthesis of this analysis emerging the most relevant metadata for 3D models of digital reconstructions. An additional platform from the institutional offering, Open Heritage 3D, was added to the pool of repositories analysed. This is a platform that collects 3D point cloud

models for cultural heritage sites from around the world.[94] In order to accurately extract the metadata in the selection repositories, sample 3D model entries for each were analysed. Each entry was saved as a screenshot in which the metadata was marked along with its category. The results of this analysis can be viewed in Appendix 5, and a synthetic summary of the documentation schemes is presented in Fig. 61.

The synthesis of the analysis further highlighted the significant differences between commercial and institutional repositories. Moreover, there are substantial variations even within repositories of the same category. This indicates that the documentation schema is not universal for 3D models and may be influenced by the specific publication objectives of a given repository. Further details on the objectives and specifications of repositories can be found in Chapter III.B.2.

C.2. Documentation schema for cultural 3D heritage models

Based on the initial findings from the analysis of metadata schemas in various repositories, preparations began for developing an in-house solution for the documentation of 3D models. The work on the documentation schema was undertaken in collaboration with the DFG 3D-Viewer project. Given the project's objectives, the schema needed to be adaptable for 3D models of cultural heritage, including those extending beyond digital 3D reconstructions. A low difficulty threshold was also established for the schema, which aimed to focus solely on the most essential elements of the documentation. Fields that were considered mandatory in the context of publishing 3D models on the web were also identified. These fields primarily focused on copyright and the identification of the object depicted in the 3D model. Topics such as the sources used, the details of the model's creation process, or specifics of the scientific design could be omitted, provided that publication ensures the model's reuse from the perspective of the FAIR principles. It was also suggested which metadata could already be published online in external databases, allowing for automatic retrieval rather than manual entry. However, it is possible that implementing this solution in a test environment may prove difficult without appropriate software support. As a result, seven key areas of documentation were identified, forming the foundation for the initial schema proposal (see Fig. 62). These areas included:

- The 3D file itself (technical specifications),
- Copyright information (author, licence, institutions holding the rights to use the model), and publication details (date and person publishing the entry),
- Creation of the 3D model (participants involved and their roles, duration of model creation),
- The real object depicted in the model (name, location, creator, creation date),
- Sources used (name, author, type, place and time of creation, catalogue ID),
- The research project (participating institutions, funding, project goals, duration).

The initial draft of the metadata documentation form was presented to the community for review during the 13th meeting of the Working Group for Digital 3D Reconstruction (Arbeitsgruppe Digitale 3D-Rekonstruktion). Participants were asked to prepare a 3D reconstruction model and complete a questionnaire about the metadata form, which was prepared in collaboration with Friedrich Schiller University Jena, based on the draft outlined above. A total of 28 responses were received, though 16 were incomplete. The average time taken to complete the form was 11.5 minutes. Respondents faced challenges in estimating the hypothesis level of their models and providing the required technical specifications. In many cases, respondents were not the

[94] https://openheritage3d.org/ (accessed 17 September 2022).

original authors of the models, and most of the 3D models were closed-source, which hindered the publication process. Additional difficulties arose around the interpretation of date and time fields (e.g., model creation period, publication date, and period represented in the reconstruction).

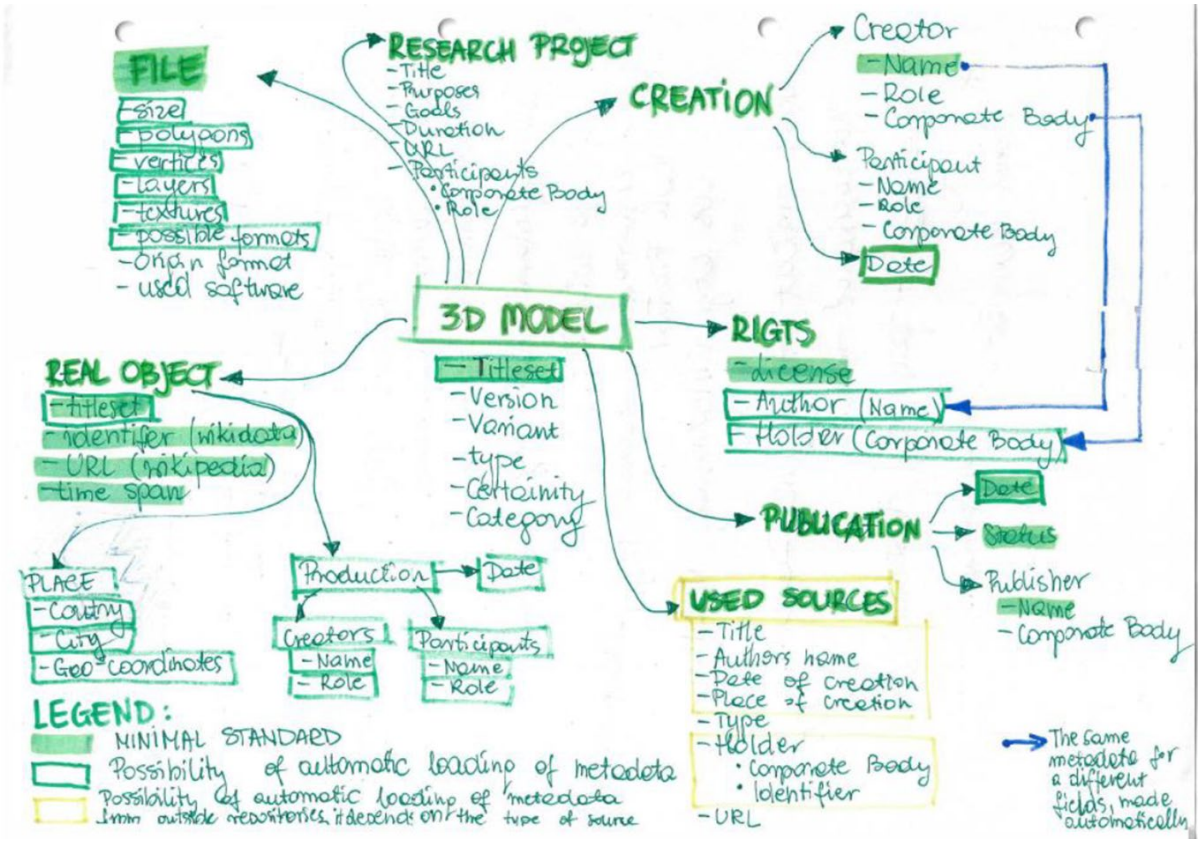


Fig. 62 Draft of the initial metadata schema for digital cultural 3D heritage.

Respondents were also invited to give feedback on the perceived gaps in the proposed metadata schema. They highlighted issues such as the inability to provide bibliographic information about sources, the lack of integration with external websites, and the difficulty in supplying certain information (e.g., technical model specifications or the primary source of reconstruction). In some cases, respondents noted that specific information (e.g., project website or institution responsible for the model) simply did not exist for their models.

Modifications were then made to the documentation scheme, which was transferred to a virtual workspace using MiroBoard (see Fig. 63). It was proposed to automatically retrieve the technical specifications of the model directly from the file and to implement fields with predefined answers selected from a list to simplify the form completion process. For the first time, the use of permanent identifiers was considered. Files with persistent identifiers, also known as authority files, are unique and allow for the unambiguous identification of a given entity, which can be a specific expression, term, person, organisation, object, place, etc. (Hengel, 2003). The search for relevant authority files to identify researchers, organisations, images, photographs, written sources, and objects of reconstitution began. Consideration was also given to the possibility of enriching the documentation by enabling uploading downloadable text files in formats such as PDF or Word.

During the scheme's development, consultations were also initiated with representatives of another project related to the documentation of digital reconstructions – the 'IDOVIR -DFG Projekt zur Dokumentation

virtueller Rekonstruktionen'.[95] The people involved in the project have many years of experience in documenting digital reconstructions. They are authors of many publications, also linked to the development of the metadata schema (Grellert & Pfarr-Harfst, 2019). Therefore, it was decided to harmonise the schemes being developed due to similar objectives and target audiences.

Once again, the Miro Board was employed to facilitate the harmonisation process, enabling the schemes to be visually compared and differences to be easily identified. The terminology used was evaluated, mutual understanding of the definitions of individual fields was confirmed, and connections were made between fields that referred to the same values. Despite the differing documentation structures, finding common ground for future collaboration in creating a standard for documenting digital reconstructions was possible.

Several conclusions emerged from the points of divergence. It was agreed that both schemes should introduce a 'project purpose' field, understood as the expected result (e.g., film, 3D print, AR application, digital model, etc.). The term 'project purpose' was also used to define the reason for initiating the project (such as a museum exhibition, a student seminar, or the celebration of a historical event anniversary). Dates were standardised according to ISO8601. Controlled vocabularies, specifically the 'relators' from the MADS/RDF (Metadata Authority Description Schema in RDF) developed by the Library of Congress,[96] were chosen to define the roles of institutions involved in the project.

The necessity of allowing the project to be divided into smaller semantic units was acknowledged. The importance of indicating the licence under which the model is uploaded was also emphasised. A gap in the permanent and unique identification of institutions was identified: the first scheme referred to addresses, emails, and telephone numbers, while the second scheme mentioned websites. This highlighted the need for an authority file for institutions. Both parties expressed an interest in using ORCID IDs (Open Researcher and Contributor IDs)[97] to identify the researchers involved in the reconstruction process.

However, there was no consensus regarding the documentation of sources. The author's proposed scheme only allowed for referencing sources published elsewhere, while the IDOVIR project proposal included the option of uploading and documenting sources directly on the platform. As the author aimed to make the 3D repository a quick and simple tool for publishing models and their documentation, the possibility of adding sources to the repository was not incorporated into the documentation scheme.

[95] https://www.dg.architektur.tu-darmstadt.de/forschung_ddu/digitale_rekonstruktion_ddu/idovir/idovir.de.jsp (accessed 15 October 2022).

[96] https://id.loc.gov/vocabulary/relators.html (accessed 07 March 2022).

[97] https://orcid.org/ (accessed 10 September 2022).

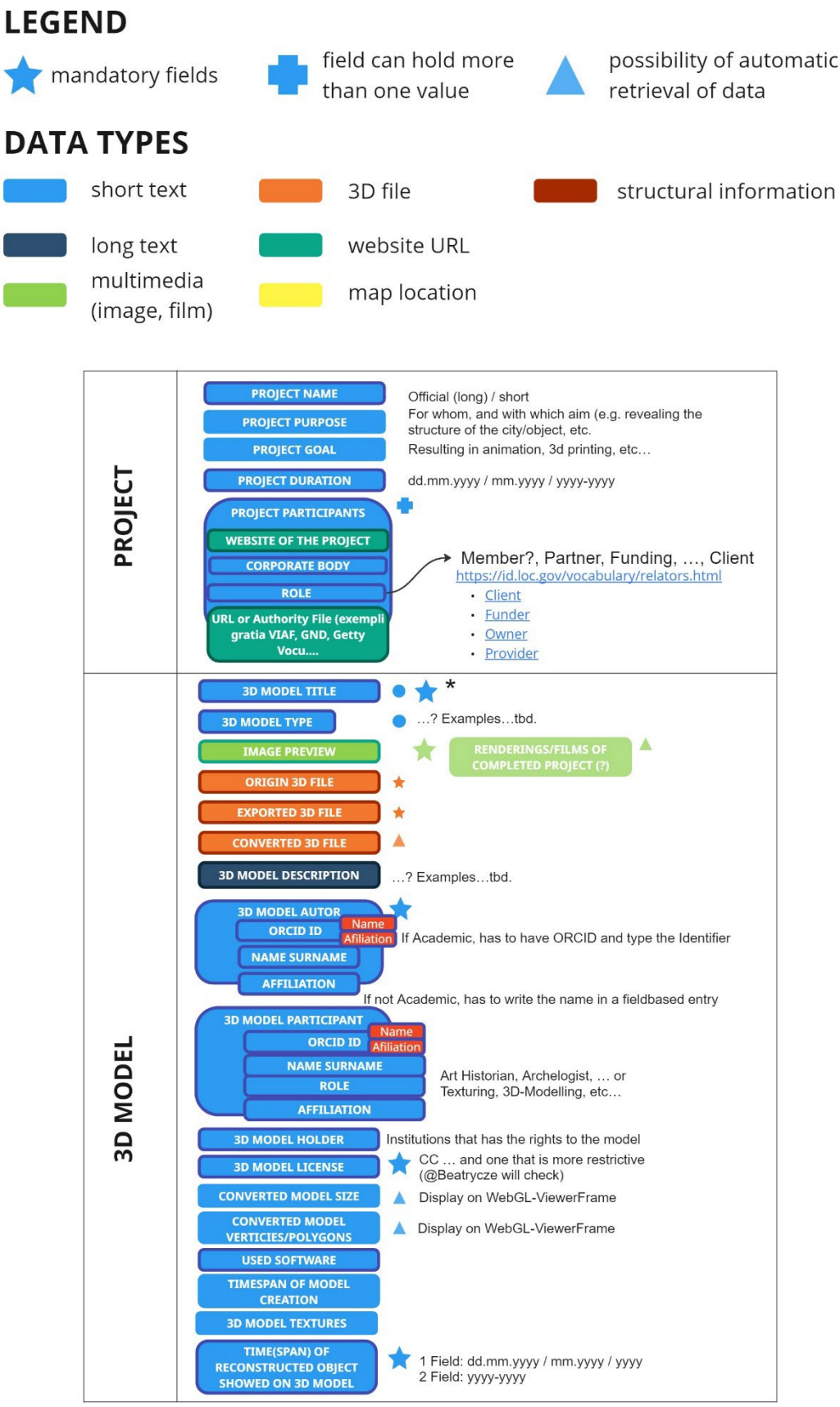


Fig. 63 The second version of the documentation scheme was prepared after receiving the first feedback from the community. The diagram distinguishes between the different types of fields using various colours and marks the mandatory fields with a star symbol next to them (Part 1, continue Fig. 64).

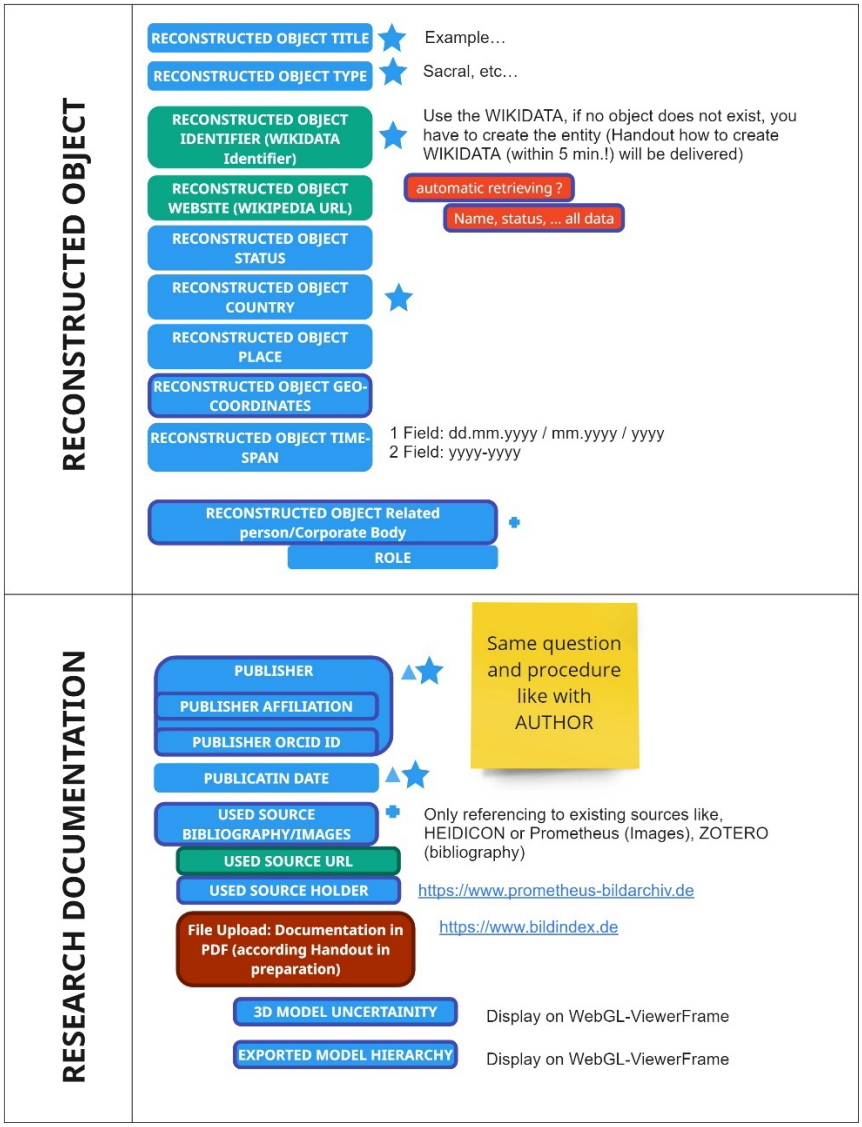


Fig. 64 The second version of the documentation scheme was prepared after receiving the first feedback from the community (Part 2).

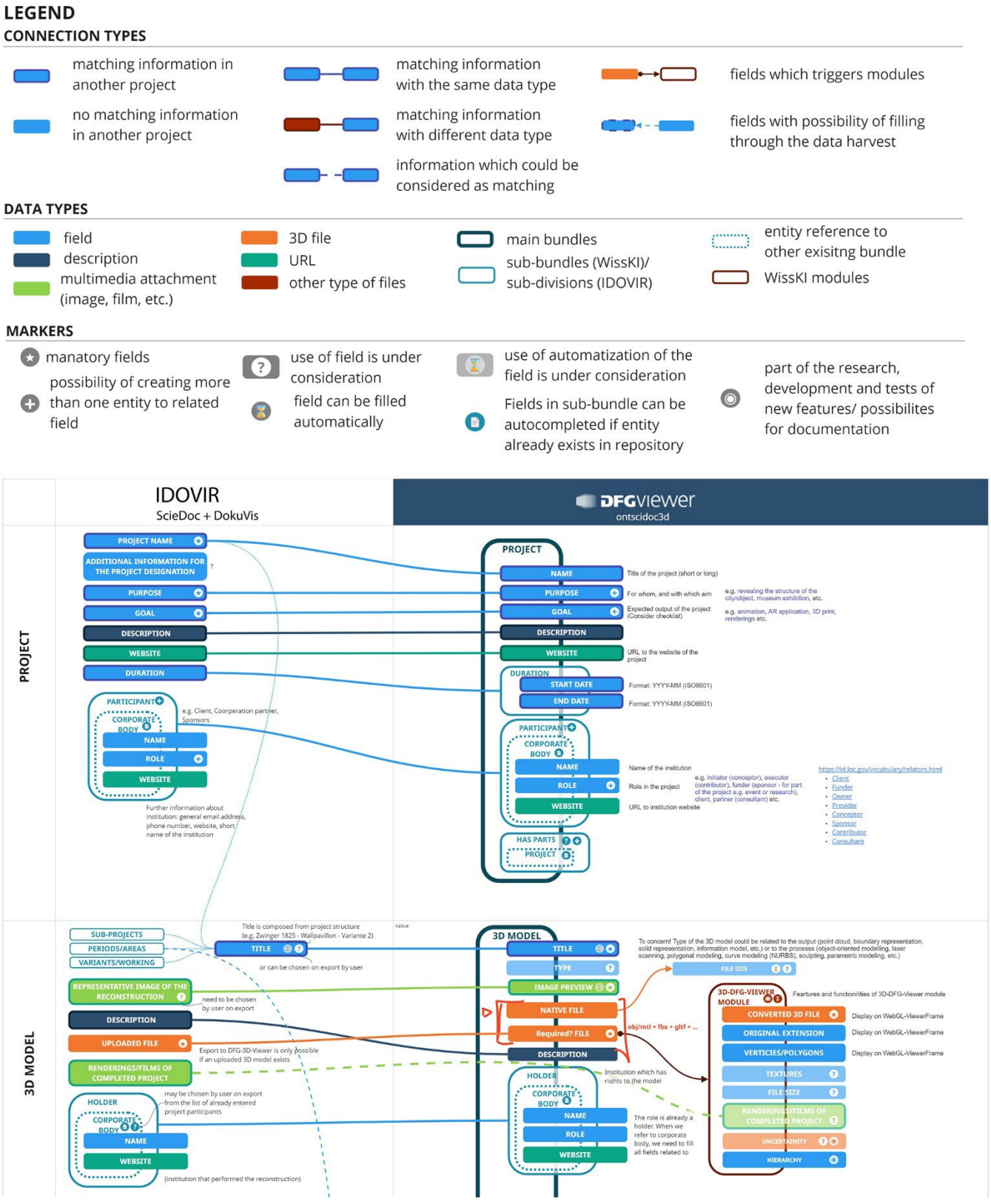


Fig. 65 Harmonisation of proposed metadata documentation scheme with the proposal of documentation prepared by IDOVIR project team (Part 1, continue on Fig. 66 & Fig. 67).

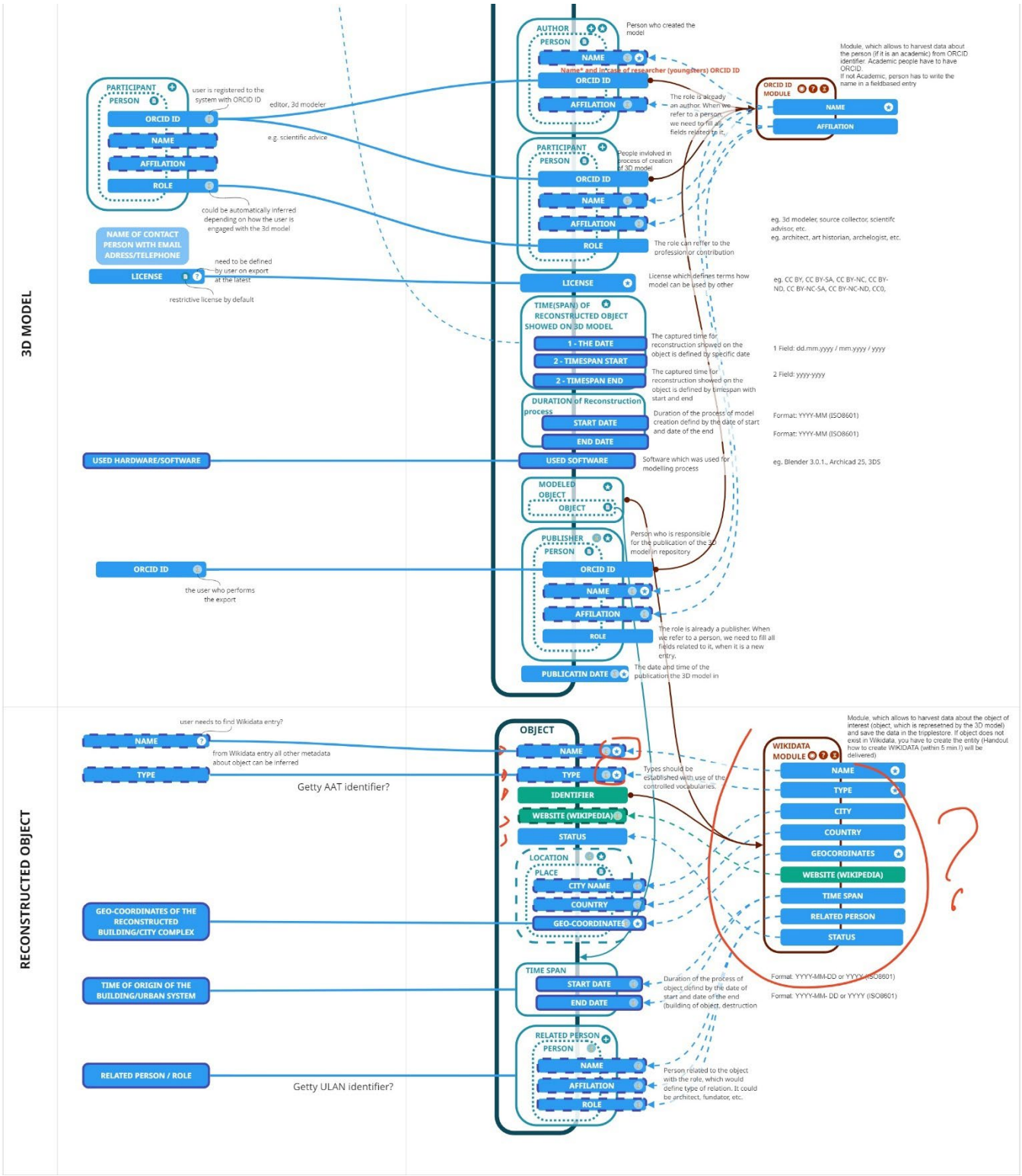


Fig. 66 Harmonisation of proposed metadata documentation scheme with the proposal of documentation prepared by IDOVIR project team (Part 2, continue on Fig. 67).

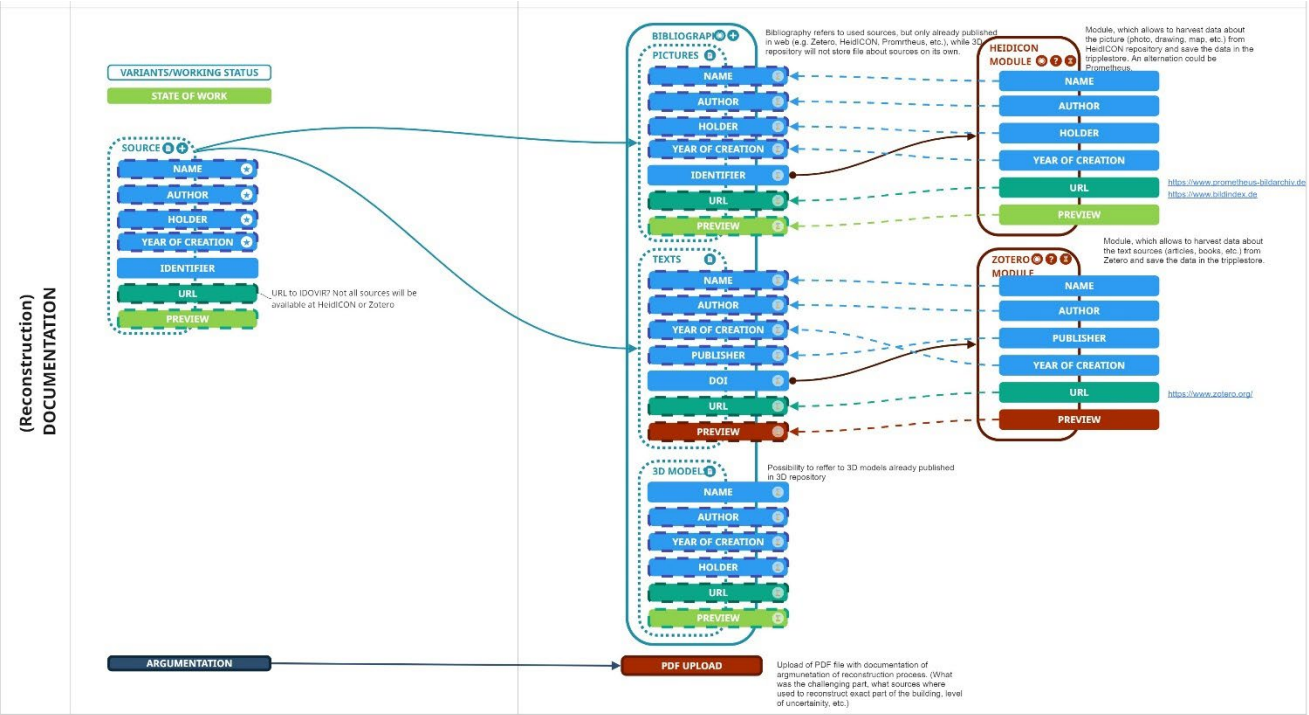


Fig. 67 Harmonisation of proposed metadata documentation scheme with the proposal of documentation prepared by IDOVIR project team (Part 3).

After a productive discussion and harmonisation of the projects, changes were made to the documentation scheme, which was subsequently re-presented to the community in the form of a survey during the 14th meeting of the Working Group for Digital 3D Reconstruction (Arbeitsgruppe Digitale 3D-Rekonstruktion). As with the first survey, this one was also prepared in collaboration with Friedrich Schiller University Jena, and respondents were asked to assume the role of a person publishing a 3D model and completing the documentation form.

In the second questionnaire, 34 responses were received, but only 12 were fully completed. Many respondents did not understand what ORCID ID was and skipped this field. There were also questions about the differences between the publisher and the model author, highlighting the need to define these terms clearly in the form. For the field specifying the time period depicted in the 3D model, many respondents did not provide specific dates but used era names or Roman numerals to indicate the period, despite the instruction to use an ISO-standard date format. Respondents were then asked to indicate any missing information they felt should be included in the form. Suggestions included the ability to specify the location of the object (e.g., using Geonames authority files), define the interior of objects, and add information about the iconography, creator, personal data, genre of the entry, object description, client and funding, as well as expand the choices of available licences. Respondents also identified problems in completing the form, with several mentioning the absence of details on modellers and associated metadata. One respondent described the project's goal as difficult to define, while another requested the ability to add annotations directly to the 3D model within the viewer.

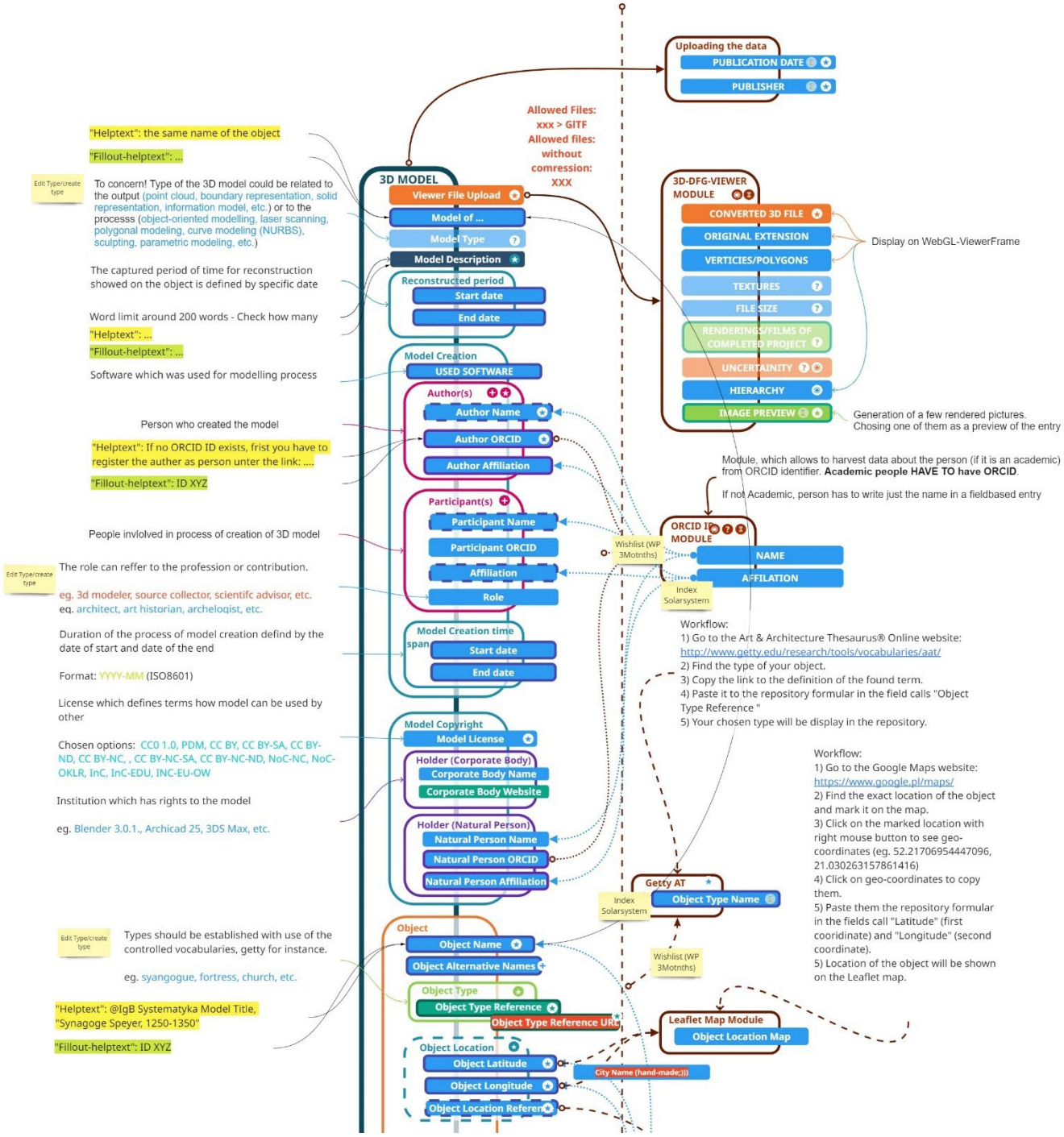


Fig. 68 Third version of the documentation scheme with the hierarchy of data model and an indication of field values (Part 1, continue on Fig. 69).

Based on the survey results, the documentation schema was revised, and preparations for its implementation in the repository began (see Fig. 68). This included defining individual types and specifying possible values, particularly for fields that would be selected from a drop-down list. The object information was expanded to include alternative names and latitude and longitude coordinates, enabling the object's location to be displayed on a map. The schema also allowed adding related historical events and figures (such as the architect or founder). The method for declaring the time period represented in the model was simplified, reducing three fields (initially

allowing either a single date or a start and end date) to just two, specifying the start and end dates. Work also began on drafting supporting text for fields that had caused difficulties for respondents in the survey. The resulting metadata schema was implemented in the 3D test repository as part of the DFG 3D-Viewer project (see Chapter IV.A.) and subsequently evaluated through a survey conducted with the project partners, as outlined in Appendix 11.

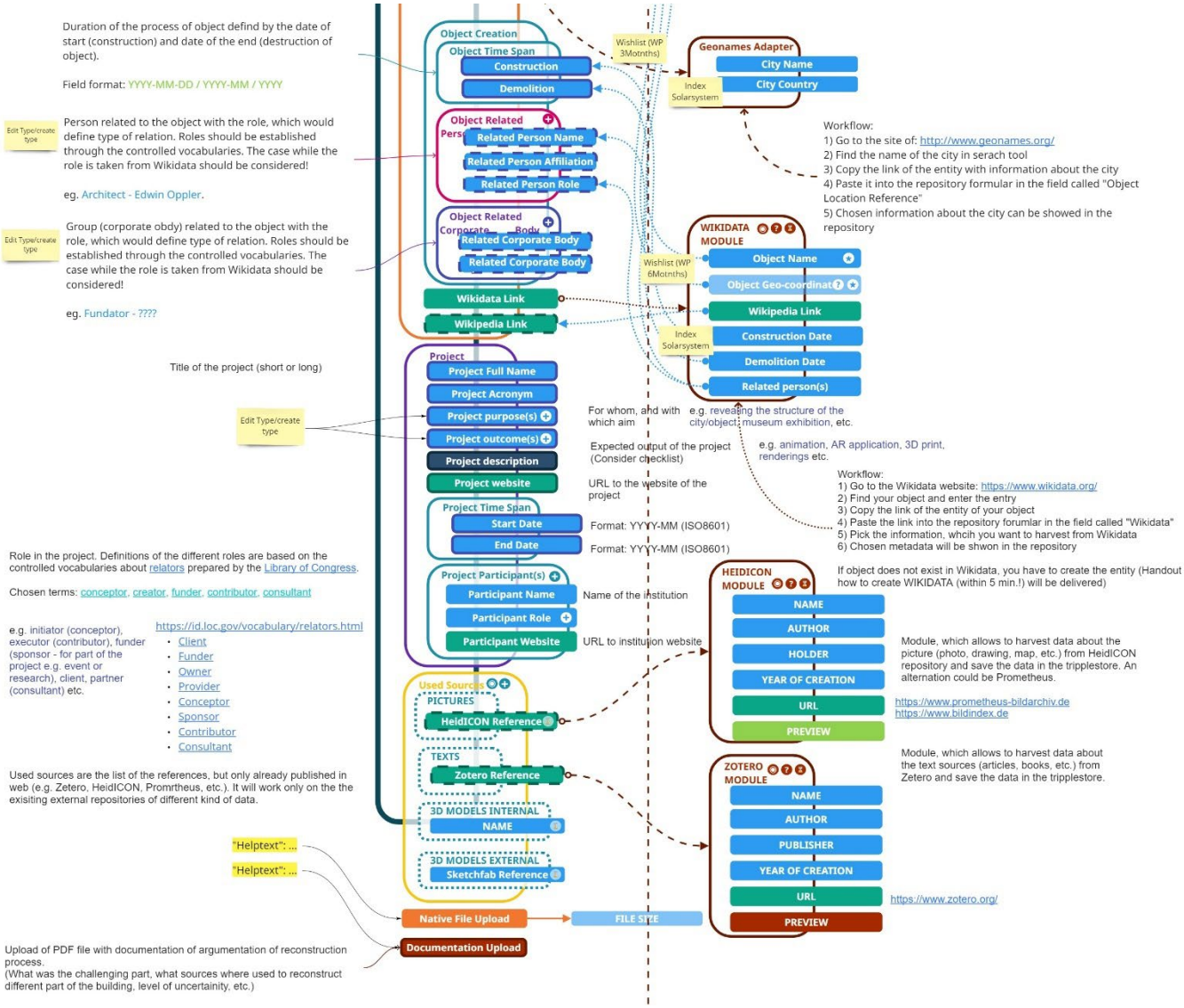


Fig. 69 Third version of the documentation scheme with the hierarchy of data model and an indication of field values (Part 2).

C.3. Emerging new approaches

Metadata for 3D cultural heritage model projects has become the focus of much ongoing research, not only in Germany but also internationally. Throughout this work, several active projects were identified that addressed this topic, all of which expressed an interest in collaborating to develop a shared approach. Seizing this opportunity, efforts were made to organise a workshop for infrastructures working with 3D cultural heritage, specifically on the topic of metadata. The aim was for each participant to present their approach to documentation, thereby initiating a search for common ground.

Initially, the group consisted of six repositories. Five of these were new infrastructures related to digital heritage (DFG 3D-Viewer,[98] IDOVIR,[99] baureka.online,[100] FID BAUdigital,[101] and Semantic Kompakkt[102]) and 3D models from ongoing research projects. The final participant was an infrastructure maintained by a university library (heidICON[103]). As the collaboration progressed, the group expanded to include three institutions focused on data aggregation (Europeana[104], Share3D[105], CARARE[106]) and one museum repository (Smithsonian3D[107]). Although each of these infrastructures deals with 3D models in the context of cultural heritage, as the study in section B.1. showed, the metadata schema can vary significantly depending on the profile of the repository in question. Therefore, the characteristics of the documentation platform of each of the contributors to this initiative have been collected (see Tab. 20).

Tab. 20 Preliminary identification of the objectives, types of resources and data schemas used of the repositories participating in the metadata workshops.

Repository	3D model type	Scope	Data model
DFG 3D-Viewer	–Hand-made models, –3D scans;	Oriented on 3D models. Focus on visualization and reusability of 3D models.	CIDOC CRM, OntSciDoc3D
IDOVIR	–Hand-made models;	Oriented on projects – 3D models are not required but can be s supplementary material. Focus on documentation of digital 3D reconstruction projects.	CIDOC CRM (considered)
baureka. online	–3D scans, –Point clouds, –SfM-models, –BIM models;	Oriented on objects – 3D models are not the only collected medium, some entries can exist without it. Focus on documentation and provision of research data concerning architecture.	RADAR (DataCite)
heidICON	–3D scans, –Hand-made models;	Oriented on digital asset – 3D models are relatively new in the system. Most entries are about other type of media. Focus on archiving of digital cultural heritage object with multidisciplinary approach.	Object-oriented and event-based, like the XML schema LIDO.
FID BAUdigital	–Hand-made models, –3D scans, –point clouds, –BIM models;	Currently available workbench is oriented on 3D models. Focus on digital research data in the disciplines of civil engineering, architecture, and urbanism.	For 3D architectural models: DURAARK-Modell for Arch. Data (buildm, e57m, ifcm)
Semantic Komappkt	–Hand-made models, –3D scans;	Oriented on 3D models. Focus on visual representation of cultural objects with semantic description of annotations.	Wikibase Generic Model for Digital Objects
Europeana	–Hand-made models, –3D scans, –Point clouds;	Oriented on digital asset – 3D models are relatively small part of the whole collection. Focus on aggregation of digital heritage resources from the whole Europe.	Europeana Data Model (EDM)
Share3D	––––––––––	Oriented on 3D models. It is not repository itself, it is an infrastructure, which allows to publish models directly into Europeana with use of Sketchfab repository.	Not known
Smithsonian 3D	–3D scans;	Oriented on 3D models. Focus on digitization museum collections.	Not known
CARARE	–Hand-made models, –3D scans, –Point clouds;	Oriented on digital asset including 3D models. Focus on guidance in creation, publication, and use of digital data, including aggregation to Europeana.	CARARE metadata schema

[98] https://dfg-viewer.de/en/dfg-3d-viewer (accessed 23 May 2023).
[99] https://idovir.com/ (accessed 23 May 2023).
[100] https://baureka.online/de (accessed 23 May 2023).
[101] https://www.fid-bau.de/en/ (accessed 23 May 2023).
[102] https://semantic-kompakkt.de/home (accessed 23 May 2023).
[103] https://heidicon.ub.uni-heidelberg.de (accessed 23 May 2023).
[104] https://www.europeana.eu/en (accessed 23 May 2023).
[105] https://share3d.eu/ (accessed 23 May 2023).
[106] https://www.carare.eu/en/ (accessed 23 May 2023).
[107] https://3d.si.edu/ (accessed 23 May 2023).

The workshop was held twice. The first took place in Mainz in early December 2022, while the second was part of the larger event, the Workshop on Research and Education in Urban History in the Age of Digital Libraries (UHDL 2023), which was held in Munich in late March 2023. Both events were conducted in a hybrid format. The initial findings from this collaboration are detailed in a publication included in the UHDL 2023 Proceedings.[108]

The workshop format was similar to the earlier harmonisation process of the documentation scheme with the IDOVIR platform. A graphical layout was prepared in Miro Board[109], where participants were asked to insert their respective documentation schemes (see Fig. 70). During the workshop, each scheme was presented by its author, allowing representatives of other infrastructures to understand the meaning of the names of the different fields and their use in the context of a given repository. Subsequently, the search for common ground began from looking for similarities in the structure and mandatory fields. In the next step, the harmonisation process started with a discussion on terminology and an attempt to identify a core documentation schema for 3D cultural heritage models.

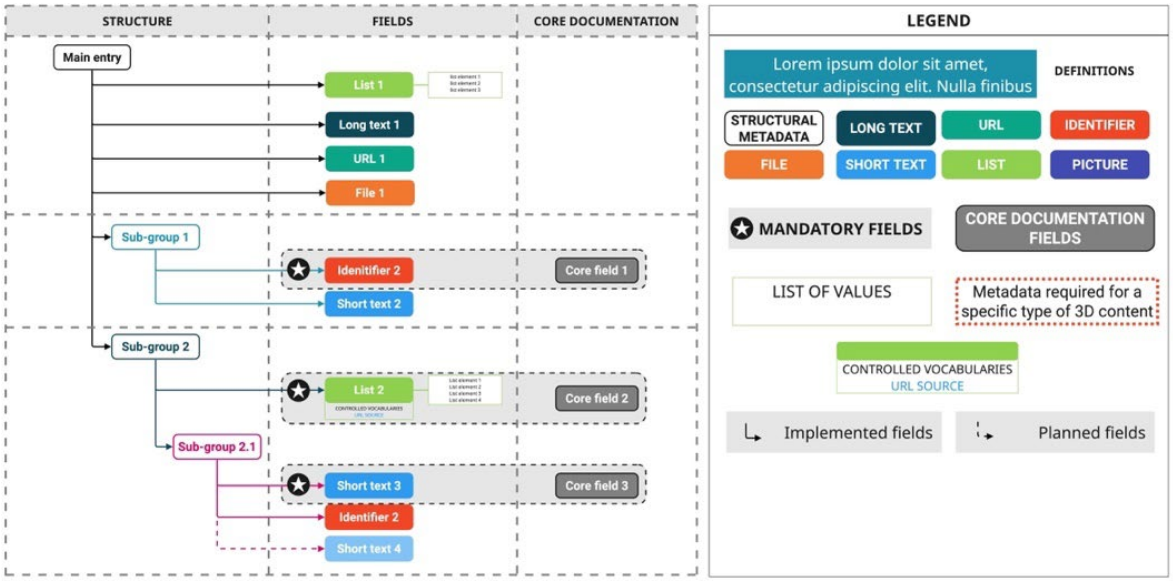


Fig. 70 Graphic layout for the presentation of the documentation schema during the metadata workshop with a legend on the meaning of colours (type of documentation field) and graphic symbols

Due to the varying approaches to the publication process and the differing scopes related to the data published around 3D modelling, there were significant differences in the comprehensiveness of the schemes. To standardise the approach, obligatory fields were identified, and an effort was made to create a mapping for the core documentation schema. The graphical representation of metadata schemas on the Miro Board enabled participants to explore the mapping between repositories. Similarities were identified in the structural elements of the documentation and individual fields, but even when fields had counterparts in multiple repositories, they were not always mandatory.

[108] See: Bajena, I., & Kuroczyński, P. (2023). Metadata for 3D Digital Heritage Models. In the Search of a Common Ground. In S. Münster, A. Pattee, C. Kröber, & F. Niebling (Eds.), Research and Education in Urban History in the Age of Digital Libraries (pp. 45–64). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-38871-2_4

[109] The MiroBoard documenting the workshop is available to the public: https://miro.com/app/board/uXjVPDUEGMY=/?share_link_id=86884542224 (accessed 22 october 2024).

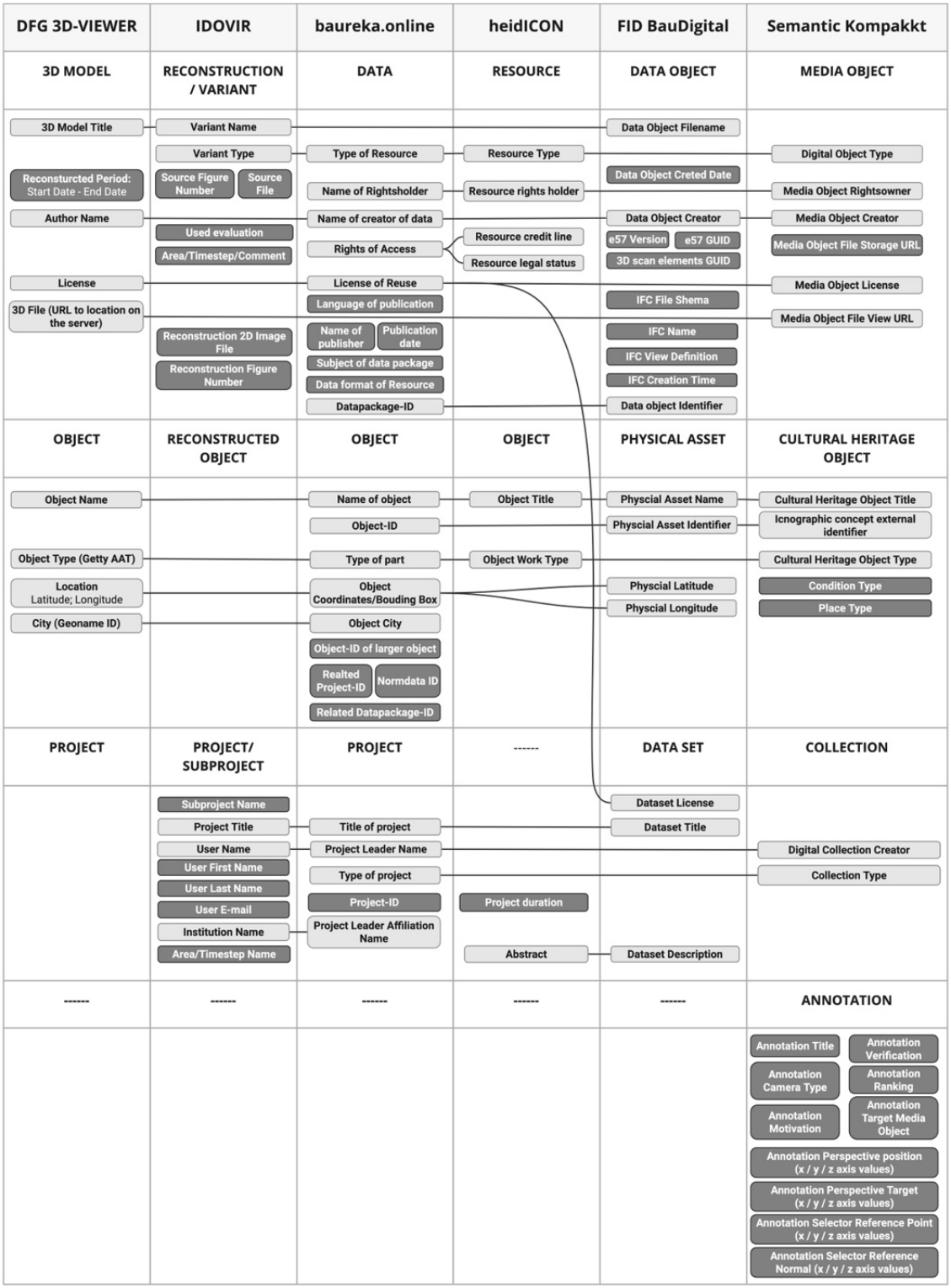


Fig. 71 Overview of core documentation schemas from six investigated data repositories. Matching fields were connected by lines and highlight in brighter colour.

The schema structure was typically based on the data upload form, with two exceptions: Semantic Kompakkt's schema was based on class hierarchy and properties, while FID BAUdigital allowed users to modify fields and add their own ontologies. Although their contribution highlighted two ontologies related to 3D models, it did not reflect the full documentation capabilities. Some fields shared the same label but stored different data types, leading to disambiguation issues. Five mappings between the DFG 3D-Viewer and other repositories were

prepared and are currently under review, with plans to extend the mapping to include all workshop participants and other relevant 3D digital heritage repositories. The complexity of graphical representations in Miro Board also raised readability concerns, prompting a planned redesign to categorise metadata into functional groups: descriptive, administrative-preservation, administrative-technical, administrative-rights, and structural metadata. Changing the field order and structure within metadata schemas will improve readability. Additionally, metadata needs to be sorted according to context, as not all metadata refers directly to the digital resource. The contexts identified were: digital resource (the 3D model), object (the real-world or hypothetical object represented), project (the creation activity, often within a scientific context), dataset (the broader data set the model belongs to), annotation (notes or multimedia attached to the model), and repository (the data repository that hosts the 3D model).

C.4. Universal schema

The workshop revealed a significant truth: a universal scheme for documenting 3D models of cultural heritage may not be achievable. Many factors influence the information reported. One of the most pertinent publications addressing metadata selection for 3D models in recent years is '3D Data Creation to Curation: Community Standards for 3D Data Preservation,' produced by the CS3DP community. This publication highlights that the complexity of metadata is largely determined by the purpose for which the 3D model is being shared. Through an analysis of various repositories, six potential reasons for publishing 3D models online were identified:

V – Easily accessible **visualization** in a 3D environment;
O – Digital documentation of **object** embedded in the 3D model;
R – Presentation of scientific **research** results;
D – Sharing models for reuse by data **download**;
A – Data a**ggregation** and advanced analysis on entire digital collections;
S – **Storytelling** about object based on annotations and hotspots.

The stated objectives form the acronym VORDAS. Each of the VORDAS objectives requires a tailored approach, with the development of specific fields that would form part of the core metadata schema. The factors determined for classifying repositories, documentation schemes, and metadata revealed that covering all aspects would result in highly detailed and complex documentation. Therefore, it was decided to create documentation templates aligned with the purpose of publishing the model online. To achieve this, a life diagram of the digital cultural heritage resource was developed, considering the elements and activities that require documentation (see Fig. 4). Although the diagram resembles a typical digital resource life cycle, placing it within the context of scholarly activity and cultural heritage has modified its structure.

The schema is based on five phases, each requiring the capture of different types of information: planning, creation, publication, reuse, and aggregation. In the **planning phase**, which occurs before modelling begins, administrative guidelines, funding, work duration, and the subject of the model are established, while research is conducted to gather the source material needed for the model (including fieldwork, site scanning, measurements, or archival research for historical sources).

The **creation phase** focuses on the modelling process or the processing of the collected data. At this stage, the model's intended purpose should already be clear. Based on this, the model's requirements and constraints are outlined. The modelling or 3D data acquisition methods, along with the hardware and software used, should also be documented during this phase.

The **publication phase** is based on making the 3D model available online. This involves choosing a platform for publication, which will determine the findability and accessibility of our model and whether it reaches the audience we are addressing. The phase also requires analysing legal issues, as the 3D model is subject to copyright and may not be published in every case. The publication itself can also be done in several ways, from publishing the project documentation itself, through renderings or animations, making the model available in the web-viewer, and finally making the 3D files available in raw or final form, in the software's native format (BLEND[110], PLN[111], C4D[112], etc.) or using 3D data exchange formats (GLB/GLTF[113], OBJ[114], DAE[115], etc.).

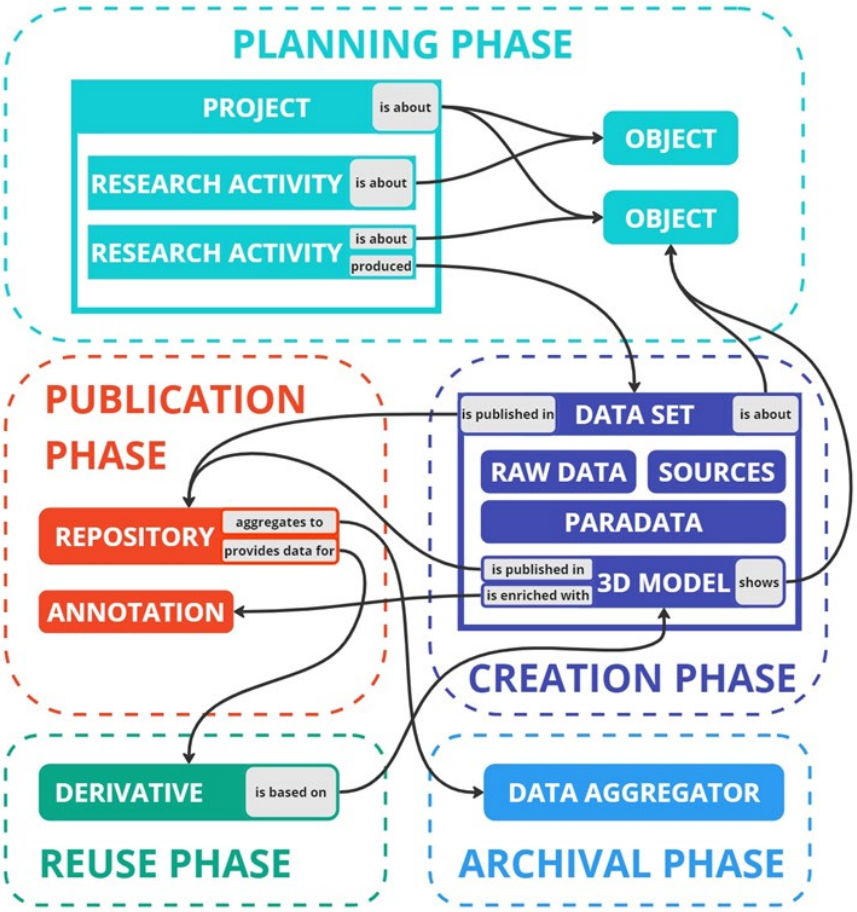


Fig. 72 Diagram of the life cycle of a 3D digital cultural heritage model highlighting the instances relevant to documentation.

The **reuse phase** applies only to cases where 3D files were made available during publication. In addition to the file itself, it requires its technical specifications and the original use for which it was prepared. If any additional elements have been prepared as part of the model (such as textures/materials, animations, or scene lighting) then the intended file use requires all files and components included in the shared package. If, on the other hand,

[110] Native file format of Blender by Blender Foundation.
[111] Native file format of Archicad by Graphisoft.
[112] Native file format of Cinema4D by MAXON COMPUTER GMBH.
[113] GL Transmission Format (GLTF) is a standard 3D file for three-dimensional scenes and models. It is open-source solution developed by Khronos Group.
[114] Wavefront is a geometry definition file format first developed by Wavefront Technologies for its Advanced Visualizer animation package.
[115] COLLADA is an interchange file format for interactive 3D applications, developed by the Khronos Group.

the file is to be made available for the possibility of further development, it is necessary to provide working files, including native formats. In the case when the file supposed to be used in a broader context (e.g., putting a finished church model into a city model) then data exchange formats should be used to use the file. Reuse also requires that conditions of use be made available to the user before downloading.

The **archiving phase** requires publication in a repository that ensures the longevity of files over the long term, such as digital libraries. The metadata in this regard should be as rich as possible to ensure that the archive has all available information about the resource. A certain solution in this regard may be to submit one's model along with the necessary metadata to data aggregator like Europeana that collects digital resources from national repositories. An example of a national repository aggregating its resources to Europeana is German Digital Library (Deutsche Digitale Biblithek – DDB), which aims to provide access to cultural and scientific heritage from all over Germany captured in digital resources. DDB prepares data packages for aggregation, including data quality check, enriching data set by adding information about data provider, clarifying copyrights and legal issues and mapping metadata to aggregator data model.

The most crucial moment of the cycle in terms of metadata is publication, as this is the point at which the person publishing decides how much information about the 3D model will be made public. Therefore, metadata from previous stages like planning and creation should be considered during publication, as well as considering the metadata needed for future use scenarios like aggregation or reuse. This means that according to the publication the following elements should be documented:

1. **Project** - the activity highest in the hierarchy of the whole process, under which we can assign all activities related to the creation of a 3D model. It most often lasts several months, requires acquisition of funds, is carried out by several institutions covered by the partnership for a specific purpose with a foreseen result. Project may involve multiple **research activities** and may covered multiple **3D models**.
2. **Research activity** - The activity of carrying out scientific research on a single object. It may consist of archival research to find historical sources, taking measurements and collecting information in the field, or digitising an existing site. The scientific activity should end with clear guidelines for modelling in terms of scope, quality, accuracy, or reliability of the study based on the source material collected and the administrative requirements of the **project**. A single research activity may produce multiple **3D models**, considering different variations of a single solution, or the progression of work overtime.
3. **Object** - an object that is the subject of a **project**, **research activity**, about which a **data set** is collected, and which is represented on **a 3D model**. It can be equally a physical existing object, a destroyed object or a concept represented by plans that have never been realised.
4. **Data Set** - a set of all collected material about the object, including historical sources, scientific publications, raw data, paradata, final files and **3D models** in a single **scientific activity** or **project**.
5. **3D Model** - A digital resource showing a specific **object**, providing a visual representation of the results of a **research activity** in three-dimensional space, created as part of the **project** and forming part of the **data set**.
6. **Publication** - Activity of publishing a **data set** or **3D model** on the web in a selected **repository**. It may (but need not) be carried out independently of the **project** and **research activity**, as part of a completely different activity

The elaboration of listed elements in terms of metadata is presented by Tab. 21. Three levels of complexity are distinguished to classify the repositories based on the target audience (basic, professional, advanced). Fields described in the table are based on a survey of metadata frameworks and schemas and research projects related to the topic (Dublin Core Metadata Initiative (DCMI) Usage Board, 2020; Hoffmann, 2020; ICOM-CIDOC

LIDO Working Group, 2021; Swiss Art Research Infrastructure project, 2020). Metadata fields for each level of complexity are described by the **name** (marked as bold text), which indicates the field meaning, and the datatype it represents (in blue colour). Fields that do not directly describe any of the six listed elements above, requires assignation of a class attribute (in green colour) instead of a datatype. The used classes and datatypes values are taken from the described schemas for structured data on the Internet by schema.org (W3C Schema.org Community Group, 2015). Fields with class attribute were given an additional attribute: "complexity" (in orange colour), to express the level of comprehensiveness of the field description in context. Four levels of complexity attribute were distinguished:

- **Identification:** A class shall be described in a minimal way allowing its identification by a single field of the text type;
- **Context:** a class description allows it to be identified in a more sophisticated way through the use of external identifiers, as well as containing additional information that defines its use in a given context, e.g. through described roles, types or relationships to other elements documented in the repository;
- **Reference:** while class is referred to the use of particular resource in context, the description should be prepared accord to the rules of bibliographic reference;
- **Record**: The class is described in a precise way, with metadata that not only allows the element to be identified in the context used, but also provides additional background information focusing on the broader view of the element.

Tab. 21 Definition of the metadata for the different categories related to the publication of a 3D digital heritage model in a three-level scale of comprehensiveness: basic, professional, and advanced.

	Basic	Professional[116]	Advanced[117]
Project	-**Title**, datatype:Text -**Description**, datatype:Text -**Start**, datatype:Date -**End**, datatype:Date _____ -**Funds** class:Organization complexity:Identification -**Partners** class:Organization complexity:Identification	Increase of complexity level for **Funds** and **Partners** to "Context". _____ -**Aims**, datatype:Text -**Website**, datatype:URL _____ -**Participants** class:Person complexity:Context -**Contact** class:ContacPoint complexity:Identification	-**Final results** class:MediaObject complexity:Identification -**Object** class:Thing complexity:Context -**Data set (output)** class:DataSet complexity:Identification -**3D Model** class:3DModel complexity:Identification -**Research publications** class:CreativeWork complexity:Reference
Research Activity	- **Type**, datatype:Text - **Topic**, datatype:Text _____ -**Participants**	Increase of complexity level for **Participants** and **Object** to "Context". _____	-**Accuracy**, datatype:Text -**Uncertainty**, datatype:Text _____ -**Data set (sources)**

[116] Professional pattern will always contain all metadata from basic pattern.

[117] Advanced pattern will always contain all metadata from professional and basic pattern.

	Basic	Professional[116]	Advanced[117]
	class:Person complexity: Identification -**Object** class:Thing complexity: Identification	-**Methods**, datatype:Text _____ -**Project** class:Activity complexity:Context	class:DataSet complexity:Context -**Data set (input)** class:DataSet complexity:Identification -**Data set (output)** class:DataSet complexity:Identification -**3D Models** class:3DModel complexity:Identification -**Research publications** class:CreativeWork complexity:Reference
Object	-**Title**, datatype:Text -**External Identifier**, datatype:URL _____ -**Classification**, class:Class complexity: Identification -**Location** class:Place complexity: Identification	Increase of complexity level for **Classification** and **Location** to "Context". _____ -**Description**, datatype:Text _____ -**External Records**, class:WebPage complexity:Reference	complexity:Record *Full object record should additionally include the creators of the object, its history, and physical attributes such as current condition, dimensions, materials, etc.*
Data set	-**Title**, datatype:Text -**ID**, datatype:Text _____ -**Publication** class: PublicationEvent complexity:Context -**Files** class:Mediaobject complexity: Identification	Increase of complexity level for **Files** to "Context" _____ -**Description**, datatype:Text _____ -**Holder** class:Agent complexity:Context -**Research activity** class:3Dmodel complexity:Identification	complexity:Record *Full data set record should describe the methods of obtaining the data set, the context in which it was obtained and the precise conditions of its possible use.*
3D Model	-**Title**, datatype:Text -**Description**, datatype:Text _____ -**Publication** class: PublicationEvent complexity:Context	Increase of complexity level for **Creators** and **Object** to "Context". _____ -**Used Software**, datatype:text -**Used Device**,	-**Project** class:Activity complexity:Context -**Data set (sources)** class:DataSet complexity:Context -**Data set (input)**

	Basic	Professional[116]	Advanced[117]
	-**Specification** class:Property complexity:Record -**Creators** class:Creator complexity: Identification -**Object** class:Thing complexity:Identification -**Visualization** class:Mediaobject complexity: Identification	datatype:text -**Creation Date,** datatype:date _____ -**Participants** class:Participant complexity:Context -**Research activity** class:3DModel complexity:Context -**Data set (output)** class:DataSet complexity: Identification	class:DataSet complexity:Identification
Publication	-**Publication Date** datatype:Date -**License**, datatype:Text _____ -**3D Model** class:3Dmodel complexity: Identification -**Publisher** class:Agent complexity: Identification	Increase of complexity level for **Publisher** and **3D Model** to "Context". _____ - **Terms of use,** datatype:Text _____ -**Data Set** class:DataSet complexity:Identification	Increase of complexity level for and **3D Model** and **Data Set** to "Record". _____ -**Data Record Reference:** datatype:URL _____ -**Repository** class:WebPage complexity:Context

Tab. 22 Documentation patterns that determine the level of complexity of documentation of individual elements related to the publication of 3D models on the web in relation to the purpose of publication.

	Visualization	Reuse	Heritage Record	Scientific research	Data aggregation
Project	Not required	Not required	Basic	Advanced	Not required
Research Activity	Basic	Professional	Basic	Advanced	Basic
Object	Basic	Basic	Advanced	Professional	Professional
Data set	Not required	Basic	Professional	Advanced	Not required
3D Model	Basic	Advanced	Basic	Professional	Professional
Publication	Basic	Professional	Basic	Professional	Advanced

The resulting three-stage elaboration of metadata against the various elements associated with the publication of 3D models on the web gives an overview of the expansion of the various sections in relation to a diverse audience. This, however, does not catch the topic of matching metadata to the purpose of publishing on the web. For this reason, an additional study was developed in which the comprehensiveness of the documentation of individual elements was matched to the purpose of publication (visualization, reuse, monument record, documentation of scientific research, data aggregation) (see Tab. 22). In this way, documentation patterns were

obtained that take into account both the purpose of the model's publication and the audience to which it is directed.

C.5. Documentation schema for digital 3D reconstruction

The search for a universal pattern and the creation of complexity models led to an additional conclusion. The documentation of 3D digital reconstructions is such a complex process that it necessitates a proposal specifically tailored to the unique requirements of this type of work, as described in section I.C. Further efforts were made to expand the overall documentation scheme (see Fig. 73). An attempt was also made to identify the main categories of units necessary for documenting digital reconstructions and to indicate points of secondary reference. Reference units that should be described in separate forms include categories such as persons, institutions, types, places, actors, or objects. These specialised documentation categories, which refer to other forms, are highlighted in the diagram with capital letters. In defining these units, the list of classes from the CIDOC CRM documentation standard, version 7.1.3, was used.[118] The overall structure of the schema follows the general guidelines for the documentation of 3D cultural heritage outlined in Chapter III.C.2.

However, some significant changes have been made to the scheme. The first was the dependence of the document fields on the typology of the entry. By analysing the user's input, the schema adjusts the documentation path by providing different fields as needed. This functionality was necessary due to the difficulty of offering specialised information based on the profession of the data depositor, or the mismatch of certain fields for specific cases, which caused confusion (e.g. reconstitution time for digitised objects or providing a permanent location for museum artefacts).

The second change involved separating the visualisation in the web viewer from the actual 3D model referred to in the schema as the resource. This adjustment stemmed from the observation that the 3D visualisation in the viewer did not accurately reflect the true state of the reconstruction. The geometry displayed is the result of exporting the model from the original software to a data exchange format, followed by further processes within the publishing platform, such as compression and file conversion. While the 3D model may appear visually similar to the original, the displayed file format contains transformed data stored differently from the source. The ability to describe file specifications, including accuracy, segmentation, and textures, has also been added, but, as noted, only applies to the documentation unit referred to as the resource.

Another difference is the introduction of the ability to create relationships between different 3D models. When documenting a resource, one of several options must be selected, which defines the structure of the entire documentation form. The first option involves documenting a resource without establishing relationships with other resources. The second option allows for the documentation of a new version of an already-documented model in the system. This feature enables the tracking of reconstruction progress and the recording of milestones in the project's development. The third option allows the creation of semantic parent-child relationships, where model fragments are documented as individual semantic units. This approach provides more precise documentation of model segments and their specific meanings. It also allows large models, which may be unoptimized for web browsing, to be divided into smaller elements better suited to the requirements of web browsers.

[118] See: https://www.cidoc-crm.org/sites/default/files/cidoc_crm_version_7.1.3.pdf (accessed 22 October 2024).

The process of creating a digital 3D reconstruction was divided into two main components: the scientific activity (focused on researching the object) and the creation activity (focused on producing the 3D model). The creation activity consists of three phases, in line with the general workflow of digital reconstruction outlined in Chapter II.A.: data acquisition, data processing, and 3D modelling. However, not all of these phases are involved in every reconstruction, so the selection of fields in the documentation form depends on the project specifications provided by the user. For data acquisition, there is also an option to document the equipment and techniques used in the process.

Another change addressed the typology of the object being reconstructed. A significant conceptual difference was observed between objects that were never realised and those that were built and later destroyed, or still exist. Objects that had or still have a physical form can be assessed in terms of the authenticity of the reconstruction and have a specific location in space. For objects that were never realised, however, it is difficult to discuss the authenticity of a reconstruction of something that never existed. In such cases, one can only attempt to capture the original idea of the project's creator—a theme explored in more detail in the publication on the Critical Digital Model (Apollonio et al., 2021). When comparing these two types of cultural heritage objects—the physical and the conceptual—it becomes clear that they represent distinct documentation cases, which is reflected in the proposed scheme. For physical objects, details such as their physical location and links to external repositories offering contextual information can be documented. For conceptual objects, obtaining such data is not possible. Instead, it is necessary to document the media holding the conceptual information, such as design drawings and other available sources.

The newly created scheme was then tested using various reconstruction scenarios to assess the number of mandatory fields required, based on the typology of the reconstruction project. Four main scenarios were prepared: the reconstruction of a physical building, the reconstruction of a past phase of a city, the reconstruction of the current state of a historical sculpture, and the reconstruction of a never-completed historical project. Additional conditions were applied to these scenarios, such as file size (whether suitable for web viewing or not) and different options for referencing existing resources. The scenarios were developed using examples of uploads made in the WissKI-based 3D Repository, about which more can be read in Chapter IV.A. All the minimum documentation scenarios developed are presented in Appendix 6, and a summary of the number of fields in the scenarios can be seen in Tab. 23.

Tab. 23 Summary of the number of mandatory fields for different upload scenarios.

	Building	City	Artefact	Concept
New object, new time step, new model	20	18	19	19
Same object, same time step, new model by different author	16	x	x	x
Same object, same time step, new model by the same author	12	x	x	x
Same object, same time step, same model, different visualisation	8	x	x	x
Same object, different time step, same author	10	10	x	x
New object, new time step, new model (file too big for upload)	18	x	x	x
Same object, same time step, same author, part of other model (semantic)	15	15	x	x

The development of the scenarios aimed to test the practical application of the new documentation schema in various situations and to determine the minimum effort required for documenting a digital reconstruction. Research on web-based data forms shows that the less effort users need to invest in completing a form, the higher the likelihood of submission. The best results are achieved when forms contain only three to five fields (Zamani, 2024). Every additional field included in the form reduces the chances of it being fully completed.

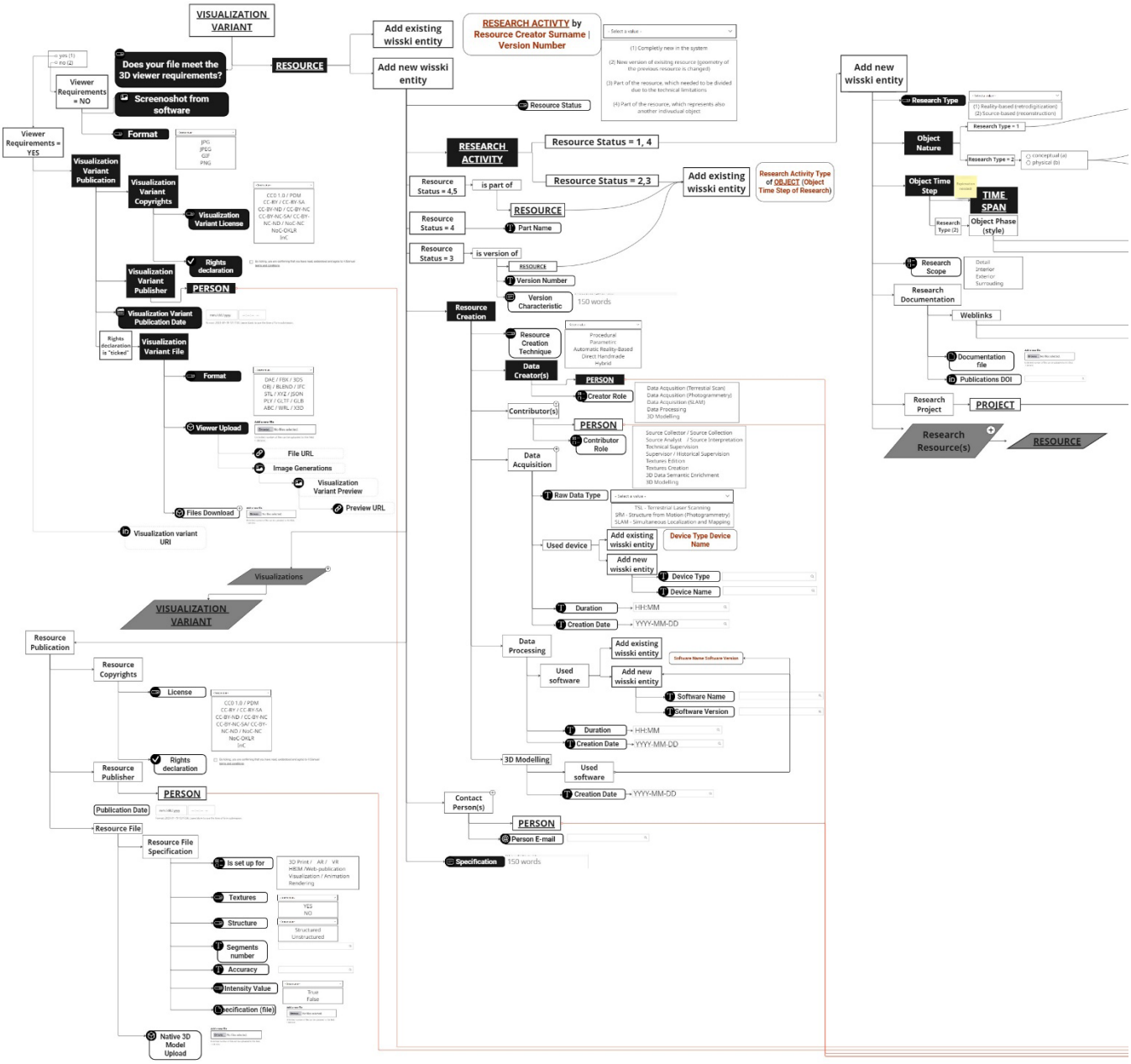
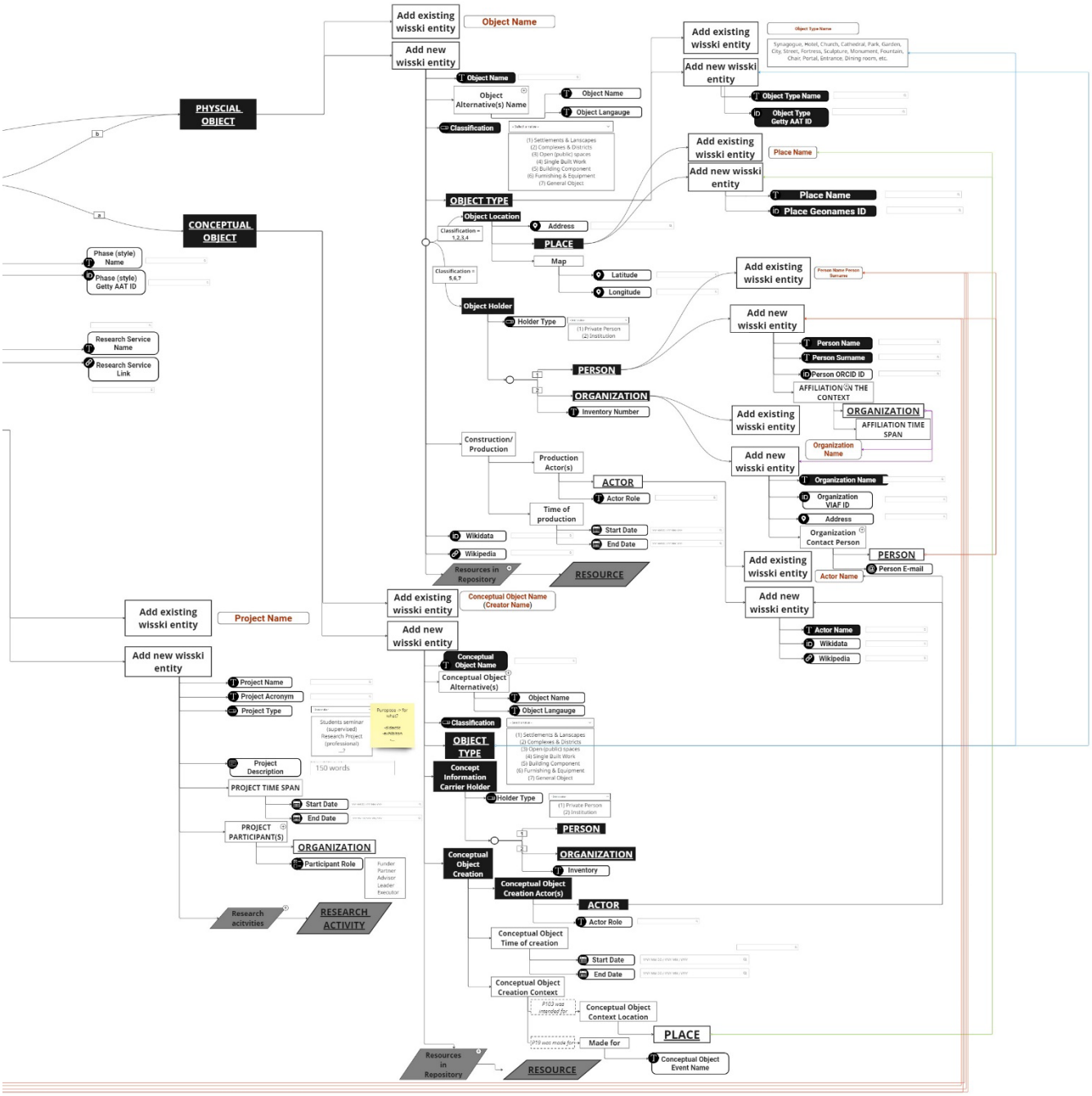


Fig. 73 Documentation scheme for 3D digital reconstruction including field types, mandatory fields (fields with black background), main documentation units (fields written in capital letters) and interdependencies between documentation units.


PHYSCIAL OBJECT
CONCEPTUAL OBJECT
Add existing wisski entity
Add new wisski entity
Object Name
Object Alternative(s) Name
Object Langauge
Classification
OBJECT TYPE
Object Location
Address
PLACE
Map
Latitude
Longitude
Object Holder
Holder Type
PERSON
ORGANIZATION
Inventory Number
Construction/ Production
Production Actor(s)
ACTOR
Actor Role
Time of production
Start Date
End Date
Wikidata
Wikipedia
Resources in Repository
RESOURCE
Place Name
Place Geonames ID
Person Name
Person Surname
Person ORCID ID
AFFILIATION IN THE CONTEXT
AFFILIATION TIME SPAN
Organization Name
Organization VIAF ID
Address
Organization Contact Person
Person E-mail
Actor Name
Object Type Name
Object Type Getty AAT ID
Phase (style) Name
Phase (style) Getty AAT ID
Research Service Name
Research Service Link
Project Name
Project Acronym
Project Type
Project Description
PROJECT TIME SPAN
PROJECT PARTICIPANT(S)
Participant Role
Research acitvities
RESEARCH ACTIVITY
Conceptual Object Name (Creator Name)
Conceptual Object Alternative(s)
Concept Information Carrier Holder
Conceptual Object Creation
Conceptual Object Creation Actor(s)
Conceptual Object Time of creation
Conceptual Object Creation Context
Conceptual Object Context Location
Made for
Conceptual Object Event Name

The type of field itself also proves to be an important factor. Text fields tend to have the lowest validity and are less inviting for users to complete. Using field types that offer prompts and reduce the intellectual effort required can relatively increase both the response rate and the accuracy of the information provided (Bargas-Avila et al., 2011).The prepared scenarios have shown that a minimum of 18 to 20 fields may be required to document a reconstruction project when creating a completely new entry. Nearly half of these fields are text-based, while the remainder are selection fields with pre-prepared responses, resulting in around 10 fields requiring manual entry. Although this is not ideal, it can be assumed that users documenting scientific projects can invest more effort into completing the data form than the average internet user. The number of required fields decreases in scenarios where reference options are used. Each subsequent entry, based on the same reference object or other common attributes, requires significantly less work—sometimes as few as 8 to 10 fields, with roughly half needing manual input. However, referencing does carry certain risks. Unrelated users creating entries may be unaware that some information is already in the system, potentially leading to duplicate entries, such as reconstructions of the same object. This, in turn, could result in disinformation within the system. To mitigate this risk, the reference system would require safeguards, including a simple method for verifying whether the information already exists in the system.

The scenarios described assume that data is entered manually without leveraging the potential of Linked Open Data. However, it is possible to connect the documentation system to external databases via an API (application programming interface). This method allows external systems to retrieve data by sending requests to a designated endpoint. Upon receiving a request, the API processes it, queries the database, and returns the requested data (Abelló Gamazo et al., 2017). However, implementing this solution requires specific prerequisites, including a well-structured API design, secure database access, and proper authentication protocols. It is also crucial to ensure that the API is optimised for performance and security (Oliveira & Fiser, 2024). However, there are drawbacks to using APIs for data retrieval. Retrieved data may not always reflect real-time changes, especially if the data is cached or if the API does not ensure immediate synchronisation with the database. Additionally, inadequate API maintenance could lead to outdated or incomplete data being provided (González-Mora et al., 2023). System dependency is another concern, where the reliability of the data depends on the performance and uptime of the API and database infrastructure. Due to the high level of programming skills required (Robillard & DeLine, 2011), this solution was not investigated in the current study.

The documentation scheme described above represents a minimalist approach, aimed at user convenience. However, when compared to the requirements of the London Charter, such as the need to cite sources and distinguish between elements with varying degrees of uncertainty in reconstruction, certain deficiencies in documenting these nuances become apparent. Therefore, this approach, defined as minimal or mandatory, is seen as providing only the basic information necessary for the publication of 3D models. It allows for the identification of the reconstructed object and time period, along with the required copyright details. However, this type of publication cannot be considered full scientific documentation of the project. Consequently, further development of the documentation scheme focused on addressing these gaps (see

Fig. 1). While the approach of using dependent fields and different documentation paths for various types of reconstruction was maintained, the emphasis shifted towards clearly distinguishing the main documentation units, without the inclusion of the dependent paths, for greater clarity.

The final scheme distinguishes five main documentation units, each highlighted in a coloured box on the diagram. The most complex documentation focuses on two units: *Digital Reconstitution* and *Cultural Heritage Object*, which are central to the reconstitution projects. The next two units, *Persons* and *Organisations*, serve more as administrative support, allowing credits to be assigned for the activities undertaken. The final documentation unit is the *ID Set*, which is the shortest of the input forms and enables machine-readable contextual information. Additionally, there is one sub-form, the *Set of Sources*, which, while not a stand-alone documentation unit, plays a crucial role in ensuring the scientific value of the publication.

The new documentation schema is designed to allow future integration of data extraction from external databases via identifiers. The *ID Set* is a documentation unit specifically oriented towards this functionality. It consists of three components: *Provider*, *Identifier*, and *Uniform Resource Identifier (URI)*. *Identifiers* is a long-lasting reference to a digital object, entity, or resource, ensuring its continued access over time, even if the underlying location or management changes (Ma et al., 2023). Unlike regular URLs, which can become obsolete if the location of a resource changes, persistent IDs are designed to remain stable, ensuring the resource can always be found. They are often used in conjunction with authority files and controlled vocabularies to maintain data integrity and interoperability across different systems. Authority files, which provide standardized and verified information about entities (e.g., persons, places, or concepts), help in disambiguating entries, ensuring that different databases refer to the same entity in a consistent manner. Controlled vocabularies standardize the terms used, reducing variability in data retrieval processes. When using an API, identifiers allow for precise querying of external databases by directly referencing these unique identifiers rather than relying on potentially ambiguous text strings. This method improves data consistency, especially in large-scale or distributed systems where multiple entries might share similar attributes. For example, in the case of bibliographic metadata, an identifier such as an ORCID or ISBN can be used to unambiguously retrieve information about an author or publication, ensuring that the correct entry is accessed despite variations in naming or description. Thus, the combination of identifiers, authority files, and controlled vocabularies greatly enhances the efficiency and accuracy of data retrieval processes through APIs. It is anticipated that identifiers will be utilised for the majority of documentation units and sub-units, including those related to persons, organisations, cultural heritage objects, historical figures, events or periods, geographical names, and art and architecture concepts. Although the use of identifiers is currently beyond the scope of this study, their inclusion in the documentation schema establishes the groundwork for future automation of data capture. This development has the potential to streamline and accelerate the documentation process significantly.

The documentation of the heritage site was enhanced with additional classifications, not only regarding the scale of the site but also its current condition. The option to link external records providing the historical context of the object was also introduced. The field for dating the object was expanded to include the historical period from which the object originates. This adjustment was necessary, as in the previous documentation scheme, many archaeologists confused the field specifying the selected time frame of the reconstruction with the original time of the object being reconstructed.

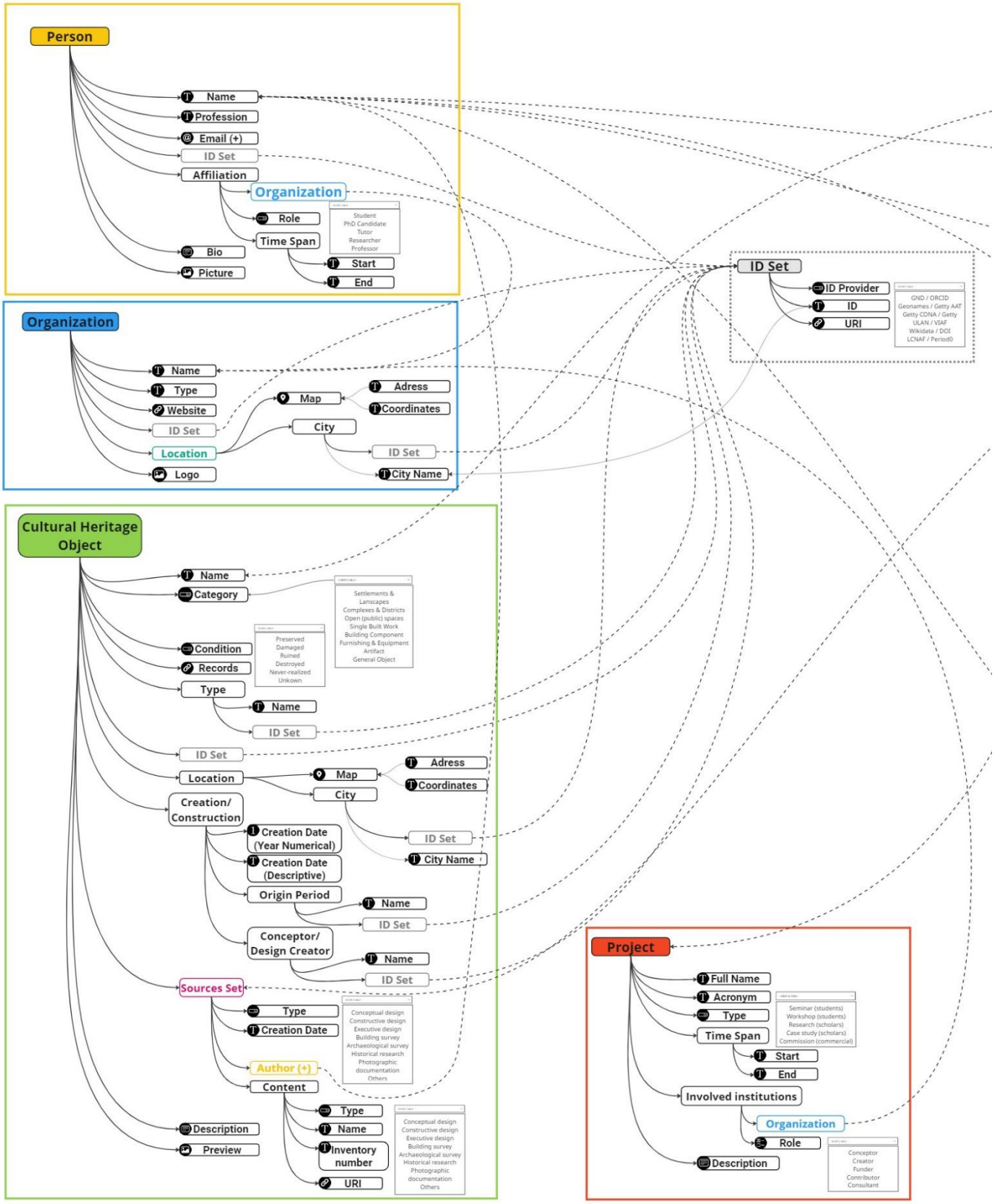
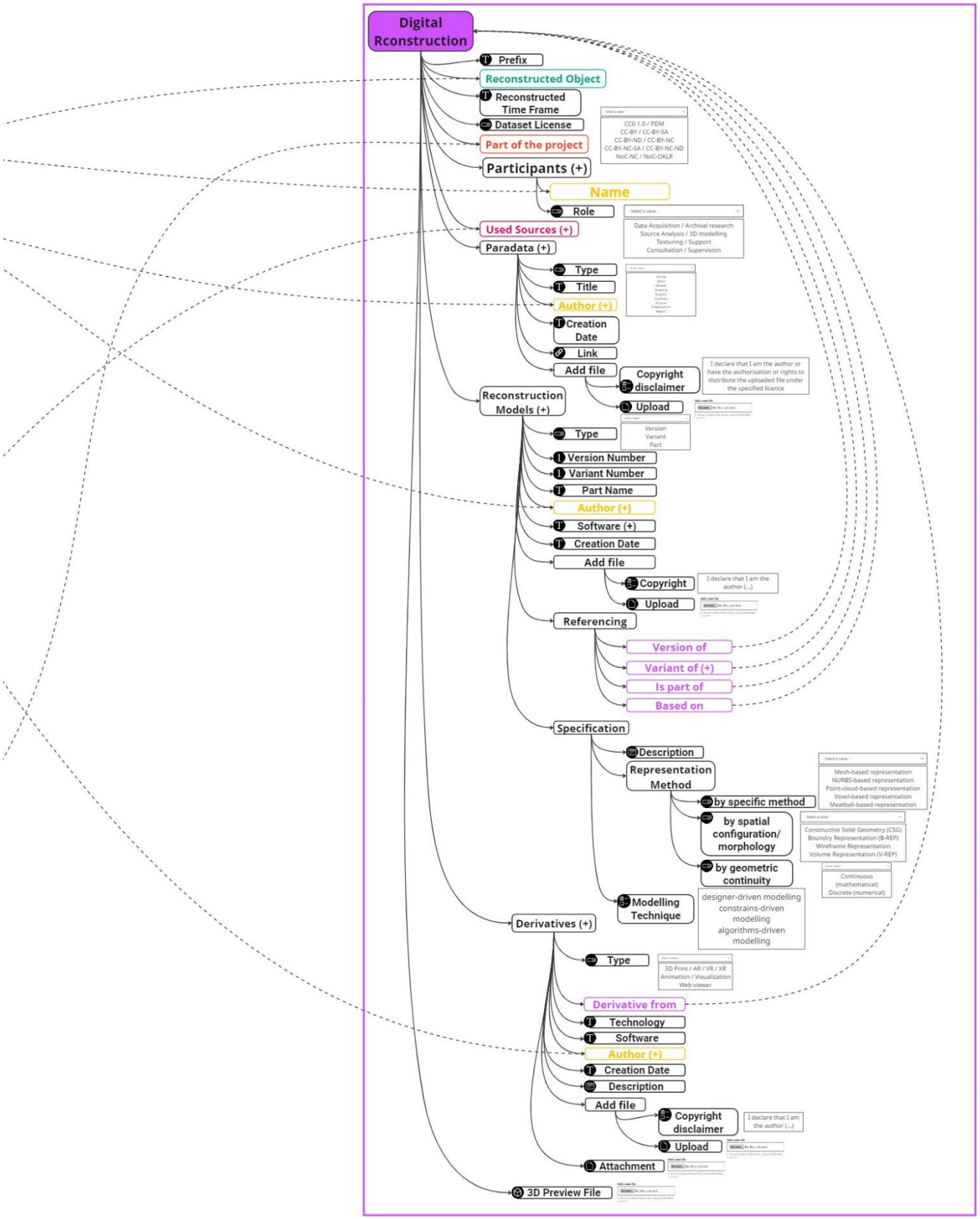


Fig. 74 Schema of full scientific documentation of the digital 3D reconstruction project maintained in accordance with London Charter requirements. The diagram distinguishes by colour the main documentation units (5+1).


Digital Rconstruction
Prefix
Reconstructed Object
Reconstructed Time Frame
Dataset License
CC0 1.0 / PDM
CC-BY / CC-BY-SA
CC-BY-ND / CC-BY-NC
CC-BY-NC-SA / CC-BY-NC-ND
NoC-NC / NoC-OKLR
Part of the project
Participants (+)
Name
Role
Data Acquisition / Archival research
Source Analysis / 3D modelling
Texturing / Support
Consultation / Supervision
Used Sources (+)
Paradata (+)
Type
Title
Author (+)
Creation Date
Link
Add file
Copyright disclaimer
I declare that I am the author or have the authorisation or rights to distribute the uploaded file under the specified licence
Upload
Reconstruction Models (+)
Type
Version
Variant
Part
Version Number
Variant Number
Part Name
Author (+)
Software (+)
Creation Date
Add file
Copyright
I declare that I am the author (...)
Upload
Referencing
Version of
Variant of (+)
Is part of
Based on
Specification
Description
Representation Method
Mesh-based representation
NURBS-based representation
Point-cloud-based representation
Voxel-based representation
Meatball-based representation
by specific method
by spatial configuration/ morphology
Constructive Solid Geometry (CSG)
Boundry Representation (B-REP)
Wireframe Representation
Volume Representation (V-REP)
by geometric continuity
Continuous (mathematical)
Discrete (numerical)
Modelling Technique
designer-driven modelling
constrains-driven modelling
algorithms-driven modelling
Derivatives (+)
Type
3D Print / AR / VR / XR
Animation / Visualization
Web viewer
Derivative from
Technology
Software
Author (+)
Creation Date
Description
Add file
Copyright disclaimer
I declare that I am the author (...)
Upload
Attachment
3D Preview File

The most significant change, however, is the introduction of the *Sources Set* documentation sub-unit. This feature allows collected sources to be recorded and classified into sets, facilitating the capture of different design phases of the building. Grouping sources into sets also streamlines the source documentation process, as it eliminates the need to describe each individual source. Although this approach results in more cursory documentation, it still provides an overview of the primary sources of knowledge used in the reconstruction. Visual representation of the sources was abandoned due to the complex copyright issues surrounding materials from archives and museums. Instead, the option to indicate the institution holding the source drawings and link to the archival entry online, if available, has been introduced. This enables the creation of a bibliographic record of historical material related to the object, which can be beneficial to other researchers.

The most significant difference between the previous and current scheme is the focus of the publication. In the previous scheme, designed for 3D cultural heritage sites, the primary object of documentation was the 3D model itself. In contrast, the current scheme for digital reconstructions centres on documenting the entire digital reconstruction process. One of the main reasons for this shift was the difficulty in documenting successive versions and derivatives of models. Creating separate entries for each new version can lead to the mistaken belief that these successive models are distinct works with different scientific values.

To address this, a reconstruction super-unit was introduced, which is divided into two sections: *Reconstruction Models* and *Derivatives*. The *Reconstruction Models* section tracks the development of the reconstruction, documenting milestones and showing different variants. By using a numbering system for versions, the progression of the work can be easily followed. Each stage can be accompanied by a file package, which may include a native file, data exchange format, or a file adhering to SRM guidelines. The *Derivatives* section focuses on models adapted for specific applications, such as 3D printing or VR. Each derivative can include technical specifications and indicate which reconstruction model it is based on.

For documenting the scientific process, users have two options. The first is to reference the source material, which is documented at the cultural object level, ensuring only the sources used in creating the model are indicated. The second option is the paradata section, which allows for the documentation of the process behind the reconstruction. This section offers flexibility, requiring only the title of the paradata resource, information about the authors, and any relevant attachments. Paradata can take many forms, including text, images, videos, and multimedia presentations. Links to material already published online can also be included to enhance understanding of the reconstruction process.

By thoroughly completing all the sections in the provided schema, the researcher can meet the recommendations of the London Charter by including both source and paradata information about the reconstruction process. However, it remains debatable whether the complexity of this schema aligns with users' needs, as it considerably complicates the publication process. Striking a balance between the minimum documentation requirements for data and those for digital reconstructions is challenging. Despite efforts to simplify documentation input, the reconstruction process remains complex, raising concerns that users unfamiliar with international criteria for digital 3D reconstruction may find the schema difficult and overly intricate. Nevertheless, to maintain the scientific quality of the published work, the complexity of the documentation must reflect the level of rigour demanded by the community.

D. Ontological approach

Metadata schema-based documentation is only the initial step in creating a robust infrastructure for data publication. Metadata schemas are useful for describing and organising information but don't automatically make computer processing possible. This restriction results from the fact that a machine can only interpret data that is organised in a way that it can comprehend and rationalise. Data must be presented in a structured, semantically rich format, like an ontology, to be machine-readable.

An ontology is a formal model used in information science that describes a group of ideas and how they relate to one another within a certain field. It offers a structure for arranging data so that machines can understand not just the data but also the connections and guidelines that govern it. Because ontologies allow data to be processed, exchanged, and integrated across various platforms in a uniform and compatible way, this is essential for web publication. Data representation benefits greatly from the application of ontology. First of all, it improves semantic clarity, which is crucial in complex domains like 3D reconstruction since it guarantees that various systems interpret the data consistently. Additionally, ontologies facilitate machine reasoning; with the structured information they give, machines may execute more complex searches, verify data consistency, and infer new relationships. Ontologies are perfect for developing domains since they are also scalable and flexible, allowing for the simple addition of new ideas and linkages without altering the general structure. By expressing the documentation schema as an ontology, data becomes human-readable and accessible for automated processing, making it more versatile and valuable for web-based applications, digital archives, and research collaborations.

D.1. Ontology for cultural heritage

Ontologies have found particular application in the cultural heritage sector for the documentation of monuments, museum catalogues and in archives (Doerr, 2009). They play a critical role in structuring, standardising, and making data interoperable across various systems and platforms. These frameworks provide a consistent means of describing, sharing, and analysing information related to artefacts, collections, and cultural institutions. Several prominent ontologies have been developed to support these objectives, each serving specific needs within the domain. However, before presenting ontological documentation schemes, it is important to clarify the significant difference between an ontology and a metadata standard. Many documentation solutions are mistakenly referred to as ontologies. An ontology contains a set of concepts that describe reality within a specific scientific domain and is primarily used for storing data. In contrast, schemas or metadata standards are simply methods for transferring information between different platforms or users. They do not define concepts but instead rely on general classes needed for the exchange of information. Examples of these schemas include Dublin Core[119], Lightweight Information Describing Objects (LIDO)[120], Metadata

[119] Dublin Core is a widely used metadata standard consisting of fifteen "core" elements, such as title, creator, and date, aimed at providing a simple and flexible framework for describing a wide range of resources, including cultural heritage objects. See: https://www.dublincore.org/ (accessed 20 October 2024).

[120] LIDO is an XML-based schema specifically designed to describe museum and collection objects, and it supports the exchange of data between institutions. It is based on the CIDOC Conceptual Reference Model (CRM), a widely accepted ontology for cultural heritage documentation. LIDO allows for detailed object descriptions, including provenance, history, and usage, and facilitates data harvesting for aggregation platforms. See: https://lido-schema.org/ (accessed 22 October 2024).

Encoding and Transmission Standard (METS), and Metadata Object Description Schema (MODS)[121]. Given their distinct functions, metadata standards will not be the focus of this work.

In terms of ontologies themselves, the cultural heritage sector has been largely dominated by the universal, formal ontology, CIDOC Conceptual Reference Model (CIDOC CRM, ISO 21127:2023). The CIDOC CRM is currently the most widely used model in cultural institutions (Münster, 2022). It provides a structured framework for documenting the complex relationships between cultural heritage objects, events, and people, allowing for more precise data integration and interoperability across institutions (Doerr, 2005). It has become the standard ontology for the sector due to its ability to handle the vast and varied information associated with cultural heritage, including physical objects, digital assets, and historical events, providing a clear way to map and connect this data. It is a well-balanced model, limited to general classes and properties that can be applied across a wide range of scientific fields. However, in cases of extensive documentation, the same classes may need to store different types of information, which can complicate the model's readability and hinder proper data retrieval. Given the complexity and multi-layered nature of 3D models, attempts to use the CIDOC CRM base for documenting digital models (Nevola et al., 2022) may fall short of providing the complete information needed for model reconstruction in the event of data loss.

Nevertheless, the CIDOC CRM can be extended with official formal ontology extensions that expand the base model for specific applications (Niccolucci & Felicetti, 2018). These extensions are often aimed at particular audiences but may still not fully meet the unique requirements of certain use cases. In some cases, application ontologies, which offer a minimal terminological structure tailored to the needs of specific communities, can provide useful concepts for broader applications (Menzel, 2003), and filling the gaps not covered by formal ontologies. But what specific gaps exist in the CIDOC CRM base model when it comes to the documentation of 3D models?

D.2. Identifying the gaps

The first concern relates to the typology of cultural heritage sites. Beyond the issue of scale—whether a 3D model represents an artefact, a building, or even an entire town—there is also the question of the object's actual condition. The object may range from being destroyed and buried in the ground to being thoroughly preserved. It might also have never been realised, with the representation only through a conceptual design captured in drawings. CIDOC CRM clearly delineates the boundaries between physical and conceptual things, but the case of cultural heritage objects often blurs this distinction. Although CIDOC CRM includes the class *E70 Thing*, which encompasses both physical and conceptual objects, its scope is too broad, and the corresponding set of properties is significantly limited.

The second issue is that CIDOC CRM was designed to document facts, leaving no space for inaccuracies or unverified information. 3D models often depict states of objects from the past that cannot be fully confirmed by any source materials. This is especially true in the case of virtual 3D reconstructions based on historical sources, where a degree of uncertainty and hypothesis must be documented as an integral part of the model. Without this information, the scientific value of the resource may be questioned. This challenge is addressed by the official CRMinf extension, the argumentation model (Doerr et al., 2023). Through the class *I5 Inference Making*,

[121] METS (Metadata Encoding and Transmission Standard) and MODS (Metadata Object Description Schema) are two important XML-based metadata standards used in the digital library and archival communities for structuring and exchanging information about digital resources. See: https://www.ideals.illinois.edu/items/5360 (accessed 23 October 2024).

the events of hypothesis formation can be documented. This can be further enriched by using the class '*I3 Inference Logic'* to describe the reasoning behind the hypothesis. Hypothetical 3D models are also frequently subject to versioning. A given set of sources may lead to multiple equivalent reconstruction variants. As research progresses through studies conducted in archives and excavation site, further versions of hypotheses may emerge, which should also be documented. The issue of object versioning is addressed in the LRMoo ontology (Bekiari et al., 2023), which is designed to capture and represent the underlying semantics of bibliographic information. However, while effective for documenting versions of traditional bibliographic references, this ontology may require adaptation to meet the needs of 3D model publication on the web.

3D models can be digital assets with varied origins, arising from both machine and human processes. Documenting these processes necessitates specific classes of events not included in the CRM base model. This topic is addressed by the official CRMdig extension (Doerr et al., 2022), which focuses on the digitisation process of any object. It introduces classes related to the actual object capture (*D2 Digitization Process*, *D11 Digital Measurement Event*, *D8 Digital Device*, *D9 Data Object*), data processing (*D7 Digital Machine Event*, *D10 Software Execution*, *D1 Digital Object*', and the creation of derivatives ('*D3 Formal Derivation*', '*D9 Data Object*'). However, it is important to note that this ontology has been developed for all digital objects and may not fully address the specifics of digitising objects into 3D form. Moreover, it primarily focuses on digital assets created by machines without addressing issues related to manual 3D modelling and data interpretation.

However, researchers have attempted to document the process of hypothetical virtual reconstitution using CIDOC CRM and its extensions (Bruseker et al., 2015). The example found shows the use of CRMbase, CRMdg, CRMinf, CRMBa and CRMgeo ontologies to capture and represent the reasoning and evidence involved in creating digital reconstructions (see Fig. 75). The model is divided into multiple phases—commissioning, documentation research, proposition identification, geometric volume reconstruction, in-situ and ex-situ reconstruction, and the final production of the virtual model. Each phase is framed as an intellectual activity grounded in research, analysis, and logical inferences. By using CIDOC CRM, the model ensures that every phase of the reconstruction process is documented in a way that captures the underlying sources, evidence, and the reasoning behind each decision. This makes the virtual reconstruction a digital artefact and a scholarly argument open to critical review. However, the presented data model does not give sufficient attention to 3D manual modelling; instead, it treats it as a purely mechanised process. While the introduction of hypothetical assumptions and the interpretation of sources are well captured, the technological execution of the model and the potential preservation of the modelling activities are underexplored. Consequently, it may not be possible to reproduce the model in its original state solely based on the documentation, as demonstrated in the study in Chapter II.C.3.4.

An alternative to formal ontologies is the development of application ontologies. Unlike formal ontologies, general frameworks are built to be consistent and applicable across various domains, and application ontologies are crafted for specific tasks or purposes. They cater to practical needs like enhancing data interoperability or supporting automated reasoning within a specific context. Formal ontologies provide a broad and logically consistent foundation that can be extended and adapted to suit more focused uses. In contrast, application ontologies are usually narrower in scope but offer greater flexibility for meeting specific requirements.

One application ontology focusing on the domain of hypothetical digital reconstructions is the Cultural Heritage Markup Language (CHML). CHML aligns with the CIDOC-CRM ISO standard (version 5.0.4. from 2011, ISO 21127:2014). It is designed to handle the complex relationships between physical objects, digital models, and

their sources, ensuring the long-term preservation and semantic integrity of these reconstructions (Hauck & Kuroczyński, 2014). The ontology allows researchers to document 3D models at various levels of abstraction, enabling the description of both existing and non-existent objects, including those reconstructed entirely from historical or hypothetical data. One of its fundamental assumptions is the need to capture and encode not only the geometric data but also the interpretative processes involved in creating these models. This includes linking each model component to its corresponding historical sources and scholarly interpretations, thus supporting transparency and reproducibility in virtual reconstructions.

Although CHML appears quite comprehensive, it has not been updated for nearly 10 years, and its further development seems to have been abandoned. Nevertheless, the foundations of the ontology, as shown in Fig. 76, reflect a thorough understanding of the reconstruction process, particularly regarding the documentation of interpretative decisions and source materials. However, there remains a gap in the communication of technical information and the selection of modelling methods.

CHML did, however, serve as a reference point for some later developments, one of which is the application ontology named Ontology for Scientific Documentation of source-based 3D reconstruction of architecture (OntSciDoc3D). This ontology is also grounded in the same CIDOC CRM ISO standard (ISO 21127:2014). It is designed to document the activities involved in the reconstruction, including the involvement of researchers, the sources used, and the hypotheses or interpretations formed during the process. The ontology allows for a transparent and traceable connection between the digital 3D model (as an immaterial product) and the physical objects or architectural structures it represents, ensuring that these digital representations are framed within a well-defined knowledge network (see Fig. 77). By considering sources of various media and genres as instances of the same class, the ontology allows for the homogenisation of otherwise heterogeneous data. This ensures that the digital model remains thoroughly documented and scientifically grounded as a product of creative, source-based activity. Once again, however, issues related to documenting the technical solutions used in the project were not addressed. Instead, the possibility of documenting the socio-historical context of the reconstruction was introduced by adding classes and properties connected to the communities, events, and historical figures associated with the reconstructed object. Compared to CHML, OntSciDoc3D offers a more humanistic approach to documenting the relationship between the object of interest and its historical significance.

Nonetheless, none of the aforementioned ontologies fully recognise the need to document the manual 3D modelling process. They consider the documentation of the 3D model as a result, without delving into the sub-processes involved in its creation. A different approach is presented by the CRMvr application ontology (Giovannini, 2018), which is aimed at practitioners of virtual 3D reconstructions. This ontology offers a method for documenting the workflow of model creation, alongside the ability to assess the scientific value of a model using factors such as Level of Element (LoE), Level of Measurement (LoM), Level of Uncertainty (LoU), Level of Accuracy (LoA), and Level of Reference (LoR). The modelling process is documented by dividing each object into elements consisting of a *V14 Profile* (the vertical cross-section) and a *V15 Path* (the horizontal path along which the profile must be extruded to obtain the desired element). The ontology also introduces two component representations of the 3D model: *V16 Morphological Representation*, which refers to the material composition of an element, and *V11 Geometrical Representation*, which refers to the geometric form of an object. A full documentation diagram of the virtual reconstitution process using the CRMvr ontology is shown in Fig. 78. While the documentation concepts presented by CRMvr are valuable, the ontology has never been converted into a digital format and exists only in written form, making it difficult to utilise. Additionally, separating each model element into a profile and a path implies a specific modelling technique that is not mainstream in 3D

modelling. Therefore, it may be more appropriate to consider a general approach to documenting the process that does not impose a particular technique.

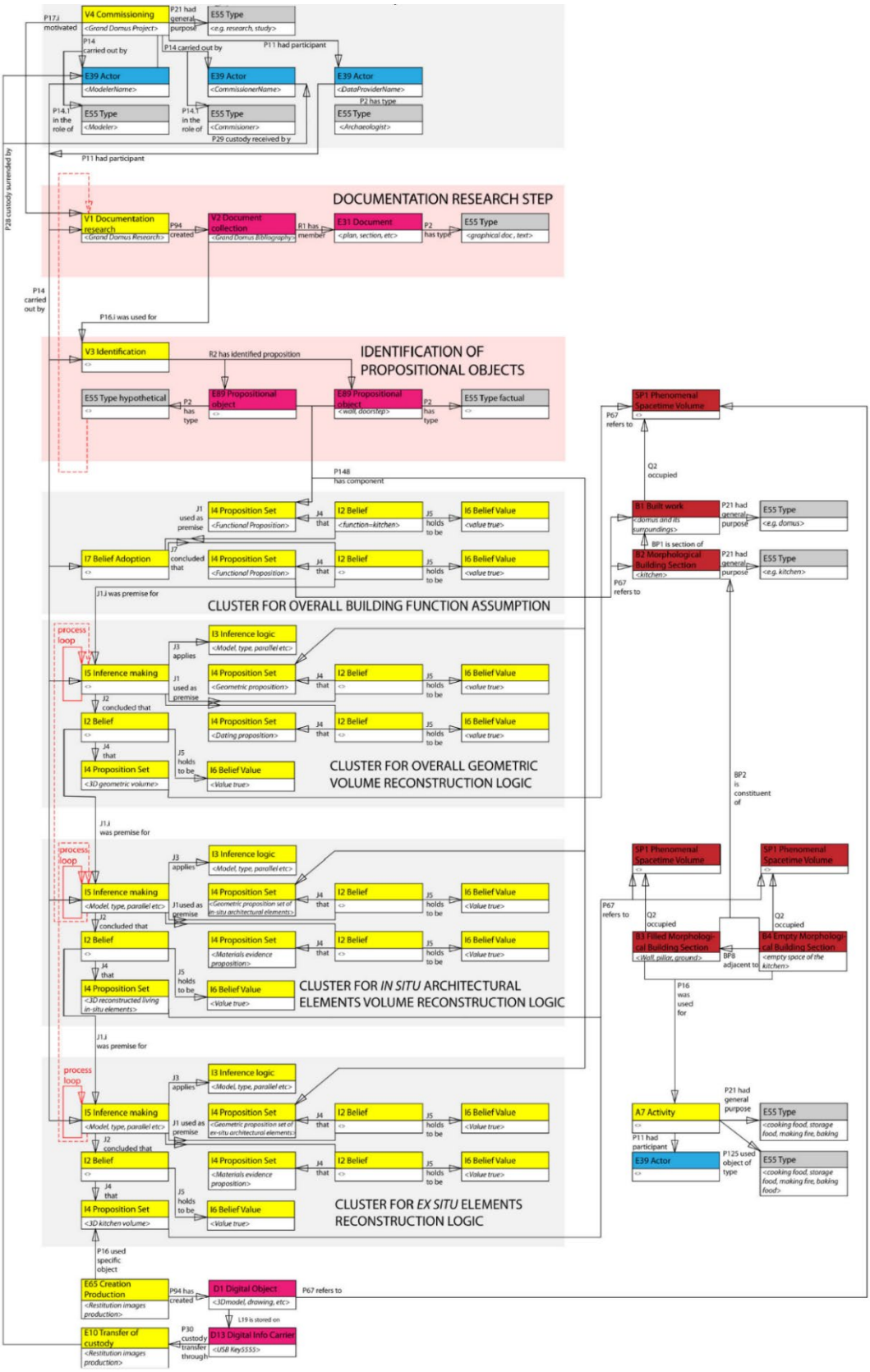


Fig. 75 Graphical presentation of the virtual reconstruction process and argumentation model with the use of CIDOC CRM and its official extensions (Bruseker et al., 2015).

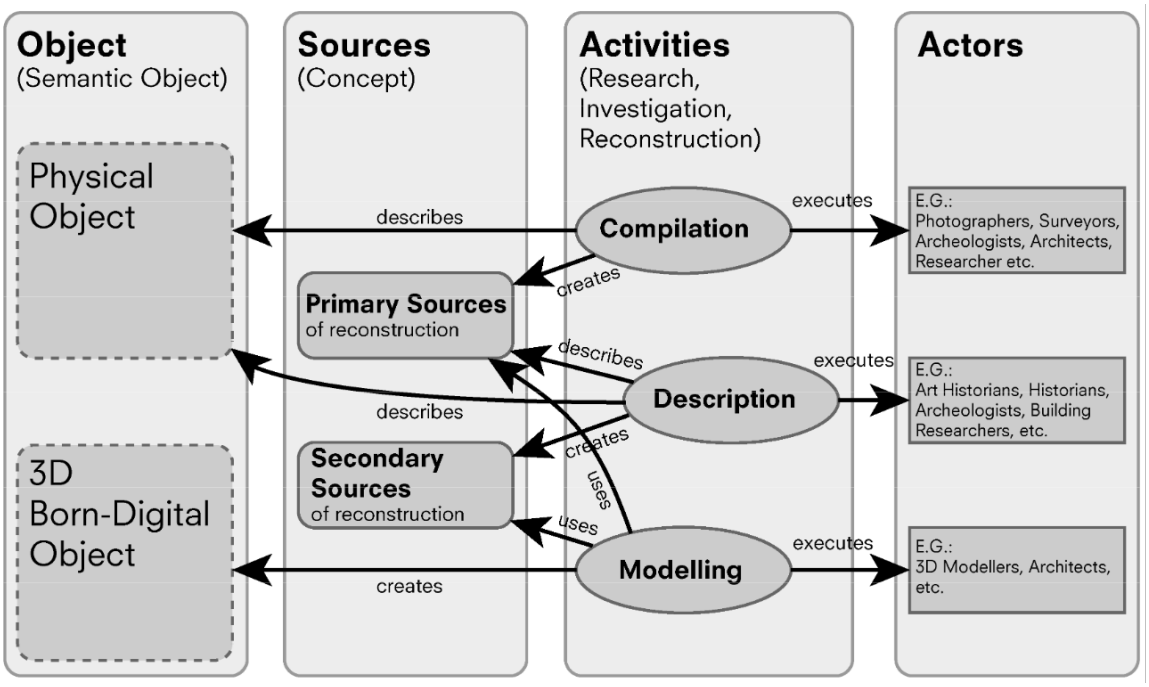


Fig. 76 The relation of sources, physical and 3D reconstruction objects as well as actors bounded together by the research/investigation and reconstruction activity in CHML (Hauck & Kuroczyński, 2014).

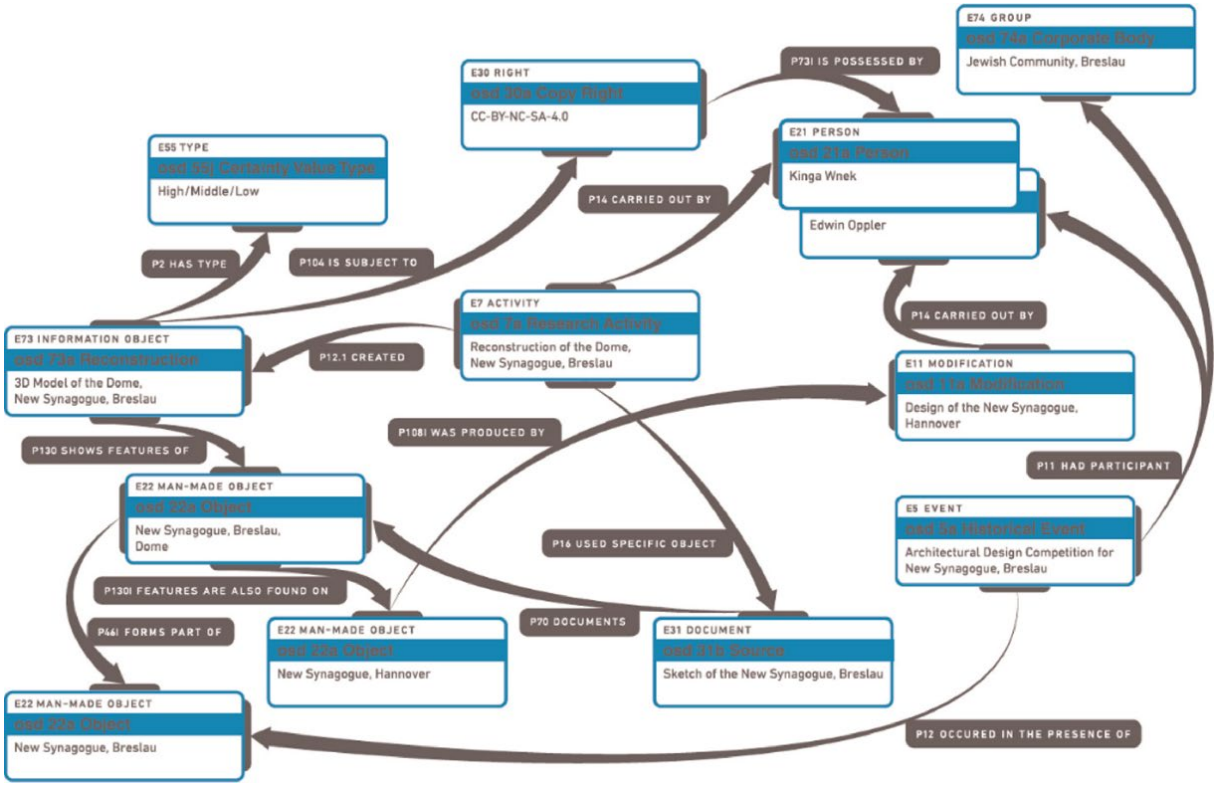


Fig. 77 Illustration of classes and relations of the application ontology "OntSciDoc3D", together with additional classes of the reference ontology CIDOC CRM, illustrated by examples.

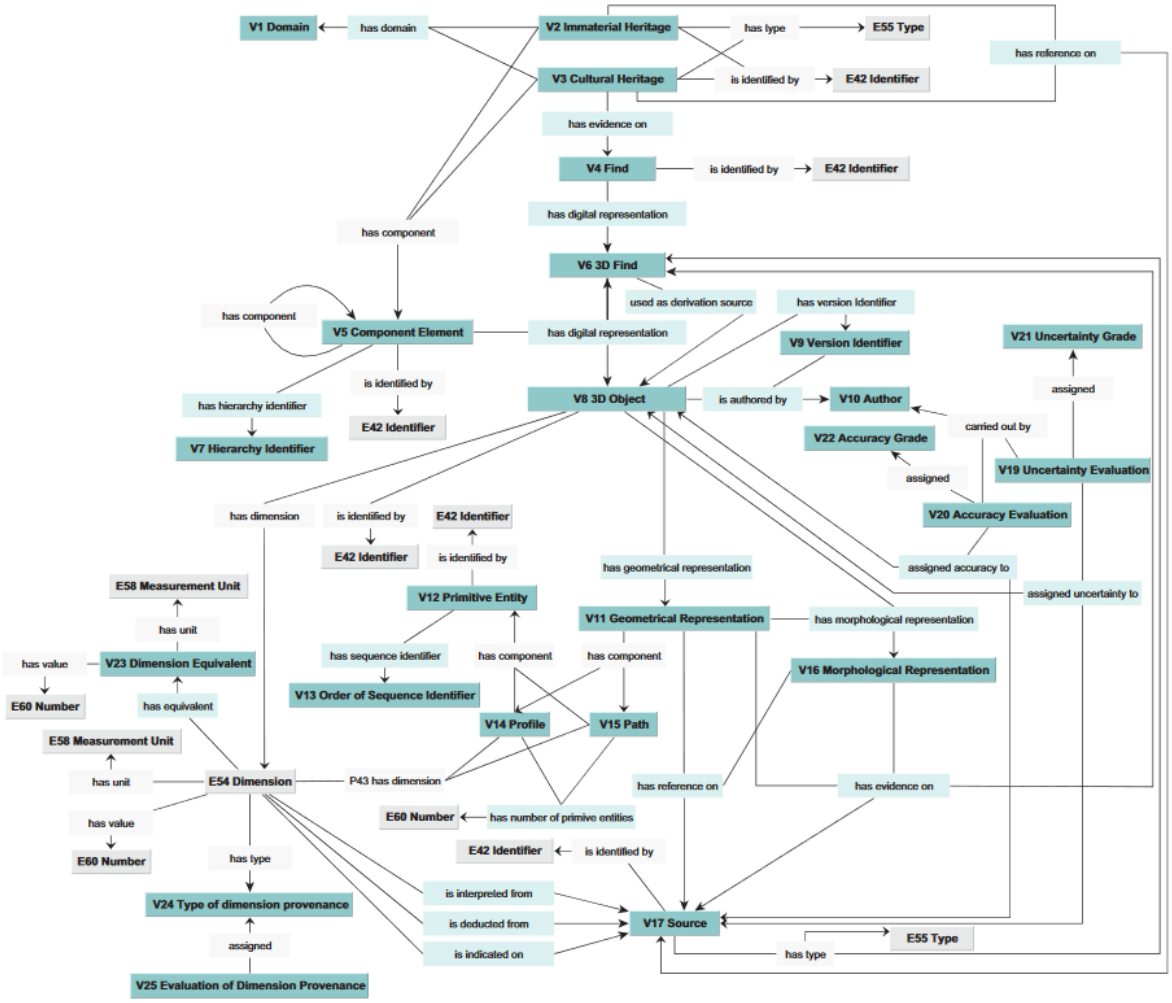


Fig. 78 Process documentation diagram using the CRMvr ontology. Turquoise colour indicates classes and properties from CRMvr, grey colour indicates classes and properties from CRM base (Giovannini, 2018).

D.3. Ontology for Preservation of Cultural Heritage 3D Models (OntPreHer3D)

The analysis of existing ontological solutions allowed the discovery of gaps in the documentation of 3D models and the development of Ontology for Preservation of Cultural Heritage 3D Models (OntPreHer3D). The results of the ontology work were presented at two conferences. The first was Terminology & Ontology: Theories and applications 2023 in Chambéry, which presented a poster on the then state of ontology development entitled: Development of the Ontology for Preserving 3D Models of Cultural Heritage.[122] The ontology continues to evolve, adapting to the needs of users, and the latest update introduces version 2.1[123]. This ontology version was

[122] A short article for the conference proceedings is in the review process. The preprint has been published on Zenodo. See: Bajena, I. (2024). Development of the Ontology for Preserving 3D Models of Cultural Heritage. Terminology & Ontology: Theories and applications (ToTh 2023), Chambéry. Zenodo. https://doi.org/10.5281/zenodo.13100996

[123] The development of ontology as well as archival versions can be found on GitHub: https://github.com/igorbajena/OntPreHer3D (accessed 24 September 2024).

presented at the Computer Applications and Quantitative Methods in Archaeology (CAA 2024) conference in Auckland in the Fair Reuse of Archive Data session.[124]

The general application of ontology may vary based on 3D content classification. 3D models of cultural heritage can be classified into different groups, the documentation of which requires different information (Münster et al., 2016). Examples could be the condition of the object (damaged, preserved, destroyed, never realised), the reconstructed time phase (present, past, or conceptual phase), or the scale of the object (artefact scale, architectural scale, or urban scale). Depending on the audience and the needs of the publisher of the 3D data, the complexity of the documentation scheme may vary considerably (Bajena & Kuroczyński, 2023). Therefore, the OntPreHer3D ontology has been developed to create several levels of complexity and to take into account shortcuts in data modelling.

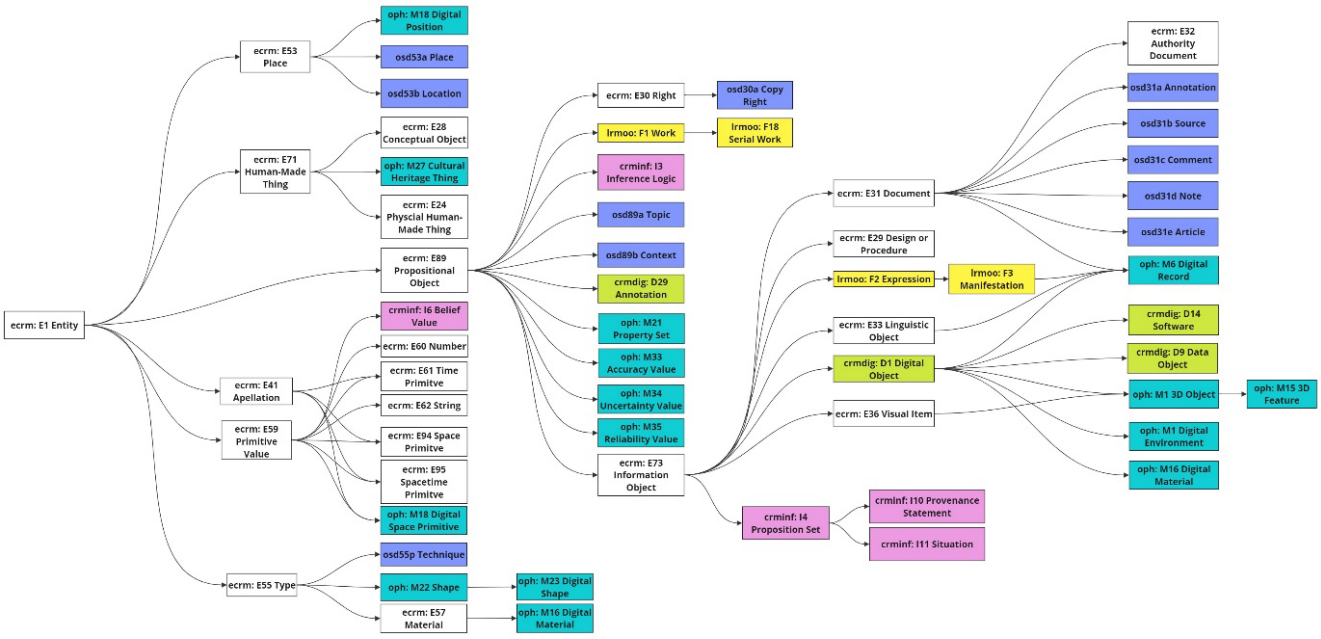


Fig. 79 Diagram illustrating the class hierarchy in OntPreHer3D. In white colour, there are classes from CRMbase (version 7.2.2), in pink from CRMinf (version 1.0), in green from CRMdig (version 3.2.1), in yellow from LRMoo (version 0.9.6) in blue from OntSciDoc3D (version 2.0) and in turquoise new classes from OntPreHer3D (version 2.1).

The ontology introduces 30 classes (see Fig. 79) and 21 properties. Their definitions are described in Appendix 8. It assumes that the basis for documentation of 3D data is identifying the relation between digital 3D objects and their real equivalent, which should happen through the event, which is the core of the event-centred CIDOC CRM approach (Bekiari et al., 2024). The OntPreHer3D followed this principle by introducing three main classes, creating the core triple of the documentation process for digital 3D objects. The first of them is the ***M1 3D Model***, a subclass of *D1 Digital Object* from CRMdig. This specialised class is necessary to distinguish differences between digital objects representing raw data and 3D models representing the final product obtained through human verification. The second class, ***M26 Cultural Heritage Thing***, is a specialisation of *E70 Thing* from CRMbase. This class was introduced to connect conceptual objects (used for visualising never-realised

[124] The article for the Conference Proceedings is in the review process. A presentation from the conference has been made available on Zenodo. See: Bajena, I. (2024, July 27). Digital reconstruction resources as FAIR data. Practical use of application Ontology for Preservation of Cultural Heritage 3D Models (OntPreHer3D). 51st International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA2024), Auckland. Zenodo. https://doi.org/10.5281/zenodo.13112090

designs) with physical objects (preserved and destroyed) while emphasising their significance in human culture. The third class is ***M25 Digital Reconstruction***, which is a specialised activity event, and a subclass of *osd7a Research Activity* from OntSciDoc3D and *D7 Digital Machine Event* from CRMdig. This class describes creating a 3D model, combining historical and archival research with automatic and manual 3D data acquisition methods. This allows for the proper classification of reconstructions, whether they are hypothetical or based on real-world data. By linking these three classes together, we establish the foundation for the digital reconstruction process, as illustrated in Fig. 80.

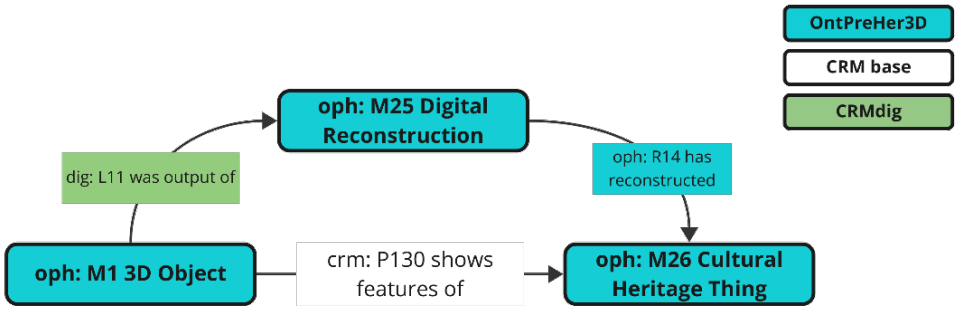


Fig. 80 The basis of the data model in the OntPreHer3D ontology for the digital reconstruction process.

When dealing with hypothetical virtual 3D reconstructions, specifying the time phase for reconstruction is crucial. This aspect is often overlooked in the case of digitised objects, with more emphasis placed on the dating of the origin of reconstructed objects, especially in archaeology. These are two distinct approaches to defining the time phase of interest. In hypothetical reconstructions, the 3D model is meant to represent a past phase of an object—one that may no longer exist, never existed, or has been significantly altered. Since objects change over time, identifying a specific moment in the past that defines the relationship between the real and the digital object becomes essential. To enable this, a new property, ***R18 simulates time***, has been introduced. This property links the reconstruction activity to the class that defines time in CRMbase: *E52 Time Span*.

The documentation of most virtual 3D reconstructions is also based on object segmentation (Apollonio, 2019; Grellert et al., 2018). That is why the proposed data model supports dividing a physical object into semantic parts using the *E25 Human-Made Feature* class from CRMbase. The digital equivalent of this segmentation can be modelled using the newly introduced ***M15 3D Feature*** class. Since the segmentation of a physical object typically relies on available sources, existing patterns from the OntSciDoc3D ontology are applied to document the fact that individual features, or segments of the object, are defined by the *osd24a Physical Source* class, and the *P62 depicts* property from CRMbase. It should be noted, however, that object segmentation on sources is most often carried out for hypothetical reconstructions. In the case of digital documentation of preserved objects in architecture, segmentation is integral to the Historic Building Information Modelling (HBIM) process. In this approach, 3D modelling is object-oriented, and segmentation comes naturally. As HBIM software serves as a database for cultural objects, all segments of the 3D model have defined specific properties (Murphy et al., 2009).In hypothetical reconstructions, historical sources serve as the carriers of information about the reconstructed segment. However, these sources may not always be reliable. They could be damaged or inconsistent with other materials. OntPreHer 3D introduces the ability to document a source's reliability level by specialising the *E55 Type* class and applying the following path: *osd24 Physical Source* -> ***R22 has reliability level*** -> ***M30 Reliability Level.***

The most significant gap identified in previously studied in ontologies for 3D digital heritage is how the 3D model is treated as a singular entity, with no differentiation between the original model and its derivatives. This leads to a common misconception in online repositories with web-based viewers, where the visible model is assumed to be the actual state of the digital object from the modelling program. This is inaccurate, as 3D viewers only support a limited range of 3D formats. Exporting these formats involves compression and conversion, which alters how 3D data is stored and displayed. Consequently, the geometry and material mapping visible in these viewers are often modified, creating a distorted model representation. Furthermore, the virtual space in which the model is displayed can also influence the perception of the model due to variations in coordinate systems or environmental settings, such as lighting or camera positioning (Haynes, 2023). To address this issue, it was determined that each 3D model (***M1 3D Object***) should be viewed as a digital object component in the form of a file (*D1 Digital Object*). The other component is the software or viewer that interprets the data, acting as an intermediary between the computer screen and the user, which is defined as the ***M17 Digital Environment***. Depending on the settings of this digital environment, the model can be represented in different ways, as indicated by the ***R17 has representation type*** property, which is linked to the *E55 Type* class from CRMbase. A diagram illustrating the data model and the logic of the ontology of source-based digital reconstruction is presented in Fig. 81.

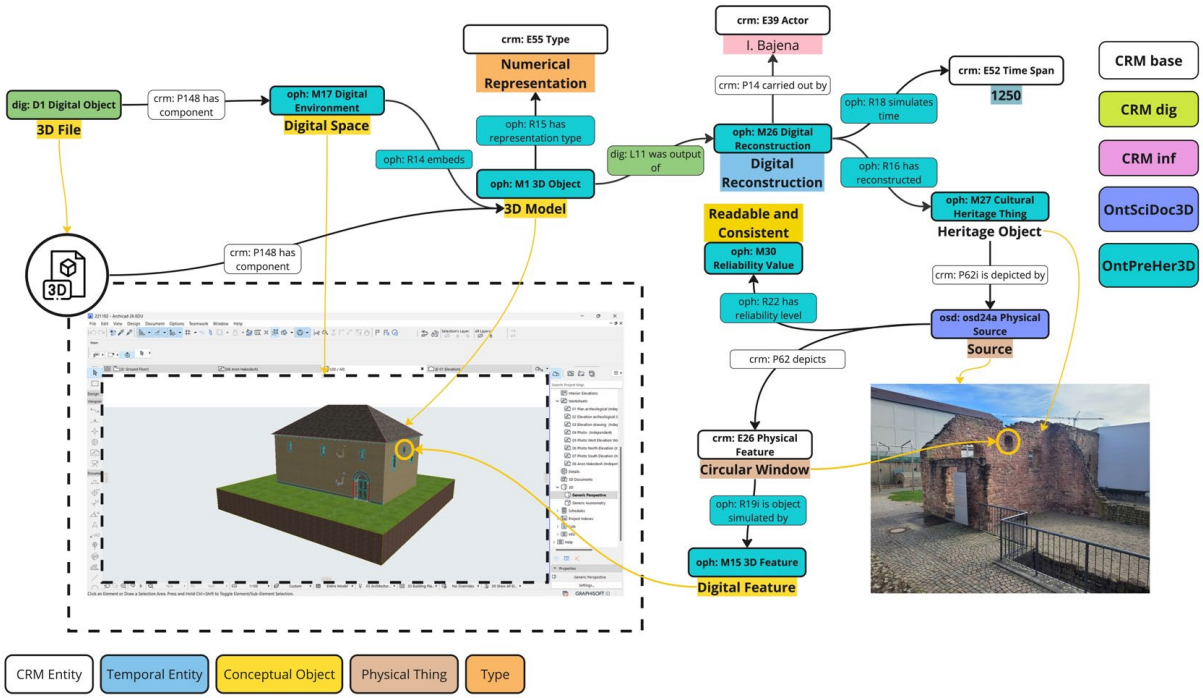


Fig. 81 Diagram illustrating the basic data model using the OntPreHer3D ontology for the digital reconstruction process with the use of shortcut property.

The diagram presents a simplified version of the documentation by using a shortcut property. In ontological data modelling, shortcuts are represented by properties substituting longer semantic expressions, which would otherwise require additional classes and properties (Fichtner & Ribaud, 2012). The shortcut here is the property ***R19i is object simulated by***, which connects the *E26 Physical Feature* with the ***M15 3D Feature***. The extended version of this shortcut with additional steps in between is shown in Fig. 82. The full pathway divides the reconstruction process into two stages: the reconstruction of the object's geometry and the reconstruction of the object's materials. A similar separation occurs in the 3D modelling process, where, in some cases, materials are

not developed at all, and the 3D model is based solely on its geometric form and a default surface finishing (Apollonio et al., 2023). For a physical object, the class describing its material is taken from the CRMbase model, and it is a specialisation of the *E55 Type* class: *E56 Material*. In contrast, for the physical geometry of the object, a new class has been created as another specialisation of *E55 Type* class: ***M21 Shape***. To keep with the concept of separating physical and digital attributes, each class has a digital equivalent as a subclass*:* ***M16 Digital Material*** and ***M23 Digital Shape***, respectively. The digital and physical attributes are connected through the ***M19 Simulation*** event, a subclass of *D10 Software Execution* from CRMdig. ***M19 Simulation*** refers to the machine process of simulating a physical attribute using computer visualisation techniques. Although it is a machine-driven process, its execution requires human input to define the parameters. Therefore, an additional attribute has been assigned to the simulation event to indicate the degree of precision with which the model has been created. The following path represents this process: ***M19 Simulation*** -> ***R21 has accuracy level*** -> ***M27 Accuracy Level***.

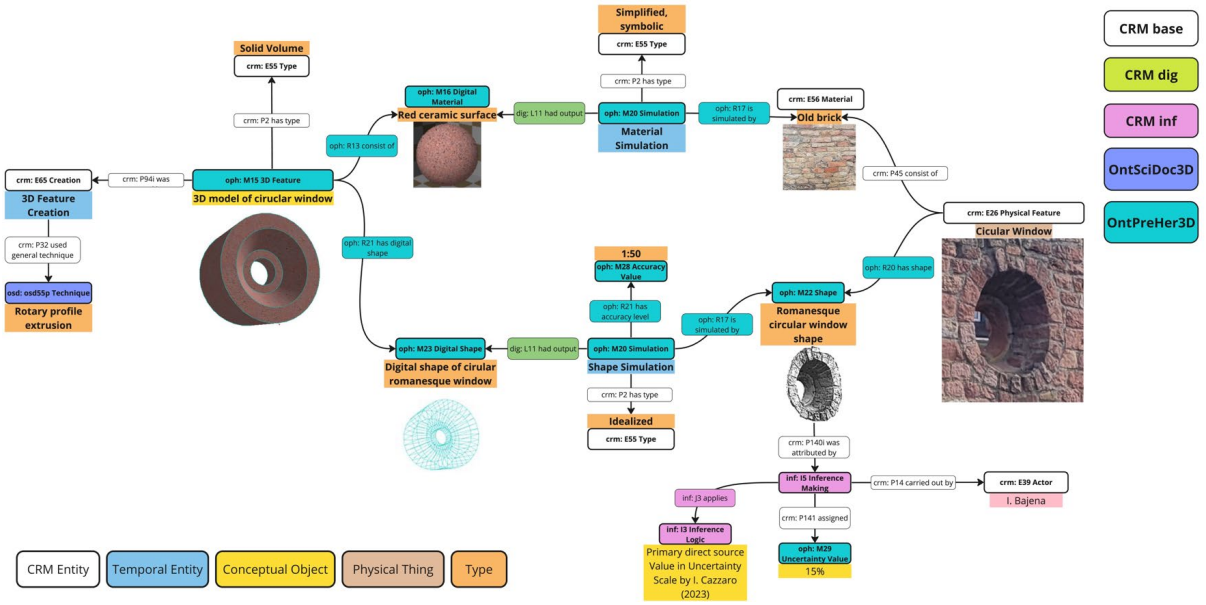


Fig. 82 Diagram illustrating the extended data model using the OntPreHer3D ontology for the hypothetical digital reconstruction process with use of simulation event.

Due to the hypothetical interpretation which affect the virtual 3D reconstructions, the ability to assess the uncertainty of 3D reconstruction was also introduced. In this process, the geometric form of an object results from the interpretation of historical sources, which can vary in accuracy and reliability. As a result, the final shape may be subject to interpretative error. To express this uncertainty, the CRMinf Argumentation Model was employed, linking the declared shape of the model segment to the *I5 Inference Making* event. To further specify the level of imprecision, the ***M28 Uncertainty Value*** class was created as an additional attribute of the inference process.

The ontology also introduces additional classes to address the process of digital model publication and file versioning. This section draws inspiration from the LRMoo model for bibliographic information. However, no classes were directly adopted from the LRMoo ontology, as it was necessary to differentiate between the traditional publication of written material and the digital publication of data. Consequently, the ***M5 Digital Publication Event*** class was introduced as a subclass of LRMoo *F30 Manifestation Creation*. As a result of this event, the ***M6 Digital Record*** class was established as a subclass of up to four other classes: *E31 Document* and

E33 Linguistic Object from CRMbase, *D1 Digital Object* from CRMdig, and *F3 Manifestation* from LRMoo. In this way, each publication of a new version or variant of the model is documented by the ***M5 Digital Publication Event***, which results in new instances of the ***M6 Digital Record***. These records can contain a variety of data.

The data model outlined above emphasises the decision-making aspects of the digital reconstruction and data interpretation process. It ensures that 3D models can be accurately reconstructed if a 3D file becomes corrupted or outdated. This is important because, as demonstrated in the study in Chapter III.C.3.4., the human element of interpretation has a significant impact on the outcome of a reconstruction. Therefore, to maintain complete information for the reconstruction of a 3D model, it would be necessary to document the shape of each object and the parameters related to the materials used. Although current ontologies allow for the documentation of these attributes (see Fig. 83), the practical application of this method remains in question. The classes introduced for capturing the attributes of digital modelling and texturing methods include ***M20 Property Set, M24 Texture Mapping***, and the property ***R19 has property value***. Manually documenting all attributes would be too time-consuming and inefficient. The only viable solution is developing a method for automatically extracting the attributes of model segments directly from 3D modelling software. Such a 3D software add-on could revolutionise preservation practices using CIDOC CRM-based ontology. The method of documenting element shapes, as described in the CRMvr ontology, could play a pivotal role in shaping the future of 3D model preservation.

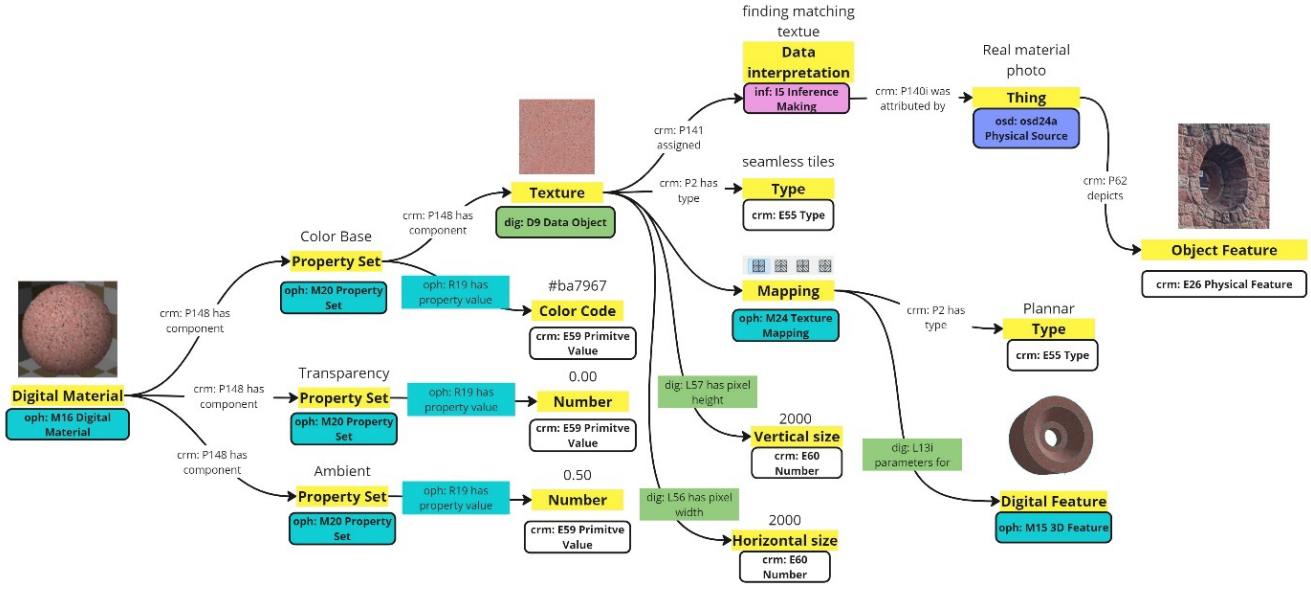


Fig. 83 Documentation scheme of selected compositional parameters of the red sandstone material used in the reconstruction of the Speyer Synagogue using OntPreHer3D ontology.

3D models are still an impermanence medium, driven by rapid technological advancements and challenges in data integration. Presenting virtual reconstructions and digitised objects requires developing a comprehensive ontological solution compatible with existing frameworks for digital objects and cultural heritage. The proposed OntPreHer3D ontology addresses these challenges by emphasising the importance of documenting the decisions made during research that influence the representation of an object's form and materials. There is a critical need to document the digital properties of simulated geometry and materials. Since human interpretation is inherently unreliable, it can yield different outcomes even when using the same source materials. This variability demonstrates that, despite having identical design assumptions, source materials, and its classifications, different modellers can produce significantly different results. Digital preservation will only

be achieved if the attributes of reconstructed models are documented in a standardised way. In an era of widespread automation of digital processes, requiring manual input of such information is inefficient and resource-intensive. Therefore, future developments in this area should focus on automating documentation methods directly from the 3D model, utilising available ontological tools.

IV. Development of infrastructure for digital 3D reconstructions

The previous chapters have illustrated the broad scope required for the infrastructure supporting the documentation and publication of digital reconstructions. Examining the platforms discussed in Chapter III.B.2., one can also observe the scarcity of open solutions for the scientific documentation of digital reconstructions. Some platforms rely on very basic information that fails to offer insight into the scientific foundations of these reconstructions. On the other hand, online documentation providing a comprehensive list of activities and sources tends to be hosted on closed platforms, often created solely for a single project's documentation. With these challenges in mind, an attempt was made to develop a complete infrastructure for documenting 3D digital reconstructions. This chapter is divided into three sections, each detailing experiences with a different infrastructure. The first section focuses on the infrastructure developed in collaboration with the DFG 3D-Viewer project[125], which offers a general approach to 3D models of cultural heritage with a low barrier to entry. The second section discusses the project's attempt to publish through the external PURE 3D infrastructure project[126], which emphasises the scientific development and presentation of 3D cultural heritage models. Lastly, the chapter explores the experience of collaborating with the CoVHer project[127], which concentrates exclusively on hypothetical digital reconstructions.

A. DFG 3D-Viewer project: WissKI-based 3D Repository for digital cultural 3D heritage

The "DFG 3D-Viewer -Infrastruktur für digitale 3D-Rekonstruktionen"is a three-phase project funded under the German Research Foundation's (DFG) 'e-Research Technologies' programme. Its primary goal is to create a 3D digital viewer infrastructure specifically for historical 3D reconstructions. The proposed solutions aim to ensure the long-term availability and archiving of raw datasets and metadata, while also facilitating collaboration and scholarly discussion around virtual models. This is achieved by generating online 3D models from commonly used data formats (Bajena & Beck, 2024). The infrastructure platform described below was developed during the first phase of the project, which took place between April 2021 and June 2023. It is important to note that the core focus of the project's infrastructure is developing an extension to the existing DFG Viewer framework, which is an open-source, web-based viewer used for various types of multimedia in libraries and archives across Germany (Goebel & Meyer, 2010). The repository discussed here served primarily as a test environment for the solutions being developed. Author's responsibilities included definition of the low-threshold requirements for the metadata for web-based visualisation, identification and description of a 3D model in the DFG Viewer and configuration of input masks for the minimal set of metadata, data indexing, management and backup. (see Chapters III.B. and III.C.). The resulting 3D Repository was also presented at the eXploЯA conference - virtual journeys to discover inaccessible heritages in Rome in March 2024.[128]

A.1. System specification

The new system's starting point was the infrastructure foundations previously tested in digital reconstruction projects by Hochschule Mainz-University of Applied Sciences (Kuroczyński et al., 2021). Several key elements

[125] https://dfg-viewer.de/en/dfg-3d-viewer (accessed 27 August 2024).

[126] https://pure3d.eu/ (accessed 26 October 2024).

[127] https://covher.eu/ (accessed 15 September 2024).

[128] The article for the conference proceedings has gone through the review process and is now in the publication phase. The preprint is available here: https://seafile.rlp.net/f/1d8c20328f2742b9a0a0/ (accessed 27 October 2024).

from this infrastructure were integrated to create the new system, including data storage space, a content management system, a virtual research environment module, ontology files, and a data model based on the ontologies in use.

The university servers at Hochschule Mainz provided data storage space, and the viewer developer outlined the minimum system requirements for these servers. These requirements included a minimum of 32GB of RAM (64GB recommended), a 4-8 core CPU (8-16 cores recommended), a Linux-based operating system, and a dedicated server for optimal performance. It also required the ability to install new software such as Blender and converters via SSH and the capacity to upload data using SCP. This infrastructure resulted in the creation of a domain with the address https://3d-repository.hs-mainz.de.

Thanks to support from the WissKI community[129], all components were successfully implemented at the initial stage, resulting in a system with the following specifications: Drupal 9.3.0, an Apache/2.4.41 (Ubuntu) web server, PHP version 8.0.24 with a 128MB memory limit, and a 10.3.34-MariaDB-0ubuntu0.20.04.1 database. Numerous extensions, primarily in the form of Drupal modules, were then installed to transform the system into a virtual research environment. The main extension used was WissKI, which enables semantic web technology while supporting simple and intuitive input interfaces (Scholz et al., 2016). As a free and open Virtual Research Environment (VRE), WissKI excels in managing scholarly data and applying Semantic Web technology. This process entails the addition of a semantic layer to data, represented as triplestores, thereby synergising conventional data storage with sophisticated semantic networking capabilities (Fichtner et al., 2023). Triplestores organise information in bundles comprising a subject, predicate, and object, utilising the RDF. It is a standardised data model format developed by the World Wide Web Consortium (W3C), tailored for publishing and exchanging meaningful data on the web. Its distinctive feature lies in its ability to amalgamate varying underlying schemas and integrate data from disparate sources.

The schema in this context refers to the OWL language used to record data, providing a comprehensive overview of the vocabulary and their interrelationships. It is designed to represent intricate and comprehensive knowledge about entities, groups of entities, and their interrelations within specific research domains by specifying a standard conceptual vocabulary. Utilising RDF for data storage facilitates the use of SPARQL. It is a protocol and RDF Query Language, adept at querying various data types. This capacity efficiently extracts information embedded within non-uniform data dispersed across various formats and sources. SPARQL's functionality resembles that of the Structured Query Language (SQL). However, unlike relational databases, where queries are confined to a single database, SPARQL enables the execution of queries across multiple endpoints. This is achieved through an HTTP-based transport protocol. The proficiency of WissKI in harnessing these tools significantly enhances the system's conformity with the FAIR Principles and the LOD technology, thereby contributing to the advancement of data accessibility and interoperability in digital preservation.

The use of the WissKI module necessitates the implementation of a specialised ontology to make data machine-readable. The CIDOC Conceptual Reference Model (CRM) was selected for this purpose as a base (Bruseker et al., 2017). It is a living standard facilitating cultural heritage documentation by providing a shared and expandable semantic framework for information integration. Initially developed in the late 1990s (Doerr & Crofts, 1999), the model continues to evolve to meet the community's requirements. This ongoing adaptation led to a significant ISO standard update based on CIDOC CRM version 7.1.1. (ISO 21127:2023). It was used for

[129] See https://wiss-ki.eu/ (accessed 27 October 2024).

data model development in the WissKI 3D Repository. The updated ontology encompasses a definition of 86 classes, categorising entities sharing common characteristics and 136 properties, delineating relationships between classes or specific attributes of a class.

Although the CIDOC CRM provides a comprehensive model, it does not encompass all aspects pertinent to 3D models and digital reconstruction. Consequently, it was necessary to augment the data model with a specialised application ontology tailored for documenting digital reconstructions, known as OntSciDoc3D (Kuroczyński & Große, 2020). This ontology was conceived to function application ontology based on the CIDOC CRM framework. As a result, the CIDOC CRM classes utilised in OntSciDoc3D were replicated, either retaining their original scope or undergoing slight modifications (e.g., E21 Person = osd 21a Person). The data model underpinning OntSciDoc3D incorporates eight principal class concepts, encompassing persons, institutions, objects, historical events, scientific activities, digital reconstructions (represented by 3D models), sources, and types. This ontology laid the foundation for the VRE developed for documenting the project of Digital Reconstruction of the New Synagogue in Breslau (Kuroczyński et al., 2021).

A.2. Data model

Formulating the documentation schema facilitates the design of the front end, namely, the system layer that interacts with the user in the CMS Drupal. This process necessitates defining the number of fields, their structure, interdependencies, and their labels and descriptions, which are instrumental in aiding user comprehension of the content within each field. However, this alone does not provide the machine-readable data. For this specific purpose, the WissKI module incorporates a tool called Pathbuilder. Its graphical interface lets users model data based on ontologies integrated into the system. The structures created in Pathbuilder are stored in the triplestore, generating a structure in the RDF file based on the data input by the user. Incorporating the data schema with semantic meaning is imperative by employing an ontology in the backend, the system's layer communicating with the server. The CIDOC CRM is a paper standard. Its use required a translation to the OWL file, which was done in the project Erlangen CRM (Goerz et al., 2008). The translation offered is subject to ongoing updates and is publicly accessible on the project's website.[130] Similarly, CIDOC CRM-referenced OntSciDoc3D was initially conceptualised as a paper ontology. It was later translated into the OWL format utilising the Protege software, after which it was made available online.[131]

The study results described in Chapter III.C.4. were used to determine the essential fields required to document 3D cultural heritage models. The new schema identifies mandatory fields that form a core set of metadata for describing 3D models of cultural heritage (see Fig. 84). These fields serve as the foundation for ensuring the proper documentation and accessibility of the models, providing crucial information to support their interpretation and use.

WissKI introduces a special tool called Pathbuilder, which provides a graphical interface for creating ontology-driven structures and translating them between Drupal and SPARQL endpoints. This allows for modelling RDF structures stored in a triple store, with Drupal managing the input forms and output display—without the need

[130] The Erlangen CRM Project (ecrm) website contains an actual version of CIDOC CRM translation into OWL and a link to a project repository in GitHub. It is available at: https://www.erlangen-crm.org/ (accessed 20 January 2024).

[131] The file containing the actual version of OntSciDoc3D is available at: https://www.ontscidoc3d.hs-mainz.de/ontology/ (accessed 19 January 2024).

for any query writing or coding.[132] Data modelling in Pathbuilder employs a hierarchical structure based on groups (called 'bundles' in Drupal) and paths (known as 'fields' in Drupal). Groups facilitate the creation of clusters for subordinate fields referring to the same class.

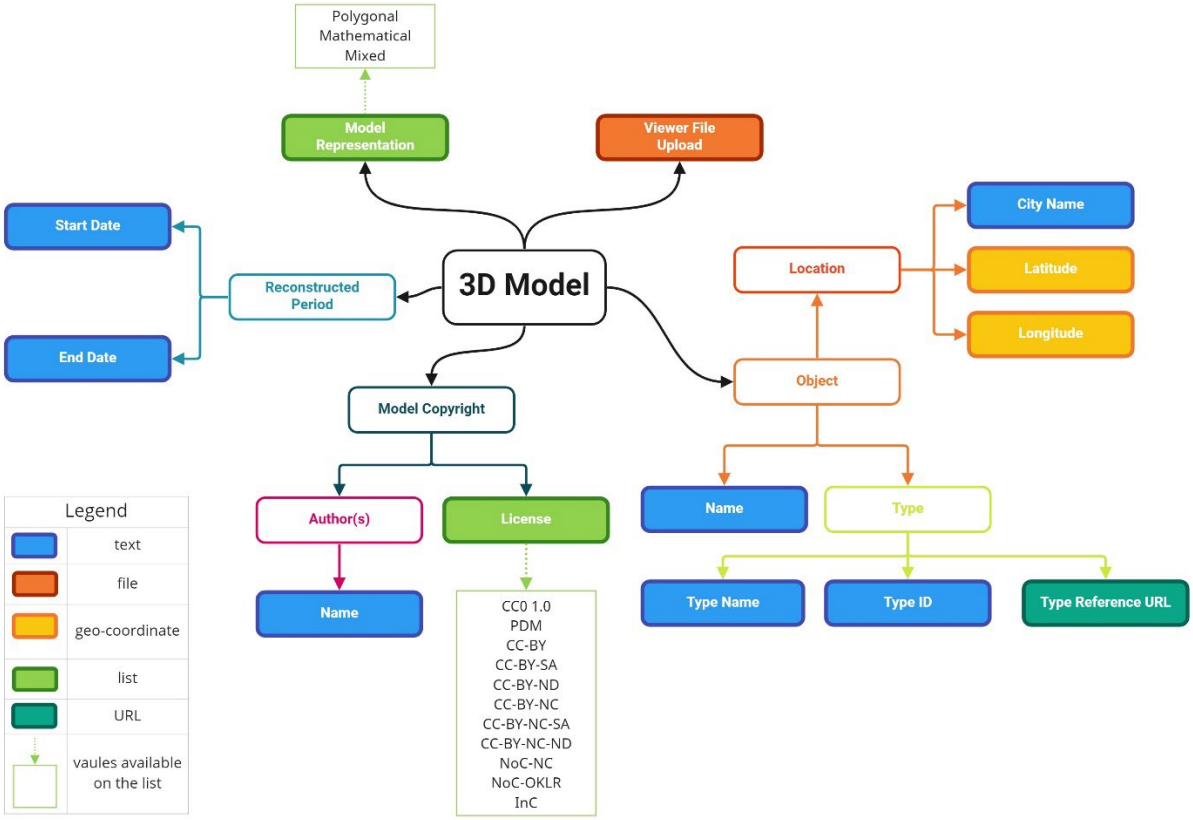


Fig. 84 is a Diagram illustrating the proposed core documentation scheme (minimum user input for publication of the 3D model) with specifications of the type of documented data.

Paths enable the creation of fields whose formatting can be adjusted via the Drupal interface. At the same time, paths define relations between the bundle and the field through subject-predicate-object configuration using ontologies. It is essential to outline the number of main groups (main bundles) which generate independent entry forms in advance. Seven main bundles have been created for the WissKI 3D Repository, listed below. The assigned class from the ontology is indicated in brackets, with 'osd' as the prefix for OntSciDoc3D and 'E' for Erlangen CRM:

- 3D Model (osd_73a_3D_Reconstruction);
- Person (osd_21a_Person);
- Institution (osd_74a_Corporate_Body);
- Object (osd_22a_Object);
- Object Type (osd_55d_Object_Type);
- City (osd_53a_Place);
- Project (E7_Activity).

[132] https://wiss-ki.eu/features/pathbuilder (accessed 17 May 2023).

Each main bundle constitutes an independent group with its own data input form. When a field inside a form refers to a whole group, then a particular field type, ‘entity reference’, is used. It can connect fields with existing groups for loading or writing comprehensive group information. Unfortunately, there are currently no suitable tools for WissKI that would enable the correct export of data for fields using entity references. The 'views data export'[133] module, which was applied, creates exports based on 'views'[134]. View is one of the core modules in Drupal, which fetches data from the backend and formats it suitably for front-end presentation. Consequently, the data exports produced are based not on the structure of the semantic model but on the view in the frontend.

Incorrect data export prevents transfer to data aggregators. On the other hand, removing the entity reference entirely would result in unfeasible referencing data within the system. Therefore, an unconventional data modelling method was developed, using a dual mechanism for field interrelation (tab. 2). Users are provided with an entity reference function within the data form view, whereas data presentation in the frontend view is achieved through paths predicated on a 'flat hierarchy'. It is based on modelling each field as a precise path with no references. Additionally, it became essential to constrain the input forms to a single one pertinent to the 3D model. Thus, the primary hierarchy of the system is anchored on one main bundle (osd_73_a_3D_Reconstruction), with all other groups conceptualised as sub-bundles (see Appendix 7 Tab. 48).

Appropriate vocabulary control also influences the data quality. It reduces the inherent ambiguity of the used terms and entities. In the Semantic Web, all individual entities need to be identified by unique User Resource Identifiers (URIs). A URI essentially serves as a web link that directs to the domain and location of the desired resource. The FAIR Principles advocate for using permanent identifiers to describe the data accurately. Controlled vocabularies afford this stability.

The WissKI 3D Repository applies a comprehensive array of controlled vocabulary types (see Fig. 85). Authority files serve to identify individuals. Open Researcher and Contributor ID (ORCID) is utilised for person identification. The Virtual International Authority File (VIAF) is employed for organisations, while geographic names are referenced using Geonames. CH objects are identified through Wikidata ID. *Die Gemeinsame Normdatei* (GND), also known as the Integrated Authority File, managed by the German National Library, is applied as an additional identifier to all the aforementioned data categories, excluding institutional roles. Currently, authority files are not directly connected to the repository. All URIs must be found and inserted manually by the user. Future enhancements of the platform are set to include the automation of this process and the capability to search for vocabulary directly from a field within the repository.

To categorise the types and attributes of individuals, controlled vocabulary lists were established. The roles of institutions in projects were articulated using selected terms from the Library of Congress Authority Files. Participant roles in the digital reconstruction process were formulated based on the Taxonomy of Digital Research Activities in the Humanities (TaDiRAH) and the MARC Code List for Relators Scheme. The Getty Art & Architecture Thesaurus (Getty AAT) was instrumental in developing classification lists for types and categories of CH objects and potential CH research project objectives. The compilation of available licenses for 3D file usage was derived from the frameworks established by RightsStatements.org and Creative Commons. The final list of 3D modelling techniques was determined based on the author's expertise, deliberations within

[133] Views Data Export module overview is available at: https://www.drupal.org/project/views_data_export (accessed 20 January 2024).
[134] Views module overview is available at: https://www.drupal.org/docs/8/core/modules/views (accessed 20 January 2024).

the European CoVHer project[135], and prevalent terms in the community. However, this list uniquely does not originate from externally recognised controlled vocabularies.

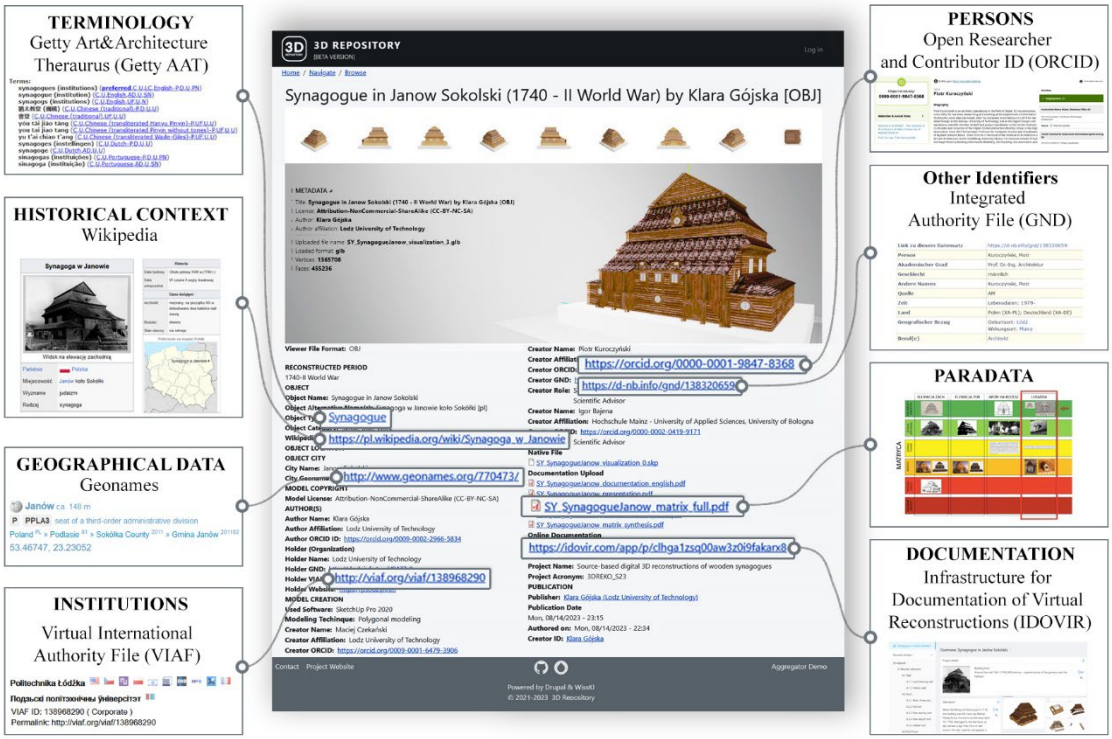


Fig. 85 Cross-referencing of context data in the example of digital reconstruction of the synagogue in Janów Sokolski by Klara Gójska and Maciej Czekański. The data is enriched through the utilization of URIs, controlled vocabulary, authority files, and paradata.

A.3. 3D viewer

The data published in the 3D Repository largely adheres to the FAIR Principles. Nonetheless, it is insufficient to ensure diverse audiences' exploration of virtual models. Consequently, exploring 3D models necessitates viewers - specialised scripts enabling model display within a window embedded in the browser page. The market offers many 3D-viewer solutions (Champion & Rahaman, 2020). The selection for the WissKI 3D Repository required a web-based solution, supportive of a broad spectrum of 3D file formats and compatible with models created manually or acquired through laser scanning and photogrammetry. Additional requisites included possible operations within the 3D environment, file compression capability, and comprehensive documentation (Bajena et al., 2022). After thorough analysis, the cross-browser JavaScript library Three.JS was chosen to develop the DFG 3D-Viewer. The application's fundamental workflow encompasses three stages: compression, conversion, and scene setup. The initial compression stage employs the DRACO algorithm (Google, 2014). to ascertain file size reduction for web browser compatibility. The second stage involves compression and format optimisation. The DFG 3D-Viewer used in the repository supports over 13 different 3D file formats, including .obj, .fbx, .dae, .stl, .glb, and .ifc. However, not all formats display optimally in the viewer. The prevailing standard for three-dimensional scenes and models is glTF (ISO/IEC 12113:2022). Thus, enhancing browser performance requires

[135] CoVHer stands for Computer-based Visualization of Architectural Cultural Heritage. The project aims to define a transparent methodology for creating and documenting the computer-based visualisation of the cultural heritage model. More information can be found at: https://covher.eu/ (accessed 23 January 2024).

conversion to GLB: glTF binary format. The final stage involves scene setup, where the optimised model is positioned, and its boundary box is calculated. These calculations facilitate automatic adjustments of lighting and camera for initial settings.

The viewer's fundamental functionality is predicated on model manipulation in the scene, encompassing adjustments to position, size, rotation, materials, light modification, and camera settings. Furthermore, the viewer enables the creation of clipping planes, which produce a transparent plane along the x, y, or z-axis, effectively slicing through the model. This capability facilitates the generation of cross-sections along all axes simultaneously. It permits a comprehensive exploration of the interior of the 3D model, a feature of particular value in exploring architectural models.

The DFG 3D-Viewer was developed as a Drupal module.[136] The module incorporates enhanced functionalities that facilitate communication with the system. One such function automatically generates nine visualisations utilising the Blender rendering engine, with the initial visualisation as an entry preview. A critical component is the conversion of the aforementioned metadata export from the view into a standardised data transmission container (Fig. 86), conforming to the Metadata Encoding and Transmission Specification (METS) and Metadata Object Description Scheme (MODS) formats. This container can facilitate data transfer to aggregating institutions like the DDB. This workflow has been evaluated on a demonstration instance, aggregating 3D models from data repositories such as Europeana, Sketchfab, 3D Repository, and UrbanHistory4D (Münster, 2023).

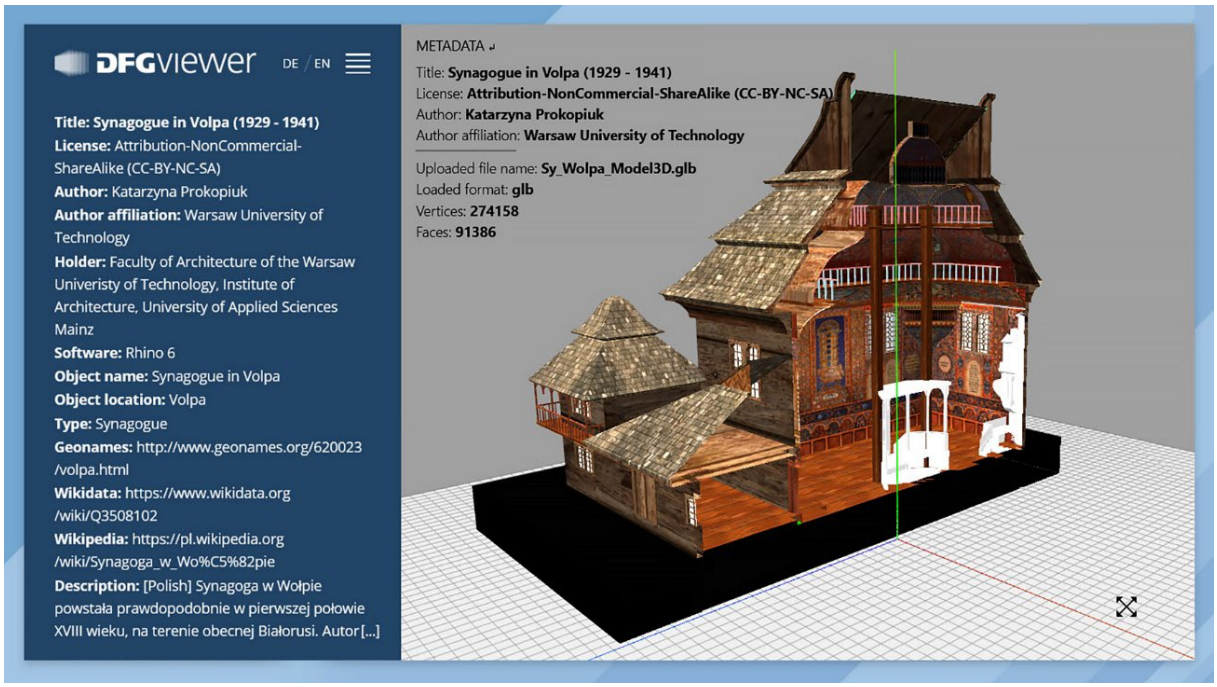


Fig. 86 Visualization of the 3D model of the Volpa synagogue reconstruction made by Katarzyna Prokopiuk in the DFG 3D-Viewer aggregation instance.

[136] Documentation of the module and viewer is on the GitHub repository of the DFG 3D-Viewer project: https://github.com/thedworak/dfg_3dviewer (accessed 23 January 2023).

A.4. System use and evaluation

A.4.1. Higher education

The repository was tested by various groups of potential users, who at the end of the process went through a survey designed to capture any aspects that raise the level of difficulty of use. The first potential use scenario was to use the repository during a student class on digital hypothetical 3D reconstruction. The repository was tested during three activities with students at different universities:

- Elective seminar about digital 3D reconstruction of wooden synagogues with students of the 8th semester of the Faculty of Architecture at the Warsaw University of Technology during the summer semester of the 2021/2022 academic year (8 entries);
- Elective joint seminar about digital 3D reconstruction of wooden synagogues with students of the 8th semester of the Faculty of Architecture at the Warsaw University of Technology and students of the Master of Architecture program at the Lodz University of Technology in the summer semester of the 2022/2023 academic year (44 entries);
- Workshop on digital 3D cultural heritage of CoVHer projects with architecture students of Warsaw University of Technology, Lodz University of Technology, Faculty of Architecture of the University of Porto, Hochschule Mainz – University of Applied Sciences and archaeology students of Autonomous University of Barcelona (13 entries).[137]

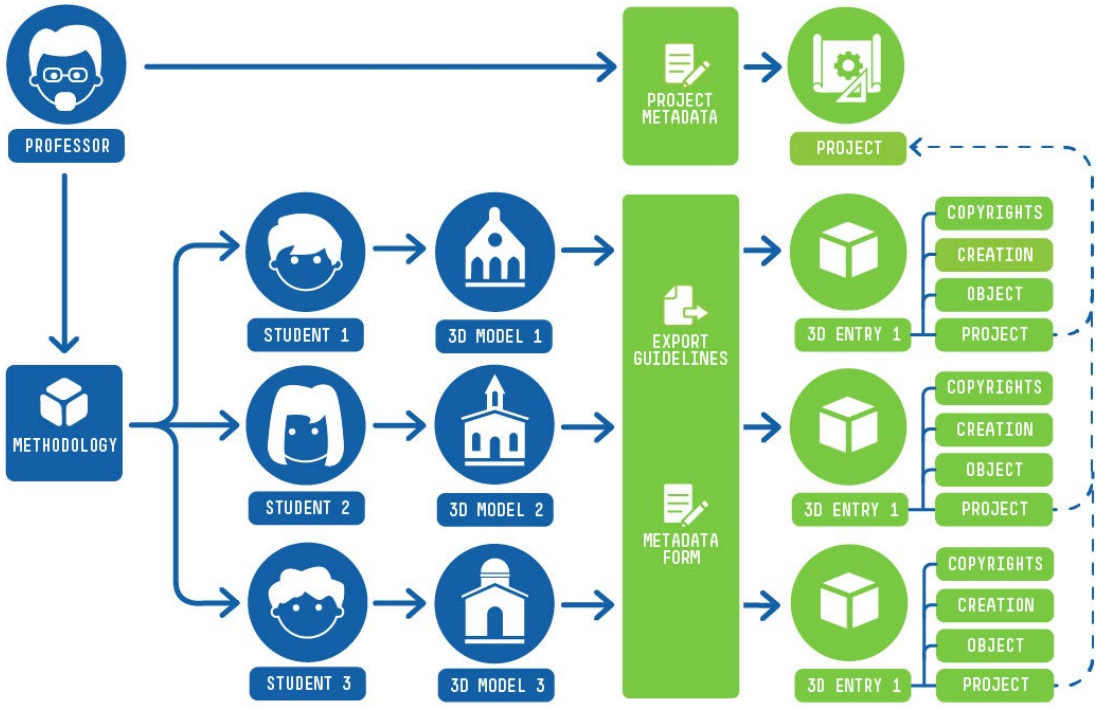
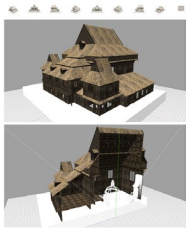
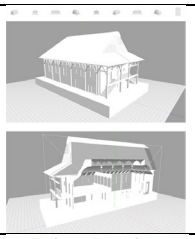
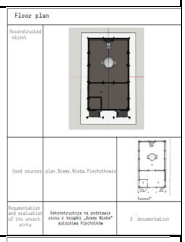
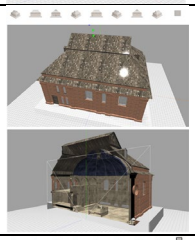
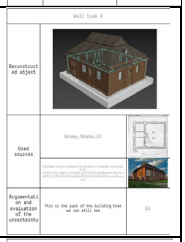
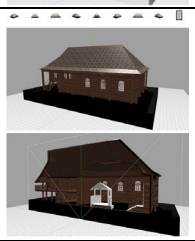
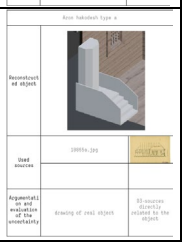


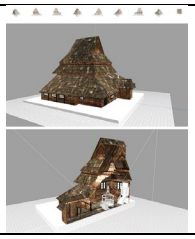
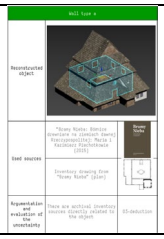
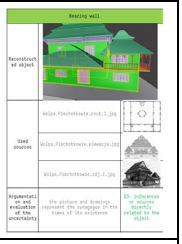
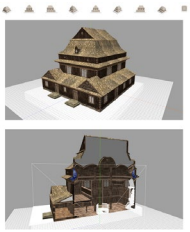
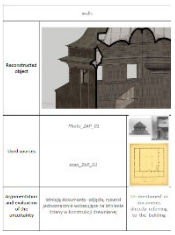
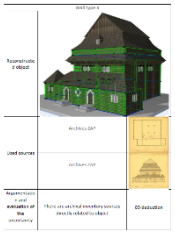
Fig. 87 3 A scenario for use of the 3D Repository with implemented project components during seminars in the education sector.

[137] See: https://covher.eu/international-workshop-on-digital-3d-heritage-exploring-3d-modelling-in-education-documentation-and-dissemination-learning-teaching-and-training-activities-covher-mainz-meeting-6-13-s/ (accessed 28 October 2024).

The test phase started with creation of the accounts in the system for all students and teachers. The teacher created a seminar project entry with the basic metadata about the seminar (name, project type, start and end date, etc.) so that the students could link their entries under one common project (a grouping element for entries in the repository). Students were briefed on the information needed to complete the form in the repository, after which they were expected to publish their 3D models with a full set of metadata during their own work (see Fig. 87). It became rapidly clear that technical support was needed. Students were mostly unable to prepare the model export in such a way that it would display correctly in the viewer. The metadata form also caused problems due to its structure based on drop-down groups of information (called groups/bundles in WissKI) and the concept of referencing existing information in the system, which was initially unclear to the students. It was noted, however, that students in the higher semesters performed significantly better, with the most substantial technical issues arising during the first edition of the seminar. The final results of this initial seminar are summarised in the Tab. 24.

Tab. 24 Summary of the results of student work during the first edition of the seminar on digital reconstructions on the Faculty of Architecture of the Warsaw University of Technology during the summer semester of the academic year 2021/2022.

	Object / software	Revision of an entry in the repository	URL	Filled pages of template	Preview of the uploaded 3D model	Preview of the entry	Preview of the filled documentation template
1	Zabłudów in SketchUp	The wall's wood texture is very dark. Glass looks like the window is completely hollow. Lack of the floor texture, blinking effect on the connection of the wall with white surface of Aron Hakodesh. Lack of the documentation files. Project section refers to the different entity than all of the others (duplication of the project in repository).	https://3d-repository.hs-mainz.de/wisski/navigate/1131/view	-			-
2	Pilica in SketchUp	Lack of textures, geometry of the object is hard to read. No metadata information about historical relations, project. Link to Wikipedia and Wikidata is missing. Lack of the presentation file.	https://3d-repository.hs-mainz.de/wisski/navigate/1140/view	8			
3	Ashmyany in 3DS Max	Roof texture has a glossy effect. Some wall textures inside the building are stretched and or ovescaled. No metadata information provided about the historical relations and project.	https://3d-repository.hs-mainz.de/wisski/navigate/1008/view	42			
4	Połaniec in Blender	Roof is very shiny and the walls seem to be very dark (texture or light issue). Some wooden textures around the windows inside are blinking. Half of the floor is black, some elements or bima/aron hakodesh have some surfaces	https://3d-repository.hs-mainz.de/wisski/navigate/762/view	27			

		in wooden texture instead of the white one. No metadata information about historical relations and modelling techniques.					
5	Hvizdets in 3DS Max & Blender	Outside displayed properly. During the section texture is blinking on the connection of Aron Hakodesh with the floor. Textures of the roof and the floor seem to be overscaled.	https://3d-repository.hs-mainz.de/wisski/navigate/744/view	22			
6	Volpa in Rhino	Glass is not transparent. Blinking textures on the connections of surfaces with different materials in section view. No metadata information about historical relations. Lack of the link to Wikipedia.	https://3d-repository.hs-mainz.de/wisski/navigate/815/view	15			
7	Suchowola in SketchUp	Long loading time. After loading the model browser slows down. Some planes of roofs have stretched textures. Very dark wood on the walls. Some blinking texture on the connection of the white and wooden surfaces. Some additional, unnecessary planes inside the building with white or sky texture. Lack of metadata about historical relations.	https://3d-repository.hs-mainz.de/wisski/navigate/796/view	16			
8	Olkieniki in Archicad	Model seems to be very dark (textures or lighting issue?). Glass is not transparent and stands out from the dark model. During using clipping planes it is not possible to see the top part of the roof. Textures are blinking on all joint surfaces between white and wooden surfaces. Lack of historical relations in metadata.	https://3d-repository.hs-mainz.de/wisski/navigate/1191/view	38			
9	Grodno in SketchUp	-	-	-	-	-	-

During the first edition of the seminar, students were also asked to upload their paradata to the repository using a simplified documentation form, which had been developed for the digital reconstruction of the Synagogue in Speyer (see Chapter II.C.3.2.). However, it became apparent that referencing sources by file name was problematic for recipients, as they lacked the necessary key to identify the origin of the source material. As a result, this tool was abandoned in subsequent editions and replaced by paradata generated through the IDOVIR system (see Chapter II.B.2.2.). After the first edition of the seminar, students were asked to complete a questionnaire consisting of four sections. The first section gathered personal data, the second focused on evaluating the process of filling in the metadata form in the 3D repository, the third assessed the experience of uploading a 3D file and displaying it in a web-based viewer, and the final section evaluated the process of completing the documentation template. The anonymous survey results are presented in Appendix 9.

Students were first asked to rate, on a 10-point scale, the clarity of the instructions for completing the metadata form and preparing the model for upload (with one being incomprehensible and 10 being simple and clear). The average score for the clarity of instructions on the form was 8.4, while the score for the instructions on preparing the model export was 8.2, indicating that the instructions were generally understandable. However, further questions about the difficulty level for completing the form and uploading the model to the repository—again using a 10-point scale where 10 indicated high difficulty—revealed that the instructions were not entirely sufficient. The average difficulty score for completing the metadata form was 5.4, and for uploading the model to the repository, 5.2, suggesting that students required a more detailed introduction to a system that seemed unintuitive for new users. Additionally, students were asked how many attempts they made to upload a file successfully and display the 3D model correctly in the viewer. None of the nine students succeeded on the first try, with most needing at least three attempts, and even then, textures were often scaled incorrectly or missing. This indicated a lack of knowledge in exporting and preparing 3D models for web publication. Finally, the time required to complete the entire process, including exporting and uploading the model and filling in the metadata form, ranged from 10 minutes to over 40 minutes, with an average of around 20 minutes, highlighting an area for improvement in developing a low-threshold infrastructure.

A.4.2. Cultural heritage institutions

A second possible scenario for the use of the repository is the archiving of 3D models of cultural heritage by cultural institutions such as museums, libraries or research units. Four partner institutions of DFG 3D-Viewer project from different fields related to digital heritage were invited to test the infrastructure under various conditions. The project partners included the University of Cologne (archaeology), Ludwig Maximilian University of Munich (art history), Brandenburg University of Technology Cottbus-Senftenberg (architecture), and the Deutsches Museum (technology history). In this collaboration, 80 3D models have been published by all partners, and their experiences have been collected through a multi-stage survey to assess the ease of use of the repository, the functionality of the viewer, the versatility of the metadata schema in relation to individual disciplines, the effectiveness of the manuals and guidelines, and any problems encountered.

In the first survey, the project partners were asked to evaluate the metadata form. The form was divided into six sections, covering general information about the 3D model, the model creation process, the object depicted, the copyright, the project within which the model was created, and the upload process. Initially, respondents were asked about their overall impression of the form. Regarding its length, the average response was 3.8 on a five-point scale, where 1 indicated it was too short and 5 too long, reflecting a satisfactory balance in the number of fields required.

Following this approach, tests were conducted on archiving 3D models using the 3D Repository and the developed framework. Four partner institutions from different fields related to digital heritage were invited to test the infrastructure under various conditions. The project partners included the University of Cologne (archaeology), Ludwig Maximilian University of Munich (art history), Brandenburg University of Technology Cottbus-Senftenberg (architecture), and the Deutsches Museum (technology history). To date, more than 40 models have been published by all partners, and their experiences have been collected through a multi-stage survey to assess the ease of use of the repository, the functionality of the viewer, the versatility of the metadata schema in relation to individual disciplines, the effectiveness of the manuals and guidelines, and any problems encountered.

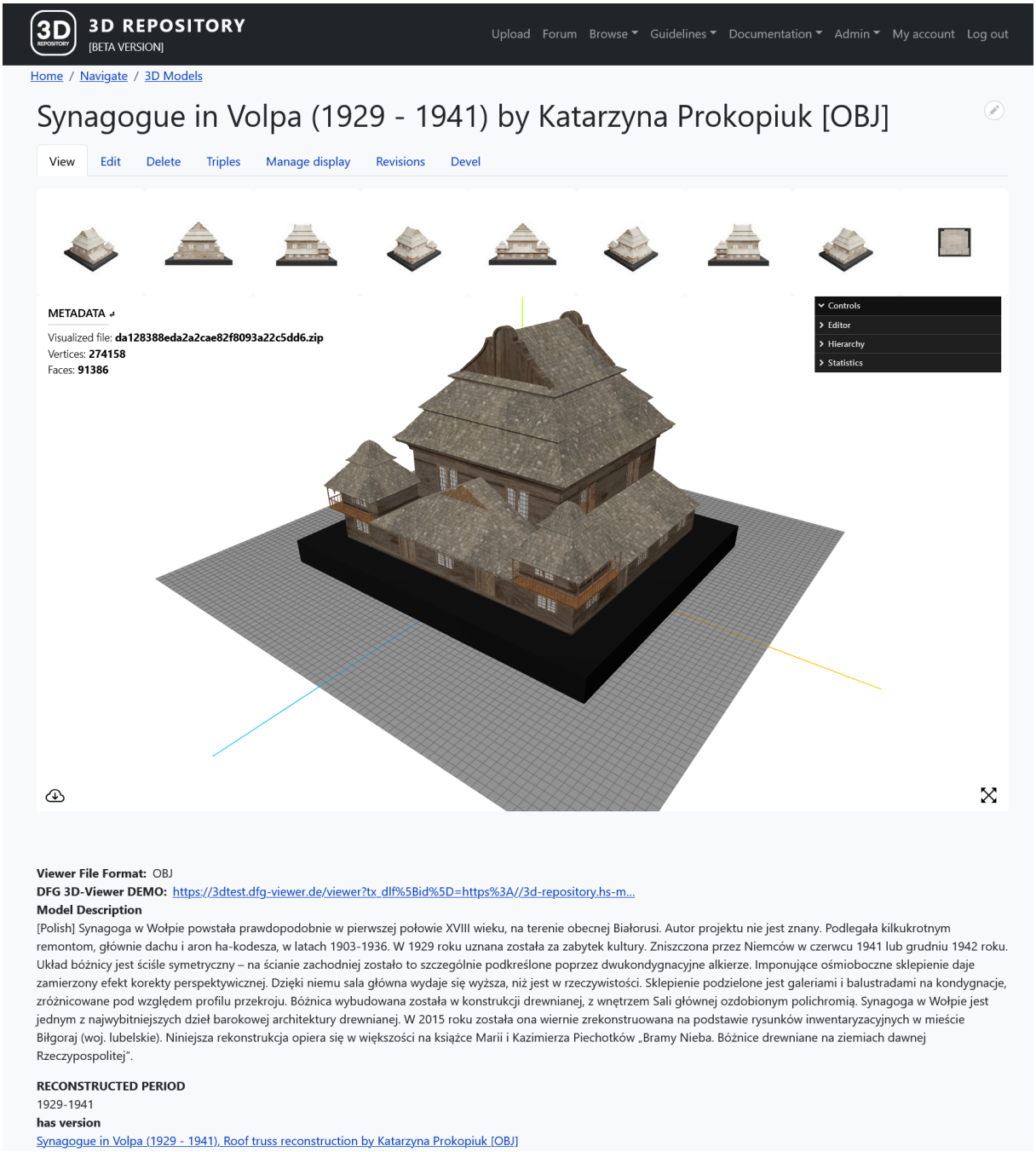


Fig. 88 Example of full documentation of the reconstruction in the WissKI-based 3D Repository of DFG 3D-Viewer project. The entry illustrates a model of a hypothetical reconstruction of the Volpa Synagogue, which was made by student Katarzyna Prokopiuk as part of an elective course at the Warsaw University of Technology in the summer semester 2021-2022 (Part 1, continue on Fig. 89).

Wikidata: https://www.wikidata.org/wiki/Q3508102
Wikipedia: https://pl.wikipedia.org/wiki/Synagoga_w_Wo%C5%82pie
OBJECT LOCATION
OBJECT CITY
City Name: Volpa
City Geonames: http://www.geonames.org/620023/
City GND: https://d-nb.info/gnd/7643902-1
MODEL COPYRIGHT
Model License: Attribution-NonCommercial-ShareAlike (CC-BY-NC-SA)
AUTHOR(S)
Author Name: Katarzyna Prokopiuk
Author Affiliation: Warsaw University of Technology
Author ORCID ID: https://orcid.org/0000-0001-8410-3936
Holder (Organization)
Holder Name: Faculty of Architecture of the Warsaw Univeristy of Technology
Holder VIAF: https://viaf.org/viaf/144776985/
Holder Website: https://www.pw.edu.pl/engpw
Holder Name: AI MAINZ: Institute of Architecture of University of Applied Sciences Mainz
Holder VIAF: http://viaf.org/viaf/170713989
Holder Website: https://architekturinstitut.hs-mainz.de/
MODEL CREATION
Used Software: Rhino 6
Modeling Techinque: NURBS and curve modeling
Creator(s)
Creator Name: Piotr Kuroczyński
Creator Affiliation: Hochschule Mainz - University of Applied Sciences
Creator ORCID: https://orcid.org/0000-0001-9847-8368
Creator GND: https://d-nb.info/gnd/138320659
Creator Role: Scientific Advisor
Creation Time Span: 2022-03-17 — 2022-05-19
Native File
131a12769d274e08d8ecb3650337a5dc.3dm
18a64e64d37b6fd985cdcd6d28ec24a6.gml
4e773d7682486f149858bdea062dbae4.skp
Documentation Upload
a765d67862fff8f6d6dd1c51ed4fca12.pdf
695ce09adf9ba8cfd18a2fa62ced7fc6.pdf
d8b82d4360c8619ee88fb831b2225d0a.pdf
PROJECT
Project Name: 3D Rekonstrukcja Synagog Seminarium wybieralne na 8. semestrze, Studia Architektury na Politechnice Warszawskiej
Project Acronym: 3DREKO
Project Purpose(s): Seminar
Project Outcome(s): report
3d representation
AR/VR application
Project Time Span: 2022-03-17 — 2022-05-19
Project Description
In the course Digital Reconstruction of Lost Architecture, 3D digital reconstruction based on historical sources is taught along with visualization of lost architecture. The topic is the architecture of wooden synagogues in the former Republic of Poland, destroyed during World War II, documented in the collection of the Department of Polish Architecture at the Faculty of Architecture of the Warsaw University of Technology during the interwar inventory. As part of the course, students learn to critically examine historical sources, and 3D modelling on the basis of pictorial representation. Interpretation of sources and hypothetical reconstruction aims to convey the method of digital reconstruction as a research tool and to highlight the potential and challenges in the context of the growing demands of the Digital Humanities. Students thus learn about architectural history, 3D modelling and visualisation through analysis and interpretation of sources. An important topic of the course is the issues of data interoperability, documentation and publication of digital 3D models for far-reaching applications in the fields of urban planning, city management, tourism, etc., among others. (digital city models, AR and VR technologies).

Project Participant(s)
Participant Role: Conceptor
PUBLICATION
Publisher: Katarzyna Prokopiuk (Warsaw University of Technology)
Publication Date
Thu, 05/19/2022 - 17:07
Authored on: Mon, 02/06/2023 - 12:32
Creator ID: Katarzyna Prokopiuk

Fig. 89 Example of full documentation of the reconstruction in the WissKI-based 3D Repository of DFG 3D-Viewer project (Part 2).

In the first survey, the project partners were asked to evaluate the metadata form. The form was divided into six sections, covering general information about the 3D model, the model creation process, the object depicted, copyright, the project within which the model was created, and the upload process (see Fig. 90). Initially, respondents were asked about their overall impression of the form. Regarding its length, the average response was 3.8 on a five-point scale, where 1 indicated it was too short and 5 too long, reflecting a satisfactory balance in the number of fields required.

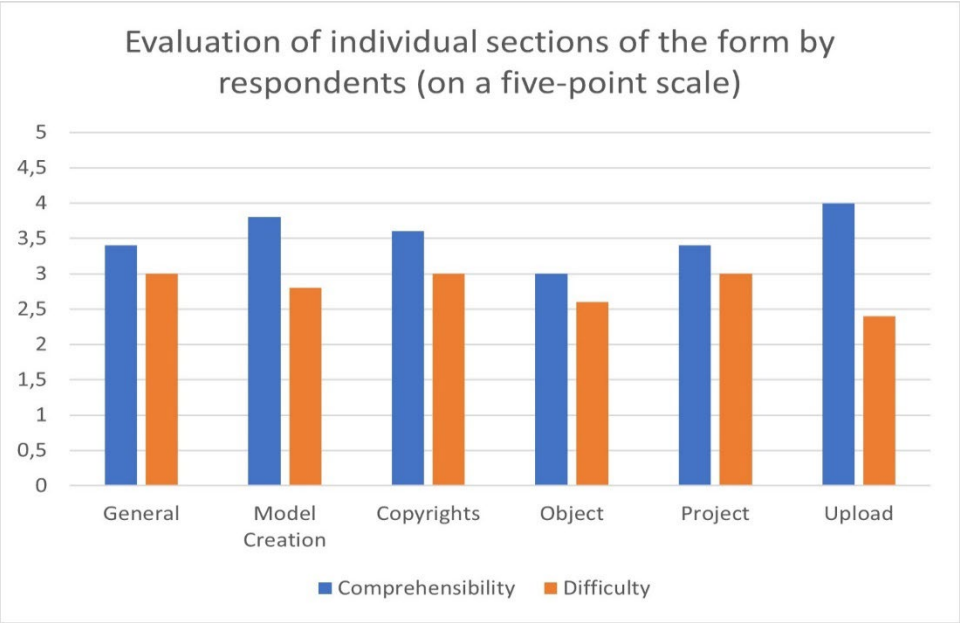


Fig. 90 Users' assessment of the clarity (orange) and difficulty of completing (blue) sections of metadata fields in the repository on a 5-point scale, taking 1 as the most negative and 5 as the most positive.

The following questions also adopted a five-point scale, assuming 1 as the most negative and 5 as positive. In terms of assessing the difficulty of filling in the form, an average score of 2 was received, indicating that those publishing often did not have detailed information about the model and needed to put in extra effort to complete all the metadata. In a more detailed assessment, the average rating for each section in this regard was between 2.6 and 3.8, with the most difficult sections to complete being the model upload (due to problems in preparing the file for web-based publication - an average rating of 2.6) and the object section (due to the initial focus of the form on architectural models, some of the fields were confusing for professionals from other disciplines). Respondents also declared a lack of information in the project section for several cases (their archives did not contain any information in this respect). When it came to assessing the clarity of the field descriptions of the individual sections, the results were more positive (see Figure 6). The most comprehensible section was the file upload (4.0) and the least comprehensible was the object (for the same reasons as before, this section finished with an average of 3.0). The remaining sections on the question of the clarity of the fields and their descriptions received averages around a score of 3.5.

Another conducted survey was focused on the 3D viewer's efficiency in practice and the solving of problems related to the incorrect display of the model in the viewer. As it emerged, users encountered problems with the proper display of the file in the viewer in almost 70% of cases, but more than half of these were solved due to the guidelines for preparing the file for export, which had begun to develop during previous tests with students. Respondents were also asked to rate the comprehensibility of the guidelines on a five-point scale (5 being the most positive). The average rating in this respect was 4.85. One objection of the respondents was the lack of coverage of some programmes in the study, which is the subject of future work updating the study.

A.4.3. Joint evaluation

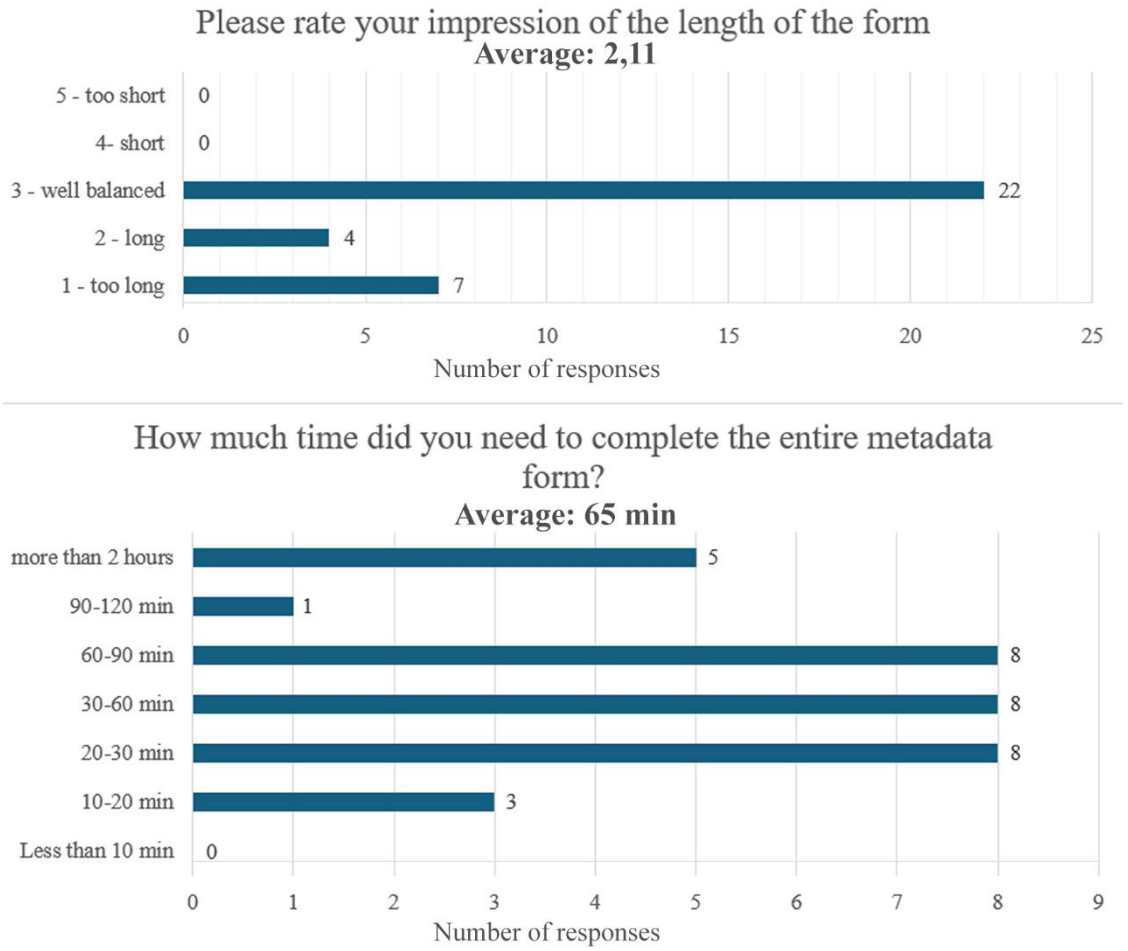


Fig. 91 The assessment of the data form in terms of its length and the time required for completion The length was evaluated on a scale ranging from 1 to 5, where 1 denoted 'too short', 5 signified 'too long', and 3 represented a 'well-balanced' length.

The beta version of the WissKI 3D Repository, initiated in June 2022, has been subjected to evaluation by two primary target groups since its launch. The initial group, composed of students in the cultural heritage domain, was tasked with showcasing the importance of documenting and publishing 3D models of digital reconstructions (see Appendix 9, Appendix 10, and Appendix 12).[138] The second group, comprising digital 3D cultural heritage professionals, predominantly focused on archiving digital assets.[139] Participants were requested

[138] Evaluations of the repository were undertaken with three student groups at separate time steps. The initial survey, conducted in June 2022, involved engineering students from the Faculty of Architecture at the Warsaw University of Technology (WUT), focusing on reconstructing wooden synagogues. A subsequent survey, a year later, encompassed a joint class on the same subject, combining students from the engineering department of the WUT with master's students from the Lodz University of Technology (TUL). The final survey occurred during an international digital reconstruction workshop under the CoVHer project in September 2023. This workshop drew participation from students specialising in cultural heritage fields (architecture, archaeology, digital humanities) from five European countries: Italy (University of Bologna), Germany (Hochschule Mainz - University of Applied Sciences), Poland (WUT and TUL), Spain (Universitat Autònoma de Barcelona), and Portugal (University of Porto).

[139] The professional survey was conducted collaboratively within the framework of the DFG 3D-Viewer project. Participation involved four institutions, each representing a diverse discipline of CH: Deutsche Museum (history of technology), BTU Cottbus (architecture), LMU Munich (art history), and University of Cologne (archaeology). This survey was divided into three sequential phases, each focusing on different aspects of utilising the WissKI 3D Repository.

to report their experiences across four categories: metadata form, 3D viewer, provided guidelines, and overall experience. A 5-point rating scale was employed to assess specific issues, with 1 being the most negative and 5 being the most positive. The form length question was an exception, where a median value of 3 was considered ideal, and extreme values indicated either excessive length or brevity. Regarding the form length (see Fig. 91), responses generally indicated a well-balanced perception. However, the average score of around 2.0 suggested a need for minor shortening (optimal value: 3.0).

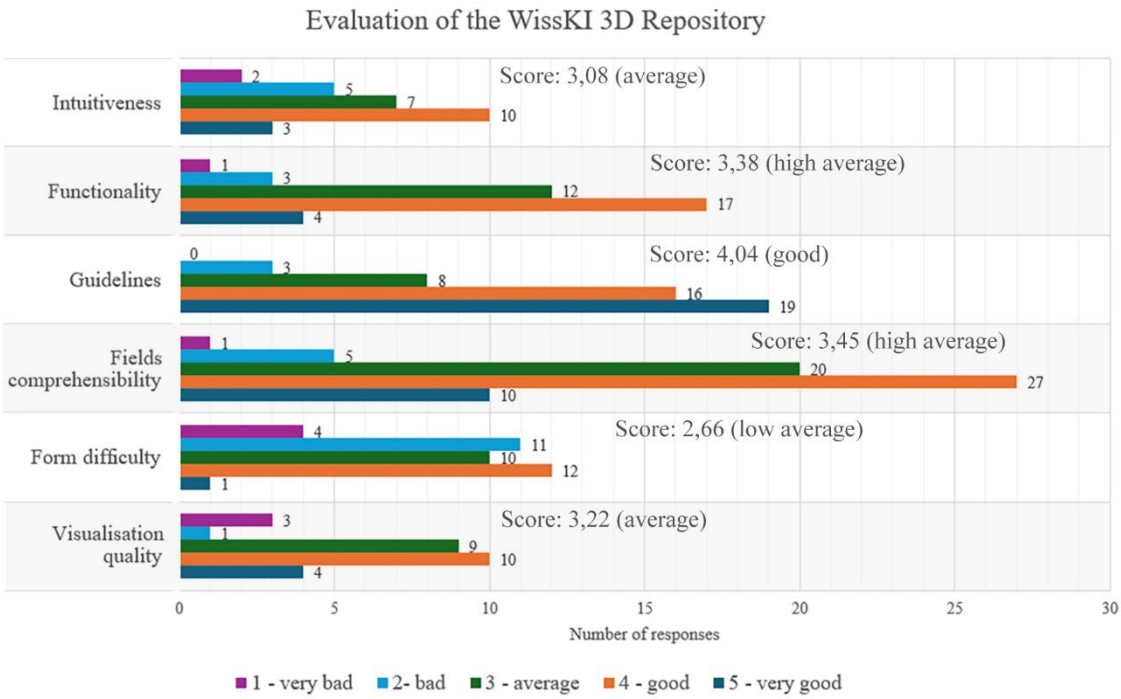


Fig. 92 The evaluation of the WissKI 3D Repository by respondents. Ratings were given on a scale from 1 to 5, with 1 the most negative and 5 the most positive. Six categories underwent evaluation: intuitiveness, functionality, guidelines, comprehensibility, difficulty, and visualisation.

The form's difficulty level (see Fig. 92) averaged at approximately 2.66, denoting a mild challenge for respondents, with professionals finding it most challenging. The average score for field comprehensibility (see Fig. 92) hovered around 3.45, implying minor difficulties in field content understanding. The results were unexpected regarding form completion time (see Fig. 85). Designed for swift documentation, respondents needed about an hour on average, with notable difficulty in preparing 3D models for accurate viewer display (see Fig. 93). On average, 3.44 attempts were needed for satisfactory visualisation, leading to the creation of additional guidelines to assist in proper model preparation and upload, rated at 4.04 (see Fig. 92) for comprehensibility (mostly understandable).

The overall impression of the repository's utility averaged at 3.38 (Moderately Usable), with users indicating a preference for using the platform for model archiving (53%), model browsing (11%), and seeking information on restorations (3%). 7% stated they would not reuse the repository, with another 7% abstaining from opinion (see Fig. 93).

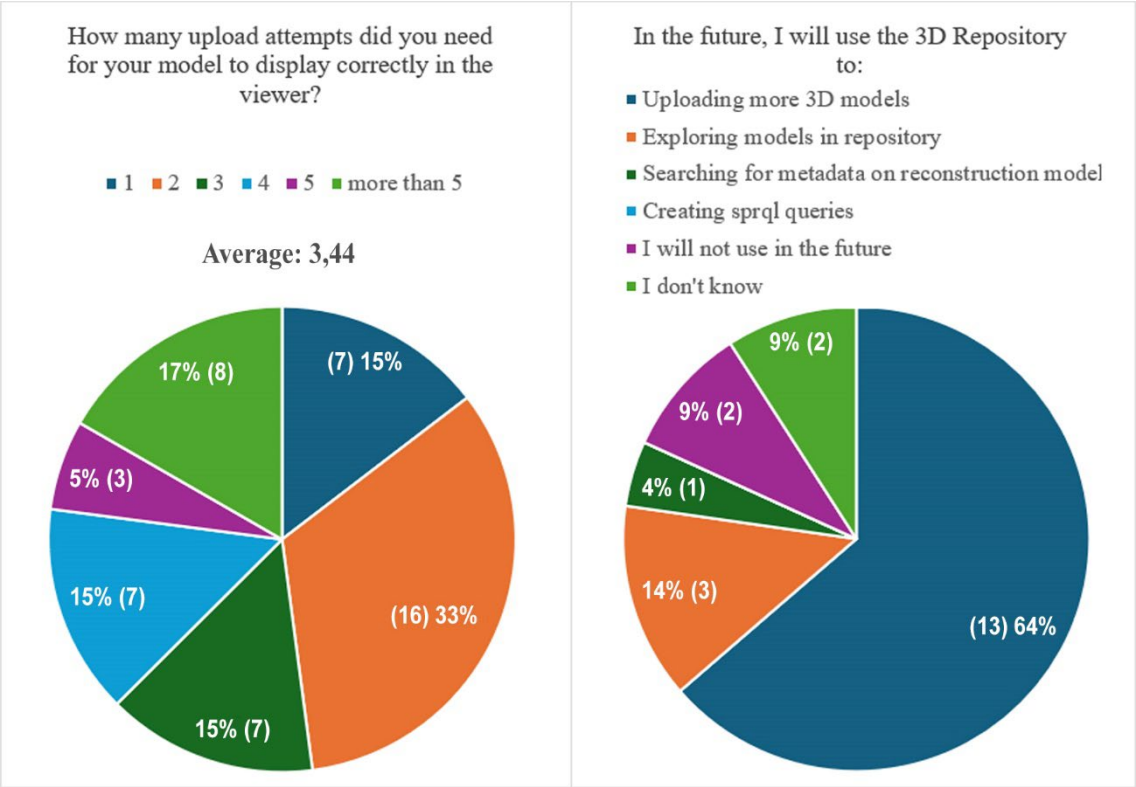


Fig. 93 The assessment of 3D data publication and the future of the WissKI 3D Repository. The left graph illustrates the number of attempts required to successfully publish a 3D model, while the right graph depicts respondents' probability of utilising the system in the future.

The WissKI 3D Repository has gathered over 150 users who have published over 250 models. The platform demonstrates uniqueness in the market regarding the wide range of 3D formats supported and the ability to document in compliance with FAIR Principles. The growing number of users and published models in the repository indicates interest among the community. Tests have shown the usefulness of using the repository for higher education and professionals' preservation of 3D digital heritage. However, drawbacks were pointed out regarding the difficulty of preparing 3D models for publication and the long documentation form. The system's operability and interface design still need to be improved to provide a fully user-friendly environment. The presented system also shows potential as an alternative to Sketchfab for publishing and exploring 3D models, surpassing its ability to document context and paradata based on ontological solutions of the Semantic Web. The activities around the DFG 3D-Viewer project also made it possible to start a shared discussion on the documentation of CH's 3D models. The presented scheme for the documentation of 3D models was aligned with proposals from other consortia during two editions of workshops on metadata for 3D cultural heritage in Mainz (2022) and Munich (2023) to agree on a common standard for the preservation of digital datasets of architecture, archaeology and art history (see Chapter III.C.3.).

Further steps lead to the approved second phase of the DFG 3D-Viewer project, initiating collaborations with multiple libraries to integrate the developed solutions in their repositories. This integration will facilitate ongoing enhancements and updates to the DFG 3D-Viewer. Additionally, plans are to build a ready-to-use

component of the WissKI 3D Repository as part of the WissKI Cloud service[140]. This service aims to offer a pre-configured system for download, enabling users to effortlessly establish their own WissKI repository for 3D models. Also, all the experiences gathered from the repository are being analysed to derive insights. These findings will significantly contribute to developing a novel platform for documenting hypothetical 3D digital reconstructions of lost and never-built architectural heritage in higher education at the European Union level, within the scope of the CoVHer project (see Chapter IV.C.).

B. PURE3D Scholarly Edition

The second infrastructure case study is based on a response to the open call of the project "PURE3D: The Infrastructure for the Publication and Preservation of 3D Scholarship," funded by Platform Digitale Infrastructuur - Social Sciences & Humanities.[141] In this instance, the user was not involved in the infrastructure development but participated as an end-user. The call was particularly appealing in the context of this work due to the opportunity to publish 3D models in a web environment while implementing a preservation strategy and ensuring the scientific quality of the output.[142]

B.1. System framework

The infrastructure is centred around a tool for creating virtual experiences using 3D models—Smithsonian Voyager. Developed by the Smithsonian Institution,[143] this tool was initially designed to facilitate the exploration of digitised museum collections. A key strength of the tool is its ability to create virtual tours by combining multiple 3D objects within a scene, adding annotations and articles to build a cohesive narrative that guides the user through the modelled environment. The developers of the tool have prepared clearly defined requirements for the models prepared for viewing on the web. 3D model must be delivered in OBJ, FBX, or glTF/GLB file format, with Draco Compression recommended for GLB files. The models should incorporate PBR extensions compatible with the three.js standard, specifically the metalness/roughness PBR shading model, as three.js do not support specular/glossiness. A 4K texture map in JPG format with 86 compressions is required for single-digitised objects, while more complex scenes should use 1024×1024 textures for the various parts. The model size should ideally not exceed 230,000 triangles for all geometry in the scene to ensure optimal performance, although slightly higher counts are acceptable for more intricate scenes. The essential model components include geometry, texture, and normals, but additional elements such as lights, cameras, and vertex colour information are not supported.

The second pillar of the infrastructure involves developing a strategy for preserving 3D models.[144] PURE3D is currently working on creating a dedicated repository for the edited models, while also collaborating with DANS,

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[140] WissKI Cloud is a service facilitating the utilisation of a pre-configured instance of WissKI, obviating the need for individual server setup. Future enhancements will enable users to customise configuration parameters tailored to specific intended uses of the system, such as a 3D model repository, image repository, scientific project documentation, and more. The service is accessible at: https://wisski.cloud/ (accessed 31 January 2024).

[141] The PURE3D Scholarly Edition call can be accessed here: https://pure3d.eu/call-for-3d-projects/ (accessed 29 August 2024).

[142] The Scholarly Edition of Reconstruction of St. Johannis Church in Mainz (800 AD) is currently being prepared for final publication by the editors of PURE3D. The preprint can be viewed at the link: https://viewer.acc.pure3d.eu/voyager-explorer-dev.html?root=models/53460aac36aa15966973df3af49793209eee2cf8/files/Documents/models/Mainz/&document=scene.svx.json (accessed 30 October 2024).

[143] See: https://smithsonian.github.io/dpo-voyager/ (accessed 29 September 2024).

[144] See: https://dev-pure3d.netlify.app/ (accessed 15 October 2024).

the Dutch national centre of expertise and repository for research data. DANS specialises in creating reusable data sets, ensuring that even if the university's servers are decommissioned after the project ends, the edited 3D models will be securely preserved in the archive.[145] The output from Smithsonian Voyager is straightforward to prepare for archiving, as all the editing data, including the 3D models, can be conveniently exported in JSON format. It is commonly used to store and exchange data between a server and a web application. This ensures that the entire content, including any annotations, narratives, and interactions, is preserved in a portable format.

The final pillar of the infrastructure is the Open Publication and Peer Review for 3D Scholarship (OPER3D),[146] which aims to address several key objectives. First, it will analyse the challenges and opportunities of publishing 3D scholarship. Second, it will explore the processes involved in peer review of 3D data and its results. Third, it seeks to position 3D publications within the evolving landscape of research evaluation. This initiative will be integrated into the PURE3D research infrastructure, where scientific arguments are embedded and driven by 3D models.

B.2. Conceptualising the Edition around St. Johannis Church in Mainz (800 AD)

The model submitted for the call was a hypothetical reconstruction of St Johannis Church in Mainz, circa 800 AD. This reconstruction was created for an exhibition with the Landesmuseum Mainz as part of the Digital Urban History Lab.[147] The project offered a fascinating insight into the historical urban development of Mainz, Worms, and Speyer between the 8th and 13th centuries. Developed in collaboration with the Institute of Architecture at Mainz University of Applied Sciences and the Department of Media Design, the lab featured interactive touchscreens, 3D digital reconstructions, and physical models of the cities, allowing for a dynamic exploration of their histories. The reconstructions were based on archaeological findings, preservation work, written records, and historical maps, with each model meticulously crafted to reflect the evolving landscapes of these cities. For instance, the oldest known map of Mainz from the 16th century shows a fertile strip within the city walls, which is supported by 10th-century written sources. Where historical evidence was limited, hypothetical elements were thoughtfully added, enhancing the authenticity of the reconstructions.
The process of preparing an edition for publication was entirely different from developing a WissKI-based Repository. This time, it required a highly conceptual design for presenting the 3D model, utilising the full range of tools provided by Smithsonian Voyager. The initial step involved creating a Persona Empathy Map, a visual tool used to deeply understand and empathise with target audiences by mapping out their thoughts, feelings, behaviours, and experiences. Typically employed in user experience (UX) design, product development, and marketing, the map helps build a detailed profile of a typical user, known as a persona (Krüger, 2022). It explores various aspects of a person's experience, such as what they see in their environment, including their surroundings, market conditions, and social influences, as well as what they hear from others, such as friends, colleagues, or social networks. It also delves into what the person thinks and feels, analysing their inner thoughts, concerns, emotions, and priorities, alongside what they say and do, reflecting their actions, behaviours, and interactions with others. For this task, a persona was created to represent a young researcher involved in digital reconstructions, using tools to publish and evaluate the results of digital reconstruction projects (see Fig. 94).

[145] The details regarding the collaboration with DANS and the inclusion of the 3D Edition in the preservation strategy were shared during the in-person training held in Maastricht in December 2023.
[146] See: https://pure3d.eu/oper3d/ (accessed 28 September 2024).
[147] See: https://architekturinstitut.hs-mainz.de/projects/duhl (accessed 28 September 2024).

Fig. 94 3D Scholarly Edition Persona Empathy Map.

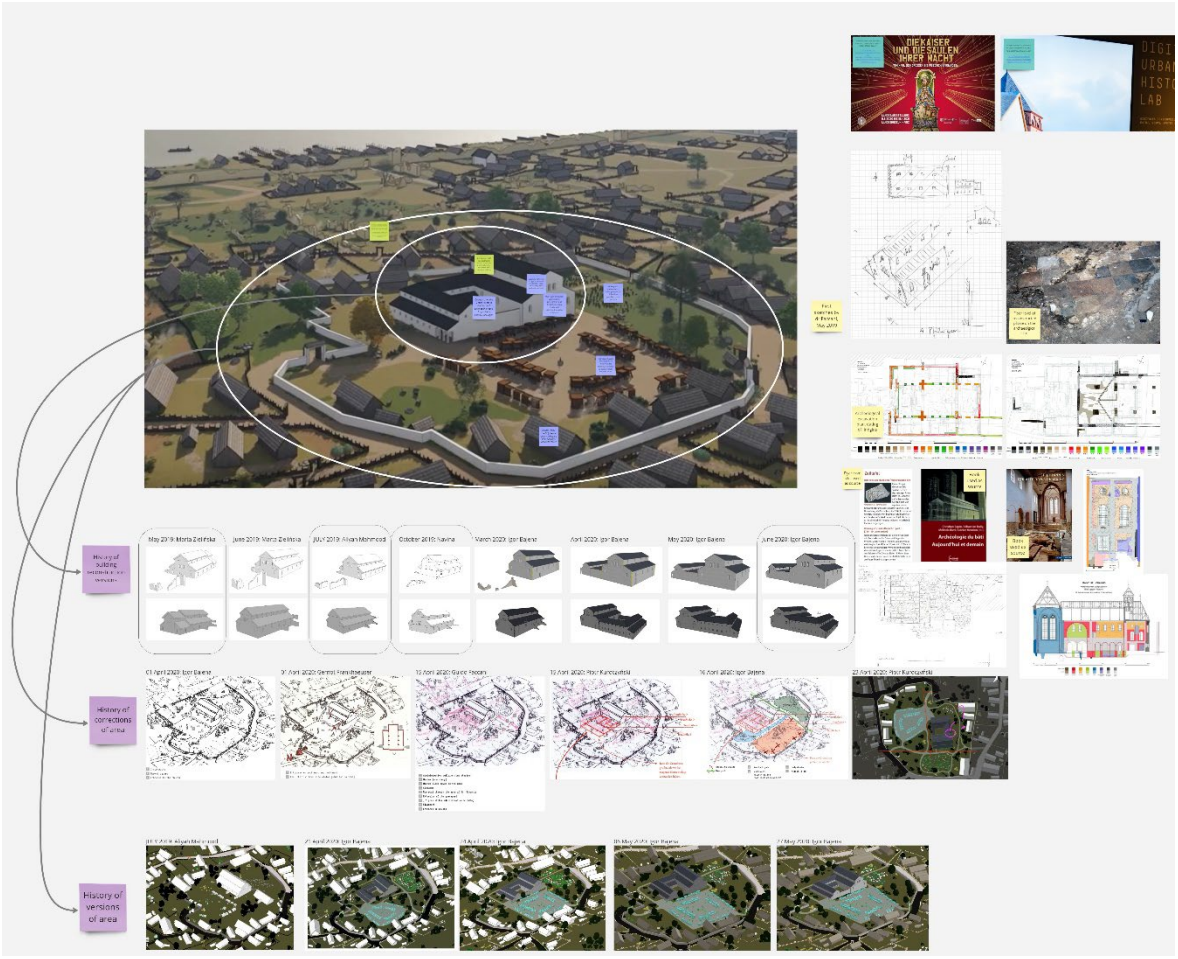


Fig. 95 Collection of materials and annotations to conceptualise the narrative around the hypothetical reconstruction of the St. Johannis church in Mainz.

Once the potential audience for the edition was identified, the next step was to conceptualise how to present the 3D model. This required abstract thinking to convey information not in the form of a static presentation or long text, commonly used by scholars, but through an interactive 3D model enhanced with multimedia that directs

the viewer's attention to specific aspects of the reconstruction (Papadopoulos & Schreibman, 2019). To achieve this, all materials and ideas were compiled, and text annotations, in the form of sticky notes, were used to visualise the reconstructions (see Fig. 95). Having all the available knowledge in one place enabled the development of three main narratives centred around the 3D model. The first was an introduction to the subject of St. Johannis Church, while the second focused on the historical significance of the church and its role in the fabric of 8th-century Mainz. The final narrative, most crucial to this project, was designed to document the entire reconstruction process, following the guidelines outlined in Chapter I.C. The conceptualisation process was overseen by assigned project mentors - in the case of the St. Johannis church in Mainz by Costas Papadopoulos and Kelly Gillikin Schoueri.

B.3. Smithsonian Voyager workflow

The conceptualisation of the narrative then had to be implemented in Smithsonian Voyager, which offers three main methods for introducing narrative into the system. The first is through articles, which allow for traditional text entries with multimedia elements similar in format to a web blog post (see Fig. 96). Articles can be displayed either alongside or as overlays on a 3D scene. While they may resemble scientific articles, their primary function is to support the main topic, the 3D model and thus should remain concise and to the point.

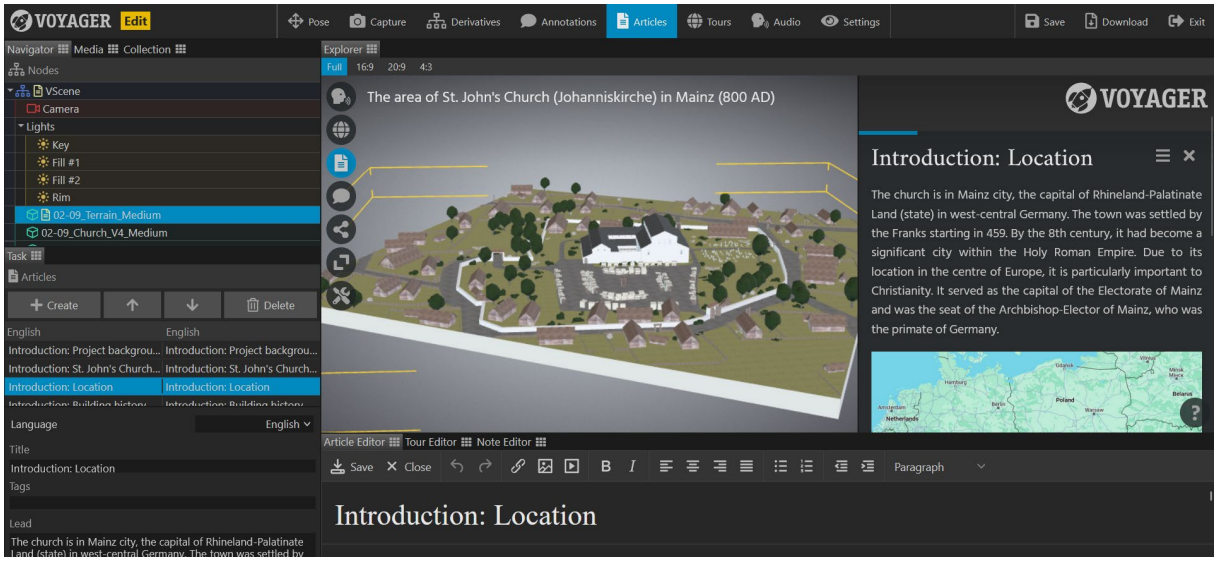


Fig. 96 Smithsonian Voyager interface with article editor.

The second method is annotations, which are designated points on the 3D model that reveal additional information when clicked (see Fig. 97). Annotations in Smithsonian Voyager can be grouped thematically. Tags can be assigned to control the visibility of specific 3D models within the scene. The third and most dynamic method is the creation of virtual tours. A virtual tour consists of steps in which the creator controls the visibility of models, the camera positioning, and the inclusion of annotations or articles (see Fig. 98). Transitions between steps are animated, creating a seamless and engaging flow. One of Smithsonian Voyager's key advantages over other viewers is adding multiple models to a single 3D scene, allowing the reconstruction model to be compared with source materials for instant verification of hypotheses. This feature also enables the creation of captivating animations that can hold the user's attention. An experiment using this method demonstrated a step-by-step

process of constructing a solid object, showing the transitions between different reconstruction versions.[148] This process was labour-intensive, requiring each element's separate export and import from various directions. Ultimately, 56 models were loaded into the scene to achieve the desired effect.

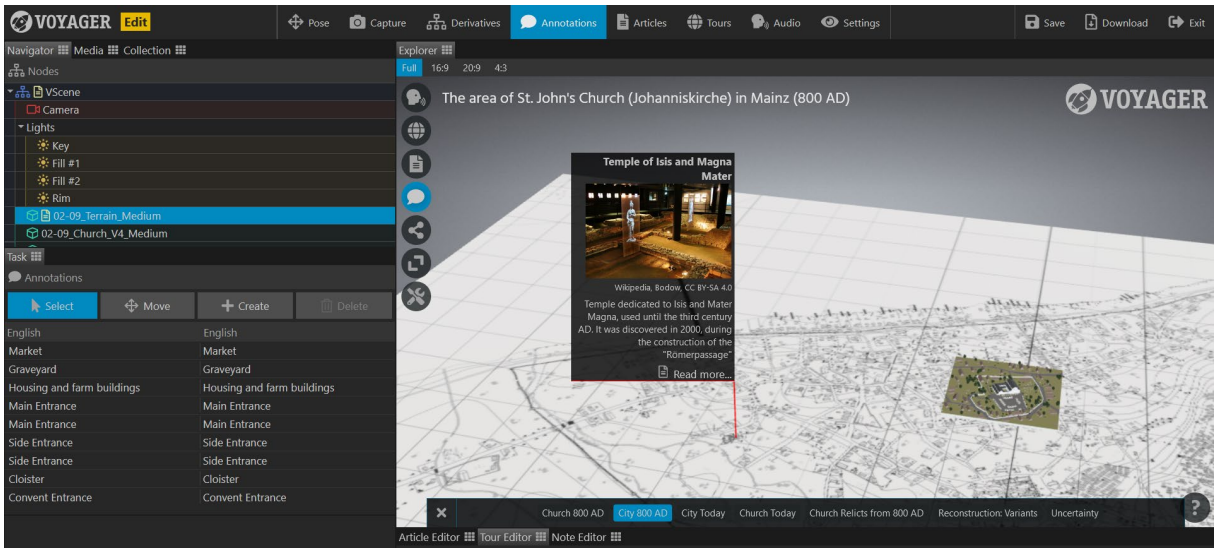


Fig. 97 Smithsonian Voyager interface with annotation editor.

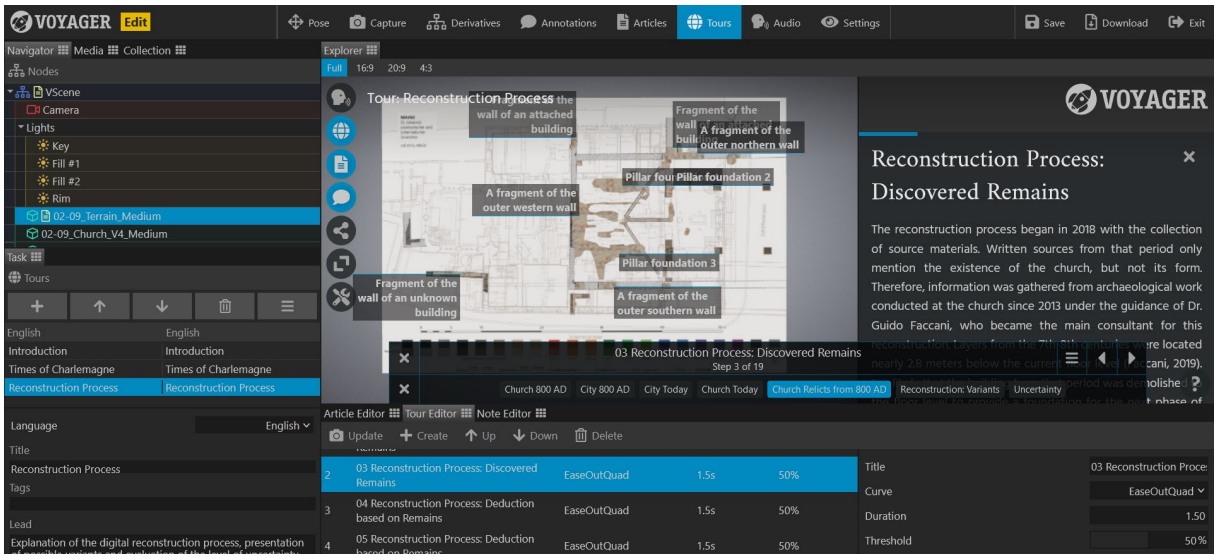


Fig. 98 Smithsonian Voyager interface with tour editor.

B.4. Reconstruction documentation

The documentation of the reconstruction process is presented in a separate virtual tour titled "Reconstruction Process". The tour uses seven dedicated articles, the content of which can be seen in Appendix 14. Initially comprising 44 steps, this was later reduced to 19 in the final version. The first step introduces the primary source used during the reconstruction: an archaeological report on the excavations currently being carried out at the church site, which provides the date of the uncovered remains (Faccani, 2020). The tour also showcases the

[148] A video documenting the changes to the Smithosnian Voyager church reconstitution options has been released: https://youtu.be/Cmyv2zvDAuk (acessed 25 June 2024).

preserved elements from the year 800, which served as the foundation for the creation of the entire hypothesis (see Fig. 99).

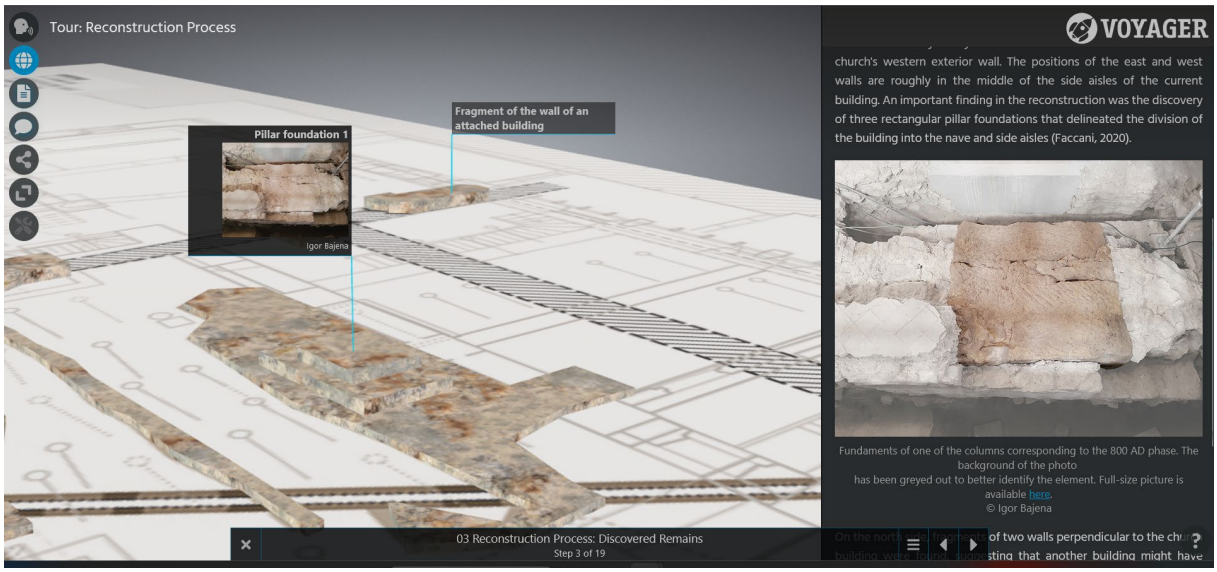


Fig. 99 Preview of a step from the viral tour showing the remains from the year 800 compared with the building plan from the archaeological report.

In the subsequent steps, deduced elements based on the remains were presented, such as additions to the floor, the wall outline, and the rhythm of the columns. These elements were represented using transparent materials to convey the hypothetical nature of the reconstruction (see Fig. 100). The height of the elongated features was shown as relatively low, indicating that the actual height is unknown. Similarly, one side of the building was left open, reflecting the fact that excavations could not be conducted in that area due to the constraints of the compact urban structure surrounding the present-day church.

Fig. 100 Preview of a step from the viral tour showing the deducted part of the reconstruction in transparent material.

The reconstruction of the church was a multi-phase effort. As the 3D model evolved, so did the on-site research, leading to new hypotheses. Throughout the process, five different versions of the reconstruction were documented. Areas of debate included the number of bays in the church's nave, the design of the choir's end,

and the building's height. The final version also introduced a bold hypothesis reconstructing the cloister based solely on a few wall remnants running perpendicular to the building's zenith. In one of the steps of the virtual tour, these variants were juxtaposed, allowing viewers to compare the differences.

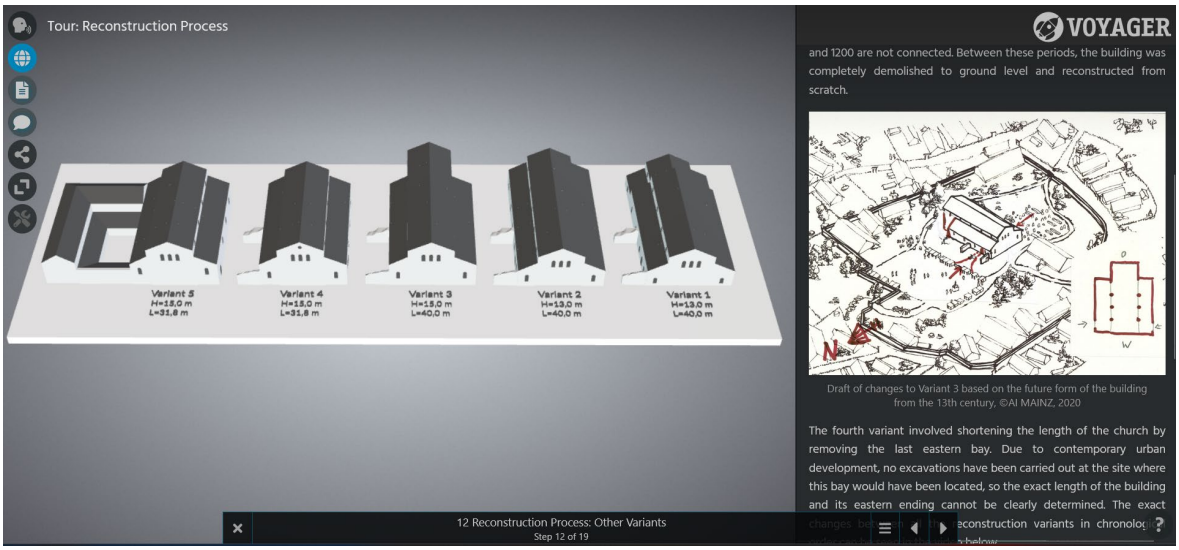
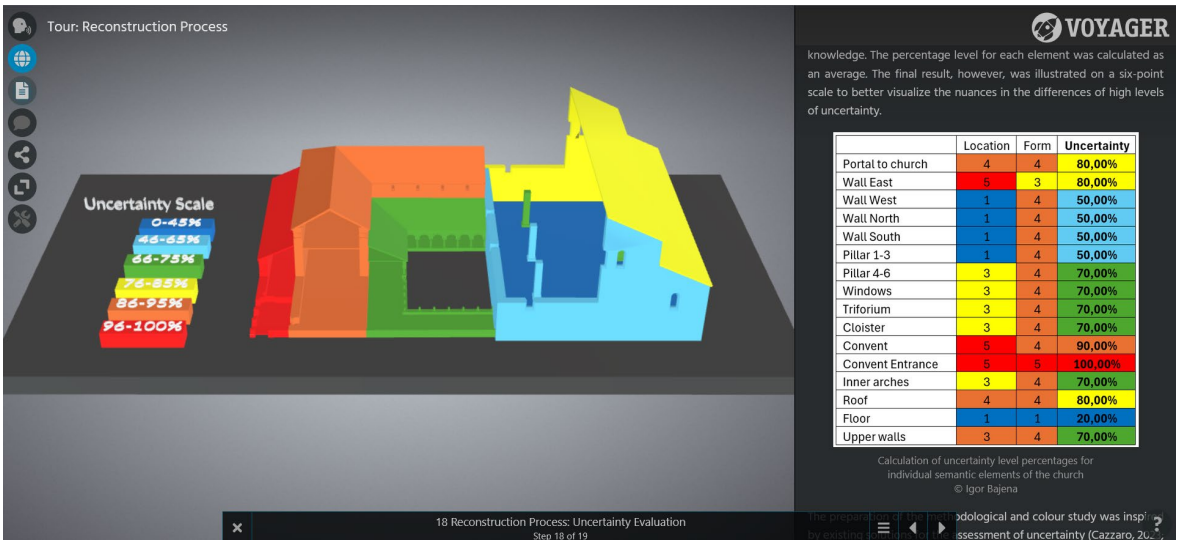


Fig. 101 is a Preview of a step from the viral tour showing the reconstruction variants, with a discussion between modellers and archaeologists presented on the drawing in the article section.

The presentation of the variants in the overview allowed for a detailed explanation of the reasoning behind selecting the final version. Additionally, an uncertainty assessment of the reconstruction was displayed in percentage terms (see Fig. 102). To visualise this uncertainty, false colours were applied, and a separate model was imported into Smithsonian Voyager, labelled with a corresponding tag. The percentage scale and a 3D legend of the colours used were also included alongside the model. The uncertainty was calculated based on two main factors: the geometric form and the location of the model segments. A semantic division of the object into sixteen segments was also provided (see Appendix 14).



	Location	Form	Uncertainty
Portal to church	4	4	80,00%
Wall East	5	3	80,00%
Wall West	1	4	50,00%
Wall North	1	4	50,00%
Wall South	1	4	50,00%
Pillar 1-3	1	4	50,00%
Pillar 4-6	3	4	70,00%
Windows	3	4	70,00%
Triforium	3	4	70,00%
Cloister	3	4	70,00%
Convent	5	4	90,00%
Convent Entrance	5	5	100,00%
Inner arches	3	4	70,00%
Roof	4	4	80,00%
Floor	1	1	20,00%
Upper walls	3	4	70,00%

Fig. 102 Preview of a step from the viral tour showing the uncertainty of reconstruction with the use of percentage values and false colours scale.

B.5. Peer review process and audience feedback

The 3D Scholarly Edition is a new approach to presenting research on 3D models of cultural heritage, and the PURE3D project is keen to gather extensive feedback on multiple levels. The first activity to engage with a potential audience was a Focus Group. Eight representatives from the scientific community, particularly those involved in digital reconstruction and research on the St Johannis Church in Mainz, were invited to participate. Their task was to review the editions and complete a questionnaire assessing how effectively the knowledge was communicated. The full survey results are presented in Appendix 15. Overall, the feedback was positive, with most participants finding the format effective and recommending it for future use. However, some noted that certain text articles were too lengthy and suggested that some of the virtual tours (which included 50 steps) should be condensed. Criticism primarily focused on the edition's broad scope, with recommendations to concentrate on illustrating specific issues more concisely. An online group meeting was also held to further discuss the strengths and weaknesses of the edition, clarifying the survey results. A graphical record of the discussion was produced using a plus-delta exercise, which noted positive aspects on the "plus" side and areas needing improvement on the "delta" side (see Fig. 103).

Fig. 103 Results of the plus delta exercise conducted with the focus group the PURE3D Edition of the St. Johannis Church reconstruction in Mainz (800 AD).

The second method for obtaining feedback was the peer-review process. PURE3D aims to function as an open journal for projects that use 3D models as the central component for making scholarly arguments, developing hypotheses, or answering research questions. The St. Johannis Reconstitution edition was one of the test cases for this peer-review process. Two peer reviewers were selected from other participants, with an additional two reviewers from outside the group, to carry out a single-blind evaluation. The review was based on criteria of value and user experience, such as whether the 3D model is central to the intended argument or narrative, whether the technical creation of the 3D model is fully documented, whether the textual and multimodal content is effective in contextualising the 3D, and whether the platform's technical affordances are used coherently and engagingly. The review consisted of nearly 20 questions, split between closed questions, where reviewers rated how well the edition met certain premises, and open questions, allowing reviewers to elaborate on their answers. Most questions focused on how well multimedia tools facilitated knowledge transfer and whether the 3D model effectively served as the edition's central argument. Although some questions felt repetitive, and the review form could benefit from minor adjustments, this process offers an innovative approach to scientific review for research presented in a non-traditional format. Peer reviews help counter one of the main criticisms of using 3D models as reliable knowledge sources. After undergoing review and revision, the final product provides a concise, scientifically rigorous presentation in an accessible and visually compelling way.

Both the peer review and the focus group survey provided valuable and insightful feedback, helping to make the edition more accessible and easier to read. The reviewers also identified technical errors that required attention. After addressing these corrections, the edition successfully passed the review process and is now in the final stages of publication. Although very effectively visual, this method of publication of 3D models required a great deal of additional work. The total time spent on conceptualising the narrative, preparing 3D models to meet viewer requirements and creating articles, annotations and virtual tours amounted to almost 100 hours. While this is certainly a novel approach to using 3D models as a scientific source of knowledge, functioning much like a journal for 3D models, several issues still need to be addressed. The transition to conceptualising the 3D model and creating a narrative is entirely new for researchers, requiring significant investment in time and effort for training the community. Although the editions are visually impressive and will be citable, extracting the desired information from them is somewhat cumbersome and does not appear machine-readable. Additionally, the PURE3D infrastructure does not solve all the challenges associated with 3D models, particularly the issues of publishing raw data or reusing 3D models as downloadable assets. This leaves room for further development of a WissKI-based repository designed specifically to facilitate data preparation for reuse.

C. CoVHer project: WissKI-based 3D Repository for digital 3D reconstruction

The final and most significant infrastructure case study was the repository created for the CoVHer project. CoVHer, which stands for Computer-based Visualisation of Architectural Cultural Heritage, is an Erasmus+ project that aims to establish applicable standards for documentation, methods, and a shared understanding (via a glossary) for the construction and evaluation of 3D models of architectural cultural heritage.[149] The premise of this repository differed slightly from that of the DFG 3D-Viewer project. Here, the focus was on the documentation of hypothetical digital reconstructions rather than on 3D digital cultural heritage in general,

[149] Website of the project: https://covher.eu/ (accessed 31 October 2024);
CoVHer Repository: https://repository.covher.eu/ (accessed 31 October 2024).

which typically refers to the digitisation of existing cultural artefacts. This shift in approach required significant changes to the metadata documentation scheme, as detailed in Chapter III.C.5.

C.1. Changes in data model

The foundation of the repository was built on the same principles as the DFG 3D-Viewer repository, utilising the WissKI system, a triplestore, and data modelling through an application ontology based on the CIDOC CRM standard (see Chapter IV.A.1.). These established components were once again employed to ensure consistency and reliability in the system's underlying architecture. The primary change involved moving away from the concept of documenting everything in a single form using a "flat hierarchy." This approach was problematic not only because it failed to leverage the potential of a hierarchical knowledge graph but also because it made the process more challenging for users, who had to manage a repeatedly nested form. Instead, several smaller forms were introduced, particularly for entities used mainly as reference material, such as people, organisations, or projects (see Fig. 74). Additionally, the documentation of the reconstructed object and the reconstruction process itself was split into two separate forms.

The separation of the forms also allowed for a more precise classification of both the reconstructed object and the reconstruction process itself. One of the most significant changes was the introduction of documentation for the available source materials, as well as the assignment of sources used in the reconstruction. Additionally, the ability to assign and describe paradata for the reconstruction was introduced, without imposing a specific format for communicating the paradata, allowing authors the freedom to choose how they wish to present it. A prefix field was also implemented, consisting of the first letters of the object's name and a numerical representation of the reconstructed phase. For example, for a reconstruction of the Synagogue of Speyer from 1250, the prefix would appear as SpSy1250. This prefix was then used to label related paradata and 3D models. Of particular importance was its role in addressing the issue of inconsistent file naming by users, a major problem in the initial repository. The introduction of the prefix aims to mitigate this issue. Another new feature was the introduction of documentation for reconstruction derivatives, which are models created for specific practical applications. Each derivative can be described in terms of its intended purpose, and users can provide multiple file formats, offering more opportunities for reuse by others.

The documentation scheme was re-modelled in the system using the pathbuilder tool. The new data model is presented in Appendix 16. The following ontologies were used:

-CIDOC CRM version 7.2.2,
-CRMdig version 3.2.1.,
-CRMinf version 1.0,
-LRMoo version 0.9.6,
-OntSciDoc3D version 2.0.,
-OntPreHer3D version 2.1.

C.2. System improvements

In addition to the data model, several other significant changes have been implemented in the system. The first was the introduction of an object overview feature on the repository's homepage, providing users with an instant snapshot of the number of models available and their geographical locations around the world (see Fig. 104). This feature helps users to quickly orient themselves and locate models of interest.

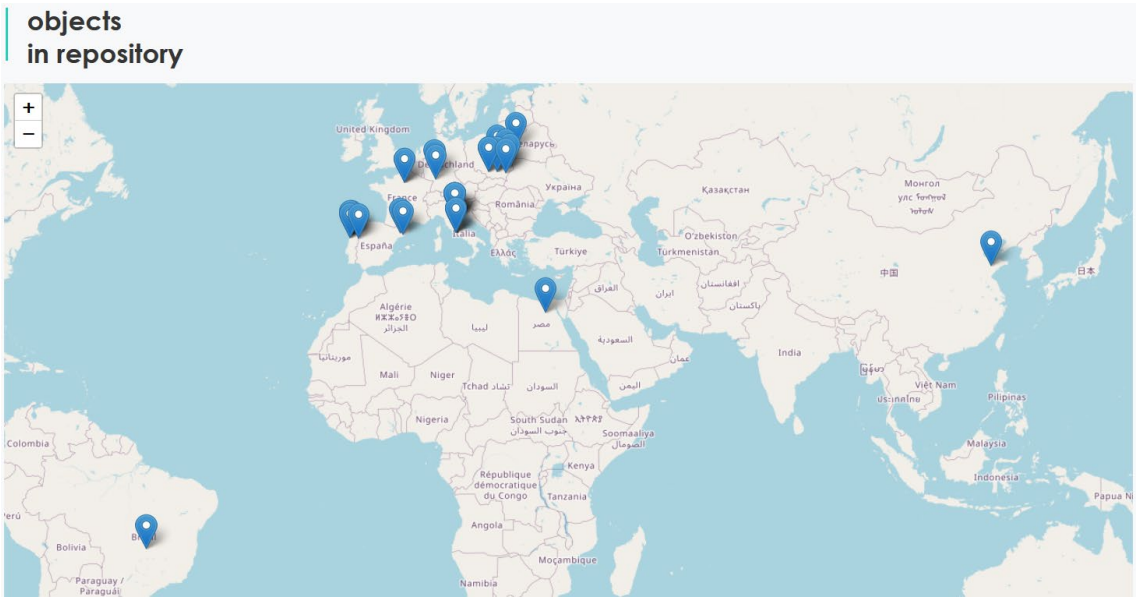
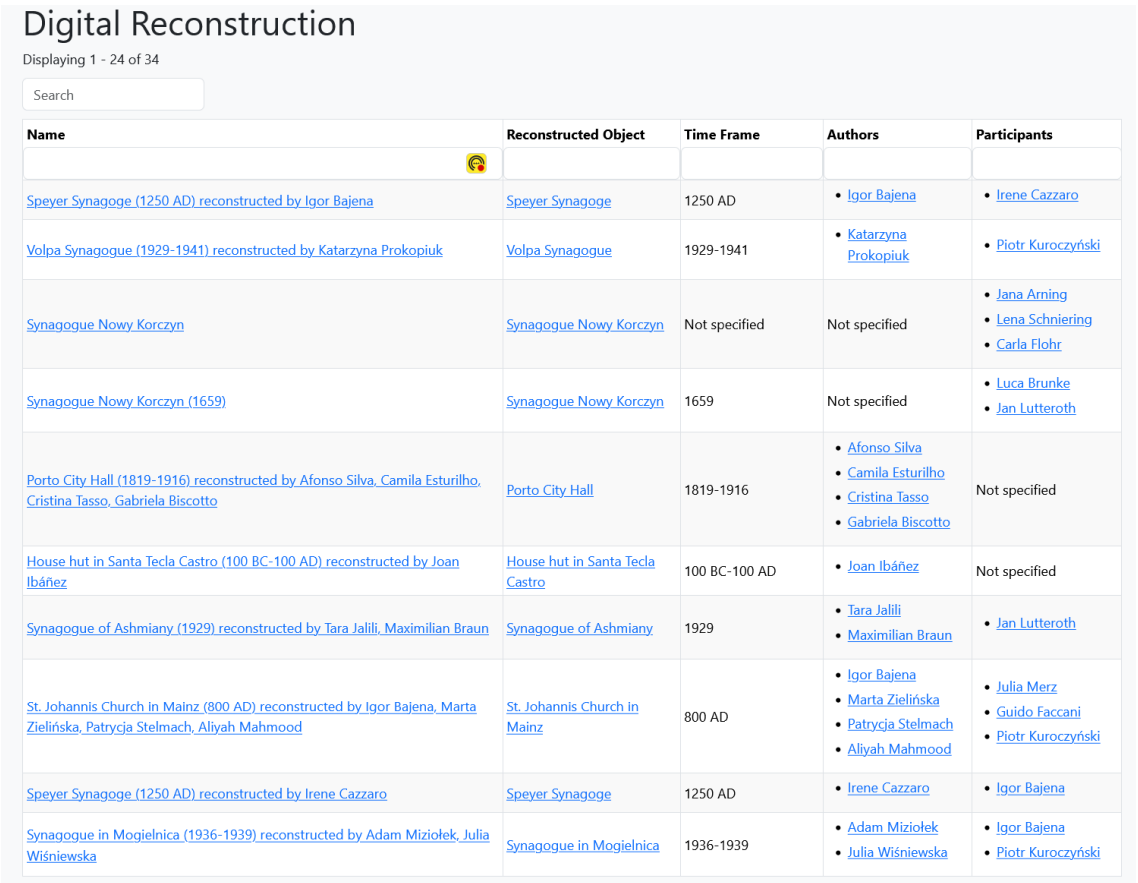


Fig. 104 Map view of objects documented in the repository.



Digital Reconstruction

Displaying 1 - 24 of 34

Search

Name	Reconstructed Object	Time Frame	Authors	Participants
Speyer Synagoge (1250 AD) reconstructed by Igor Bajena	Speyer Synagoge	1250 AD	• Igor Bajena	• Irene Cazzaro
Volpa Synagogue (1929-1941) reconstructed by Katarzyna Prokopiuk	Volpa Synagogue	1929-1941	• Katarzyna Prokopiuk	• Piotr Kuroczyński
Synagogue Nowy Korczyn	Synagogue Nowy Korczyn	Not specified	Not specified	• Jana Arning • Lena Schniering • Carla Flohr
Synagogue Nowy Korczyn (1659)	Synagogue Nowy Korczyn	1659	Not specified	• Luca Brunke • Jan Lutteroth
Porto City Hall (1819-1916) reconstructed by Afonso Silva, Camila Esturilho, Cristina Tasso, Gabriela Biscotto	Porto City Hall	1819-1916	• Afonso Silva • Camila Esturilho • Cristina Tasso • Gabriela Biscotto	Not specified
House hut in Santa Tecla Castro (100 BC-100 AD) reconstructed by Joan Ibáñez	House hut in Santa Tecla Castro	100 BC-100 AD	• Joan Ibáñez	Not specified
Synagogue of Ashmiany (1929) reconstructed by Tara Jalili, Maximilian Braun	Synagogue of Ashmiany	1929	• Tara Jalili • Maximilian Braun	• Jan Lutteroth
St. Johannis Church in Mainz (800 AD) reconstructed by Igor Bajena, Marta Zielińska, Patrycja Stelmach, Aliyah Mahmood	St. Johannis Church in Mainz	800 AD	• Igor Bajena • Marta Zielińska • Patrycja Stelmach • Aliyah Mahmood	• Julia Merz • Guido Faccani • Piotr Kuroczyński
Speyer Synagoge (1250 AD) reconstructed by Irene Cazzaro	Speyer Synagoge	1250 AD	• Irene Cazzaro	• Igor Bajena
Synagogue in Mogielnica (1936-1939) reconstructed by Adam Miziołek, Julia Wiśniewska	Synagogue in Mogielnica	1936-1939	• Adam Miziołek • Julia Wiśniewska	• Igor Bajena • Piotr Kuroczyński

Fig. 105 Navigation view between reconstructions in the form of a table with selected metadata and column filters.

The second change involved replacing the traditional 3D model navigation with a reconstruction overview. We introduced tables displaying selected metadata instead of the previous grid view for model previews. These tables allow users to filter by each column, enabling more efficient searches and making it easier to compare models based on specific criteria (see Fig. 105). The most significant update, however, was the restructuring of the entries themselves. We reorganised the metadata into thematic tables, creating clearer, more coherent records

that improve readability and enhance the overall visual presentation (see Fig. 106 & Fig. 107). This new approach not only enhances usability but also allows for a more intuitive exploration of the repository, making the process of finding and understanding reconstructions much smoother for both experienced users and newcomers.

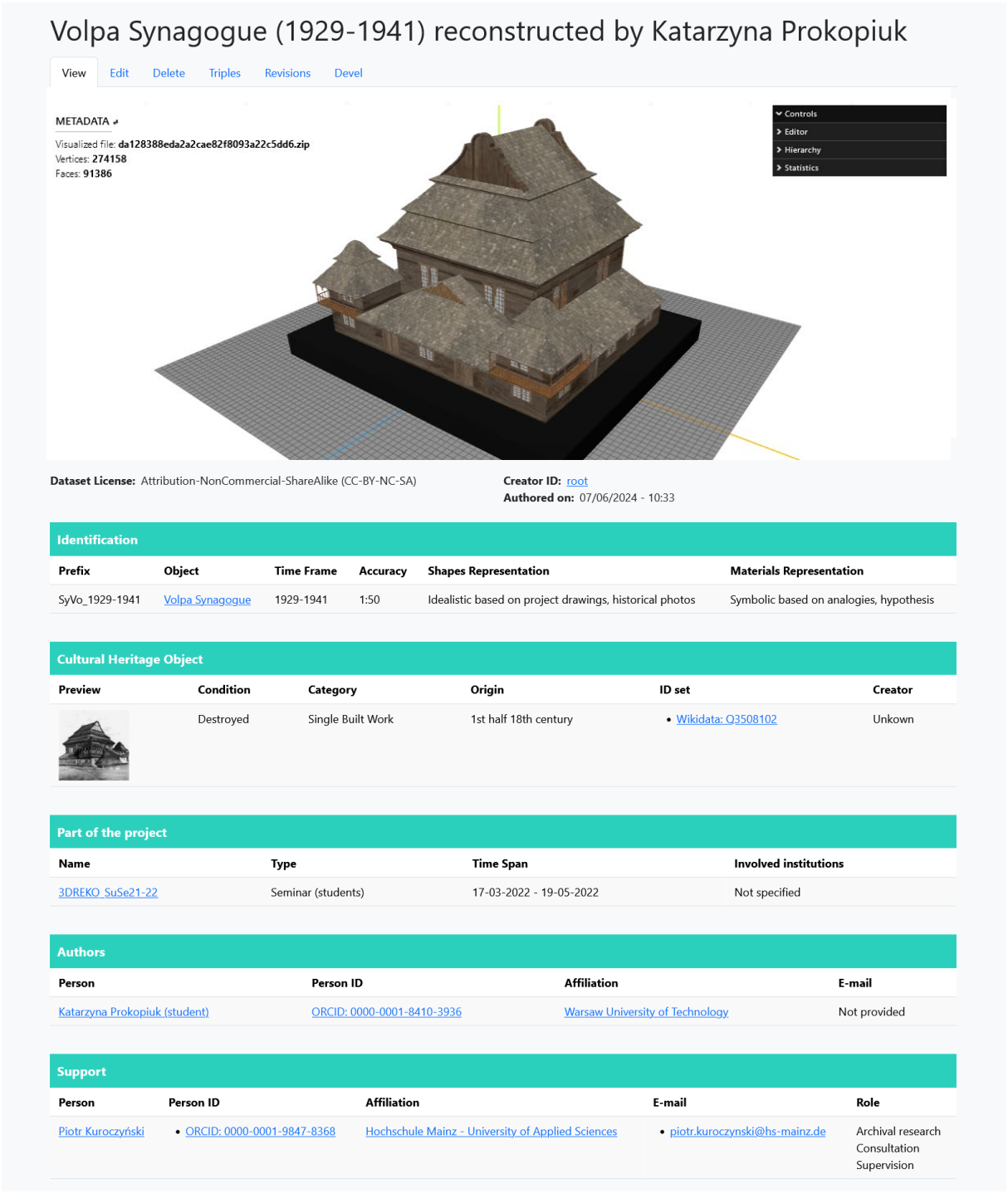
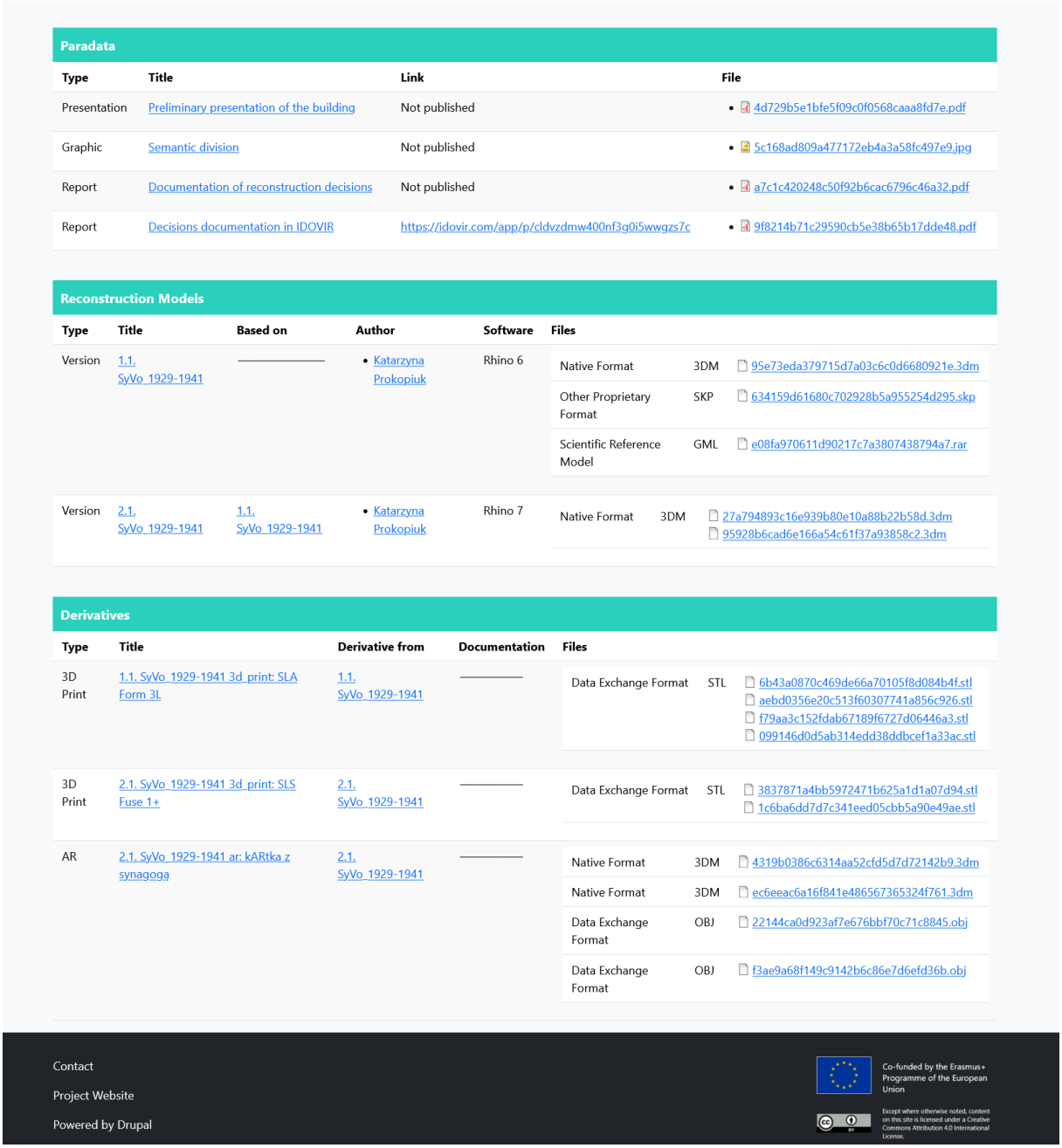


Fig. 106 Example of a record regarding digital restoration in the CoVHer repository (part 1).

The ORCID API was implemented to allow users to register with the system through an external authentication process, eliminating the need to verify each new user manually. By using ORCID, the system can rely on a trusted, academic-based identity management service, simplifying the registration process while ensuring the authenticity of users. This approach reduces administrative workload and enhances security by integrating a

widely accepted academic standard for user identification. Moreover, it improves the user experience by streamlining the sign-up process, allowing researchers to quickly connect their existing ORCID profiles to the system, and ensuring their contributions are tied to a recognised, verifiable identity. This method of external authentication promotes easier access to the platform, encourages wider adoption, and ensures that users' professional profiles remain accurate and up to date.



Paradata

Type	Title	Link	File
Presentation	Preliminary presentation of the building	Not published	• 4d729b5e1bfe5f09c0f0568caaa8fd7e.pdf
Graphic	Semantic division	Not published	• 5c168ad809a477172eb4a3a58fc497e9.jpg
Report	Documentation of reconstruction decisions	Not published	• a7c1c420248c50f92b6cac6796c46a32.pdf
Report	Decisions documentation in IDOVIR	https://idovir.com/app/p/cldvzdmw400nf3g0i5wwgzs7c	• 9f8214b71c29590cb5e38b65b17dde48.pdf

Reconstruction Models

Type	Title	Based on	Author	Software	Files
Version	1.1. SyVo 1929-1941	————	• Katarzyna Prokopiuk	Rhino 6	Native Format 3DM 95e73eda379715d7a03c6c0d6680921e.3dm Other Proprietary Format SKP 634159d61680c702928b5a955254d295.skp Scientific Reference Model GML e08fa970611d90217c7a3807438794a7.rar
Version	2.1. SyVo 1929-1941	1.1. SyVo 1929-1941	• Katarzyna Prokopiuk	Rhino 7	Native Format 3DM 27a794893c16e939b80e10a88b22b58d.3dm 95928b6cad6e166a54c61f37a93858c2.3dm

Derivatives

Type	Title	Derivative from	Documentation	Files
3D Print	1.1. SyVo 1929-1941 3d_print: SLA Form 3L	1.1. SyVo 1929-1941	————	Data Exchange Format STL 6b43a0870c469de66a70105f8d084b4f.stl aebd0356e20c513f60307741a856c926.stl f79aa3c152fdab67189f6727d06446a3.stl 099146d0d5ab314edd38ddbcef1a33ac.stl
3D Print	2.1. SyVo 1929-1941 3d_print: SLS Fuse 1+	2.1. SyVo 1929-1941	————	Data Exchange Format STL 3837871a4bb5972471b625a1d1a07d94.stl 1c6ba6dd7d7c341eed05cbb5a90e49ae.stl
AR	2.1. SyVo 1929-1941 ar: kARtka z synagogą	2.1. SyVo 1929-1941	————	Native Format 3DM 4319b0386c6314aa52cfd5d7d72142b9.3dm Native Format 3DM ec6eeac6a16f841e486567365324f761.3dm Data Exchange Format OBJ 22144ca0d923af7e676bbf70c71c8845.obj Data Exchange Format OBJ f3ae9a68f149c9142b6c86e7d6efd36b.obj

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Fig. 107 Example of a record regarding digital restoration in the CoVHer repository (part 2).

C.3. Users feedback

The repository was tested during the CoVHer project workshop held in Porto in September 2024, where 24 reconstitution projects were successfully documented using the platform. Following the workshop, a survey was conducted to gather feedback from the students to assess their overall experience with the new platform (see Appendix 13). The survey sought to understand how intuitive and effective the repository was in documenting the projects and identify any difficulties or areas for improvement. The students' feedback highlighted key insights, which will inform further refinements to ensure the platform meets user needs more effectively in future iterations. This feedback is essential as it provides real-world testing of the repository's usability and helps in aligning the platform with the practical demands of the academic and research community.

Overall, most users found the 3D repository to be intuitive, with nearly half giving it a high score of 4/5, though there is still room for improvement as no respondents gave it a perfect score and a significant portion (15.4%) felt the platform could be more intuitive. The metadata forms posed some difficulty for a considerable number of users, with 61.6% rating the difficulty level at 4 or 5, suggesting that the forms could benefit from simplification or more user guidance. While the majority found the field names and descriptions relatively straightforward, a notable percentage may have encountered some ambiguity or confusion, as indicated by the lower scores. Time taken to complete the forms varied widely, with many needing under an hour, though a few participants required more than 2 hours, signalling that complexity or lack of clarity might have delayed some users, highlighting a need for optimization. Most users are satisfied with the amount of information required, indicating that the forms strike a balance between comprehensive documentation and not overwhelming the user, though a small group still feels the forms are too lengthy. Feedback suggests a mix of technical challenges, such as slow servers and system errors, alongside content-related difficulties, like trouble with source documentation, suggesting that improving these areas could lead to a more streamlined user experience. Dividing the large form into smaller sections was a successful modification, with nearly all users finding this change beneficial. 40% of users published multiple versions, phases, or variants of their models, though only 20% published several elements as separate components, indicating that while many are using the platform's capacity to manage multiple versions, breaking models into individual components is less frequently used, possibly due to the extra detail or knowledge required. The 'Prefix' system for naming conventions was found valid and practical by 53.8%, but 30.8% found it challenging to understand and use, highlighting a need for better explanations or training. Instructions for the metadata forms were generally effective, though improvements could be made for file preparation instructions, as 38.5% of respondents spent over an hour preparing models for upload, with 23.1% spending between 20 and 45 minutes, suggesting that simplifying the model preparation process could enhance user experience. Importantly, 76.9% of respondents indicated they would continue using the repository for future data publication, showing overall satisfaction despite some areas for improvement. In conclusion, the survey results suggest that the 3D Repository is well-received, but simplifying metadata forms, streamlining model preparation, and addressing technical issues such as server speed and naming conventions could make it more efficient and user-friendly.

V. Conclusion

Digital 3D reconstructions vary widely in their scope and methodology, yet to ensure their scientific value, certain fundamental criteria must be met. These include segmenting objects, linking each part to relevant sources, and assessing the uncertainty of reconstructions. Transparency in these processes is essential, as it allows for critical evaluation, validation, and further development of models. However, documentation must extend beyond the interpretation of sources to include the technical aspects of the modelling process, such as the tools and software used. Given the inherent risks of data loss in digital environments, meticulous technical records play a crucial role in ensuring the long-term preservation of reconstructions.

The CoVHer repository, developed as part of this research, has laid the foundation for such structured documentation. It adheres to the Scientific Reference Model methodology, ensuring that 3D models are published in standard formats, facilitating both reference and reuse. By integrating bibliographic documentation that meets the requirements of the London Charter, the repository also addresses key copyright concerns related to historical materials. The detailed recording of paradata and derivatives further strengthens the ability to verify and explore both the technical and conceptual aspects of reconstructions. In doing so, the system fosters interdisciplinary collaboration and pushes the boundaries of what can be achieved with 3D reconstructions. Despite these contributions, several limitations remain. The repository does not yet include formalized metrics for evaluating uncertainty within reconstructions, a critical aspect of assessing their reliability. The OntPreHer3D ontology, introduced in this dissertation, establishes a framework for integrating such metrics in the future. However, implementing uncertainty evaluation at scale remains a challenge, particularly given user reluctance to engage with extensive documentation processes. A potential solution involves automating data extraction, reducing the burden on users by leveraging application programming interfaces (APIs) to retrieve metadata from external repositories. This would streamline the documentation workflow, but such integration remains technically complex and requires further research.

Another significant limitation pertains to technological constraints. The repository, as a university-driven initiative, lacks the infrastructure to continuously update web server specifications, web viewers, or memory storage capacities in line with advancing technology. Large-scale archives often handle these issues, but for smaller academic projects, maintaining state-of-the-art technological capabilities is challenging. Future collaborations with larger preservation institutions or research consortia could help mitigate these limitations. A key strength of this research lies in its interdisciplinary nature, situated at the intersection of architecture, art history, archaeology, digital humanities, computer graphics, web design, user experience, data science, and computer science. While no fundamentally new modelling techniques were introduced, the novelty of this work stems from its ability to synthesize knowledge across multiple fields and apply it to a unified framework for documenting 3D reconstructions. However, as I am not an IT specialist, this work inherently has technical constraints, particularly in resolving complex computational challenges related to web-based repositories and data interoperability.

One of the most pressing issues encountered during this research was user experience. Students participating in my courses frequently expressed concerns that the platform was too complex and required more intuitive data retrieval options. While the vision of seamless data integration via APIs remains promising, discussions with specialists revealed that API calls to multiple repositories remain inefficient and technically demanding. The development of a more user-friendly interface, with enhanced search functionalities and intuitive workflows, is

a major goal for future iterations of the repository. However, designing such an interface requires dedicated expertise, funding, and time—resources that were beyond the scope of this dissertation. The impact of interface limitations on the perception and usability of the repository is a crucial lesson learned, highlighting the need for further investment in UX design for digital reconstruction platforms.

A particularly revealing insight from this research is the recognition that many key decisions in the reconstruction process occur during the 3D modelling phase. The ability to automatically capture and document these decisions within the software itself would significantly improve the quality and efficiency of reconstruction records. Some existing plug-ins allow for in-model documentation, but the next major step would be to connect these tools directly to a centralized repository. Such an approach would enable automated data transfer from modelling software to a structured documentation system, reducing the effort required for manual input while ensuring that interpretative choices are preserved in real time.

If these records were standardized using an ontological framework such as OntPreHer3D, they could be seamlessly integrated across different file formats and platforms. This would create a comprehensive ecosystem where metadata, sources, paradata, and interpretative decisions are all stored alongside the 3D model. This vision represents an ideal "documentation jackpot": a system that is automatic, minimally intrusive for users, and ontology-driven, allowing data retrieval from controlled vocabularies and authoritative thesauri. Achieving this level of automation would revolutionize how hypothetical reconstructions are preserved, shared, and assessed.Beyond the documentation pipeline, publishing and preserving 3D reconstructions remains an evolving challenge. Two key factors must be considered when making 3D models available for academic use:

1. Usability and interoperability – Models should be available in structured formats that facilitate easy reuse. For models serving as components of larger scenes, glTF is a practical choice due to its compatibility with web browsers. However, when the primary goal is to store and share data-rich models, formats such as IFC or CityGML are preferable, as they support detailed metadata attribution.

2. Credibility and scholarly validation – Ensuring the academic reliability of 3D models requires a peer review process like that used in traditional research publications. Platforms such as PURE3D, which provide a framework for peer-reviewed 3D scholarly editions, represent a promising model. Integrating such validation processes into digital reconstruction workflows would enhance both the credibility and citation potential of 3D models in academia.

While the field of 3D reconstruction infrastructure is still in development, the momentum behind it continues to grow. The challenges outlined in this dissertation—from uncertainty quantification and technological constraints to usability improvements and automated documentation—are areas that require further investigation. However, the potential impact of structured digital reconstructions across cultural heritage, architecture, and interdisciplinary research is undeniable.

By addressing these challenges, future research can move towards standardizing documentation, enhancing automation, and improving usability in digital reconstruction workflows. If developments in ontology-driven documentation, automated metadata extraction, and peer-reviewed 3D publishing continue, digital reconstructions have the potential to become a cornerstone of research in multiple disciplines, offering unprecedented insights into historical, archaeological, and architectural studies. I hope that my contributions in this dissertation serve as a stepping stone toward a more structured, accessible, and academically rigorous future for 3D digital reconstructions.

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Appendix 1: Publications classification

Below is a list of the 457 publications collected in the Zotero library, along with the classifications in relation to the journal or publishing discipline, the professions of the authors, and the countries of the institutes affiliated with the authors.

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
1	1988	Colley, S. M.; Todd, S. J. P.; Campling, N. R.	Three-dimensional computer graphics for archaeological data exploration: An example from Saxon Southampton	Journal of Archaeological Science	Archaeology	Archaeologist; Computer Engineer; Computer Scientist	UK; UK; UK
2	1989	Reilly, P.	Data visualization in archaeology	IBM Systems Journal	Archaeology	Archaeologist	UK
3	1989	Burridge, J. M.; Collins, B. M.; Galton, B. N.; Halbert, A. R.; Heywood, T. R.; Latham, W. H.; Phippen, R. W.; Quarendon, P.; Reilly, P.; Ricketts, M. W.; Simmons, J.; Todd, S. J. P.; Walter, A. G. N.; Woodwark, J. R.	The WINSOM solid modeller and its application to data visualization	IBM Systems Journal	Computing and Processing	Computer Graphic; Computer Scientist; Computer Scientist; Computer Scientist; Computer Scientist; Computer Graphic; Chemist; Software Engineer; Archaeologist; Mathematician; Physicist; Computer Engineer; Computer Engineer; Engineer	UK; UK; UK; UK; UK; UK; UK; UK; UK; UK; UK; UK
4	1989	Reilly, P.; Shennan, S.	Applying Solid Modelling and Animated Three-Dimensional Graphics	Computer applications and quantitative methods in archaeology (CAA)	Archaeology	Archaeologist; Archaeologist	UK; UK
5	1990	Reilly, P.	Towards a virtual archaeology	Computer applications and quantitative methods in archaeology (CAA)	Archaeology	Archaeologist	UK
6	1991	Alkhoven, P.	The Reconstruction of the Past: the Application of NewTechniques for Visualisation and Research in Architectural History	Computer-Aided Architectural Design (CAAD)	Architecture	Art Historian	NL

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
7	1991	Woodwark, J.	Reconstructing history with computer graphics	IEEE Computer Graphics and Applications	Computer Graphic	Engineer	UK
8	1992	Ozawa, K.	Reconstruction of Japanese Ancient Tombs and Villages	Computer Applications and Quantitative Methods in Archaeology (CAA)	Archaeology	Civil Engineer	JP
9	1995	Miller, P.; Richards, J.	The good, the bad, and the downright misleading: archaeological adoption of computer visualization	Computer Applications and Quantitative Methods in Archaeology 1994	Archaeology	Archaeologist; Archaeologist	UK; UK
10	1995	Kotsakis, K.; Andreou, S.; Vargas, A.; Papoudas, D.	Reconstructing a Bronze Age Site with CAD	Computer Applications and Quantitative Methods in Archaeology 1994	Archaeology	Archaeologist; Archaeologist; Archaeologist; Archaeologist	GR; UK; UK; GR
11	1995	Kemp, D.	Personal Computer-Based Three-Dimensional Reconstruction Modelling of Standing Buildings	Computer Applications and Quantitative Methods in Archaeology	Archaeology	Architect	UK
12	1996	Kalvin, A.; Remy, A.; Ardito, O.; Morla, K.; Nolasco, E.; Prado, J.; Franco, R.; Murga, A.; Wiese, G.	Using visualization in the archaeological excavations of a pre-Inca temple in Peru	Proceedings of Seventh Annual IEEE Visualization '96	Visualization	Computer Scientist; Engineer; Engineer; Information Scientist; Engineer; Engineer; Archaeologist; Archaeologist; Art Historian	US; PE; PE; PE; PE; PE; PE; PE
13	1998	Kim, T.; Muller, J.	A Technique for 3D Building Reconstruction	Photogrammetric Engineering & Remote Sensing	Remote Sensing	Geoinformatic Engineer Engineer; Geoinformatic Engineer	KP; UK
14	1998	Richards, J. D.	Recent trends in computer applications in archaeology	Journal of Archaeological Research	Archaeology	Archaeologist	UK
15	1999	Strothotte, T., Masuch, M., Isenberg, T.	Visualizing knowledge about virtual reconstructions of ancient architecture	Proceedings Computer Graphics International CGI-99	Computer Graphic	Computer Scientist; Computer Scientist; Computer Graphic	DE; DE; DE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
16	2000	Barcelo, J.	Visualizing What Might Be. An Introduction to Virtual Reality in Archaeology	Virtual Reality in Archaeology	Virtual Reality	Archaeologist	ES
17	2000	Frischer, B.; Niccolucci, F.; Ryan, N. S.; Barceló, J.	From CVR to CVRO: The Past, Present, and Future of Cultural Virtual Reality	Virtual Archaeology between Scientific Research and Territorial Marketing, proceedings of the VAST EuroConference, Arezzo, Italy	Virtual Archaeology	Virtual Archaeologist; Architect; Computer Scientist; Archaeologist	US; IT; UK; ES
18	2000	Forte, M.	ABOUT VIRTUAL ARCHAEOLOGY: DISORDERS, COGNITIVE INTERACTIONS AND VIRTUALITY	Virtual reality in archaeology	Virtual Reality	Virtual Archaeologist	IT
19	2000	Alonso Martínez, N.	Virtual reality as an extension of the archaeological record. Reconstruction of an Iron Age fortress: Els Vilars (Arbeca, Catalonia, Spain)	Virtual Reality in Archaeology.	Virtual Reality	Archaeologist	ES
20	2000	Kantner, J.	Realism vs. reality: Creating virtual reconstructions of prehistoric architecture	Virtual reality in archaeology	Virtual Reality	Anthropologist	US
21	2000	Forte, M.; Borra, D.	THE ESTENSE CASTLE OF FERRARA {ITALY): MULTIMEDIA PROJECT AND VIRTUAL RECONSTRUCTION	Virtual reality in archaeology	Virtual Reality	Virtual Archaeologist; Archaeologist	IT; IT
22	2000	Lucet, G.	VISUALISATION OF VIRTUAL ENVIRONMENTS OF ANCIENT ARCHITECTURE: THE PROBLEM OF ILLUMINATION	Virtual Reality in archaeology.	Archaeology	Architect	MX
23	2000	Martens, F.; Legrand, J.; Legrand, P.; Loots, L.; Waelkens, M.	Computer-aided design and archaeology at Sagalassos: methodology and possibilities of CAD reconstructions of archaeological sites	Virtual Reality in Archaeology	Virtual Reality	Archaeologist; Engineer; Engineer; Geoscientist; Archaeologist	BE; BE; BE; DE; BE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
24	2000	Louhivuori, M.; Soederlund, A.	VIRTUAL MODEL OF THE BASILICA OF EMMAUS-NICOPOLIS	Virtual reality in archaeology	Virtual Reality	Humanist; Designer	IL; FI
25	2000	Feihl, O.	THE USE OF DIGITAL PHOTOGRAMMETRY AND GEOMETRIC MODELLING IN MEDIEVAL ARCHAEOLOGY	Virtual reality in archaeology	Virtual Reality	Archaeologist	CH
26	2001	Snyder, A. B.; Paley, S. M.	Experiencing an Ancient Assyrian Palace: Methods for a Reconstruction	ACADIA 2001: Reinventing the Discourse	Architecture	Architect; Archaeologist	US; US
27	2001	Barceló, J. A.	VIRTUAL REALITY AND SCIENTIFIC VISUALIZATION: WORKING WITH MODELS AND HYPOTHESES	International Journal of Modern Physics	Physics	Archaeologist	ES
28	2001	Ryan, N.	Documenting and validating Virtual Archaeology	Archeologia e Calcolatori	Virtual Archaeology	Computer Scientist	UK
29	2001	Freudenberg, B.; Masuch, M.; Röber, N.; Strothotte, T.	The Computer-Visualistik-Raum: veritable and inexpensive presentation of a virtual reconstruction	Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage	Archaeology	Software Engineer; Computer Graphic; Computer Graphic; Computer Scientist	DE; DE; DE; DE
30	2001	Pollefeys, M.; Van Gool, L.; Akkermans, I.; De Becker, D.; Demuynck, K.	A guided tour to virtual Sagalassos	Proceedings of the 2001 conference on Virtual reality, archeology, and cultural heritage	Archaeology	Computer Scientist; Computer Engineer; Computer Scientist; Software Engineer; Computer Scientist	BE; BE; BE; BE; BE
31	2002	Jablonka, P.; Kirchner, S.; Serangeli, J.	TroiaVR: A virtual reality model of troy and the troad	CAA2002	Archaeology	Archaeologist; Computer Scientist; Archaeologist	DE; DE; DE
32	2002	El-Hakim, S.	Semi-automatic 3D Reconstruction of Occluded and Unmarked Surfaces from Widely Separated Views	International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Information Technology	Engineer	CA

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
33	2002	Hanke, K.; Oberschneider, M.	THE MEDIEVAL FORTRESS KUFSTEIN, AUSTRIA - AN EXAMPLE FOR THE RESTITUTION AND VISUALIZATION OF CULTURAL HERITAGE	Proc. ISPRS Commission V Symposium	Remote Sensing	Geoinformatic Engineer; Designer	AT; AT
34	2002	Martens, B.; Peter, H.	Developing Systematics Regarding Virtual Reconstruction of Synagogues	ACADIA 2002: Thresholds Between Physical and Virtual	Architecture	Architect; Architect	AT; AT
35	2002	Martens, B.; Herbert, P.	Virtual Reconstruction of Synagogues Systematic Maintenance of Modeling Data	eCAADe 2002: Connecting the Real and the Virtual	Computer-Aided Design	Architect; Architect	AT; AT
36	2003	Roussou, M.; Drettakis, G.	Photorealism and Non-Photorealism in Virtual Heritage Representation	VAST 2003: The 4th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage	Cultural Heritage	Computer Scientist; Computer Graphic	UK; FR
37	2003	Jones, M.	SOUTHAMPTON IN 1454: A THREE-DIMENSIONAL MODEL OF THE MEDIEVAL TOWN	3D Visualisation in the Arts Network (3DVISA)	Visualisation	Virtual Archaeologist	UK
38	2003	Bakker, G.; Meulenberg, F.; Rode, J. D.	Truth and credibility as a double ambition: reconstruction of the built past, experiences and dilemmas	The Journal of Visualization and Computer Animation	Visualization	Art Historian; Humanist; Artist	NL; NL; NL
39	2004	Czyżewski, Ł.	The Virtual Trip Through The Medieval Toruń. Possibilities of using the open source and shareware software in multimedia projects and archaeological interactive, virtual reconstructions of medieval architecture	Computer Applications and Quantitative Methods in Archaeology (CAA)	Archaeology	Archaeologist	PL
40	2004	Grün, A.; Remondino, F.; Zhang, L.	Photogrammetric Reconstruction of the Great Buddha of Bamiyan, Afghanistan	The Photogrammetric Record	Engineering	Geodesist; Computer Scientist; Physicist	CH; IT; CN
41	2004	Vatanen, I.	Argumentation Paths in Information Infrastructure of the Archaeological Virtual Realities	CAA2004	Archaeology		

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
42	2004	Suveg, I.; Vosselman, G.	Reconstruction of 3D building models from aerial images and maps	ISPRS Journal of Photogrammetry and Remote Sensing	Engineering	Computer Scientist; Geoinformatic Engineer	NL; NL
43	2004	Kensek, K. M.; Dodd, L. S.; Cipolla, N.	Fantastic reconstructions or reconstructions of the fantastic? Tracking and presenting ambiguity, alternatives, and documentation in virtual worlds	Automation in Construction	Engineering	Architect; Archaeologist; Art Historian	US; US; US
44	2004	Niccolucci, F.; Hermon, S.	A Fuzzy Logic Approach to Reliability in Archaeological Virtual Reconstruction	Computer Applications and Quantitative Methods in Archaeology (CAA)	Archaeology	Architect; Archaeologist	IT; CY
45	2004	Barelkowski, R.	The Optimization of Assumptions of the Reconstruction of Monumental Objects of Romanesque and Gothic Architecture - Computer Aided Archeological and Architectural Research	eCAADe 2004: Architecture in the Network Society	Architecture	Architect	PL
46	2004	Dudek, I.; Blaise, J.	GRAPHIC VARIABLES FOR DYNAMIC 2D/3D DOCUMENTATION VISUALISATION IN THE CONTEXT OF HISTORICAL ARCHITECTURE	ICHIM 04' (International Cultural Heritage Informatics Meeting), Digital Culture & Heritage	Cultural Heritage	Architect; Architect	FR; FR
47	2004	Scagliarini, D.	The Role of Scientific Reconstruction in Virtual Archaeology. Education, Communication and Valorization. The “Pompei - Insula del Centenario (IX 8) Project”	Computer Applications and Quantitative Methods in Archaeology (CAA)	Archaeology	Archaeologist	IT
48	2004	Olsen, S.; Brickman, A.; Cai, Y.	Discovery by Reconstruction: Exploring Digital Archeology	SIGCHI Workshop Proceedings	Digital Humanities	Archaeologist; Art Historian; Computer Scientist	US; US; US

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
49	2005	Gutierrez, D.; Frischer, B.; Cerezo, E.; Gomez, I. A.; Sobreviela, E.	Virtual Crowds in a Digital Colosseum	Virtual Retrospect 2005	Visualization	Computer Graphic; Virtual Archaeologist; Computer Graphic; Computer Graphic; Computer Graphic	ES; US; ES; ES; ES
50	2005	Dudek, I.; Blaise, J.	From Artefact Representation to Information Visualisation: Genesis of Informative Modelling	Smart Graphics	Information Technology	Architect; Architect	FR; FR
51	2005	Pescarin, S.; Pescarin, S.; Forte, M.; Guidazzoli, A.	OpenHeritage: an integrated approach to web 3D	Proceedings of the ISPRS Working Group V/4 Workshop 3D-ARCH 2005: Virtual Reconstruction and Visualization of Complex Architectures	Visualization	Digital Humanist; Digital Humanist; Virtual Archaeologist; Art Historian	IT; IT; IT; IT
52	2005	Hermon, S.	Some Evaluations of the Potential Impact of Virtual Reality on the Archaeological Scientific Research	Virtual reality at Work in the 21st Century	Virtual Reality	Archaeologist	CY
53	2005	Zuk, T.; Carpendale, S.; Glanzman, W.	Visualizing Temporal Uncertainty in 3D Virtual Reconstructions.	VAST 2005: The 6th International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage	Cultural Heritage	Computer Scientist; Computer Scientist; Archaeologist	CA; CA; CA
54	2006	Beacham, R.; Denard, H.; Niccolucci, F.	An Introduction to the London Charter	The Evolution of Information Communication Technology in Cultural Heritage: Where Hi-tech Touches the Past: Risks and Challenges for the 21st Century	Cultural Heritage	Art Historian; Art Historian; Architect	UK; UK; IT
55	2006	Vandevyvere, H.; Neuckermans, H.; Jonge, K.	Digital historical reconstruction: Case studies of an interdisciplinary task	International Journal of Design Sciences and Technology	Engineering	Architect; Architect; Conservation Scientist	BE; BE; BE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
56	2006	Hermon, S.; Nikodem, J.; Perlingieri, C.	Deconstructing the VR - Data Transparency, Quantified Uncertainty and Reliability of 3D Models	International Symposium on Virtual Reality, Archaeology and Cultural Heritage VAST (2006)	Cultural Heritage	Archaeologist; Computer Scientist; Archaeologist	CY; PL; IT
57	2006	Barelkowski, R.; Chodor, J.	The Visualization – Visual Comparative Analysis of Early Romanesque Churches	eCAADe 2006: Communicating Space(s)	Architecture	Architect; Artist	PL; PL
58	2006	Koller, D.; Levoy, M.	Computer-aided Reconstruction and new Matches in The Forma Urbis Romae	Bullettino della commissione archeologica comunale di Roma : supplementi : 15, 2006	Computer Graphic	Computer Scientist; Computer Graphic	US; US
59	2006	Beraldin, J.; Picard, M.; El-Hakim, S.; Godin, G.; Borgeat, L.; Blais, F.; Paquet, E.; Rioux, M.; Valzano, V.; Bandiera, A.	Virtual Reconstruction of Heritage Sites: Opportunities and Challenges Created by 3D Technologies	Recording, Modeling and Visualization of Cultural Heritage	Digital Heritage	Information Scientist; Information Scientist; Engineer; Information Scientist; Information Scientist; Information Scientist; Information Scientist; Information Scientist; Information Scientist; Digital Humanist; Computer Graphic	CA; CA; CA; CA; CA; CA; CA; CA; IT; IT
60	2007	Hermon, S.; Nikodem, J.	3D Modelling as a Scientific Research Tool in Archaeology	3D Modelling and Visualisation	Archaeology	Archaeologist; Computer Scientist	CY; PL
61	2007	De Luca, L.; Véron, P.; Florenzano, M.	A generic formalism for the semantic modeling and representation of architectural elements	The Visual Computer	Visualization	Architect; Computer Scientist; Architect	FR; FR; FR
62	2007	Styliadis, A. D.	Digital documentation of historical buildings with 3-d modeling functionality	Automation in Construction	Engineering	Engineer	GR
63	2007	Ogleby, C.	THE "TRUTHLIKENESS" OF VIRTUAL REALITY RECONSTRUCTIONS OF ARCHITECTURAL HERITAGE: CONCEPTS AND METADATA.	3D-ARCH 2007 "Virtual Reconstruction and Visualization of Complex Architectures"	Digital 3D Reconstruction	Geoscientist	AU

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
64	2007	Kanaya, I.; Kawae, Y.; Sato, K.; Kamei, H.	Digital Modeling of Monument of Queen Khentkawes	3D-ARCH 2007 "Virtual Reconstruction and Visualization of Complex Architectures"	Digital 3D Reconstructio n	Engineer; Archaeologist; Engineer; Archaeologist	JP; JP; JP; JP
65	2007	Frischer, B.; Stinson, P.	The importance of scientific authentication and a formal visual language in virtual models of archaeological sites: the case of the House of Augustus and the Villa of the Mysteries	INTERPRETING THE PAST Heritage, New Technologies and Local Develoment Flemish Heritage Institute Provincial Archaeological Museum Ename Province of East-Flanders Ename Center for Public Archaeology and Heritage Presentation	Archaeology	Virtual Archaeologist; Digital Humanist	US; US
66	2007	Llobera, M.	Reconstructing visual landscapes	World Archaeology	Archaeology	Anthropologist	US
67	2007	Hermon, S.; Sugimoto, G.; Mara, H.	The London Charter and its Applicability	International Cultural Heritage Informatics Meeting 2007 (VAST)	Archaeology	Archaeologist; Artist; Computer Scientist	CY; IT; DE
68	2008	Park, H.	Parametric Variations of Palladio's Villa Rotonda	International Journal of Architectural Computing	Architecture	Architect	US
69	2008	Levy, R.; Dawson, P.	Structural analysis: a tool for testing 3D computer reconstructions of Thule whalebone houses	Conference on Computer Applications and Quantitative Methods in Archaeology (CAA)	Archaeology	Archaeologist; Archaeologist	CA; CA
70	2008	Langó, P.; Réti, Z.; Türk, A. A.	Reconstruction and 3D-Modelling of a Unique Hungarian Conquest Period (10th Century AD) Horse Burial	Computer Applications and Quantitative Methods in Archaeology (CAA)	Archaeology	Archaeologist; Archaeologist; Archaeologist	HU; HU; HU

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
71	2008	Fantini, F.; Pini, S.	Villa Adriana's Serapeum: Optimized 3D models for knowledge and distribution of archaeological sites	Computer Applications and Quantitative Methods in Archaeology (CAA)	Archaeology	Architect; Architect	IT; IT
72	2008	Beale, G.	Visualising Discourse: An Approach to Archaeological Uncertainty. Interpretation and Reconstruction of the Grandi Magazzini di Settimio Severo at Portus, Italy.	On the Road to Reconstructing the Past. Computer Applications and Quantitative Methods in Archaeology	Archaeology	Archaeologist	UK
73	2008	Agapiou,, A.; Doulamis, N.; Ioannides, M.; Ioannidis, C.	Three-Dimensional Reconstruction for Cultural Heritage Visualization: Application to the Byzantine Churches of Cyprus	Computer Applications and Quantitative Methods in Archaeology (CAA).	Archaeology	; Computer Engineer; Computer Scientist; Computer Scientist	; GR; CY; CY
74	2008	Wood, J.	Visualizations of Furness Abbey: From Romantic Ruin to Computer Model	English Heritage Historical Review	Art History	Archaeologist	UK
75	2008	Pauwels, P.; Verstraeten, R.; Meyer, R.; Campenhout, J.	Architectural Information Modelling for Virtual Heritage Application	International Conference on Virtual Systems and Multimedia (VSMM)	Visualization	Architect; Architect; ;	BE; BE; ;
76	2008	Manferdini, A. M.; Remondino, F.; Baldissini, S.; Gaiani, M.; Benedetti, B.	3D MODELING AND SEMANTIC CLASSIFICATION OF ARCHAEOLOGICAL FINDS FOR MANAGEMENT AND VISUALIZATION IN 3 D ARCHAEOLOGICAL DATABASES	Proceedings of VSMM	Computer Graphic	Architect; Computer Scientist; Architect; Architect; Physicist	IT; IT; IT; IT; IT
77	2008	Francesco, G. D.; D'Andrea, A.	Standards and Guidelines for Quality Digital Cultural Three-Dimensional Content Creation	Digital Heritage. p. 229-233, , ISBN/ISSN: 978-963-9911-00-0	Digital Heritage	Art Historian; Archaeologist	IT; IT
78	2008	Hermon, S.	Reasoning in 3D: a Critical appraisal of the role of 3D modeling and Virtual Reconstructions in archaeology	Beyond Illustration: 2D and 3D Technologies as Tools for Discovery in Archaeology	Visualization	Archaeologist	CY

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
79	2008	Chevrier, C.; Perrin, J.	INTERACTIVE PARAMETRIC MODELLING. POG a tool the cultural heritage monument 3D reconstruction	CAADRIA 2008	Computer-Aided Design	Computer Graphic; Architect	FR; FR
80	2009	Anderson, E.; McLoughlin, L.; Liarokapis, F.; Peters, C.; Petridis, P.; Freitas, S.	Serious Games in Cultural Heritage	VAST 2009: 10th International Symposium on Virtual Reality, Archaeology and Cultural Heritage	Cultural Heritage	Computer Graphic; Computer Graphic; Computer Engineer; Computer Scientist; Computer Scientist; Games Developer	UK; UK; UK; UK; UK; UK
81	2009	Boeykens, S.; Neuckermans, H.	Architectural design analysis, historical reconstruction and structured archival using 3D Models	Joining Languages, Cultures and Visions, CAADFutures 2009	Architecture	Architect; Architect	BE; BE
82	2009	PATAY-HORVÁTH, A.	Virtual 3D Reconstruction of the East Pediment of the Temple of Zeus at Olympia | CHNT Archiv	CHNT14	Cultural Heritage	Humanist	HU
83	2009		London Charter		Visualisation		
84	2009	Boeykens, S.; Quintero, M. S.; Neuckermans, H.	IMPROVING ARCHITECTURAL DESIGN ANALYSIS USING 3D MODELING AND VISUALIZATION TECHNIQUES	VSMM 2008 Digital Heritage – Proceedings of the 14th International Conference on Virtual Systems and Multimedia	Cultural Heritage	Architect; Architect; Architect	BE; BE; BE
85	2009	Murphy, M.; McGovern, E.; Pavia, S.	Historic building information modelling (HBIM)	Structural Survey	Architecture	Engineer; Geodesist; Engineer	IE; IE; IE
86	2009	Koller, D.; Frischer, B.; Humphreys, G.	Research challenges for digital archives of 3D cultural heritage models	Journal on Computing and Cultural Heritage	Digital Humanities	Computer Scientist; Virtual Archaeologist; Computer Scientist	US; US; US
87	2009	Horna, S.; Meneveaux, D.; Damiand, G.; Bertrand, Y.	Consistency constraints and 3D building reconstruction	Computer-Aided Design	Architecture	Computer Scientist; Information Scientist; Computer Graphic; Computer Scientist	FR; FR; FR; FR

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88	2009	Remondino, F.; El-Hakim, S.; Girardi, S.; Rizzi, A.; Benedetti, S.; Gonzo, L.	3D Virtual reconstruction and visualization of complex architectures. The 3D-ARCH project	International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Information Technology	Computer Scientist; Engineer; Architect; Computer Scientist; Computer Graphic; Engineer	IT; CA; IT; IT; IT; IT
89	2009	Fleury, P.; Madeleine, S.	An interactive Visit of the city of Rome in the fourth century A.D.	37th annual international conference on Computer Applications and Quantitative Methods in Archaeology (CAA) : Making History Interactive	Archaeology	Humanist; Virtual Archaeologist	FR; FR
90	2010	Chevrier, C.; Charbonneau, N.; Grussenmeyer, P.; Perrin, J.	Parametric Documenting of Built Heritage: 3D Virtual Reconstruction of Architectural Details	International Journal of Architectural Computing	Architecture	Computer Graphic; Architect; Engineer; Architect	FR; FR; FR; FR
91	2010	Dylla, K.; Frischer, B.; Mueller, P.; Ulmer, A.; Haegler, S.	Rome Reborn 2.0: A Case Study of Virtual City Reconstruction Using Procedural Modeling Techniques	Computer Applications and Quantitative Methods in Archaeology	Archaeology	Computer Scientist; Virtual Archaeologist; Computer Graphic; Software Engineer; Software Engineer	US; US; CH; CH; CH
92	2010	Apollonio, F. I.; Corsi, C.; Gaiani, M.; Baldissini, S.	An Integrated 3D Geodatabase for Palladio's Work	International Journal of Architectural Computing	Architecture	Architect; Architect; Architect; Architect	IT; IT; IT; IT
93	2011	Guidi, G.; Russo, M.	Reality-Based and Reconstructive models: Digital Media for Cultural Heritage Valorization	SCIRES-IT - SCIentific RESearch and Information Technology	Information Technology	Engineer; Architect	IT; IT
94	2011	Dawson, P.; Levy, R.; Lyons, N.	'Breaking the fourth wall': 3D virtual worlds as tools for knowledge repatriation in archaeology	Journal of Social Archaeology	Archaeology	Archaeologist; Archaeologist; Archaeologist	CA; CA; CA
95	2011	Rua, H.; Alvito, P.	Living the past: 3D models, virtual reality and game engines as tools for supporting archaeology and the reconstruction of cultural heritage – the case-study of the Roman villa of Casal de Freiria	Journal of Archaeological Science	Archaeology	Engineer; Architect	PT; PT

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96	2011	Cothren, J.; Fredrick, D.; Limp, W. F.; De Noble, T.; Barnes, A.; Goodmaster, C.; Stevens, C.	Visualizing the Roman City: Viewing the Past Through Multidisciplinary Eyes	Computer Applications and Quantitative Methods in Archaeology (CAA)	Archaeology	Geoscientist; Humanist; Geoscientist; Architect; Geoinformatic Engineer; Anthropologist; Architect	US; US; US; US; US; US; US
97	2011	Lopez-Menchero, V. M.; Grande, A.	THE PRINCIPLES OF THE SEVILLE CHARTER	CIPA Heritage	Cultural Heritage	Virtual Archaeologist; Virtual Archaeologist	ES; ES
98	2011	Martens, B.; Peter, H.	Potemkin Village, reloaded - Visualisation of Destroyed Synagogues within the Cityscape of Vienna	Proceedings of the 9th EAEA Conference 2009,	Architecture	Architect; Architect	AT; AT
99	2011	Kersten, T. P.; Heiden, R.	Virtual 3D Model of the Antique Temple Construction in Sirwah (Republic of Yemen) for Archaeological Object Documentation by Terrestrial Laser Scanning and Digital Photogrammetry	Computer Applications and Quantitative Methods in Archaeology (CAA)	Archaeology	Geodesist; Geoscientist	DE; DE
100	2011	Fleury, P.; Madeleine, S.	Reconstruction of Ancient Rome in Interactive Virtual Reality	DMACH 2011 : Digital Media and its Applications in Cultural Heritage	Cultural Heritage	Humanist; Virtual Archaeologist	FR; FR
101	2011	Georgiou, R.; Hermon, S.	A London Charter's Visualization: The Ancient Hellenistic-Roman Theatre in Paphos	VAST11	Virtual Reality	Computer Engineer; Archaeologist	CY; CY
102	2011	Pfarr-Harfst, M.	Documentation system for digital reconstructions Reference to the Mausoleum of the Tang-Dynastie at Zhaoling, in Shaanxi Province	CHNT16	Cultural Heritage	Architect	DE
103	2011	Beacham, R. C.	Concerning the Paradox of Paradata. Or, “I don’t want realism; I want magic!”	Virtual Archaeology Review	Virtual Archaeology	Art Historian	UK
104	2011	Hermon, S.; Kalisperis, L.	Between the Real and the Virtual: 3D visualization in the Cultural Heritage domain - expectations and prospects	Virtual Archaeology Review	Virtual Archaeology	Archaeologist; Computer Scientist	CY; CY

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105	2012	Patay-Horváth, A.	Reconstructions of the East Pediment of the Temple of Zeus at Olympia – A Comparison of Drawings, Plaster Casts and Digital Models	International Journal of Heritage in the Digital Era	Digital Heritage	Humanist	HU
106	2012	Boeykens, S.; Himpe, C.; Martens, B.	A Case Study of Using BIM in Historical Reconstruction - The Vinohrady Synagogue in Prague	Digital Physicality - Proceedings of the 30th eCAADe Conference	Architecture	Architect; Architect; Architect	BE; BE; AT
107	2012	Niccolucci, F.	Setting Standards for 3D Visualization of Cultural Heritage in Europe and Beyond	Paradata and Transparency in Virtual Heritage	Digital Heritage	Architect	IT
108	2012	El-Hakim, S.; Whiting, E.; Gonzo, L.; Girardi, S.	3-D RECONSTRUCTION OF COMPLEX ARCHITECTURES FROM MULTIPLE DATA	3D Virtual Reconstruction and Visualization of Complex Architectures (3D-Arch'2005)	Digital 3D Reconstruction	Engineer; Architect; Engineer; Architect	CA; US; IT; IT
109	2012	Kanaya, I.; Kawae, Y.; Sato, K.; Kamei, H.	Digitizing Egyptian Heritages	Virtual Archaeology 2012	Virtual Archaeology	Engineer; Archaeologist; Engineer; Archaeologist	JP; JP; JP; JP
110	2012	Guidi, G.; Frischer, B.; Lucenti, I.	Rome Reborn - Virtualizing the ancient imperial Rome	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Engineer; Virtual Archaeologist; Designer	IT; US; IT
111	2012	Denard, H.	A New Introduction to The London Charter	Paradata and Transparency in Virtual Heritage	Digital Heritage	Art Historian	UK
112	2012	Fleury, P.; Madeleine, S.	Reviving Ancient Rome: Virtual Reality at the Service of Cultural Heritage	Progress in cultural heritage preservation : 4th International Conference, EuroMed 2012	Cultural Heritage	Humanist; Virtual Archaeologist	FR; FR
113	2012	Jones, M.	Hypothesizing Southampton in 1454: A Three-dimensional Model of the Medieval Town1	Paradata and Transparency in Virtual Heritage	Digital Heritage	Virtual Archaeologist	UK

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114	2012	Havemann, S.	Intricacies and Potentials of Collecting Paradata in the 3D Modeling Workflow	Paradata and Transparency in Virtual Heritage	Digital Heritage	Computer Scientist	AT
115	2012	Hermon, S.	Scientific method, chaîne opératoire and visualization: 3D modelling as a research tool in archaeology	Paradata and Transparency in Virtual Heritage	Digital Heritage	Archaeologist	CY
116	2012	Lo Buglio, D.; De Luca, L.	Representation of architectural artifacts: definition of an approach combining the complexity of the 3d digital instance with the intelligibility of the theoretical model.	SCIRES-IT	Information Technology	Architect; Architect	FR; FR
117	2012	Forte, M.; Pescarin, S.	Behaviours, interactions and affordance in virtual archaeology	Paradata and Transparency in Virtual Heritage	Digital Heritage	Virtual Archaeologist; Digital Humanist	IT; IT
118	2013	Fassi, F.; Fregonese, L.; Ackermann, S.; De Troia, V.	COMPARISON BETWEEN LASER SCANNING AND AUTOMATED 3D MODELLING TECHNIQUES TO RECONSTRUCT COMPLEX AND EXTENSIVE CULTURAL HERITAGE AREAS	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Engineer; Architect; Geodesist; Engineer	IT; IT; IT; IT
119	2013	Butnariu, S.; Florin, G.; Petre, O.	Methodology for 3D reconstruction of objects for teaching virtual restoration	International Journal of Computer Science Research and Application	Computer Science	Engineer; ;	RO; ;
120	2013	Kontogianni, G.; Georgopoulos, A.; Saraga, N.; Alexandraki, E.; Tsogka, K.	3D VIRTUAL RECONSTRUCTION OF THE MIDDLE STOA IN THE ATHENS ANCIENT AGORA	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Engineer; Engineer; Engineer; Museologist; Archaeologist	GR; GR; GR; GR; GR

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121	2013	Münster, S.	WORKFLOWS AND THE ROLE OF IMAGES FOR VIRTUAL 3D RECONSTRUCTION OF NO LONGER EXTANT HISTORIC OBJECTS	ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Digital Humanist	DE
122	2013	Dell'Unto, N.; Leander, A. M.; Dellepiane, M.; Callieri, M.; Ferdani, D.; Lindgren, S.	Digital reconstruction and visualization in archaeology: Case-study drawn from the work of the Swedish Pompeii Project	2013 Digital Heritage International Congress (DigitalHeritage)	Digital Heritage	Archaeologist; Archaeologist; Computer Graphic; Computer Graphic; Archaeologist; Digital Humanist	SE; SE; IT; IT; IT; SE
123	2013	Bendicho, V. M. L.	International Guidelines for Virtual Archaeology: The Seville Principles	Good Practice in Archaeological Diagnostics	Archaeology	Archaeologist	ES
124	2013	Apollonio, F. I.; Gaiani, M.; Sun, Z.	3D MODELING AND DATA ENRICHMENT IN DIGITAL RECONSTRUCTION OF ARCHITECTURAL HERITAGE	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Architect; Architect; Architect	IT; IT; IT
125	2013	Boeykens, S.	Reflections on the Digital Reconstruction of the Portico and Garden Pavilion of the Rubens House	Architectura Moderna 11: The notion of the Painter-Architect in Italy and the Southern Low Countries	Architecture	Architect	BE
126	2013	Pfarr-Harfst, M.	Virtual Scientific Models	Electronic Visualisation and the Arts (EVA 2013)	Art History	Architect	DE
127	2013	Huvila, I.	The Unbearable Complexity of Documenting Intellectual Processes: Paradata and Virtual Cultural Heritage Visualisation	Human IT: Journal for Information Technology Studies as a Human Science	Digital Humanities	Computer Scientist	SE

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128	2013	Guidi, G.; Russo, M.; Angheleddu, D.	DIGITAL RECONSTRUCTION OF AN ARCHAEOLOGICAL SITE BASED ON THE INTEGRATION OF 3D DATA AND HISTORICAL SOURCES	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Engineer; Architect; Engineer	IT; IT; IT
129	2013	Micoli, L.; Guidi, G.; Angheleddu, D.; Russo, M.	A multidisciplinary approach to 3D survey and reconstruction of historical buildings	2013 Digital Heritage International Congress (DigitalHeritage)	Digital Heritage	Engineer; Engineer; Engineer; Architect	IT; IT; IT; IT
130	2013	Grellert, M.; Pfarr-Harfst, M.	25 years virtual reconstructions: Current challenges and the comeback of physical models	2013 Digital Heritage International Congress (DigitalHeritage)	Digital Heritage	Architect; Architect	DE; DE
131	2013	Earl, G.	Modeling in Archaeology: Computer Graphic and other Digital Pasts	Perspectives on Science	Information Technology	Archaeologist	UK
132	2014	Gomes, L.; Regina Pereira Bellon, O.; Silva, L.	3D reconstruction methods for digital preservation of cultural heritage: A survey	Pattern Recognition Letters	Computer Science	Engineer; Engineer; Computer Scientist	BR; BR; BR
133	2014	Hauck, O.; Kuroczynski, P.	Cultural Heritage Markup Language How to Record and Preserve 3D Assets of Digital Reconstruction	CHNT19	Cultural Heritage	Architect;	DE;
134	2014	Galiana, M.; Más, Á.; Lerma, C.; Jesús Peñalver, M.; Conesa, S.	Methodology of the Virtual Reconstruction of Arquitectonic Heritage: Ambassador Vich's Palace in Valencia	International Journal of Architectural Heritage	Architecture	Architect; Architect; Architect; ; Art Historian	ES; ES; ES; ; ES
135	2014	Münster, S.; Prechtel, N.	Beyond Software. Design Implications for Virtual Libraries and Platforms for Cultural Heritage from Practical Findings	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Digital Humanist; Cartographist	DE; DE
136	2014	Kuroczyński, P.	Digital Reconstruction and Virtual Research Environments – A question of documentation standards	Proceedings of the annual conference of CIDOC 2014 in Dresden, Germany.	Information Technology	Architect	DE

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137	2014	Patay-Horváth, A.	The virtual 3D reconstruction of the east pediment of the temple of Zeus at Olympia an old puzzle of classical archaeology in the light of recent technologies	Digital Applications in Archaeology and Cultural Heritage	Cultural Heritage	Humanist	HU
138	2014	Kowal, S.	The virtual reconstruction of a settlement. The protocity of Pułtusk, 13th–14th century	Kwartalnik Architektury i Urbanistyki; 2014; No 2	Architecture	Architect	PL
139	2014	Rodrigues, N.; Magalhães, L.; Moura, J.; Chalmers, A.	Reconstruction and generation of virtual heritage sites	Digital Applications in Archaeology and Cultural Heritage	Cultural Heritage	Computer Scientist; Computer Engineer; Computer Engineer; Computer Scientist	PT; PT; PT; UK
140	2014	Kuroczyński, P.; Dworak, D.; Hauck, O. B.	Digital Reconstruction of Cultural Heritage – Questions of documentation and visualisation standards for 3D content	5th EUROMED Conference	Cultural Heritage	Architect; Software Engineer; Architect	DE; PL; DE
141	2015	Chevrier, C.; Jacquot, K.; Humbert, P.; Ben, S.; Halin, G.	Virtual 3D reconstruction of Plans-Reliefs from historical document analysis for valorisation applications	Digital Heritage International Congress DH'15	Digital Heritage	Computer Graphic; Architect; Architect; Computer Graphic; Computer Scientist	FR; FR; FR; FR; FR
142	2015	Barazzetti, L.; Banfi, F.; Brumana, R.; Oreni, D.; Previtali, M.; Roncoroni, F.	HBIM and augmented information: towards a wider user community of image and range-based reconstructions	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Geoscientist; Architect; Architect; Architect; Civil Engineer; Archaeologist	IT; IT; IT; IT; IT; IT
143	2015	Lavrič, M.	3D Reconstruction of a Balneum in a Roman Villa Rustica, Mošnje, Slovenia	2nd International Congress on Digital Heritage 2015, Volume 2	Digital Heritage	Archaeologist	SI
144	2015	Denard, H.	Ecologies of research and performance: preservation challenges in the London Charter	Preserving Complex Digital Objects	Digital Heritage	Art Historian	UK

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145	2015	Kowal, S.; Koszewski, K.; Slyk, J.; Wrona, S.	Parametric Methods in Reconstruction of the Medieval Proto-Town in Pultusk, Poland	eCAADe 2015 : Real time - Extending the reach of computation	Computer-Aided Design	Architect; Architect; Architect; Architect	PL; PL; PL; PL
146	2015	Saldaña, M.	An Integrated Approach to the Procedural Modeling of Ancient Cities and Buildings	Digital Scholarship in the Humanities	Digital Humanities	Architect	US
147	2015	Apollonio, F. I.; Giovannini, E. C.	A paradata documentation methodology for the Uncertainty Visualization in digital reconstruction of CH artifacts	SCIRES-IT - SCIentific RESearch and Information Technology	Information Technology	Architect; Architect	IT; IT
148	2015	Münster, S.; Kuroczyński, P.; Pfarr-Harfst, M.; Grellert, M.; Lengyel, D.	Future Research Challenges for a Computer-Based Interpretative 3D Reconstruction of Cultural Heritage - A German Community's View	ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Digital Humanist; Architect; Architect; Architect; Architect	DE; DE; DE; DE; DE
149	2015	Verdiani, G.	Reading the project and “reverse design”:	CHNT20	Cultural Heritage	Architect	IT
150	2015	Fallavollita, F.; Ballabeni, M.; Foschi, R.; Perugini, G.	Semantic description of three-dimensional models of Bologna porches	SCIRES-IT	Information Technology	Architect; Architect; Architect; Architect	IT; IT; IT; IT
151	2015	Demetrescu, E.	Archaeological stratigraphy as a formal language for virtual reconstruction. Theory and practice	Journal of Archaeological Science	Archaeology	Archaeologist	IT
152	2015	Vincent, M.; Flores Gutiérrez, M.; Coughenour, C.; Manuel, V.; Bendicho, V. M.; Remondino, F.; Fritsch, D.	Crowd-sourcing the 3D Digital Reconstructions of Lost Cultural Heritage	2015 Digital Heritage	Cultural Heritage	Archaeologist; Art Historian; Engineer; ; Digital Humanist; Computer Scientist; Geodesist	ES; ES; DE; ; ES; IT; DE
153	2015	Gabellone, F.	The Contribution Of The 3D Study For New Reconstructive Proposals Of Lecce In Roman Age	1st International Conference on Metrology for Archaeology	Archaeology	Architect	IT

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154	2015	Quattrini, R.; Baleani, E.	Theoretical background and historical analysis for 3D reconstruction model. Villa Thiene at Cicogna	Journal of Cultural Heritage	Cultural Heritage	Architect; Architect	IT; IT
155	2015	Bruseker, G.; Guillem, A.; Carboni, N.	Semantically Documenting Virtual Reconstruction: Building a Path to Knowledge Provenance	ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Computer Scientist; Digital Humanist; Data Scientist	GR; FR; FR
156	2015	Bentkowska-Kafel, A.	Debating Digital Art History	DAH-Journal	Art History	Art Historian	UK
157	2015	Berggren, Å.; Dell'Unto, N.; Forte, M.; Haddow, S.; Hodder, I.; Issavi, J.; Lercari, N.; Mazzucato, C.; Mickel, A.; Taylor, J. S.	Revisiting reflexive archaeology at Çatalhöyük: integrating digital and 3D technologies at the trowel's edge	Antiquity	Art History	Archaeologist; Archaeologist; Virtual Archaeologist; Archaeologist; Anthropologist; Anthropologist; Digital Humanist; Archaeologist; Anthropologist; Archaeologist	SE; SE; IT; US; US; US; US; US; UK
158	2016	Grellert, M.	Rapid Prototyping in the Context of Cultural Heritage and Museum Displays	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Architect	DE
159	2016	Wahbeh, W.; Nebiker, S.; Fangi, G.	COMBINING PUBLIC DOMAIN AND PROFESSIONAL PANORAMIC IMAGERY FOR THE ACCURATE AND DENSE 3D RECONSTRUCTION OF THE DESTROYED BEL TEMPLE IN PALMYRA	ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Architect; Geoinformatic Engineer; Geoinformatic Engineer	CH; CH; IT
160	2016	Prechtel, N.; Münster, S.	Cultural Heritage in a Spatial Context – Towards an Integrative, Interoperable, and Participatory Data and Information Management	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Cartographist; Digital Humanist	DE; DE
161	2016	Wagener, O.; Seitz, C.; Havemann, S.	Medieval Castles and their Landscape	Virtual Palaces, Part II Lost Palaces and their Afterlife	Art History	Art Historian; Computer Scientist; Computer Scientist	DE; DE; AT

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162	2016	Quattrini, R.; Pierdicca, R.; Frontoni, E.; Barcaglioni, R.	VIRTUAL RECONSTRUCTION OF LOST ARCHITECTURES: FROM THE TLS SURVEY TO AR VISUALIZATION	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Architect; Architect; Architect; Architect	IT; IT; IT; IT
163	2016	Themistocleous, K.	Debate and Considerations on Using Videos for Cultural Heritage from Social Media for 3D Modelling	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Architect	CY
164	2016	Tait, E.; Laing, R.; Grinnall, A.; Burnett, S.; Isaacs, J.	(Re)presenting heritage: Laser scanning and 3D visualisations for cultural resilience and community engagement	Journal of Information Science	Information Technology	Information Scientist; Architect; Information Scientist; Information Scientist; Computer Graphic	UK; UK; UK; UK; UK
165	2016	Stiller, J.; Wintergrün, D.	Digital Reconstruction in Historical Research and Its Implications for Virtual Research Environments	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Information Scientist; Information Scientist	DE; DE
166	2016	Rozanska, A.; Koryciński, W.	Reconstruction of Wooden “Polish Manor”	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Art Historian; Conservation Scientist	PL; PL
167	2016	Pfarr-Harfst, M.; Wefers, S.	Digital 3D Reconstructed Models – Structuring Visualisation Project Workflows	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Architect; Computer Scientist	DE; DE
168	2016	Pfarr-Harfst, M.; Grellert, M.	The Reconstruction – Argumentation Method: Proposal for a Minimum Standard of Documentation in the Context of Virtual Reconstructions	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Architect; Architect	DE; DE

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169	2016	Münster, S.; Kröber, C.; Weller, H.; Prechtel, N.	Researching Knowledge Concerns in Virtual Historical Architecture	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Digital Humanist; Information Scientist; Cartographist; Cartographist	DE; DE; DE; DE
170	2016	Martens, B.; Peter, H.	Virtual Reconstruction of Synagogues in Lodz	Urban Jewis Cemeteries	Cultural Heritage	Architect; Architect	AT; AT
171	2016	Münster, S.; Kröber, C.; Hegel, W.; Pfarr-Harfst, M.; Prechtel, N.; Uhlemann, R.; Henze, F.	First Experiences of Applying a Model Classification for Digital 3D Reconstruction in the Context of Humanities Research	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Digital Humanist; Information Scientist; Digital Humanist; Architect; Cartographist; Digital Humanist; Geoscientist	DE; DE; DE; DE; DE; DE; DE
172	2016	Kuroczyński, P.; Hauck, O.; Dworak, D.	3D Models on Triple Paths - New Pathways for Documenting and Visualizing Virtual Reconstructions	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Architect; Architect; Software Engineer	DE; DE; PL
173	2016	Ioannides, M.; Ioannidis, C.; Enkleistriotis, A. N.; Castrillo, D.; Chatzigrigoriou, P.; Papageorgiou, E.; Leventis, G.; Nikolakopoulou, V.; Athanasiou, V.; Bourexis, F.; Soile, S.; Verykokou, S.; De Castrillo, M. C.; Sovis, C.	Towards Monuments' Holistic Digital Documentation: the Saint Neophytos Enkleistriotis Case Study	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Computer Scientist; Computer Scientist; Theologist ; Architect; Civil Engineer; Architect; Civil Engineer; Mathematician; Computer Graphic; Geoinformatic Engineer; Geoinformatic Engineer; Geoinformatic Engineer; Architect; Computer Graphic	CY; CY; CY; CY; CY; CY; CY; CY; GR; GR; GR; CY; AT
174	2016	Dworak, D.; Kuroczyński, P.	Virtual Reconstruction 3.0: New Approach of Web-based Visualisation and Documentation of Lost Cultural Heritage	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Software Engineer; Architect	PL; DE
175	2016	Beacham, R. C.	Defining our terms in heritage visualization	Paradata and Transparency in Virtual Heritage	Digital Heritage	Art Historian	UK

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176	2016	Cawthorne, D.; Irodotou, R.	Proportional Systems in the Design of the Cathedral of St. George of the Greeks, Cyprus	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Humanist; Architect	UK; UK
177	2016	Reilly, P.; Todd, S.; Walter, A.	Rediscovering and modernising the digital Old Minster of Winchester	Digital Applications in Archaeology and Cultural Heritage	Cultural Heritage	Archaeologist; Computer Engineer; Computer Scientist	UK; UK; UK
178	2016		A Model Classification for Digital 3D Reconstruction in the Context of Humanities Research | SpringerLink	3D Research Challenges in Cultural Heritage II	Cultural Heritage		
179	2016	Bruschke, J.; Wacker, M.	Simplifying Documentation of Digital Reconstruction Processes	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Computer Scientist; Computer Scientist	DE; DE
180	2016	Pierdicca, R.; Frontoni, E.; Malinverni, E. S.; Colosi, F.; Orazi, R.	Virtual reconstruction of archaeological heritage using a combination of photogrammetric techniques: Huaca Arco Iris, Chan Chan, Peru	Digital Applications in Archaeology and Cultural Heritage	Cultural Heritage	Architect; Architect; Civil Engineer; Archaeologist; Humanist	IT; IT; IT; IT; IT
181	2016	Attenni, M.; Bartolomei, C.; Ippolito, A.	Digital Documentation: Villa Borghese	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Architect; Architect; Engineer	IT; IT; IT
182	2016	Clarke, J. R.	3D Model, Linked Database, and Born-Digital E-Book: An Ideal Approach to Archaeological Research and Publication	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Art Historian	US
183	2016	Pfarr-Harfst, M.	Typical Workflows, Documentation Approaches and Principles of 3D Digital Reconstruction of Cultural Heritage	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Architect	DE

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184	2016	von Schwerin, J.; Lyons, M.; Loos, L.; Billen, N.; Auer, M.; Zipf, A.	Show Me the Data!: Structuring Archaeological Data to Deliver Interactive, Transparent 3D Reconstructions in a 3D WebGIS	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Archaeologist; Archaeologist; Geoinformatic Engineer; Geoinformatic Engineer; Geoinformatic Engineer; Geoinformatic Engineer	DE; DE; DE; DE; DE; DE
185	2016	Galeazzi, F.	Towards the definition of best 3D practices in archaeology: Assessing 3D documentation techniques for intra-site data recording	Journal of Cultural Heritage	Cultural Heritage	Archaeologist	UK
186	2016	Mezzino, D.; Pei, C. W.; Santana-Quintero, M. E.	Interpretation of Sensor-Based 3D Documentation	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Architect; Conservation Scientist; Civil Engineer	CA; BE; CA
187	2016	Beetz, J.; Blümel, I.; Dietze, S.; Fetahui, B.; Gadiraju, U.; Hecher, M.; Krijnen, T.; Lindlar, M.; Tamke, M.; Wessel, R.; Yu, R.	Enrichment and Preservation of Architectural Knowledge	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Architect; Information Scientist; Computer Scientist; Computer Scientist; Computer Scientist; Computer Graphic; Software Engineer; Digital Humanist; Architect; Computer Graphic; Data Scientist	NL; DE; DE; DE; DE; AT; NL; DE; DK; DE; DE
188	2016	Apollonio, F. I.	Classification Schemes for Visualization of Uncertainty in Digital Hypothetical Reconstruction	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Architect	IT
189	2016	Münster, S.; Hegel, W.; Kröber, C.	A Model Classification for Digital 3D Reconstruction in the Context of Humanities Research	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Digital Humanist; Digital Humanist; Information Scientist	DE; DE; DE
190	2016	Blümm, M.; Schmunk, S.	Digital Research Infrastructures: DARIAH	3D Research Challenges in Cultural Heritage II	Cultural Heritage	Digital Humanist; Digital Humanist	DE; DE
191	2016	Di Mascio, D.; Chiuini, M.; Fillwalk, J.; Pauwels, P.	3D Digital Reconstructions of Lost Buildings: A first critical framing	Complexity & Simplicity	Architecture	Architect; Architect ; Information Scientist; Architect	UK; US; US; BE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
192	2017	Messemer, H.	The Beginnings of Digital Visualization of Historical Architecture in the Academic Field	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Art Historian	DE
193	2017	Câmara, A. G. d.; Murteira, H.; Rodrigues, P.	City & Spectacle: A Vision of Lisbon Before the 1755 Great Earthquake	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Art Historian; Art Historian; Art Historian	PT; PT; PT
194	2017	Hoppe, S.; Breitling, S.	Virtual Palaces, Digital Images – an Introduction	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Art Historian; Architect	DE; DE
195	2017	Rykl, M.	Virtual Reconstructions and Building Archaeology in Bohemia. A Digital Model of the 14th-Century House U zvonu ('Zur Glocke' / 'At the Sign of the Bell') in Prague	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Architect	CZ
196	2017	Grellert, M.; Haas, F.	Sharpness Versus Uncertainty in 'Complete Models'. Virtual Reconstructions of the Dresden Castle in 1678	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Architect; Geoscientist	DE; DE
197	2017	Jahn, P. H.; Wacker, M.; Welich, D.	Back to the Future. Visualizing the Planning and Building of the Dresden Zwinger from the 18th until the 19th Century	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Art Historian; Computer Scientist; Museologist	DE; DE; DE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
198	2017	Mollenhauer, A.; Topal, T.	3D-Model as a Basis for the Discussion on the Reconstruction of the Aleppo Bazaar	CHNT22	Cultural Heritage	Archaeologist; Architect	DE; DE
199	2017	Wagener, O.; Seitz, C.; Havemann, S.	Medieval Castles and their Landscape. A Case Study towards Historic Reconstruction	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Art Historian; Computer Scientist; Computer Scientist	DE; DE; AT
200	2017	Lopes, A. C. G.	Virtually Rebuilding the Palace of Vila Viçosa in Portugal. From the Present to the Time of D. Teodósio I (16th Century)	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Architect	PT
201	2017	Breitling, S.; Buba, M.; Fuhrmann, J.	Building Knowledge Spaces. Scientific Reconstruction and Modeling of the Medieval City of Bamberg	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Architect; Computer Graphic; Archaeologist	DE; DE; DE
202	2017	Verdiani, G.; Carrara, M.; Lami, S.	Destroyed Places and Ancient Wars. Digital Tools for the Montecastrese Fortress	Studies in Digital Heritage	Digital Heritage	Architect; Archaeologist; Architect	IT; IT; IT
203	2017	Chandler, T.; Polkinghorne, M.	A Review of Sources for Visualising the Royal Palace of Angkor, Cambodia, in the 13th Century	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Virtual Archaeologist; Archaeologist	AU; AU
204	2017	Lengyel, D.; Toulouse, C.	Visualisation of Uncertainty in Archaeological Reconstructions	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Architect; Architect	DE; IT

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
205	2017	Galeazzi, F.; Di Giuseppantonio Di Franco, P.	Theorising 3D Visualisation Systems in Archaeology: Towards more effective design, evaluations and life cycles	Internet Archaeology	Virtual Archaeology	Archaeologist; Archaeologist	UK; UK
206	2017	Galeazzi, F.	3D recording, documentation and management of cultural heritage	International Journal of Heritage Studies	Digital Humanities	Archaeologist	UK
207	2017		Seville Principles		Virtual Archaeology		
208	2017	Lombaerde, P.; Muylle, M.	Visualizations of Rubens's Palazzos of the 17th Century in the Antwerp 'Nieuwstadt'	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Designer; Designer	BE; BE
209	2017	Patay-Horváth, A.; Christiansen, L.	From Reconstruction to Analysis. Re-use and re-purposing of 3D scan datasets obtained from ancient Greek marble sculpture	Studies in Digital Heritage	Digital Heritage	Humanist; Information Scientist	HU; US
210	2017	Jasink, A. M.; Faralli, C.; Kruklidis, P.	MUSINT II: A Complex Project on a Virtual and Interactive Museum Involving Institutions of Florence, Rome and Heraklion	Studies in Digital Heritage	Digital Heritage	Art Historian; Computer Scientist; Architect	IT; IT; IT
211	2017	Wefers, S.; Karmacharya, A.; Pfarr-Harfst, M.; Boochs, F.	Digital 3D reconstructed models A proposition for structuring visualisation workflows using semantic technologies for recommendations	Studies in Digital Heritage	Digital Heritage	Computer Scientist; Information Scientist; Architect; Engineer	DE; DE; DE; DE
212	2017	Scopigno, R.; Callieri, M.; Dellepiane, M.; Ponchio, F.; Potenziani, M.	Delivering and using 3D models on the web: are we ready?	Virtual Archaeology Review	Virtual Archaeology	Computer Scientist; Computer Graphic; Computer Graphic; Computer Graphic; Computer Graphic	IT; IT; IT; IT; IT

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
213	2017	Maiwald, F.; Vietze, T.; Schneider, D.; Henze, F.; Münster, S.; Niebling, F.	PHOTOGRAMMETRIC ANALYSIS OF HISTORICAL IMAGE REPOSITORIES FOR VIRTUAL RECONSTRUCTION IN THE FIELD OF DIGITAL HUMANITIES	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Geodesist; Engineer; Engineer; Geoscientist; Digital Humanist; Computer Scientist	DE; DE; DE; DE; DE; DE
214	2017	Münster, S.; Köhler, T.	3D Reconstruction of Cultural Heritage Artifacts. A Literature Based Survey of Recent Projects and Workflows	Virtual Palaces, Part II: Lost Palaces and their Afterlife. Virtual Reconstruction between Science and Media	Art History	Digital Humanist; Digital Humanist	DE; DE
215	2017	Münster, S.; Kröber, C.; Weller, H.; Prechtel, N.	Virtual Reconstruction of Historical Architecture as Media for Knowledge Representation	Mixed Reality and Gamification for Cultural Heritage	Virtual Reality	Digital Humanist; Information Scientist; Cartographist; Cartographist	DE; DE; DE; DE
216	2017	Parrinello, S.; di Pavia, U.; Bursich, D.; di Milano, U.	3D Documentation for the Study of the UNESCO Site of Masada: Methodologies and Applied Research for the Analysis of Roman Fields	CHNT22	Cultural Heritage	Architect; ; Archaeologist;	IT; ; IT;
217	2017	Marsicano, L.; Malatesta, S. G.; Lella, F.; D'Ignazio, E.; Massacci, E.; Onofri, S.	Maxentius 3D Project	Studies in Digital Heritage	Digital Heritage	Digital Humanist; Digital Humanist; Art Historian; Archaeologist; Archaeologist; Archaeologist	IT; IT; IT; IT; IT; IT
218	2017	López-Menchero Bendicho, V. M.; Flores Gutiérrez, M.; Vincent, M. L.; Grande León, A.	Digital Heritage and Virtual Archaeology: An Approach Through the Framework of International Recommendations	Mixed Reality and Gamification for Cultural Heritage	Virtual Reality	Virtual Archaeologist; Art Historian; Archaeologist; Virtual Archaeologist	ES; ES; ES; ES
219	2017	Kuroczyński, P.	Virtual Research Environment for digital 3D reconstructions – Standards, thresholds and prospects	Studies in Digital Heritage	Digital Heritage	Architect	DE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
220	2017	Kowal, S.; Koszewski, K.; Słyk, J.; Wrona, S.	Digital Method for Verifying Archaeological Hypotheses. Medieval Gord Under Pułtusk Castle	Studies in Digital Heritage	Digital Heritage	Architect; Architect; Architect; Architect	PL; PL; PL; PL
221	2017	Kolenda, J.; Markiewicz, M.	A Medieval Bishop's Palace in Milicz: 3D Reconstruction as a Method of a Research Hypotheses Presentation	Studies in Digital Heritage	Digital Heritage	Archaeologist; Archaeologist	PL; PL
222	2017	Długosz, E.; Duda, E.; Jodłowiec-Dziedzic, A.; Niemice, D.; Bieroń, T.	The bastion of tradition	The bastion of tradition	Cultural Heritage	Historian; Architect; Art Historian; ; Translator	PL; PL; PL; ; PL
223	2017	Denker, A.	Rebuilding Palmyra virtually: recreation of its former glory in digital space	Virtual Archaeology Review	Virtual Archaeology	Engineer	TR
224	2017	Sgherri, E.; Anzani, G.	The Fortress of Riolo Terme, near Ravenna: digital survey and 3D printing for cultural dissemination	Studies in Digital Heritage	Digital Heritage	Architect; Architect	IT; IT
225	2017	Apollonio, F. I.; Fallavollita, F.; Giovannini, E. C.; Foschi, R.; Corso, S.	The reconstruction of drawn architecture	Studies in Digital Heritage	Digital Heritage	Architect; Architect; Architect; Architect; Architect	IT; IT; IT; IT; IT
226	2017	Apollonio, F.; Gaiani, M.; Fallavollita, F.; Giovannini, E.; Foschi, R.	A Journey in the Fourteenth Century. A Digital Reconstruction of Piazza delle Erbe in Verona	diségno	Visualization	Architect; Architect; Architect; Architect; Architect	IT; IT; IT; IT; IT
227	2017	Portalés, C.; Alonso-Monasterio, P.; Viñals, M. J.	Reconstrucción virtual y visualización 3d del yacimiento arqueológico Castellet de Bernabé (Lliria, España)	Virtual Archaeology Review	Virtual Archaeology	Geoscientist; Humanist; Geodesist	ES; ES; ES
228	2017	Piccoli, C.	Visualizing antiquity before the digital age: Early and late modern reconstruction drawings of Greek and Roman cityscapes	in ANALECTA PRAEHISTORICA LEIDENSIA 47 - EXCERPTA ARCHAEOLOGICA LEIDENSIA II	Art History	Digital Humanist	NL
229	2017	Wallace, C.; Dedík, L.; Minaroviech, J.; Moullou, D.	3D Modeling and Virtual Access of Omega House in the Athenian Agora	CHNT22	Cultural Heritage	Geographist; Engineer; Architect; Archaeologist	CA; SK; SK; GR

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
230	2017	Grellert, M.; Pfarr-Harfst, M.; Schmid, J.	Documentation for Virtual Reconstructions. One Year R-A-M – Reconstruction-Argumentation-Method – A Report of First Experiences	Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018. CHNT 23	Cultural Heritage	Architect; Architect; Architect	DE; DE; DE
231	2017	Kurdiovsky, R.	Using the 3D-Model of the Vienna Hofburg to Store Written and Pictorial Historical Sources from Collections and Archives	CHNT22	Cultural Heritage	Art Historian	AT
232	2017	Battini, C.; Sorge, E.	Amphitheater of Volterra: Case Study for the Representation of Excavation Data	Studies in Digital Heritage	Digital Heritage	Civil Engineer; Archaeologist	IT; IT
233	2017	Elgewely, E.	3D Reconstruction of Furniture Fragments from the Ancient Town of Karanis	Studies in Digital Heritage	Digital Heritage	Art Historian	EG
234	2017	Demetrescu, E.; Fanini, B.	A white-box framework to oversee archaeological virtual reconstructions in space and time: Methods and tools	Journal of Archaeological Science: Reports	Archaeology	Archaeologist; Computer Scientist	IT; IT
235	2018	Seidel-Grzesińska, A.; Wyrzykowska, M.	Cataloguing Monuments - Some Changes in the Documentary Work of Art Historians in Silesia over the Past 150 Years	Digital Research and Education in Architectural Heritage	Architecture	Art Historian; Art Historian	PL; PL
236	2018	Cantini, L.	Historical Buildings Affected by Failures. The Case of the Basilica di Collemaggio in L'Aquila	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Architect	IT
237	2018	Banfi, F.; Stanga, C.; Brumana, R.	A Digital Workflow for Built Heritage: From SCAN-to-BIM Process to the VR-Tour of the Basilica of Sant'Ambrogio in Milan	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Architect; Architect; Architect	IT; IT; IT

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
238	2018	Previtali, M.; Banfi, F.	Towards the Definition of Workflows for Automation in HBIM Generation	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Civil Engineer; Architect	IT; IT
239	2018	Schäfer, U. U.	Uncertainty Visualization and Digital 3D Modeling in Archaeology. A Brief Introduction.	International Journal for Digital Art History	Art History	Art Historian	DE
240	2018	Chen, S.; Yang, H.; Wang, S.; Hu, Q.	Surveying and Digital Restoration of Towering Architectural Heritage in Harsh Environments: a Case Study of the Millennium Ancient Watchtower in Tibet	Sustainability	Digital Heritage	Architect; Architect; Architect; Engineer	CN; CN; CN; CN
241	2018	Comes, R.; Tompa, V.; Bodi, Ş.; Neamtu, C.; Török, K. F.	FROM THEORY TO PRACTICE: DIGITAL RECONSTRUCTION AND VIRTUAL REALITY IN ARCHAEOLOGY	JOURNAL OF ANCIENT HISTORY AND ARCHAEOLOGY	Art history	Engineer; Engineer; Engineer; Engineer; Museologist	RO; RO; RO; RO; RO
242	2018	Vranich, A.	Reconstructing ancient architecture at Tiwanaku, Bolivia: the potential and promise of 3D printing	Heritage Science	Cultural Heritage	Archaeologist	US
243	2018	Ortiz-Cordero, R.; León Pastor, E.; Hidalgo Fernández, R. E.	Proposal for the improvement and modification in the scale of evidence for virtual reconstruction of the cultural heritage: A first approach in the mosque-cathedral and the fluvial landscape of Cordoba	Journal of Cultural Heritage	Cultural Heritage	Computer Graphic; Computer Graphic; Geoscientist	ES; ES; ES
244	2018	Scianna, A.; Gaglio, G. F.; La Guardia, M.	BIM Modelling of Ancient Buildings	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Geoscientist; Computer Scientist; Computer Scientist	IT; IT; IT
245	2018	Kuşu, S.	The Reconstruction of Urartu Buildings of Altıntepe in Virtual Environment	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Archaeologist	TR

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
246	2018	Tucci, G.; Conti, A.; Fiorini, L.	3-D Survey and Structural Modelling: The Case of the San Giovanni Baptistery in Florence	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Geoscientist; Geoscientist; Civil Engineer	IT; IT; IT
247	2018	Acke, L.; De Vis, K.; De Kock, T.; Indekeu, E.; Van Goethem, J.; Van Akeleyen, S.; Cornelis, M.; Verlinden, J.; Verwulgen, S.	Treatise of Digital Reconstruction and Restauration of Lace Porcelain	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Conservation Scientist; Conservation Scientist; Geologist; Designer; Neuroradiologist; Designer; Designer; Designer	BE; BE; BE; BE; BE; BE; BE; BE
248	2018	Maiwald, F.; Barthel, K.; Bruschke, J.; Friedrichs, K.; Kröber, C.; Münster, S.; Niebling, F.	Research and Communication of Urban History in 4D Using Historical Photographs – A Status Report of the Research Group UrbanHistory4D	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Geodesist; Designer; Computer Scientist; Art Historian; Information Scientist; Digital Humanist; Computer Scientist	DE; DE; DE; DE; DE; DE; DE
249	2018	Bennoui-Ladraa, B.; Chennaoui, Y.	Use of photogrammetry for Digital Surveying, documentation and communication of the cultural heritage. Example regarding virtual reconstruction of the access doors for the nameless temple-Tipasa-Algeria	Studies in Digital Heritage	Digital Heritage	Archaeologist; Architect	DZ; DZ
250	2018	Piccoli, C.	Visualizing cityscapes of Classical antiquity : from early modern reconstruction drawings to digital 3D models : With a case study from the ancient town of Koroneia in Boeotia, Greece	Visualizing cityscapes of Classical antiquity	Art History	Digital Humanist	NL
251	2018	Niebling, F.; Maiwald, F.; Barthel, K.; Latoschik, M. E.	4D Augmented City Models, Photogrammetric Creation and Dissemination	Digital Research and Education in Architectural Heritage	Architecture	Computer Scientist; Geodesist; Designer; Information Scientist	DE; DE; DE; DE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
252	2018	Pfarr-Harfst, M.	Practice – Research Challenges – Standards! A Reflection of Digital 3D Reconstructed Models for Urban Structures	Digital Research and Education in Architectural Heritage	Architecture	Architect	DE
253	2018	Apollonio, F. I.	The Production of 3D Digital Archives and the Methodologies for Digitally Supporting Research in Architectural and Urban Cultural Heritage	Digital Research and Education in Architectural Heritage	Architecture	Architect	IT
254	2018	Demetrescu, E.	Virtual Reconstruction as a Scientific Tool: The Extended Matrix and Source-Based Modelling Approach	Digital Research and Education in Architectural Heritage	Architecture	Archaeologist	IT
255	2018	Herold, H.; Hecht, R.	3D Reconstruction of Urban History Based on Old Maps	Digital Research and Education in Architectural Heritage	Architecture	Urbanist; Cartographist	DE; DE
256	2018	Mori, N.; Higo, T.; Suemori, K.; Suita, H.; Yasumuro, Y.	Visualization of the Past-to-Recent Changes in Cultural Heritage Based on 3D Digitization	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Engineer; Archaeologist; Art Historian; Historian; Computer Engineer	JP; JP; JP; JP; JP
257	2018	Hermoza, R.; Sipiran, I.	3D Reconstruction of Incomplete Archaeological Objects Using a Generative Adversarial Network	Proceedings of Computer Graphics International 2018	Computer Graphics	Computer Engineer; Computer Scientist	PE; PE
258	2018	Hou, M.; Yang, S.; Hu, Y.; Wu, Y.; Jiang, L.; Zhao, S.; Wei, P.	Novel Method for Virtual Restoration of Cultural Relics with Complex Geometric Structure Based on Multiscale Spatial Geometry	ISPRS International Journal of Geo-Information	Information Technology	Engineer; Engineer; Engineer; Architect; Cartographist; Geoscientist; Architect	CN; CN; CN; CN; CN; CN; CN
259	2018	Münster, S.; Friedrichs, K.; Hegel, W.	3D Reconstruction Techniques as a Cultural Shift in Art History?	International Journal for Digital Art History	Art History	Digital Humanist; Art Historian; Digital Humanist	DE; DE; DE
260	2018	Senior, T. J.	Reconstructing St. Katharinen: Archival Archaeology in Action	Studies in Digital Heritage	Digital Heritage	Digital Humanist	UK

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
261	2018	Kepczynska-Walczak, A.; Martens, B.	Special Panel Session on "Digital Heritage"	Computing for a Better Tomorrow - Volume 1/Vol. 1	Computer Science	Architect; Architect	PL; AT
262	2018	Bruschke, J.; Maiwald, F.; Münster, S.; Niebling, F.	Browsing and Experiencing Repositories of Spatially Oriented Historic Photographic Images	Studies in Digital Heritage	Digital Heritage	Computer Scientist; Geodesist; Digital Humanist; Computer Scientist	DE; DE; DE; DE
263	2018	Münster, S.; Kuroczyński, P.; Messemer, H.	Digital 3D Reconstruction Projects and Activities in the German-Speaking Countries	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Digital Humanist; Architect; Art Historian	DE; DE; DE
264	2018	Attenni, M.; Bianchini, C.; Ippolito, A.	Emerging Technologies for Archaeological Heritage:: Knowledge, Digital Documentation, and Communication	Oceans of Data	Archaeology	Architect; Conservation Scientist; Engineer	IT; IT; IT
265	2018	Krusche, K.	3D Documentation and Visualization of the Forum Romanum: The DHARMA Forum Project	Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection	Digital Heritage	Architect	US
266	2018	Grellert, M.; Darmstadt, T.; Apollonio, F. I.; Martens, B.; Wien, T.; NUßBAUM, N.	Working Experiences with the Reconstruction Argumentation Method (RAM) – Scientific Documentation for Virtual Reconstruction	Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018. CHNT 23	Cultural Heritage	Architect; ; Architect; Architect; ; Art Historian	DE; ; IT; AT; ; DE
267	2018	Boeykens, S.; Maekelberg, S.; Jonge, K. D.	(Re-)Creating the past: 10 years of digital historical reconstructions using BIM	International Journal for Digital Art History	Art History	Architect; Art Historian; Conservation Scientist	BE; BE; BE
268	2018	Micoli, L.; Barsanti, S. G.; Malik, U.; Guidi, G.	3D data integration for the digital reconstruction of cultural heritage monuments	IOP Conference Series: Materials Science and Engineering	Engineering	Engineer; Archaeologist; Architect; Engineer	IT; IT; IT; IT

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269	2018	Andreas, N.	MODELLING THE EFFECTS OF DAYLIGHT SCATTERING BY WINDOW GLASS: THE CASE OF SIXTH CENTURY HAGIA SOPHIA IN ISTANBUL	ANNALES du 21 e CONGRÈS de l'ASSOCIATION INTERNATIONALE pour l'HISTOIRE du VERRE	Art History	Engineer	DE
270	2019	Champion, E. M.	From Historical Models to Virtual Heritage Simulations: 3D models, digital history, theory, virtual heritage	Der Modelle Tugend 2.0: Digitale 3D-Rekonstruktion als virtueller Raum der architekturhistoris chen Forschung	Architecture	Architect	AU
271	2019	Rabinowitz, A.	Communicating in Three Dimensions: Questions of Audience and Reuse in 3D Excavation Documentation Practice	Studies in Digital Heritage	Digital Heritage	Archaeologist	US
272	2019	Tichindelean, M. T.	Digital Reconstruction of the Akhenaten Torso in the Brooklyn Museum	Studies in Digital Heritage	Digital Heritage	Art Historian	US
273	2019	Bernardi, L.; Busana, M. S.; Centola, V.; Marson, C.; Sbrogiò, L.	The Sarno Baths, Pompeii: Architecture development and 3D reconstruction	Journal of Cultural Heritage	Cultural Heritage	Archaeologist; Archaeologist; Archaeologist; Archaeologist; Archaeologist	IT; IT; IT; IT; IT
274	2019	Agustín, L.; Quintilla, M.	VIRTUAL RECONSTRUCTION IN BIM TECHNOLOGY AND DIGITAL INVENTORIES OF HERITAGE	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Architect; Architect	ES; ES
275	2019	Torresani, A.; Remondino, F.	Videogrammetry vs Photogrammetry for heritage 3D reconstruction	Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W15	Engineering	Geoscientist; Computer Scientist	IT; IT
276	2019	Champion, E.; Rahaman, H.	3D Digital Heritage Models as Sustainable Scholarly Resources	Sustainability	Digital Heritage	Architect; Architect	AU; AU

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277	2019	Kargas, A.; Loumos, G.; Varoutas, D.	Using Different Ways of 3D Reconstruction of Historical Cities for Gaming Purposes: The Case Study of Nafplio	Heritage	Cultural Heritage	Economist; Computer Graphic; Information Scientist	GR; GR; GR
278	2019	Harrison, L. K.	A Roadmap to Applied Digital Heritage: Introduction to the Special Issue on Digital Heritage Technologies, Applications and Impacts	Studies in Digital Heritage	Digital Heritage	Digital Humanist	US
279	2019	Piccoli, C.	Visualizing domestic interiors in 17th century Amsterdam: 3D/4D data integration and hypothesis testing platforms	Virtual Interiors	Art History	Digital Humanist	NL
280	2019	Cook, K.; Hill, G.	Digital Heritage as Collaborative Process: Fostering Partnerships, Engagement and Inclusivity	Studies in Digital Heritage	Digital Heritage	Anthropologist; Archaeologist	CA; CA
281	2019	Johnston, E.; Richison, M.; Vujnovic, M.; Elias, W. R.	Augmented Asbury Park: Designing Augmented Reality 3D Content: augmented reality, boardwalk history, community mapping, digital design, experience design, history, interactive design, local history, locative media, memory, mobile technologies, new media, three-dimensional modelling, virtual architecture	Der Modelle Tugend 2.0: Digitale 3D-Rekonstruktion als virtueller Raum der architekturhistorischen Forschung	Architecture	Architect; Artist; Journalist; Designer	US; US; US; US
282	2019	Apollonio, F.	From text and drawing to model: 3D virtual reconstruction, 3D semantic segmentation, C. N. Ledoux, knowledge representation	Der Modelle Tugend 2.0: Digitale 3D-Rekonstruktion als virtueller Raum der architekturhistorischen Forschung	Architecture	Architect	IT

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283	2019	Apollonio, F.	Conceptual modelling and cognitive process in 3D virtual reconstruction: 3D virtual reconstruction, 3D semantic segmentation, conceptual modeling, knowledge representation	Der Modelle Tugend 2.0: Digitale 3D-Rekonstruktion als virtueller Raum der architekturhistorischen Forschung	Architecture	Architect	IT
284	2019	Ronzino, P.	CRMba: An ontological model for encoding buildings archaeology documentation: BIM, buildings archaeology, CIDOC CRM, CRMba, ontological extensions	Der Modelle Tugend 2.0: Digitale 3D-Rekonstruktion als virtueller Raum der architekturhistorischen Forschung	Architecture	Information Scientist	IT
285	2019	Tanasi, D.; Gradante, I.; Hassam, S.	Best Practices for 3D Digital Recording and Global Sharing of Catacombs from Late Roman Sicily	Studies in Digital Heritage	Digital Heritage	Anthropologist; Archaeologist; Digital Humanist	US; IT; US
286	2019	Karelin, D.; Karelina, M.	Methods of reconstructions' presentation and the peculiarities of human perception: 3D reconstruction, angle of view, architecture, methodology, perspective, plane of projection, presentation, Rauschenbach, viewpoint, visualisation	Der Modelle Tugend 2.0: Digitale 3D-Rekonstruktion als virtueller Raum der architekturhistorischen Forschung	Architecture	Architect; Architect	RU; RU
287	2019	Statham, N.	Scientific rigour of online platforms for 3D visualization of heritage	Virtual Archaeology Review	Virtual Archaeology	Computer Scientist	SE
288	2019	Özdemir, E.; Toschi, I.; Remondino, F.	A MULTI-PURPOSE BENCHMARK FOR PHOTOGRAMMETRIC URBAN 3D RECONSTRUCTION IN A CONTROLLED ENVIRONMENT	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Geoscientist; Geoscientist; Computer Scientist	RU; IT; IT

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289	2019	Landes, T.; Heissler, M.; Koehl, M.; Benazzi, T.; Nivola, T.	UNCERTAINTY VISUALIZATION APPROACHES FOR 3D MODELS OF CASTLES RESTITUTED FROM ARCHEOLOGICAL KNOWLEDGE	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Engineer; Archaeologist; Civil Engineer; Geoinformatic Engineer; Geoinformatic Engineer	FR; FR; FR; FR; FR
290	2019	Münster, S.; Apollonio, F. I.; Bell, P.; Kuroczynski, P.; Di Lenardo, I.; Rinaudo, F.; Tamborrino, R.	DIGITAL CULTURAL HERITAGE MEETS DIGITAL HUMANITIES	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Digital Humanist; Architect; Art Historian; ; Digital Humanist; Architect; Urbanist	DE; IT; DE; ; CH; IT; IT
291	2019	Windhager, F.; Federico, P.; Schreder, G.; Glinka, K.; Dörk, M.; Miksch, S.; Mayr, E.	Visualization of Cultural Heritage Collection Data: State of the Art and Future Challenges	IEEE Transactions on Visualization and Computer Graphics	Visualization	Information Scientist; Engineer; Psychologist; Cultural Scientist; Digital Humanist; Computer Scientist; Psychologist	AT; AT; AT; DE; DE; AT; AT
292	2019	Berner, K.; Eisenmann, U.; Hell, G.; Saler, H.	Visualisation of Cultural Heritage Developing a 3D online information system on the example of the Maulbronn monastery complex	Visualisation	Visualisation	Geoinformatic Engineer; Information Scientist; Information Scientist; Information Scientist	DE; DE; DE; DE
293	2019	Stathopoulou, E.; Welponer, M.; Remondino, F.	OPEN-SOURCE IMAGE-BASED 3D RECONSTRUCTION PIPELINES: REVIEW, COMPARISON AND EVALUATION	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Engineer; Engineer; Computer Scientist	IT; IT; IT
294	2019	Münster, S.	Digital Heritage as a Scholarly Field—Topics, Researchers, and Perspectives from a Bibliometric Point of View (Text with EEA relevance)	Journal on Computing and Cultural Heritage	Digital Humanities	Digital Humanist	DE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
295	2019	Tommasi, C.; Fiorillo, F.; Jiménez Fernández-Palacios, B.; Achille, C.	ACCESS AND WEB-SHARING OF 3D DIGITAL DOCUMENTATION OF ENVIRONMENTAL AND ARCHITECTURAL HERITAGE	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Architect; Architect; Cartographist; Geodesist	IT; IT; ES; IT
296	2019	Schreibman, S.; Papadopoulos, C.	Textuality in 3D: three-dimensional (re)constructions as digital scholarly editions	International Journal of Digital Humanities	Digital Humanities	Digital Humanist; Digital Humanist	NL; NL
297	2019	Papadopoulos, C.; Schreibman, S.	Towards 3D Scholarly Editions: The Battle of Mount Street Bridge	Digital Humanities Quarterly	Digital Humanities	Digital Humanist; Digital Humanist	NL; NL
298	2020	Clinton, M. G.	Online Gaming as Digital Heuristics: The House of the Rhyta at Pseira	Studies in Digital Heritage	Digital Heritage	Archaeologist	US
299	2020	Kuroczyński, P.; Große, P.	OntSciDoc3D – Ontology for Scientific Documentation of source-based 3D reconstruction of architecture	CHNT25	Cultural Heritage	Architect; Art Historian	DE; DE
300	2020	Diara, F.; Rinaudo, F.	IFC Classification for FOSS HBIM: Open Issues and a Schema Proposal for Cultural Heritage Assets	Applied Sciences	Engineering	Architect; Architect	IT; IT
301	2020	Soto-Martin, O.; Fuentes-Porto, A.; Martin-Gutierrez, J.	A Digital Reconstruction of a Historical Building and Virtual Reintegration of Mural Paintings to Create an Interactive and Immersive Experience in Virtual Reality	Applied Sciences	Engineering	Engineer; Digital Humanist; Engineer	ES; ES; ES
302	2020	Vaienti, B.; Apollonio, F. I.; Gaiani, M.	Analysis of Leonardo da Vinci's Architecture through Parametric Modeling: A Method for the Digital Reconstruction of the Centrally Planned Churches Depicted in Ms. B	Heritage	Cultural Heritage	Architect; Architect; Architect	IT; IT; IT

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303	2020	Yang, X.; Grussenmeyer, P.; Koehl, M.; Macher, H.; Murtiyoso, A.; Landes, T.	Review of built heritage modelling: Integration of HBIM and other information techniques	Journal of Cultural Heritage	Cultural Heritage	Engineer; Engineer; Civil Engineer; Engineer; Engineer; Engineer	FR; FR; FR; FR; FR; FR
304	2020	Huggett, J.	Virtually Real or Really Virtual: Towards a Heritage Metaverse	Studies in Digital Heritage	Digital Heritage	Archaeologist	UK
305	2020	Notarian, M.	Introduction to the Special Issue on 3D Methodologies in Mediterranean Archaeology	Studies in Digital Heritage	Digital Heritage	Archaeologist	US
306	2020	Grobe, L. O.; Noback, A.; Inanici, M.	Challenges in the simulation of the daylight distribution in late antique Hagia Sophia	Proceedings of the International Hagia Sophia Symposium	Art History	Architect; Engineer; Architect	CH; DE; US
307	2020	Davidde Petriaggi, B.; Stefanile, M.; Petriaggi, R.; Lagudi, A.; Peluso, R.; Di Cuia, P.	Reconstructing a Submerged Villa Maritima: The Case of the Villa dei Pisoni in Baiae	Heritage	Cultural Heritage	Conservation Scientist; Conservation Scientist; Conservation Scientist; Engineer; Computer Graphic; Computer Graphic	IT; IT; IT; IT; IT; IT
308	2020	Doulamis, A.; Voulodimos, A.; Protopapadakis, E.; Doulamis, N.; Makantasis, K.	Automatic 3D Modeling and Reconstruction of Cultural Heritage Sites from Twitter Images	Sustainability	Digital Heritage	Computer Engineer; Computer Engineer; Computer Engineer; Computer Engineer; Computer Graphic	GR; GR; GR; GR; MT
309	2020	Balletti, C.; Dabrowski, M.; Guerra, F.; Vernier, P.	Digital reconstruction of a lost heritage: the San Geminiano's church in San Marco's Square in Venice	IMEKO TC4 International Conference on Metrology for Archaeology and Cultural Heritage	Cultural Heritage	Geodesist; Architect; Architect; Geodesist	IT; IT; IT; IT
310	2020	Champion, E.; Rahaman, H.	Survey of 3D digital heritage repositories and platforms	Virtual Archaeology Review	Virtual Archaeology	Architect; Architect	AU; AU

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311	2020	Comes, R.; Neamțu, C.; Buna, Z. L.; Bodi, Ș.; Popescu, D.; Tompa, V.; Ghinea, R.; Mateescu-Suciu, L.	ENHANCING ACCESSIBILITY TO CULTURAL HERITAGE THROUGH DIGITAL CONTENT AND VIRTUAL REALITY: A CASE STUDY OF THE SARMIZEGETUSA REGIA UNESCO SITE	JOURNAL OF ANCIENT HISTORY AND ARCHAEOLOGY	Art history	Engineer; Engineer; Engineer; Engineer; Engineer; Engineer; Archaeologist	RO; RO; RO; RO; RO; RO; RO
312	2020	Pikulski, P.	Digital Monument Reconstruction in Architectural Studies: Synthesis of Research on the Previously Unknown Form of the Palace in Łobzów (Cracow) from the Period of the Rule of John III Sobieski	Mesto a dejiny	Art History	Architect	PL
313	2020	Fuchs, W.	Confronting Vitruvius: a geometric framework and design methodology for Roman rectangular temples	Journal of Roman Archaeology	Archaeology	Architect	US
314	2021	Fuchs, W.	New evidence for the design and urban integration of the Forum of Caesar, Forum of Augustus, Curia Julia, and Chalcidicum	Journal of Roman Archaeology	Archaeology	Architect	US
315	2021	Huffman, K. L.; Giordano, A.	Visualizing Venice to Visualizing Cities - Advanced Technologies for Historical Cities Visualization	Research and Education in Urban History in the Age of Digital Libraries	Art History	Art Historian; Architect	US; IT
316	2021	Koszewski, K.	Visual Representations in Digital 3D Modeling/Simulation for Architectural Heritage	Research and Education in Urban History in the Age of Digital Libraries	Art History	Architect	PL
317	2021	Pietroni, E.; Ferdani, D.	Virtual Restoration and Virtual Reconstruction in Cultural Heritage: Terminology, Methodologies, Visual Representation Techniques and Cognitive Models	Information	Information Technology	Art Historian; Archaeologist	IT; IT

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318	2021	Farella, E. M.; Özdemir, E.; Remondino, F.	4D Building Reconstruction with Machine Learning and Historical Maps	Applied Sciences	Engineering	Architect; Geoscientist; Computer Scientist	IT; RU; IT
319	2021	Nishanbaev, I.; Champion, E.; McMeekin, D. A.	A Web GIS-Based Integration of 3D Digital Models with Linked Open Data for Cultural Heritage Exploration	ISPRS International Journal of Geo-Information	Information Technology	Computer Scientist; Architect; Software Engineer	AU; AU; AU
320	2021	Kuroczyński, P.; Bajena, I.; Große, P.; Jara, K.; Wnęk, K.	Digital Reconstruction of the New Synagogue in Breslau: New Approaches to Object-Oriented Research	Research and Education in Urban History in the Age of Digital Libraries	Art History	Architect; Architect; Art Historian; Art Historian; Architect	DE; DE; DE; PL; PL
321	2021	Demetrescu, E.; Ferdani, D.	From Field Archaeology to Virtual Reconstruction: A Five Steps Method Using the Extended Matrix	Applied Sciences	Engineering	Archaeologist; Archaeologist	IT; IT
322	2021	Moore, K. B.	Virtual Reconstructions in Bernardino Amico's Treatise on the Plans and Images of the Sacred Buildings of the Holy Land	Studies in Digital Heritage	Digital Heritage	Art Historian	US
323	2021	Fallica, S.; Garozzo, R.; Santagati, C.	Retraced memories - virtual reconstruction of an architectural landmark	Virtual Archaeology Review	Virtual Archaeology	Architect; Architect; Architect	IT; IT; IT
324	2021	Barratt, R. P.	Speculating the Past: 3D Reconstruction in Archaeology	Virtual Heritage: A Concise Guide	Digital Heritage	Archaeologist	UK
325	2021	Apollonio, F. I.; Fallavollita, F.; Foschi, R.	The Critical Digital Model for the Study of Unbuilt Architecture	Research and Education in Urban History in the Age of Digital Libraries	Art History	Architect; Architect; Architect	IT; IT; IT
326	2021	Malik, U. S.; Tissen, L.; Vermeeren, A.	3D Reproductions of Cultural Heritage Artifacts: Evaluation of Significance and Experience	Studies in Digital Heritage	Digital Heritage	Architect; Designer; Civil Engineer	IT; NL; NL
327	2021	Russo, M.	AR in the Architecture Domain: State of the Art	Applied Sciences	Engineering	Architect	IT

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328	2021	Neamțu, C.; Bratu, I.; Măruțoiu, C.; Măruțoiu, V. C.; Nemeș, O. F.; Comes, R.; Bodi, Ș.; Buna, Z.; Popescu, D.	Component Materials, 3D Digital Restoration, and Documentation of the Imperial Gates from the Wooden Church of Voivodeni, Sălaj County, Romania	Applied Sciences	Engineering	Engineer; Physicist; Theologist; Theologist; Theologist; Engineer; Engineer; Engineer; Engineer	RO; RO; RO; RO; RO; RO; RO; RO; RO
329	2021	Ferwati, M. S.; El Menshawy, S.	Virtual reconstruction of the historic city of Al-Zubarah in Qatar	Digital Applications in Archaeology and Cultural Heritage	Cultural Heritage	Architect; Humanist	QA; QA
330	2021	Ugwitz, P.; Herman, L.; Stachoň, Z.	3D VISUALIZATION OF HISTORICAL BUILDINGS: METHODS, THEIR UTILITY IN THE TOURISM INDUSTRY AND BEYOND	Regionální rozvoj mezi teorií a praxí	Architecture	Geographist; Geographist; Geographist	CZ; CZ; CZ
331	2021	Blundell, J.; Clark, J. L.; DeVet, K. E.; Hardesty, J. L.	Metadata Requirements for 3D Data	3D Data Creation to Curation: Community Standards for 3D Data Preservation	Computer Science	Computer Engineer; Digital Humanist; Digital Humanist; Data Scientist	US; US; US; US
332	2021	Golubiewski-Davis, K.; Maisano, J.; McIntosh, M.; Moore, J.; Niven, K.; Rourk, W.; Snyder, R.	Best Practices for 3D Data Preservation	3D Data Creation to Curation: Community Standards for 3D Data Preservation	Computer Science	Digital Humanist; Geoscientist; Digital Humanist; Data Scientist; Archaeologist; Architect; Computer Scientist	US; US; US; US; UK; US; US
333	2021	Homburg, T.; Cramer, A.; Raddatz, L.; Mara, H.	Metadata schema and ontology for capturing and processing of 3D cultural heritage objects	Heritage Science	Cultural Heritage	Computer Scientist; Art Historian; Data Scientist; Computer Scientist	DE; DE; DE; DE
334	2021	Germano', G.	3D Reconstruction of a Roman Bridge in Canosa di Puglia (Italy)	Studies in Digital Heritage	Digital Heritage	Archaeologist	IT
335	2021	Di Mascio, D.	Architecture, Narrative and Interaction in the Cityscapes of the Assassin's Creed Series	A New Perspective of Cultural DNA	Heritage Studies	Architect	UK
336	2021	Trizio, I.; Demetrescu, E.; Ferdani, D.	Virtual reconstruction and restoration. Comparing methodologies, practices, and experiences	DISEGNARECON	Digital Heritage	Engineer; Archaeologist; Archaeologist	IT; IT; IT

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337	2021	Bruschke, J.; Wacker, M.; Niebling, F.	Comparing Methods to Visualize Orientation of Photographs: A User Study	Research and Education in Urban History in the Age of Digital Libraries	Art History	Computer Scientist; Computer Scientist; Computer Scientist	DE; DE; DE
338	2021	Grellert, M.; Wölfel, N.; Ristow, S.; Özcan, E.; Wiehen, M.	The Medieval Jewish Quarter in Cologne: A virtual reconstruction of 6000 m² of archaeology	Proceedings of the International Conference on Cultural Heritage and New Technologies, Vienna	Cultural Heritage	Architect; Architect; Archaeologist; Archaeologist; Archaeologist	DE; DE; DE; DE; DE
339	2021	Liritzis, I.; Volonakis, P.; Vosinakis, S.	3D Reconstruction of Cultural Heritage Sites as an Educational Approach. The Sanctuary of Delphi	Applied Sciences	Engineering	Archaeologist; Computer Engineer; Information Scientist	CN; CN; GR
340	2021	Trebeleva, G.; Glazov, K.; Kizilov, A.; Sakania, S.; Yurkov, V.; Yurkov, G.	Roman Fortress Pitiunt: 3D-Reconstruction of the Monument Based on the Materials of Archaeological Research and Geological Paleoreconstructions	Applied Sciences	Engineering	Archaeologist; Archaeologist; Engineer; Humanist; Archaeologist; Engineer	RU; RU; RU; GE; RU; RU
341	2021	Mosconi, C.; Smart, A.; Nevola, F.	Visualising the past: Defining the standards for digital reconstructions of past landscapes	Proceedings of the International Conference on Cultural Heritage and New Technologies	Cultural Heritage	Art Historian; Computer Scientist; Art Historian	UK; UK; UK
342	2021	Cruz, T.	Visualising the Past through the Virtual Image: Virtual Reconstitutions as interpretations of knowledge	Proceedings of the International Conference on Cultural Heritage and New Technologies	Cultural Heritage	Architect	PT
343	2021	Horňák, M.; Hrnčiarik, E.; Minaroviech, J.	Hypothetical reconstruction of a late ancient residence at Podunajské Biskupice	Proceedings of the International Conference on Cultural Heritage and New Technologies	Cultural Heritage	Archaeologist; Archaeologist; Architect	SI; SI; SK

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344	2021	Kröber, C.; Hammel, K.; Schade, C.; Filz, N.; Dewitz, L.	User Involvement for Application Development: Methods, Opportunities and Experiences from Three Different Academic Projects	Research and Education in Urban History in the Age of Digital Libraries	Art History	Information Scientist; Computer Scientist; Digital Humanist; Computer Scientist; Digital Humanist	DE; DE; DE; DE; DE
345	2021	Münster, S.; Lehmann, C.; Lazariv, T.; Maiwald, F.; Karsten, S.	Toward an Automated Pipeline for a Browser-Based, City-Scale Mobile 4D VR Application Based on Historical Images	Research and Education in Urban History in the Age of Digital Libraries	Art History	Digital Humanist; Data Scientist; Data Scientist; Geodesist; Digital Humanist	DE; DE; DE; DE; DE
346	2021	Lanjouw, T.	The digital 3D reconstruction of the 18th c. Bloemstraat and Eerste Bloemdwarstraat	4DRL Report Series 3	Digital 3D Reconstruction	Archaeologist	NL
347	2022	Kaplan, K.	Real-Time Rendering Engines Help Visualize, Model, and Animate Ancient Cities: An Example in Antioch	Applied Sciences	Engineering	Computer Scientist	TR
348	2022	Gerding, H.; Dell'Unto, N.	The Basilica Sempronia and the Forum Romanum	Opuscula 15	Archaeology	Archaeologist; Archaeologist	SE; SE
349	2022	Cherkes, B.; Linda, S.; Rozhko, V.; Yasinskyi, M.	Graphical 3D Reconstruction of the Tustan Rock Fortress, Ukraine, in the Study and the Promotion of Architectural Heritage Sites	Wiadomości Konserwatorskie Journal of Heritage Conservation	Architecture	Architect; Architect; Architect; Architect	UA; PL; UA; UA
350	2022	Fritsch, B.; Götz, S.; Filser, W.; Reinfeld, M.; Klose, C.; Vitti, P.	Mixing Methods: The Use of 3D Techniques at the Ancient Villa of Capo di Sorrento	Studies in Digital Heritage	Digital Heritage	Archaeologist; Archaeologist; Archaeologist; Archaeologist; Archaeologist; Architect	DE; DE; DK; DE; DE; US
351	2022	Comes, R.; Neamțu, C. G. D.; Grec, C.; Buna, Z. L.; Găzdac, C.; Mateescu-Suciu, L.	Digital Reconstruction of Fragmented Cultural Heritage Assets: The Case Study of the Dacian Embossed Disk from Piatra Roșie	Applied Sciences	Engineering	Engineer; Engineer; Engineer; Engineer; Historian; Archaeologist	RO; RO; RO; RO; RO; RO
352	2022	Münster, S.	Digital 3D Technologies for Humanities Research and Education: An Overview	Applied Sciences	Engineering	Digital Humanist	DE

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353	2022	Champion, E.; Nurmikko-Fuller, T.; Grant, K.	9 Alchemy and Archives, Swords, Spells, and Castles: Medieval-modding Skyrim	Teaching the Middle Ages through Modern Games	Digital Heritage	Architect; Digital Humanist; Art Historian	AU; AU; AU
354	2022	Bruderer, O.	The virtual model in archaeology: Continuity of the 3D medium in documentation, reconstruction, and publication	Proceedings of the International Conference on Cultural Heritage and New Technologies, Vienna, Band 25	Cultural Heritage	Computer Graphic	CH
355	2022	Bauer, P.	3D documentation and virtual reconstruction of the castle of Waldstein: The combination of low-cost photogrammetry and a geodetic survey	Proceedings of the International Conference on Cultural Heritage and New Technologies, Vienna, Band 25	Cultural Heritage	Geodesist	AT
356	2022	Bent, G. R.; Pfaff, D.; Brooks, M.; Radpour, R.; Delaney, J.	A practical workflow for the 3D reconstruction of complex historic sites and their decorative interiors: Florence As It Was and the church of Orsanmichele	Heritage Science	Cultural Heritage	Art Historian; Engineer; Digital Humanist; Conservation Scientist; Imaging Scientist	US; US; US; US; US
357	2022	Cáceres-Criado, I.; García-Molina, D. F.; Mesas-Carrascosa, F.; Triviño-Tarradas, P.	Graphic representation of the degree of historical-archaeological evidence: the 3D reconstruction of the “Baker’s House”	Heritage Science	Cultural Heritage	Engineer; Engineer; Geodesist; Engineer	ES; ES; ES; ES
358	2022	Cazzaro, I.	Dialogues between different disciplines (and languages): a shared terminology for hypothetical 3D digital reconstructions and for the classification of their level of uncertainty	Dialogues. Visions and visuality. Witnessing Communicating Experimenting	Visualization	Architect	IT
359	2022	Chabuk, M. A.; AlAmiri, S. A.	Virtual Reconstruction in 3D Documentation of Built Cultural Heritage	Journal of STEPS for Humanities and Social Sciences	Digital Humanities	Engineer; Architect	IQ; IQ

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360	2022	Wang, T.; Zhao, L.	[Retracted] Virtual Reality-Based Digital Restoration Methods and Applications for Ancient Buildings	Journal of Mathematics	Mathematics	Engineer; Architect	CN; CN
361	2022	Croce, P.; Leccese, F.; Mordagà, M.; Salvadori, G.	Towards reconstructing the Shakespeare's first Globe Theatre: A virtual model for research and development	Frontiers of Architectural Research	Architecture	Engineer; Engineer; Civil Engineer; Engineer	IT; IT; IT; IT
362	2022	Frischer, B.	3D Urban Models as Tools for Research and Discovery Two Case Studies of the Rostra in the Roman Forum Utilizing Rome Reborn	Critical Archaeology in the Digital Age: Proceedings of the 12th EMA Visiting Scholar's Conference	Archaeology	Virtual Archaeologist	US
363	2022	Keep, T.	The Mernda VR Project: The Creation of a VR Reconstruction of an Australian Heritage Site	Journal of Computer Applications in Archaeology	Archaeology	Archaeologist	AU
364	2022	Yörük, A. A.; Bülbül, M. A.; Hajısmaıl, S.	3D Architectural Heritage Platform	Digital international journal of Architecture Art Heritage	Art History	Architect; Computer Engineer; Architect	TR; TR; TR
365	2022	Farroni, L.; Faienza, M.; Matteo Flavio Mancini, M. F. M.	New Perspectives for Drawings in Italian Architecture Archives: Reflections and Experiments	diségno	Visualization	Architect; Architect;	IT; IT;
366	2022	Nevola, F.; Cooper, D.; Capulli, C.; Brunke, L.	Immersive Renaissance Florence: Research-Based 3-D Modeling in Digital Art and Architectural History	Getty Research Journal	Art History	Art Historian; Art Historian; Art Historian; Virtual Archaeologist	UK; UK; IT; UK
367	2022	Stylianidis, E.; Evangelidis, K.; Vital, R.; Dafiotis, P.; Sylaiou, S.	3D Documentation and Visualization of Cultural Heritage Buildings through the Application of Geospatial Technologies	Heritage	Cultural Heritage	Engineer; Geoinformatic Engineer; Designer; Geodesist; Geoinformatic Engineer	GR; GR; IL; GR; GR
368	2022	Albrezzi, F.; Bonnett, J.; Gniady, T.; Richards-Rissetto, H.; Snyder, L.	Accessing 3D Data	3D Data Creation to Curation: Community Standards for 3D Data Preservation	Computer Science	Digital Humanist; Historian; Digital Humanist; Archaeologist; Architect	US; CA; US; US; US

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369	2022	Zhang, X.; Zhi, Y.; Xu, J.; Han, L.	Digital Protection and Utilization of Architectural Heritage Using Knowledge Visualization	Buildings	Architecture	Physicist; Art Historian; Art Historian; Computer Scientist	CN; CN; CN; CN
370	2022	Parfenov, V.; Igoshin, S.; Masaylo, D.; Orlov, A.; Kuliashou, D.	Use of 3D Laser Scanning and Additive Technologies for Reconstruction of Damaged and Destroyed Cultural Heritage Objects	Quantum Beam Science	Information Technology	Engineer; Engineer; Engineer; Engineer; Engineer	RU; RU; RU; RU; RU
371	2022	Fazio, L.; Lo Brutto, M.; Gonizzi Barsanti, S.; Malatesta, S. G.	The Virtual Reconstruction of the Aesculapius and Hygeia Statues from the Sanctuary of Isis in Lilybaeum: Methods and Tools for Ancient Sculptures' Enhancement	Applied Sciences	Engineering	Humanist; Engineer; Engineer; Digital Humanist	IT; IT; IT; IT
372	2022	Sánchez-Sánchez, Y.; Elez, J.; Silva, P. G.; Santos-Delgado, G.; Giner-Robles, J. L.; Reicherter, K.	3D Modelling of Archaeoseismic Damage in the Roman Site of Baelo Claudia (Gibraltar Arc, South Spain)	Applied Sciences	Engineering	Geologist; Geologist; Geologist; Engineer; Geologist; Engineer	ES; ES; ES; ES; ES; DE
373	2022	Quintilla-Castán, M.; Martínez-Aranda, S.; Agustín-Hernández, L.	DIGITAL 3D INVENTORY FOR THE PROMOTION AND CONSERVATION OF THE ARCHITECTURAL HERITAGE	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Architect; Architect; Engineer	ES; ES; GR
374	2022	Lazna, R.; Barvir, R.; Vondrakova, A.; Brus, J.	Creating a Haptic 3D Model of Wenceslas Hill in Olomouc	Applied Sciences	Engineering	Geoscientist; Geoinformatic Engineer; Geoinformatic Engineer; Geoinformatic Engineer	CZ; CZ; CZ; CZ
375	2022	Verdiani, G.; Charalambous, A.; Ricci, Y.	Digital heritage consolidation and innovation, three case studies between documentation and divulgation aims	Technical Annals	Engineering	Architect; Architect; Architect	IT; IT; IT

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376	2023	Doria, E.; Fu, H.; Picchio, F.	Digital Reconstruction for the Analysis of Conservation State: The Transmission of Historical Memory of St. George and the Dragon Tile in San Michele Basilica Facade	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Architect; Engineer; Architect	IT; IT; IT
377	2023	Messemer, H.	Potentials for Research in Urban History–Online Research Tool 4D Community Browser	Research and Education in Urban History in the Age of Digital Libraries	Art History	Art Historian	DE
378	2023	van den Heuvel, D.; Noordegraaf, J.	Unpacking Urban Life in the Past: "Time Machine" as a Data Visualization and Analysis Tool	Visual and Multimodal Urban Sociology, Part A	Digital Humanities	Humanist; Humanist	NL; NL
379	2023	Bajena, I.; Kuroczyński, P.	Metadata for 3D Digital Heritage Models. In the Search of a Common Ground	Research and Education in Urban History in the Age of Digital Libraries	Art History	Architect; Architect	IT; DE
380	2023	Limoncelli, M.	"Sources of Research" for the Virtual Reconstruction of Ancient Monuments: The Case of Architectural Models	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Humanist	IT
381	2023	Pelliccio, A.; Saccucci, M.; Miele, V.	De RE Virtual RES. The Virtual Reconstruction of Rocca Janula in Cassino for a Meaningful "Reading" of the Historical Stratification	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Civil Engineer; Civil Engineer; Urbanist	IT; IT; PL
382	2023	Kulawik, B.	The Accademia de lo Studio de l'Architettura—A Database Project	Research and Education in Urban History in the Age of Digital Libraries	Art History	Art Historian	CH
383	2023	Maiwald, F.; Komorowicz, D.; Munir, I.; Beck, C.; Münster, S.	Semi-automatic Generation of Historical Urban 3D Models at a Larger Scale Using Structure-from-Motion, Neural Rendering and Historical Maps	Research and Education in Urban History in the Age of Digital Libraries	Art History	Geodesist; Computer Engineer; Geoinformatic Engineer; Digital Humanist; Digital Humanist	DE; DE; DE; DE; DE

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384	2023	Marra, A.; Trizio, I.; Savini, F.	Multidisciplinary Approach for the Knowledge of Historical Built: Digital Tools for the Virtual Restoration	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Civil Engineer; Engineer; Civil Engineer	IT; IT; IT
385	2023	Popova, D.	Digital Reconstruction of Lost Architectural Heritage on the Case Study of Two 19th Century Houses	Digital Presentation and Preservation of Cultural and Scientific Heritage	Cultural Heritage	Art Historian	BG
386	2023	Zhang, Z.; Zou, Y.; Xiao, W.	Exploration of a virtual restoration practice route for architectural heritage based on evidence-based design: a case study of the Bagong House	Heritage Science	Cultural Heritage	Artist; Civil Engineer; Architect	CN; CN; CN
387	2023	Apollonio, F. I.; Fallavollita, F.; Foschi, R.	An Experimental Methodology for the 3D Virtual Reconstruction of Never Built or Lost Architecture	Research and Education in Urban History in the Age of Digital Libraries	Art History	Architect; Architect; Architect	IT; IT; IT
388	2023	Rizzo, C.; Galizia, M.; Santagati, C.	The Virtual Reconstruction of the Cine-teatro Olympia in Catania for the Documentation and Memory of Places	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Architect; Architect; Architect	ES; IT; IT
389	2023	Bajena, I.; Kuroczyński, P.	DEVELOPMENT OF THE METHODOLOGY AND INFRASTRUCTURE FOR DIGITAL 3D RECONSTRUCTION	(IN)TANGIBLE HERITAGE(S): Design, culture and technology – past, present, and future	Cultural Heritage	Architect; Architect	IT; DE
390	2023	Gabellone, F.	Virtual Restoration and Persuasive Storytelling for a Virtual Visit to Palazzo Rosso, Genoa	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Architect	IT

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391	2023	Valiente, E. E.; D'Amico, F. C.; da Casa Martín, F.	Architecture and Archeology. Virtual Reconstruction of Ipi's Tomb TT315 in Deir-el-Bahari, Theban, Egypt	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Architect; Architect; Architect	ES; ES; ES
392	2023	Canciani, M.	Digital Heritage: Before, During and After COVID-19: The Aurelian Walls as a Case Study	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Architect	IT
393	2023	Chías, P.; Abad, T.; Fernández-Trapa, L.	From Design to Construction: Digital Reconstruction of the Convent's Kitchen Area in the Monastery of El Escorial	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Architect; Architect; Architect	ES; ES; DE
394	2023	Barsanti, S. G.	Structural Investigation on 3D Reality Based Models for Cultural Heritage Conservation and Virtual Restoration	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Archaeologist	IT
395	2023	Apollonio, F. I.; Fallavollita, F.; Foschi, R.	Systematizing Virtual Reconstruction of Lost or Never Built Architectures	Transizioni / Transitions	Visualization	Architect; Architect; Architect	IT; IT; IT
396	2023	Pattee, A.; Burioni, M.; Hoppe, S.; Hindmarch, J.; Hess, M.	Historical Construction Research Based Upon 3D Digital Documentation of the Baroque Palais im Grossen Garten in Dresden	Research and Education in Urban History in the Age of Digital Libraries	Art History	Art Historian; Art Historian; Art Historian; Engineer; Conservation Scientist	DE; DE; DE; DE; DE
397	2023	Germanó, G.	Diachronic 3D Reconstruction of a Roman Bridge: A Multidisciplinary Approach	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Archaeologist	IT

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
398	2023	Cazzaro, I.	A shared terminology for hypothetical 3D digital reconstructions in the field of Cultural Heritage	(In)tangible Heritage(s): a conference on design, culture and technology - past, present and future	Cultural Heritage	Architect	IT
399	2023	Garofalo, V.; Lepre, E.; Mancino, C. A.	Castellaccio of Monreale: From the Survey to the Visualisation of Virtual Reconstructions	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Architect; Architect; Architect	IT; IT; IT
400	2023	Blaise, J.; Dudek, I.; Bergerot, L.; Simon, G.	Visual encoding of a 3D virtual reconstruction's scientific justification: feedback from a proof-of-concept research	CAA2023	Archaeology	Architect; Architect; Architect; Theologist	FR; FR; FR; FR
401	2023	Brusaporci, S.; Forgione, A.; Graziosi, F.; Franchi, F.; Mantini, S.; Maiezza, P.; Tata, A.; Vespasiano, L.	The “Amiternum Project” on Archaeological Site Valorisation	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Civil Engineer; Archaeologist; Computer Scientist; Computer Engineer; Art Historian; Architect; Architect; Humanist	IT; IT; IT; IT; IT; IT; IT
402	2023	Ferdani, D.; Demetrescu, E.; Cavalieri, M.	Interpreting and Visualizing the Past Through Virtual Archaeology: From Site to Museum Experience	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Archaeologist; Archaeologist; Humanist	IT; IT; BE
403	2023	Brown, C.; Yao, S.; Zhang, X.; Brown, C.; Caven, J.; Uplekar Krusche, K.; Wang, C.	Visualizing digital architectural data for heritage education	Electronic Imaging	Visualization	Software Engineer; Computer Scientist; Physicist; Software Engineer; Architect; ; Architect	US; US; CN; US; US; ; US
404	2023	Gros, A.; Guillem, A.; De Luca, L.; Baillieul, É.; Duvocelle, B.; Malavergne, O.; Leroux, L.; Zimmer, T.	Faceting the post-disaster built heritage reconstruction process within the digital twin framework for Notre-Dame de Paris	Scientific Reports	Information Technology	Architect; Digital Humanist; Architect; Art Historian; Mathematician; Information Scientist; Geologist; Art Historian	FR; FR; FR; FR; CN; FR; FR; FR

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
405	2023	Valenti, R.; Cantone, F.; Paternò, E.	Methodological Practice for the Physical and Virtual Reconstruction of “Absent” Museum Goods: Hypotheses for Their Protection, Valorization and Inclusive Dissemination	Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage	Cultural Heritage	Architect; Architect; Architect	IT; IT; IT
406	2023	Li, Y.; Du, Y.; Yang, M.; Liang, J.; Bai, H.; Li, R.; Law, A.	A review of the tools and techniques used in the digital preservation of architectural heritage within disaster cycles	Heritage Science	Cultural Heritage	Architect; Architect; Architect; Architect; Architect; Architect; Architect	CN; CN; CN; CN; CN; CN; UK
407	2023	Akçam ErgiN, İ. D.	Digital Approach in Conservation of Heritage: 3D Virtual Reconstruction Applications in Ancient Cities	Mimarlık Bilimleri ve Uygulamaları Dergisi (MBUD)	Digital Heritage	Architect	TR
408	2023	Tsaknaki, E.; Anastasovitis, E.; Georgiou, G.; Alagialoglou, K.; Mavrokostidou, M.; Kartsiakli, V.; Aidonis, A.; Protopsalti, T.; Nikolopoulos, S.	Designing Stories from the Grave: Reviving the History of a City through Human Remains and Serious Games	Computer Applications and Quantitative Methods in Archaeology 2023	Archaeology	Information Scientist; Computer Scientist; Archaeologist; Architect; Museologist; Archaeologist; Anthropologist; Archaeologist; Computer Engineer	GR; GR; GR; GR; GR; GR; GR; GR; GR
409	2023	Chen, S.; Fan, G.; Li, J.	Improving completeness and accuracy of 3D point clouds by using deep learning for applications of digital twins to civil structures	Advanced Engineering Informatics	Computer Science	Architect; Engineer; Engineer	CN; CN; AU
410	2023	Rueff, B.; Pinto, A.; Messini, K.; Procopiou, H.	Senses and Activities: a Virtual Reconstruction of the Potter’s Workshop and the North Area of Quartier Mu at Malia (c. 1800-1700 BC)	Studies in Digital Heritage	Digital Heritage	Archaeologist; Archaeologist; Artist; Archaeologist	GR; FR; GR; FR
411	2023	Malik, U. S.; Garzulino, A.; Curto, D. D.	3D Heterogeneous Dataset for Structural Analysis of Historic Buildings. A Discussion on Process Pipelines	Studies in Digital Heritage	Digital Heritage	Architect; Architect; Architect	IT; IT; IT

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
412	2023	Doungtap, S.; Petchhan, J.; Phanichraksaphong, V.; Wang, J.	Towards Digital Twins of 3D Reconstructed Apparel Models with an End-to-End Mobile Visualization	Applied Sciences	Engineering	Computer Scientist; Engineer; Computer Engineer; Computer Scientist	TW; TW; TW; TW
413	2023	Tytarenko, I.; Pavlenko, I.; Dreval, I.	3D Modeling of a Virtual Built Environment Using Digital Tools: Kilburun Fortress Case Study	Applied Sciences	Engineering	Urbanist; Computer Scientist; Urbanist	UA; UA; UA
414	2023	Grellert, M.; Wacker, M.; Bruschke, J.; Stille, W.; Beck, D.	Documentation and Evaluation of Virtual Reconstructions	IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage	Cultural Heritage	Architect; Computer Scientist; Computer Scientist; Information Scientist; Software Engineer	DE; DE; DE; DE; DE
415	2023	Mader-Kratky, A.; Buchinger, G.; Langendorf, A.	From Archival Sources to a 3D-Visualization of Baroque Urban Topography: Vienna, Neuer Markt, C. 1760	Research and Education in Urban History in the Age of Digital Libraries	Art History	Art Historian; Art Historian; Archaeologist	AT; AT; AT
416	2023	Maiwald, F.; Bruschke, J.; Schneider, D.; Wacker, M.; Niebling, F.	Giving Historical Photographs a New Perspective: Introducing Camera Orientation Parameters as New Metadata in a Large-Scale 4D Application	Remote Sensing	Engineering	Geodesist; Computer Scientist; Engineer; Computer Scientist; Computer Scientist	DE; DE; DE; DE; DE
417	2023	Mazzacca, G.; Karami, A.; Rigon, S.; Farella, E. M.; Trybala, P.; Remondino, F.	NERF FOR HERITAGE 3D RECONSTRUCTION	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Computer Scientist; Information Scientist; Computer Scientist; Architect; Engineer; Computer Scientist	IT; IT; IT; IT; IT; IT
418	2023	Apollonio, F. I.; Fallavollita, F.; Foschi, R.	The Critical Digital Model and Two Case Studies: the Churches of Santa Margherita and Santo Spirito in Bologna	Nexus Network Journal	Visualization	Architect; Architect; Architect	IT; IT; IT
419	2023	Oh, J.; Bae, M. J.	PRODUCTION OF DIGITAL CONTENT (3D ASSET) SOURCE RESOURCES FOR CULTURAL HERITAGE	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Digital Media Engineer; Digital Media Engineer	KP; KP

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
420	2023	Callieri, M.; Berggren, Å.; Dell'Unto, N.; Derudas, P.; Dininno, D.; Ekengren, F.; Naponiello, G.	The Dynamic Collections – a 3D Web Platform of Archaeological Artefacts designed for Data Reuse and Deep Interaction	CAA2023	Archaeology	Computer Graphic; Archaeologist; Archaeologist; Archaeologist; Archaeologist; Archaeologist; Archaeologist	IT; SE; SE; SE; SE; SE; SE
421	2023	Zhao, D.; Liu, C.; Zhang, X.; Zhai, X.; Deng, Y.; Chen, H.; Hu, J.; Liu, D.; Luo, P.	3D Digital Modeling as a Sustainable Conservation and Revitalization Path for the Cultural Heritage of Han Dynasty Stone Reliefs	Sustainability	Digital Heritage	Engineer; Humanist; Physicist; Architect; Architect; Architect; Computer Engineer; Computer Scientist; Architect	CN; CN; CN; CN; CN; CN; CN; CN; CN
422	2023	Walmsley, A. P.; Lindstaedt, M.; Schnelle, M.; Kersten, T. P.	Virtual Reality for Spatial Research in Archaeology: Proto-typing 3D Reconstruction Tools for the Site of Yeha, Ethiopia	Publikationen der Deutschen Gesellschaft für Photogrammetrie, Fernerkundung und Geoinformation e.V., Band 31,Tagungsband der 43. Wissenschaftlich-Technischen Jahrestagung der DGPF	Information Technology	Engineer; 3D Analyst; Archaeologist; Geodesist	DE; DE; DE; DE
423	2023	Avci, A. B.; Akyol, G.	THE ROLE OF DIGITAL TECHNOLOGIES IN ENHANCING HERITAGE TOURISM. IV. BASKENT INTERNATIONAL CONFERENCE ON MULTIDISCIPLINARY STUDIES.	4. BASKENT INTERNATIONAL CONFERENCE ON MULTIDISCIPLINARY	Multidisciplinary	Architect; Architect	TR; TR
424	2023	Cáceres-Criado, I.; Triviño-Tarradas, P.; Valderrama-Zafra, J. M.; García-Molina, D. F.	Proposition for the graphic representation, interpretation and evaluation of the degree of terrain resolution in virtual reconstructions	Journal of Cultural Heritage	Cultural Heritage	Engineer; Engineer; Engineer; Engineer	ES; ES; ES; ES
425	2023	Cazzaro, I.	Uncertainty in Hypothetical 3D Reconstructions: Technical, Visual and Cultural 'Transitions'	Transizioni / Transitions	Visualization	Architect	IT

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
426	2023	Chen, Y.; Wu, Y.; Sun, X.; Ali, N.; Zhou, Q.	Digital Documentation and Conservation of Architectural Heritage Information: An Application in Modern Chinese Architecture	Sustainability	Digital Heritage	Conservation Scientist ; Architect; Artist; Architect; Architect	CN; CN; IT; PK; CN
427	2023	Croce, V.; Caroti, G.; Piemonte, A.; De Luca, L.; Véron, P.	H-BIM and Artificial Intelligence: Classification of Architectural Heritage for Semi-Automatic Scan-to-BIM Reconstruction	Sensors	Engineering	Engineer; Civil Engineer; Civil Engineer; Architect; Computer Scientist	IT; IT; IT; FR; FR
428	2023	Lee, J.; An, D. W.	Utilization of 3D Scan Data: “Representation” of Korean Wooden Architectural Heritage	Sustainability	Digital Heritage	Architect; Architect	KP; KP
429	2023	Abd Hamid, N. F.	Systematic Literature Review of the Digital Transformation of Cultural Heritage Assets during the COVID-19 Pandemic	International Journal of Real Estate Studies	Digital Heritage	Urbanist	MY
430	2023	Herrero-Tejedor, T. R.; Maté-González, M. Á.; Pérez-Martín, E.; López-Cuervo, S.; López De Herrera, J.; Sánchez-Aparicio, L. J.; Villanueva Llauradó, P.	Documentation and Virtualisation of Vernacular Cultural Heritage: The Case of Underground Wine Cellars in Atauta (Soria)	Heritage	Cultural Heritage	Engineer; Cartographist; Engineer; Cartographist; Engineer; Civil Engineer; Civil Engineer	ES; ES; ES; ES; ES; ES; ES
431	2023	Rafeiro, J.; Tomé, A.	Finding the Lost 16th-Century Monastery of Madre de Deus: A Pedagogical Approach to Virtual Reconstruction Research	Heritage	Cultural Heritage	Architect; Civil Engineer	JP; PT
432	2023	Husheng, P.; Li, P.; Zhang, L.	Digital Immersion Technology and Its Strategy in the Field of Urban and Architectural Heritage Conservation	Conservation of Urban and Architectural Heritage - Past, Present and Future	Architecture	Architect; Art Historian; Physicist	CN; CN; CN
433	2023	Komorowicz, D.; Sang, L.; Maiwald, F.; Cremers, D.	Colouring the Past: Neural Historical Buildings Reconstruction from Archival Photography	Computer Vision and Pattern Recognition	Information Technology	Computer Engineer; Computer Graphic; Geodesist; Computer Graphic	DE; DE; DE; DE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
434	2023	Bianconi, F.; Filippucci, M.; Cornacchini, F.; Meschini, M.; Mommi, C.	CULTURAL HERITAGE AND VIRTUAL REALITY: APPLICATION FOR VISUALIZATION OF HISTORICAL 3D REPRODUCTION	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Civil Engineer; Civil Engineer; Civil Engineer; Civil Engineer; Civil Engineer	IT; IT; IT; IT; IT
435	2023	Kuroczyński, P.; Bajena, I. P.; Große, P.	Digital Urban History Lab – Serious 3D in Research, Education and Popularization of Cultural Heritage	Research and Education in Urban History in the Age of Digital Libraries	Art History	Architect; Architect; Art Historian	DE; DE; DE
436	2023	Kuroczyński, P.; Apollonio, F. I.; Bajena, I. P.; Cazzaro, I.	SCIENTIFIC REFERENCE MODEL – DEFINING STANDARDS, METHODOLOGY AND IMPLEMENTATION OF SERIOUS 3D MODELS IN ARCHAEOLOGY, ART AND ARCHITECTURAL HISTORY	The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Engineering	Architect; Architect; Architect; Architect	DE; IT; DE; IT
437	2024	Iacono, S.; Scaramuzzino, M.; Martini, L.; Panelli, C.; Zolezzi, D.; Perotti, M.; Traverso, A.; Vercelli, G. V.	Virtual Reality in Cultural Heritage: A Setup for Balzi Rossi Museum	Applied Sciences	Engineering	Engineer; Engineer; Digital Humanist; Conservation Scientist; Engineer; Engineer; Archaeologist; Engineer	IT; IT; IT; IT; IT; IT; IT; IT
438	2024	Guillem, A.; Samuel, J.; Gesquière, G.; De Luca, L.; Abergel, V.	Versioning Virtual Reconstruction Hypotheses: Revealing Counterfactual Trajectories of the Fallen Voussoirs of Notre-Dame de Paris using Reasoning and 2D/3D Visualization \star	ESWC 2024	Information Technology	Digital Humanist; Computer Scientist; Computer Scientist; Architect; Architect	FR; FR; FR; FR; DE
439	2024	Raykovska, M.; Jones, K.; Klecherova, H.; Alexandrov, S.; Petkov, N.; Hristova, T.; Ivanov, G.	Implementing Digital Documentation Techniques for Archaeological Artifacts to Develop a Virtual Exhibition: the Necropolis of Baley Collection	Computer Applications and Quantitative Methods in Archaeology 2023	Archaeology	Architect; Virtual Archaeologist; Archaeologist; Archaeologist; Engineer; Archaeologist; Archaeologist	BG; UK; BG; BG; BG; BG; BG

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
440	2024	Münster, S.; Apollonio, F. I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P. H.; Kurdiovsky, R.; Kuroczyński, P.; Lutteroth, J.; Messemer, H.; Schelbert, G.	Infrastructure	Handbook of Digital 3D Reconstruction of Historical Architecture	Architecture	Digital Humanist; Architect; Information Scientist; Architect; Architect; Computer Scientist; Art Historian; Art Historian; Architect; Art Historian; Art Historian; Art Historian	DE; IT; DE; IT; IT; DE; CY; DE; AT; DE; DE; DE; DE
441	2024	Münster, S.; Apollonio, F. I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P. H.; Kurdiovsky, R.; Kuroczyński, P.; Lutteroth, J.; Messemer, H.; Schelbert, G.	Visualization	Handbook of Digital 3D Reconstruction of Historical Architecture	Architecture	Digital Humanist; Architect; Information Scientist; Architect; Architect; Computer Scientist; Art Historian; Art Historian; Architect; Art Historian; Art Historian; Art Historian	DE; IT; DE; IT; IT; DE; CY; DE; AT; DE; DE; DE; DE
442	2024	Münster, S.; Apollonio, F. I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P. H.; Kurdiovsky, R.; Kuroczyński, P.; Lutteroth, J.; Messemer, H.; Schelbert, G.	Scholarly Community	Handbook of Digital 3D Reconstruction of Historical Architecture	Architecture	Digital Humanist; Architect; Information Scientist; Architect; Architect; Computer Scientist; Art Historian; Art Historian; Architect; Art Historian; Art Historian; Art Historian	DE; IT; DE; IT; IT; DE; CY; DE; AT; DE; DE; DE; DE
443	2024	Münster, S.; Apollonio, F. I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P. H.; Kurdiovsky, R.; Kuroczyński, P.; Lutteroth, J.; Messemer, H.; Schelbert, G.	3D Modeling	Handbook of Digital 3D Reconstruction of Historical Architecture	Architecture	Digital Humanist; Architect; Information Scientist; Architect; Architect; Computer Scientist; Art Historian; Art Historian; Architect; Art Historian; Art Historian; Art Historian	DE; IT; DE; IT; IT; DE; CY; DE; AT; DE; DE; DE; DE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
444	2024	Münster, S.; Apollonio, F. I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P. H.; Kurdiovsky, R.; Kuroczyński, P.; Lutteroth, J.; Messemer, H.; Schelbert, G.	Workflows	Handbook of Digital 3D Reconstruction of Historical Architecture	Architecture	Digital Humanist; Architect; Information Scientist; Architect; Architect; Architect; Computer Scientist; Art Historian; Art Historian; Architect; Art Historian; Art Historian; Art Historian	DE; IT; DE; IT; IT; DE; CY; DE; AT; DE; DE; DE; DE
445	2024	Apollonio, F.; Fallavollita, F.; Foschi, R.; Smurra, R.	Multi-Feature Uncertainty Analysis for Urban-Scale Hypothetical 3D Reconstructions: Piazza delle Erbe Case Study	Heritage	Cultural Heritage	Architect; Architect; Architect; Architect	IT; IT; IT; IT
446	2024	Münster, S.; Apollonio, F. I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P. H.; Kurdiovsky, R.; Kuroczyński, P.; Lutteroth, J.; Messemer, H.; Schelbert, G.	Basics and Definitions	Handbook of Digital 3D Reconstruction of Historical Architecture	Architecture	Digital Humanist; Architect; Information Scientist; Architect; Architect; Architect; Computer Scientist; Art Historian; Art Historian; Architect; Art Historian; Art Historian; Art Historian	DE; IT; DE; IT; IT; DE; CY; DE; AT; DE; DE; DE; DE
447	2024	Münster, S.; Apollonio, F. I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P. H.; Kurdiovsky, R.; Kuroczyński, P.; Lutteroth, J.; Messemer, H.; Schelbert, G.	Legislation	Handbook of Digital 3D Reconstruction of Historical Architecture	Architecture	Digital Humanist; Architect; Information Scientist; Architect; Architect; Architect; Computer Scientist; Art Historian; Art Historian; Architect; Art Historian; Art Historian; Art Historian	DE; IT; DE; IT; IT; DE; CY; DE; AT; DE; DE; DE; DE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
448	2024	Münster, S.; Apollonio, F. I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P. H.; Kurdiovsky, R.; Kuroczyński, P.; Lutteroth, J.; Messemer, H.; Schelbert, G.	Documentation	Handbook of Digital 3D Reconstruction of Historical Architecture	Architecture	Digital Humanist; Architect; Information Scientist; Architect; Architect; Computer Scientist; Art Historian; Art Historian; Architect; Art Historian; Art Historian; Art Historian	DE; IT; DE; IT; IT; DE; CY; DE; AT; DE; DE; DE; DE
449	2024	Blaise, J.-Y.; Dudek, I.; Bergerot, L.; Simon, G.	Visual encoding of a 3D virtual reconstruction's scientific justification: feedback from a proof-of-concept research	Computer Applications and Quantitative Methods in Archaeology 2023	Archaeology	Architect; Architect; Architect; Theologist	FR;FR; FR; FR
450	2024	Münster, S.; Apollonio, F. I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P. H.; Kurdiovsky, R.; Kuroczyński, P.; Lutteroth, J.; Messemer, H.; Schelbert, G.	Introduction	Handbook of Digital 3D Reconstruction of Historical Architecture	Architecture	Digital Humanist; Architect; Information Scientist; Architect; Architect; Architect; Computer Scientist; Art Historian; Art Historian; Architect; Art Historian; Art Historian; Art Historian	DE; IT; DE; IT; IT; DE; CY; DE; AT; DE; DE; DE; DE
451	2024	Glazov, K.; Trebeleva, G.; Abornev, I.; Sakania, S.; Yurkov, V.; Yurkov, G.	Three-Dimensional Reconstruction of the Early Christian Temples of the Roman Fortress of Pitiunt	Applied Sciences	Engineering	Archaeologist; Archaeologist; Archaeologist; Humanist; Archaeologist; Engineer	RU; RU; RU; GE; RU; RU
452	2024	Münster, S.; Apollonio, F. I.; Bluemel, I.; Fallavollita, F.; Foschi, R.; Grellert, M.; Ioannides, M.; Jahn, P. H.; Kurdiovsky, R.; Kuroczyński, P.; Lutteroth, J.; Messemer, H.; Schelbert, G.	Scholarly Method	Handbook of Digital 3D Reconstruction of Historical Architecture	Architecture	Digital Humanist; Architect; Information Scientist; Architect; Architect; Architect; Computer Scientist; Art Historian; Art Historian; Architect; Art Historian; Art Historian; Art Historian	DE; IT; DE; IT; IT; DE; CY; DE; AT; DE; DE; DE; DE

Nr	Year	Authors	Title	Publication	Discipline	Profession	Country
453	2024	Bereczki, Z.	Construction of a Gothic Church Tower: A 3D Visualisation Based on Drawn Sources and Contemporary Artefacts	Heritage	Cultural Heritage	Civil Engineer	HU
454	2024	Neamțu, C.; Comes, R.; Popovici, D.; Băutu, E.; Liliana, M.; Syrotnik, A.; Popovici, M.	Evaluating User Experience in the Context of Cultural Heritage Dissemination Using Extended Reality: A Case Study of the Dacian Bronze Matrix with Hollow Design	J. Comput. Cult. Herit.	Cultural Heritage	Engineer; Engineer; Computer Scientist; Mathematician; ; Computer Engineer; Architect	RO; RO; RO; RO; ; FR; RO
455	2024	Rodriguez-Garcia, B.; Guillen-Sanz, H.; Checa, D.; Bustillo, A.	A systematic review of virtual 3D reconstructions of Cultural Heritage in immersive Virtual Reality	Multimedia Tools and Applications	Information Science	Computer Engineer; Computer Engineer; Computer Engineer; Computer Engineer	ES; ES; ES; ES
456	2024	Cuperschmid, A. R. M.; Costa, A. P.; Neves, I.; Fonseca, F. R.; Cuperschmid, E. M.	Virtual Reconstruction of the Deconstructed Heritage: The Former Building of the Belo Horizonte School of Medicine	J. Comput. Cult. Herit.	Cultural Heritage	Architect; Architect; Architect; Architect; Microbiologist	BR; BR; BR; BR; BR
457	2024	Yan, J.; Shan, X.	Design of Iterative Reconstruction Method of Landscape Environment Based on Deep Belief Network	Computer-Aided Design and Applications	Virtual archaeology	Computer Engineer; Computer Engineer	CN; CN

Appendix 2: Digital 3D reconstruction principles evaluation

Below the principles from the London Charter (2009), Seville Principles (2017), the 5-star deployment scheme for Linked Open Data, and FAIR Principles regarding documentation (Tab. 25, Tab. 26) and Publication are extracted. The second part of this Appendix contains an evaluation of three chosen documentation methods (Tab. 27) and three chosen publication tools (Tab. 28) in light of the principles from previous tables.

Tab. 25 A list of guidelines related to the documentation of digital reconstruction extracted from the London Charter (LC) and the Seville Principles (SP). The yellow colour distinguishes the principles for documentation content from the grey colour for documentation output and the green colour for visual presentation.

Document	Code	Text of principle	Topic	Group
London Charter	*LC 3*	*In order to ensure the intellectual integrity of computer-based visualisation methods and outcomes, relevant research sources should be identified and evaluated in a structured and documented way.*	*Sources, Structure*	*Documentation Output*
	LC 4.1	*Documentation strategies should be designed and resourced in such a way that they actively enhance the visualisation activity by encouraging, and helping to structure, thoughtful practice.*	*Structure*	*Documentation Output*
	LC 4.2	*Documentation strategies should be designed to enable rigorous, comparative analysis and evaluation of computer-based visualisations, and to facilitate the recognition and addressing of issues that visualisation activities reveal.*	*Evaluation*	*Documentation Output*
	LC 4.3	*Documentation strategies may assist in the management of Intellectual Property Rights or privileged information.*	*Intellectual Property*	*Documentation Content*
	LC 4.4	*It should be made clear to users what a computer-based visualisation seeks to represent, for example the existing state, an evidence-based restoration or an hypothetical reconstruction of a cultural heritage objector site, and the extent and nature of any factual uncertainty.*	*Knowledge Claims*	*Documentation Content*
	LC 4.5	*A complete list of research sources used and their provenance should be disseminated.*	*Sources*	*Documentation Content*
	LC 4.6	*Documentation of the evaluative, analytical, deductive, interpretative and creative decisions made in the course of computer-based visualisation should be disseminated in such a way that the relationship between research sources, implicit knowledge, explicit reasoning, and visualisation-based outcomes can be understood.*	*Paradata*	*Documentation Content*
	LC 4.7	*The rationale for choosing a computer-based visualisation method, and for rejecting other methods, should be documented and disseminated to allow the activity's methodology to be evaluated and to inform subsequent activities.*	*Methodology*	*Documentation Content*
	LC 4.8	*A description of the visualisation methods should be disseminated if these are not likely to be widely understood within relevant communities of practice.*	*Methods*	*Documentation Content*

Document	Code	Text of principle	Topic	Group
	LC 4.9	*Where computer-based visualisation methods are used in interdisciplinary contexts that lack a common set of understandings about the nature of research questions, methods and outcomes, project documentation should be undertaken in such a way that it assists in articulating such implicit knowledge and in identifying the different lexica of participating members from diverse subject communities.*	*Terminology*	*Documentation Content*
	LC 4.10	*Computer-based visualisation outcomes should be disseminated in such a way that the nature and importance of significant, hypothetical dependency relationships between elements can be clearly identified by users and the reasoning underlying such hypotheses understood.*	*Levels of Hypothesis*	*Visualisation Presentation*
	LC 4.11	*Documentation should be disseminated using the most effective available media, including graphical, textual, video, audio, numerical or combinations of the above.*	*Formats*	*Documentation Output*
	LC 4.12	*Documentation should be disseminated sustainably with reference to relevant standards and ontologies according to best practice in relevant communities of practice and in such a way that facilitates its inclusion in relevant citation indexes.*	*Standards*	*Documentation Output*
Seville Principles	*SP 4.2*	*Prior to the development of any computer-based visualisation, the ultimate purpose or goal of our work must always be completely clear*	*Goals*	*Documentation Content*
	SP 4.4	*Computer-based visualisation normally reconstructs or recreates historical buildings and environments as we believe them to have been in the past. For that reason, it should always be possible to distinguish what is real, genuine or authentic from what is not. In this sense, authenticity must be a permanent operational concept in any virtual archaeology project.*	*Authenticity*	*Visualization Presentation*
	SP 4.4.1	*Since archaeology is complex and not an exact and irrefutable science, it must be openly committed to making alternative virtual interpretations provided they afford the same scientific validity. When that equality does not exist, only the main hypothesis will be endorsed.*	*Versioning*	*Visualisation Presentation*
	SP 4.4.2	*When performing virtual restorations or reconstructions, these must explicitly or through additional interpretations show the different levels of accuracy on which the restoration or reconstruction is based.*	*Levels of Hypothesis*	*Visualisation Presentation*
	SP 4.4.3	*In so far as many archaeological remains have been and are being restored or reconstructed, computer- based visualisation should really help both professionals and the public to differentiate clearly between: remains that have been conserved "in situ"; remains that have been returned to their original position (real anastylosis); areas that have been partially or completely rebuilt on original remains; and finally, areas that have been restored or reconstructed virtually.*	*Authenticity*	*Visualisation Presentation*
	SP 4.5.1	*The historical rigour of any computer-based visualisation of the past will depend on both the rigour with which prior archaeological research has been performed and the rigour with which that information is used to create the virtual model.*	*Historical rigour, Paradata*	*Documentation Content*

Document	Code	Text of principle	Topic	Group
	SP 4.5.2	*All historical phases recorded during archaeological research are extremely valuable. Thus, a rigorous approach would not be one that shows only the time of splendour of reconstructed or recreated archaeological remains but rather one that shows all the phases, including periods of decline. Nor should it display an idyllic image of the past with seemingly newly-constructed buildings, people who look like models, etc., but rather a real image, i.e. with buildings in varying states of conservation, people of different sizes and weights, etc.*	*Historical rigour, Phases*	*Visualisation Presentation*
	SP 4.5.3	*The environment, landscape or context associated with archaeological remains is as important as the ruin itself (Charter of Krakow, 2000). Charcoal, paleobotanical, paleozoological and physical paleoanthropological research must serve as a basis for conducting rigorous virtual recreations of landscape and context. They cannot systematically show lifeless cities, lonely buildings or dead landscapes, because this is an historical falsehood.*	*Historical rigour, Context*	*Visualisation Presentation*
	SP 4.7.1	*It is clear that all computer-based visualisation involves a large amount of scientific research. Consequently, for the virtual archaeology projects to achieve scientific and academic rigour it is essential to prepare documentary bases in which to gather and present the entire work process in a completely transparent fashion: objectives, methodology, techniques, reasoning, origin and characteristics of the sources of research, results and conclusions.*	*Transparency*	*Documentation Output*

Tab. 26 A list of guidelines related to the publication of digital reconstructions extracted from the London Charter (LC), the Seville Principles (SP), the FAIR Principles (FP) and the 5-star Open Data scheme (5OD). The blue colour distinguishes rules for findability from yellow for availability, orange for interoperability, green for reuse, and purple for preservation.

Document	Code	Text of principle	Topic	Group
London Charter	*LC 4.2*	*Documentation strategies should be designed to enable rigorous, comparative analysis and evaluation of computer-based visualizations, and to facilitate the recognition and addressing of issues that visualisation activities reveal.*	*Evaluation*	*Reuse*
	LC 5	*Strategies should be planned and implemented to ensure the long-term sustainability of cultural heritage-related computer-based visualisation outcomes and documentation, in order to avoid loss of this growing part of human intellectual, social, economic and cultural heritage.*	*Long-term Sustainability*	*Preservation*
	LC 5.1	*The most reliable and sustainable available form of archiving computer- based visualisation outcomes, whether analogue or digital, should be identified and implemented*	*Archiving*	*Preservation*
	LC 5.2	*Digital preservation strategies should aim to preserve the computer- based visualisation data, rather than the medium on which they were originally stored, and also information sufficient to enable their use in the future, for example through migration to different formats or software emulation.*	*Data Formats*	*Preservation*

Document	Code	Text of principle	Topic	Group
	LC 6	*The creation and dissemination of computer-based visualisation should be planned in such a way as to ensure that maximum possible benefits are achieved for the study, understanding, interpretation, preservation and management of cultural heritage.*	*Dissemination*	*Accessibility*
	LC 6.1	*The aims, methods and dissemination plans of computer-based visualisation should reflect consideration of how such work can enhance access to cultural heritage that is otherwise inaccessible due to health and safety, disability, economic, political, or environmental reasons, or because the object of the visualisation is lost, endangered, dispersed, or has been destroyed, restored or reconstructed.*	*Access*	*Accessibility*
	LC 6.2	*Projects should take cognizance of the types and degrees of access that computer-based visualisation can uniquely provide to cultural heritage stakeholders, including the study of change over time, magnification, modification, manipulation of virtual objects, embedding of datasets, instantaneous global distribution.*	*Licensing*	*Reuse*
Seville Principles	*SP 4.7*	*All computer-based visualisation must be essentially transparent, i.e. testable by other researchers or professionals, since the validity, and therefore the scope, of the conclusions produced by such visualisation will depend largely on the ability of others to confirm or refute the results obtained.*	*Transparency*	*Reuse*
	SP 4.7.3	*In the interests of scientific transparency, it is necessary to create a large globally-accessible database with projects that offer optimum levels of quality (Art 8.4), without undermining the creation of national or regional databases of this type.*	*Database*	*Findability*
FAIR Principles	*FAIR F1*	*(Meta)data are assigned a globally unique and persistent identifier*	*Persistent Identifiers*	*Findability*
	FAIR F2	*Data are described with rich metadata (defined by R1 below).*	*Metadata*	*Findability*
	FAIR F3	*Metadata clearly and explicitly includes the identifier of the data they describe.*	*Metadata, Persistent Identifier*	*Findability*
	FAIR F4	*(Meta)data are registered or indexed in a searchable resource.*	*Indexing*	*Findability*
	FAIR A1	*(Meta)data are retrievable by their identifier using a standardised communications protocol.*	*Retrievability*	*Accessibility*
	FAIR A1.1	*The protocol is open, free and universally implementable*	*Retrievability*	*Accessibility*
	FAIR A1.2	*The protocol allows for an authentication and authorisation procedure where necessary*	*Retrievability*	*Accessibility*
	FAIR A2	*Metadata is accessible, even when the data are no longer available.*	*Preservation*	*Accessibility*

Document	Code	Text of principle	Topic	Group
	FAIR I1	*(Meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.*	*Data Format*	*Interoperability*
	FAIR I2	*(Meta)data use vocabularies that follow FAIR principles.*	*Vocabulary*	*Interoperability*
	FAIR I3	*(Meta)data include qualified references to other (meta)data.*	*Referencing*	*Interoperability*
	FAIR R1	*(Meta)data are richly described with a plurality of accurate and relevant attributes*	*Metadata*	*Reuse*
	FAIR R1.1	*(Meta)data are released with a clear and accessible data usage license.*	*Licensing*	*Reuse*
	FAIR R1.2	*(Meta)data are associated with detailed provenance.*	*Data Provenance*	*Reuse*
	FAIR R1.3	*(Meta)data meet domain-relevant community standards.*	*Standards*	*Reuse*
5-star Open Data Scheme	*5OD 1*	*Available on the web (whatever format) but with an open licence, to be Open Data.*	*Licensing*	*Accessibility*
	5OD 2	*Available as machine-readable structured data (e.g. excel instead of an image scan of a table).*	*Data Format*	*Interoperability*
	5OD 3	*as (2) plus a non-proprietary format (e.g. CSV instead of Excel).*	*Data Format*	*Accessibility*
	5OD 4	*In addition to all the above, use open standards from W3C (RDF and SPARQL) to identify things so that people can point at your stuff.*	*Data Format, Standards*	*Interoperability*
	5OD 5	*All the above, plus: Link your data to other people's data to provide context.*	*Referencing*	*Findability*

Tab. 27 Summary of selected documentation methods (knowledge graph[150], R-A-M[151] & Web-visualisation with annotations[152]) in light of documentation principles extracted from the London Charter (LC) and the Seville Principles (SP). The yellow colour distinguishes the principles for documentation content from the grey colour for documentation output and the green colour for visual presentation.

Group	Topic	Code	*Knowledge graph using ontology*	*Reconstruction-Argumentation-Method (R-A-M)*	*Web-based visualisation with annotations*
Documentation Content	*Intellectual Property*	*LC 4.3*	*YES*	*YES*	*YES*
	Knowledge Claims	*LC 4.4*	*NO in this case, although this method makes it possible*	*PARTLY by comparing the visualisation with a photograph of the current state and argumentation*	*NO*
	Sources	*LC 4.5*	*YES*	*YES*	*NO, but it should be possible through annotations*
	Paradata	*LC 4.6*	*YES*	*NO in this case, although this method makes it possible*	*NO*
	Methodology	*LC 4.7*	*YES*	*YES*	*NO*
	Methods	*LC 4.8*	*YES*	*YES*	*NO*
	Terminology	*LC 4.9*	*YES*	*NO*	*NO*
	Goals	*SP 4.2*	*YES*	*YES*	*NO*
	Historical rigor, Paradata	*SP 4.5.1*	*YES*	*YES*	*NO*
Visualization Presentation	*Levels of Hypothesis*	*LC 4.10*	*YES*	*YES*	*NO*
	Authenticity	*SP 4.4*	*NO in this case, although this method makes it possible*	*PARTLY by comparing the visualization with a photograph of the current state and argumentation*	*NO*
	Versioning	*SP 4.4.1*	*NO in this case, although this method makes it possible*	*YES*	*NO*

[150] on the example of VRE for reconstructing the new Synagogue in Wroclaw: https://www.new-synagogue-breslau-3d.hs-mainz.de/ (accessed 05 January 2024).

[151] on the example of the Tell Halaf reconstitution entry from the SciDoc: http://dmz-39.architektur.tu-darmstadt.de/reconstruction/?ac=project&cm=view&project_id=20 (accessed 05 January 2024).

[152] on the example of the Bar Hill Fort Reconstruction from Sketchfab: https://sketchfab.com/3d-models/bar-hill-fort-reconstruction-antonine-wall-6d04c19858b8421ebd034ba13abf4831 (accessed 05 January 2024).

Group	Topic	Code	*Knowledge graph using ontology*	*Reconstruction-Argumentation-Method (R-A-M)*	*Web-based visualisation with annotations*
	Levels of Hypothesis	*SP 4.4.2*	*NO in this case, although this method makes it possible*	*NO*	*NO*
	Authenticity	*SP 4.4.3*	*NO in this case, although this method makes it possible*	*PARTLY by comparing the visualization with a photograph of the current state and argumentation*	*NO*
	Historical rigor, Phases	*SP 4.5.2*	*NO in this case, although this method makes it possible*	*NO in this case, although this method makes it possible*	*NO*
	Historical rigor, Context	*SP 4.5.3*	*YES*	*YES*	*YES*
Documentation Output	*Sources, Structure*	*LC 3*	*YES*	*YES*	*PARTLY, because the annotation introduces a structure, but does not include sources*
	Structure	*LC 4.1*	*YES*	*YES*	*YES*
	Evaluation	*LC 4.2*	*YES*	*YES*	*YES*
	Formats	*LC 4.11*	*YES*	*YES, given the legal restrictions*	*YES*
	Standards	*LC 4.12*	*YES, in terms of ontological solutions*	*YES, referring to local standards used at TU Darmstadt*	*NO*
	Transparency	*SP 4.7.1*	*YES*	*YES*	*NO*

Tab. 28 Summary of selected documentation methods in light of documentation principles extracted from the London Charter (LC), the Seville Principles (SP), the FAIR Principles (FP) and the 5-star Open Data scheme (5OD). The blue colour distinguishes rules for findability, from yellow for availability, orange for interoperability, green for reuse, and purple for preservation.

Group	Topic	Code	*Closed Virtual Research Environment (VRE)* [153]	*Open, institutional repository for projects documentation: SciDoc* [154]	*Open, commercial repository for 3D models: Sketchfab* [155]
Findability	*Database*	*SP 4.7.3*	*PARTLY, published database is searchable worldwide*	*NO*	*YES*
	Persistent Identifiers	*FAIR F1*	*YES*	*NO*	*NO*
	Metadata	*FAIR F2*	*YES*	*YES*	*NO*
	Metadata, Persistent Identifier	*FAIR F3*	*YES*	*NO*	*NO*
	Indexing	*FAIR F4*	*YES*	*NO*	*YES*
	Referencing	*5OD 5*	*YES*	*NO*	*YES*
Accessibility	*Dissemination*	*LC 6*	*YES*	*PARTLY because the system does not support 3D content*	*YES*
	Access	*LC 6.1*	*YES*	*YES*	*YES*
	Retrievability	*FAIR A1*	*YES*	*NO*	*NO*
	Retrievability	*FAIR A1.1*	*YES*	*YES*	*YES*
	Retrievability	*FAIR A1.2*	*YES*	*YES*	*YES*
	Preservation	*FAIR A2*	*YES*	*NO*	*NO*
	Licensing	*5OD 1*	*YES*	*NO*	*YES*
	Data Format	*5OD 3*	*YES*	*NO*	*NO*

[153] on the example of VRE for reconstructing the new Synagogue in Wroclaw: https://www.new-synagogue-breslau-3d.hs-mainz.de/, (accessed 05 January 2024).

[154] on the example of the Tell Halaf reconstitution entry from the SciDoc: http://dmz-39.architektur.tu-darmstadt.de/reconstruction/?ac=project&cm=view&project_id=20 (accessed 05 January 2024).

[155] on the example of the Bar Hill Fort Reconstruction from Sketchfab: https://sketchfab.com/3d-models/bar-hill-fort-reconstruction-antonine-wall-6d04c19858b8421ebd034ba13abf4831 (accessed 05 January 2024).

Group	Topic	Code	*Closed Virtual Research Environment (VRE)* [153]	*Open, institutional repository for projects documentation: SciDoc* [154]	*Open, commercial repository for 3D models: Sketchfab* [155]
Interoperability	*Data Format*	*FAIR I1*	*YES*	*NO*	*NO*
	Vocabulary	*FAIR I2*	*YES*	*NO*	*NO*
	Referencing	*FAIR I3*	*YES*	*NO*	*YES*
	Data Format	*5OD 2*	*YES*	*NO*	*NO*
	Data Format, Standards	*5OD 4*	*YES*	*NO*	*NO*
Reuse	*Evaluation*	*LC 4.2*	*YES*	*YES*	*PARTLY, it is not possible to display the model with the sources*
	Licensing	*LC 6.2*	*YES*	*YES*	*YES*
	Transparency	*SP 4.7*	*YES*	*YES*	*NO*
	Metadata	*FAIR R1*	*YES*	*YES*	*NO*
	Licensing	*FAIR R1.1*	*YES*	*NO*	*YES*
	Data Provenance	*FAIR R1.2*	*YES*	*YES*	*NO*
	Standards	*FAIR R1.3*	*YES, in terms of ontological solutions*	*YES, referring to local standards used at TU Darmstadt*	*NO*
Preservation	*Long-term Sustainability*	*LC 5*	*NO*	*NO*	*NO*
	Archiving	*LC 5.1*	*NO*	*NO*	*NO*
	Data Formats	*LC 5.2*	*YES*	*YES*	*NO*

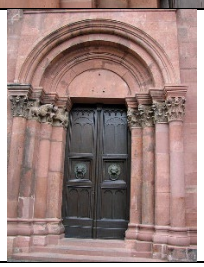
Appendix 3: Classification of sources for Case Study SpSya1250

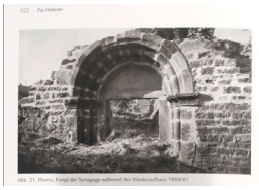
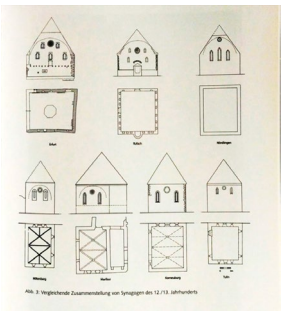
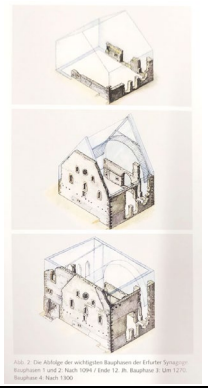
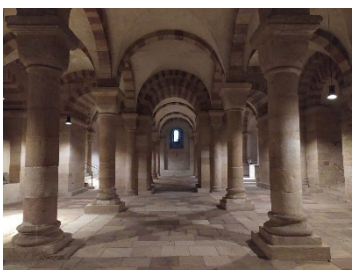
The Appendix below shows the classification and provenance of all source materials provided to those modelling the Case Study of a hypothetical digital reconstruction of Speyer Synagogue in the 13th century. Each source file was given name according to the developed naming convention, in order to facilitate the documentation process, according to the following pattern:

- Books: book_nr (see Tab. 33).
- Research articles: article_nr (see Tab. 33).
- Descriptions: text_nr (see Tab. 33).
- Photos of items from the location photo_location_nr (see Tab. 32).
- Reconstruction rendering: reconstruction_nr_rendering_nr (see Tab. 34).
- 3D models: reconstruction_nr_model_nr (see Tab. 34).
- Archaeological reports: report_nr (see Tab. 30).
- Researchers drawings: drawing_nr (see Tab. 31).
- Analogies: analogy_nr (see Tab. 29).
- Starting materials and guidelines: guideline_nr (see Tab. 35).

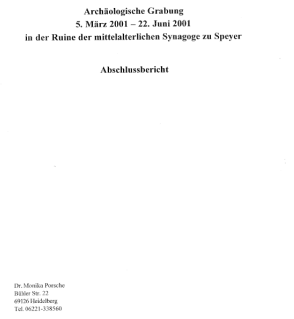
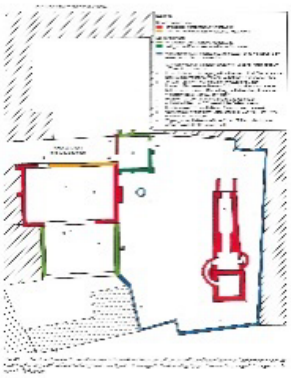
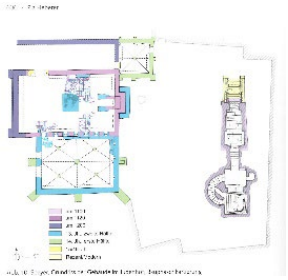
The synagogue has been visited by Irene Cazzaro, who collected a series of photos of the remains (both in the original location and in the nearby museum). The remains have been interpreted especially in the light of some drawings such as the plan and the front view of the east facade. These drawings can be found in the explanatory panels in the location, as well as in some books (as an example: Heberer 2010). Bibliographical research followed this first phase and was conducted both in libraries and online. Most of the sources are articles published after the excavations in the early 2000s; one of the descriptions was published in 1759. These texts describe what is known or assumed about the configuration of the synagogue. However, there are some parts that are only slightly (or not at all) described, thus we need to search - both in books and online - for analogies with structures from the same historical period or with similar constructive systems. The following images illustrate the main collected sources according to these different research phases. In addition, a location map has been prepared, showing the position of each image taken, which can be seen on the Fig. 108.

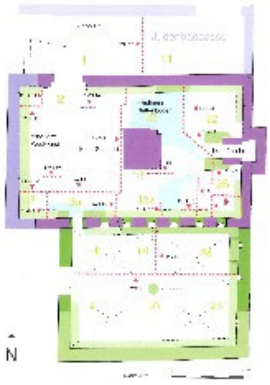
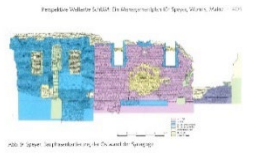
Tab. 29 Overview and origin of sources related to the analogies used to reconstruct elements of the synagogue that have not survived (such as the portal, roof, and details) were carefully considered. The analogies were selected based on objects from the same period, with some also chosen due to their geographical proximity. This approach allowed for the reconstruction to be informed by relevant historical and cultural context, ensuring that the missing elements were recreated in a manner consistent with surviving structures from similar locations and timeframes.

Analogies				
Object	Provenance	Name of the file	Description	Preview
Eastern portal of the Cathedral in Mainz (Germany)	https://www.1000-jahre-mainzer-dom.de/rundgang/ostbau.html	analogy_01_01.jpg	Upper part of the portal	
		analogy_01_02.jpg	Detail of column capitals	
		analogy_01_03.jpg	Picture of the entire eastern portal	
		analogy_01_description.txt	Description of the object from the source page in German	✗
Portal of the St Mary's Church in Great Bradley (Great Britain)	https://greatbradley.weebly.com/romanesque-architecture.html	analogy_02_01.jpg	Picture of the entire portal	
		analogy_02_02.jpg	Detail of portal column base	
		analogy_02_03.jpg	Detail of column capital	

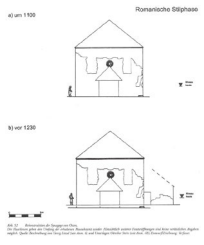
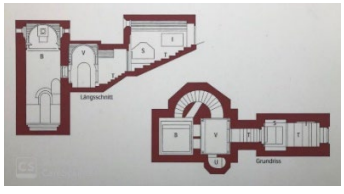
		analogy_02_04.jpg	Detail of column capital on the other side of the portal	
		analogy_02_description.txt	Description of the object from the source page in English	✗
Portal of the Worms Synagogue (Germany)	„Perspektive Welterbe SchUM: Ein Managementplan für Speyer, Worms, Mainz - Bestandsaufnahme und Desiderate“ Heberer, Pia. (2013) - In: Die SchUM-Gemeinden Speyer, Worms, Mainz S. 393-446	analogy_03.jpg	Historical photo of the portal of the Worms Synagogue in 1959/61	
Synagogues in Erfurt, Rufach, Nördlingen, Miltenberg, Maribor, Korneuburg, Tulln (Germany)	„Diaspora-Architektur: Synagogen im Kontext mittelalterlicher Städte“ Untermann, Matthias. (2013) - In: Die SchUM-Gemeinden Speyer, Worms, Mainz S. 283-296	analogy_04.jpg	Sketches of plans for medieval German synagogues from the late 12th and early 13th centuries. Particularly noteworthy is the form of the roof, for which no sources are available for the Synagogue in Speyer	
Walls of the Erfurt Synagogue (Germany)	„Diaspora-Architektur: Synagogen im Kontext mittelalterlicher Städte“ Untermann, Matthias. (2013) - In: Die SchUM-Gemeinden Speyer, Worms, Mainz S. 283-296	analogy_05.jpg	Sketches showing the reconstruction of the missing elements of the synagogue’s masonry structure based on deduction	
Crypt of the Speyer cathedral (Germany)	Private photos made by Irene Cazzaro	analogy_06.jpg	The synagogue (topic of reconstruction) and the cathedral were built at the same time and by the same craftsmen. It means that we can use some of the elements of the cathedral to the reconstruction of the synagogue.	

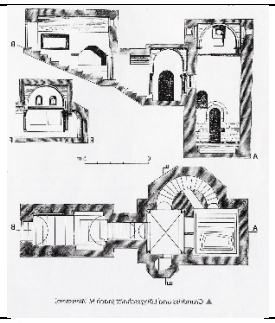
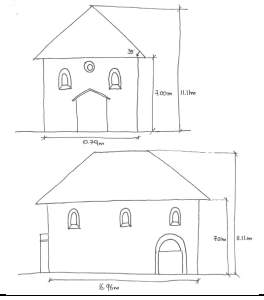
Tab. 30 Overview and provenance of sources related to the archaeological reports carried out on the site.

Archaeological reports			
Provenance	Name of the file	Description	Preview
-	report_text.pdf	The entire text reports on the archaeological excavations carried out between 3 March and 22 June 2001 on the ruins of the medieval synagogue in Speyer by Monika Porsche.	 Archäologische Grabung 5. März 2001 – 22. Juni 2001 in der Ruine der mittelalterlichen Synagoge zu Speyer Abschlussbericht
Archäologische Grabung 5. März 2001 - 22. Juni 2001 in der Ruine der mittelalterlichen Synagoge zu Speyer Abschlussbericht. Porsche, Monika.	report_drawing_01.jpg	Johannes Becker, Description of St. Free Roman Empire city of Speyer together with the four suburbs in 1773 [StA SP 1 aA nr, 895/1] Entry of names and dimensions in the cadastre on a scale 1:200 circumscription M. Porsche	
Information table on the site of the remains of the synagogue in Speyer	report_drawing_02.jpg	Plan of the synagogue distinguishing the different historical phases of the building by Monika Porsche and Pia Herber	
"Das mittelalterliche jüdische Erbe von Erfurt - Forschung und Vermittlung" Sczech, Karin, Stürzebecher, Maria. (2013) - In: Die SchUM-Gemeinden Speyer, Worms, Mainz S. 377-392	report_drawing_03.jpg	Drawing illustrating different construction phases of the building on the plan of the synagogue	

Archaeological reports			
Provenance	Name of the file	Description	Preview
Archäologische Grabung 5. März 2001 - 22. Juni 2001 in der Ruine der mittelalterlichen Synagoge zu Speyer Abschlussbericht. Porsche, Monika.	report_drawing_04.jpg	Plan of the Synagogue in Speyer with	
"Das mittelalterliche jüdische Erbe von Erfurt - Forschung und Vermittlung" Sczech, Karin, Stürzebecher, Maria. (2013) - In: Die SchUM-Gemeinden Speyer, Worms, Mainz S. 377-392	report_drawing_05.jpg	Drawing illustrating different construction phases of the building on the elevation of the synagogue	

Tab. 31 Overview and provenance of drawings illustrated object of study.

Drawings					
Name of the file	Description	Author	Provenance	Date	Preview
drawing_01.jpg	Sketches of the hypothetical reconstruction of the east elevation of the Synagogue in Speyer in 1100 and before 1230	Christoph Engels	Engels, Christoph, "Gedanken zur Baugeschichte der mittelalterlichen Synagoge in Speyer", Pfälzer Heimat, 52 (2001), S. 61-72	2001	
drawing_02.jpeg	Section and plan of the Mikwe in Speyer	Based on the drawing by H. Weisstein, 1885	Panel found on the site	2022	

Drawings					
Name of the file	Description	Author	Provenance	Date	Preview
drawing_03.jpeg	Section and plan of the Mikwe in Speyer	Based on the drawing by H. Weisstein, 1885	The name of this file in the folder "Synagoge_SP_1200" is: "SP_Heberer Porsche, Baugeschichte, 24_2_[Floss]". I haven't found a paper corresponding to it.		
drawing_04.pdf	Sketch of the hypothetical reconstruction of the east and north elevation of the Synagogue in 1250 with dimensions	Aliyah Mahmood	Archive of AI MAINZ. Sources used for the sketch are unknown!	2020	

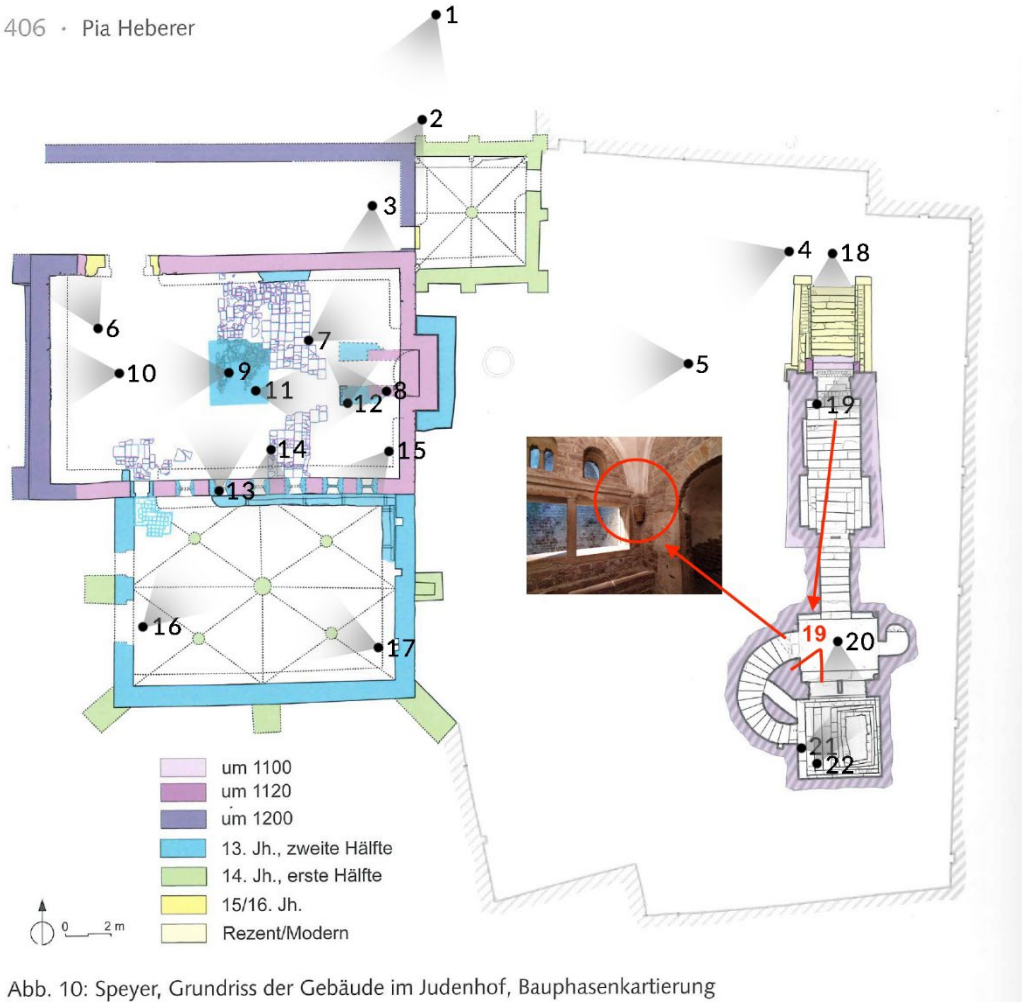


Abb. 10: Speyer, Grundriss der Gebäude im Judenhof, Bauphasenkartierung

Fig. 108 Map illustrating the location where photographs of the site were taken. Photos are described in Tab. 32 according to the numbers from this map. The map base used comes from the article "Das mittelalterliche jüdische Erbe von Erfurt -

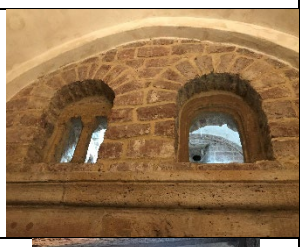
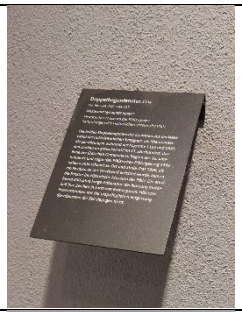
Forschung und Vermittlung“ by Karin Sczech & Maria Stürzebecher (2013) - In: Die SchUM-Gemeinden Speyer, Worms, Mainz, p. 377-392.

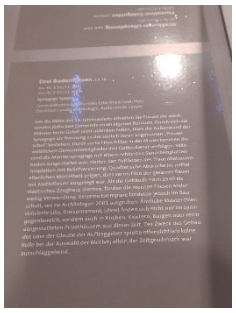
Tab. 32 Overview and provenance of photographs from the site.

Photos					
Author	Provenance	Date	Name of the file	Description	Preview
Irene Cazzaro	Private collection of Irene Cazzaro	23.01.2023	photo_location_01.jpg	General view of the synagogue from North	
			photo_location_02.jpg	General view of the synagogue from North	
			photo_location_03.jpg	Synagogue - part of the external surface of the northern wall	
			photo_location_04.jpg	Outer surface of the eastern wall of the synagogue (right) and the Frauenschul (left)	
			photo_location_05.jpg	Synagogue - outer surface of the eastern wall	
			photo_location_06.jpg	Synagogue - inner surface of the northern wall	

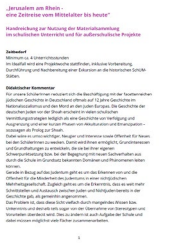
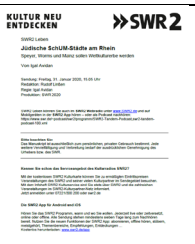
Photos					
Author	Provenance	Date	Name of the file	Description	Preview
			photo_location_07.jpg	Synagogue - part of the inner surface of the northern and eastern wall	
			photo_location_08.jpg	Synagogue - inner surface of the western wall	
			photo_location_09.jpg	Synagogue - inner surface of the western wall	
			photo_location_10.jpg	Synagogue - detail of the inner surface of the western wall	
			photo_location_11.jpg	Synagogue - inner surface of the eastern wall	
			photo_location_12.jpg	Synagogue - part of the inner surface of the northern wall	

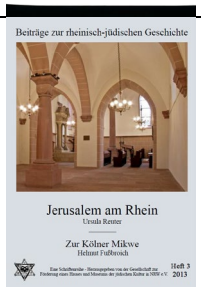
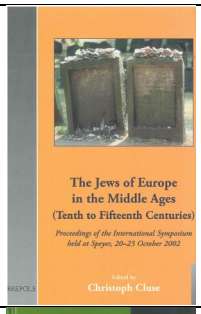
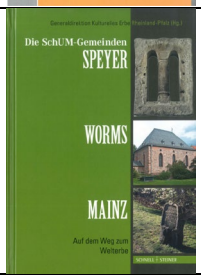
Photos					
Author	Provenance	Date	Name of the file	Description	Preview
			photo_location_13.jpg	Synagogue - inner surface of the northern wall	
			photo_location_14.jpg	Synagogue - part of the inner surface of the southern wall (towards the Frauenschul)	
			photo_location_15.jpg	Synagogue - part of the inner surface of the southern wall	
			photo_location_16.jpg	Synagogue - part of the outer surface of the southern wall (from the Frauenschul)	
			photo_location_17.jpg	Inner surface of the southern wall of the Frauenschul (left) and the synagogue (right)	
			photo_location_18.jpg	Entrance to the Mikwa	
			photo_location_19.jpg	Mikwa - detail of the vestibule	

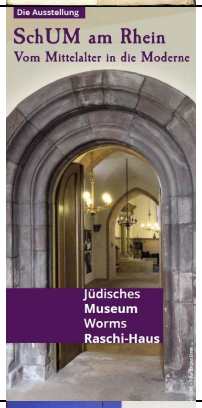
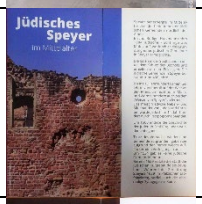
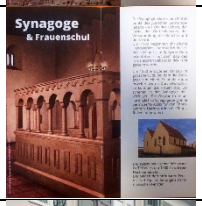
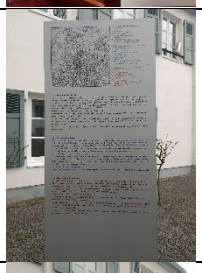
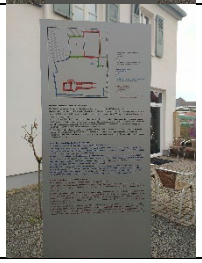
Photos					
Author	Provenance	Date	Name of the file	Description	Preview
			photo_location_20.jpg	Mikwa - detail of the vestibule	
			photo_location_21.jpg	Mikwa - shaft with basin from bottom to top	
			photo_location_22.jpg	Mikwa - shaft with basin from bottom to top	
	Photographs belong to the private collection of Irene Cazzaro. Physical remains and descriptions belong to the SchUM Museum in Speyer	23.01.2022	photo_museum_01.jpg	Physical remains of the western windows detached from the original structure of the synagogue and exposed in the museum.	
			photo_museum_02.jpg	Description of the windows in “photo_museum_01 ”	
			photo_museum_03.jpg	Floor tile from the Frauenschul	

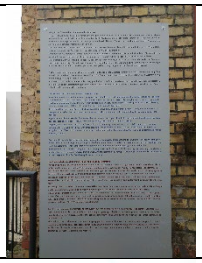
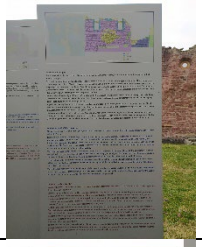
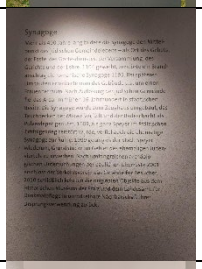
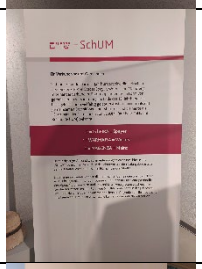
Photos					
Author	Provenance	Date	Name of the file	Description	Preview
			photo_museum_04.jpg	Description of the three floor tiles from the Frauenschul exhibited in the museum (“photo_museum_03” is one of them)	

Tab. 33 Overview and provenance of text sources (books, articles, leaflets, etc.).

Texts					
Name of the file	Title	Authors	Publisher	Date	Preview
article_01.pdf	„... war gezieret an den getünchten Mauern mit Gemählden“ Die Synagoge in Speyer In Die jüdische Gemeinde von Erfurt und die SchUM-Gemeinden: Kulturelles Erbe und Vernetzung	Pia Heberer	Bussert & Stadeler	2012	
article_02.pdf	Villa Spira -civitas: Zwei mittelalterliche Judensiedlungen in Speyer? in Zeitschrift für die Gesichte des Oberrheins	Monika Porsche		2003	
article_03.pdf	„Jerusalem am Rhein - eine Zeitreise vom Mittelalter bis heute“ Handreichung zur Nutzung der Materialsammlung im schulischen Unterricht und für außerschulische Projekte		Schumstaedte.de guidelines	2019 or after	
article_04.pdf	Jüdische SchUM-Städte am Rhein Speyer, Worms und Mainz sollen Weltkulturerbe werden in Kultur Neu Entdecken	Igal Aviden	SWR2 Leben	31.01. 2020	

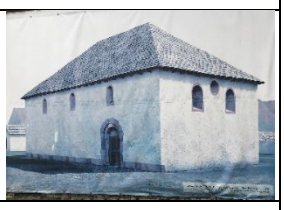
Texts					
Name of the file	Title	Authors	Publisher	Date	Preview
article_05.pdf	Ausgrabung und präsentation eines Mittelalterlichen rituralbades in sondershausen in Synagogen, mikwen, siedlungen Jüdisches alltagsleben im lichte Neuer archäologischer funde	Falk Nicol und Diethard Walter	Schriften des Archäologischen Museums Frankfurt	2004	
article_06.pdf	Mittelalterliche Synagoge in Speyer Forschung und Rekonstruktion in Europas Juden in Mittelalter	Pia Heberer	Herausgeben vom Historischen Museum der Pfalz Speyer	2004	
book_01.pdf	Jerusalem am Rhein Die SchUM-Gemeinden Speyer, Worms und Mainz in Beiträge zur rheinisch-jüdischen Geschichte	Ursula Reuter	Eine Schriftenreihe - Herausgegeben von der Gesellschaft zur Förderung eines Hauses und Museums der jüdischen Kultur in NRW e.V.	2013	
book_02.pdf	The Jews of Europe in the Middle Ages (Tenth to Fifteenth Centuries) Proceedings of the International Symposium held at Speyer, 20-25 October 2002	Eds.: Christoph Cluse	Brepols Publishers n.v., Turnhout, Belgium	2004	
book_03 (folder)	Die SchUM-Gemeinden Speyer - Worms - Mainz Auf dem Weg zum Welterbe	Eds.: Pia Heberer Ursula Reuter	Schnell & Steiner	2013	

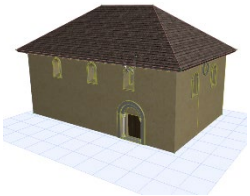
Texts					
Name of the file	Title	Authors	Publisher	Date	Preview
book_04 (folder)	Die SchUM-Städte Speyer Worms Mainz: Ausflugsziele zu den Kulturstätten des Judentums am Rhein	Matthias Preißler	Schnell & Steiner	2013	
description_01.jpg	Description of the Speyer Synagogue	Georg Litzel		1759	
flyer_01.pdf	Die Ausstellung: SchUM am Rhein Von Mittelalter in die Moderne	???	Jüdisches Museum Worms Raschi-Haus	2021	
flyer_02.jpg	Jüdisches in Speyer in Mittelalter		SchUM Museum Speyer		
flyer_03.jpg	Synagoge & Frauenschul		SchUM Museum Speyer		
infoboard_01.jpg	Jewish life in medieval Speyer		SchUM Museum Speyer - at location of syangoge ruins		
infoboard_02.jpg	The medieval “Jewish courtyard” and its buildings		SchUM Museum Speyer - at location of syangoge ruins		

Texts					
Name of the file	Title	Authors	Publisher	Date	Preview
infoboard_03.jpg	The “Frauenschul” and other gothic transformations		SchUM Museum Speyer - at location of syangoge ruins		
infoboard_04.jpg	The eastern wall of the synagogue		SchUM Museum Speyer - at location of syangoge ruins		
infoboard_05.jpg	Eastern wall of woman’s prayer hall		SchUM Museum Speyer - at location of syangoge ruins		
infoboard_06.jpg	Synagoge		SchUM Museum Speyer		
infoboard_07.jpg	Ein Verbund von drei Gemeinden		SchUM Museum Speyer		
infoboard_08.jpg	Die mittelalterliche Synagoge in Speyer		SchUM Museum Speyer		

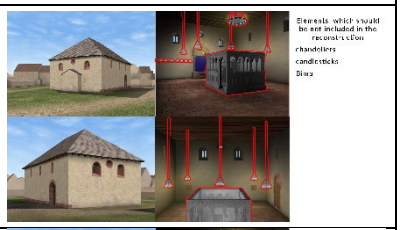
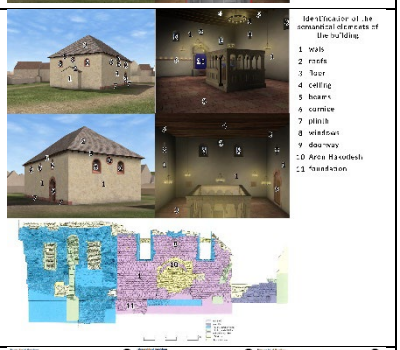
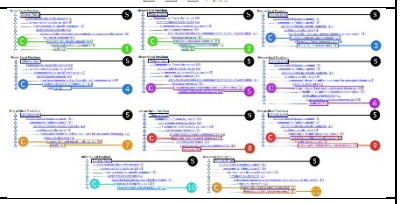
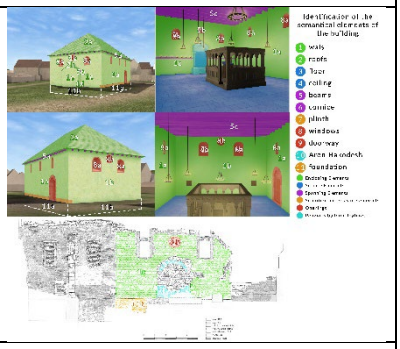
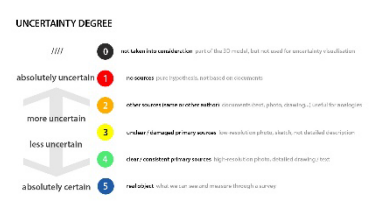
Texts					
Name of the file	Title	Authors	Publisher	Date	Preview
museum_labels_01.jpg	The Jews in Speyer in middle ages; The synagogue; Double arched windows		SchUM Museum Speyer		
museum_labels_02.jpg	Fragment of round arch; Cushion capital; Pillar base; Three floor tiles		SchUM Museum Speyer		

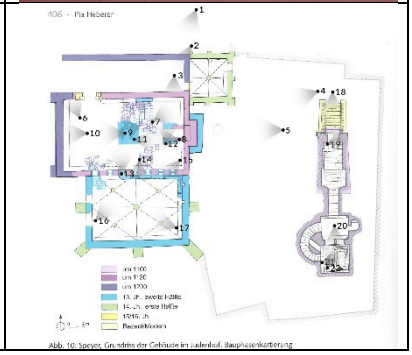
Tab. 34 Overview and provenance o sources based on digital reconstruction projects of the site (3D models, visualisations, reports).

3D reconstructions					
Provenance	Source	Name of the file	Description	Date	Preview
"The medieval synagogue Speyer 3D computer reconstruction" by Architectura Virtualis with cooperation of the TU-Darmstadt	http://www.architectura-virtualis.de/rekonstruktion/synagogespeyer/pdf/2004_synagoge_speyer.pdf	reconstruction_01_flyer.pdf	Short presentation of the project "Die mittelalterliche Synagoge Speyer. 3D Computer Rekonstruktion".	2003	
	Private collection of Irene Cazzaro	reconstruction_01_rendering_01.jpg	Photo of the 2003 synagogue visualization banner in the building location	2003	
	http://www.architectura-virtualis.de/rekonstruktion/synagogespeyer.php?lang=de&img=0&file=0	reconstruction_01_rendering_02.jpg	Interior visualisation of the synagogue in the Romanesque phase - view 1	2003	

3D reconstructions					
Provenance	Source	Name of the file	Description	Date	Preview
	http://www.architectura-virtualis.de/rekonstruktion/synagogespeyer.php?lang=de&img=9&file=7	reconstruction_01_rendering_03.jpg	Interior visualisation of the synagogue in the Romanesque phase with superimposition of a photograph of the current state of the building - view 2	2003	
	http://www.architectura-virtualis.de/rekonstruktion/synagogespeyer.php?lang=de&img=10&file=7	reconstruction_01_rendering_04.jpg	Interior visualisation of the synagogue in the Romanesque phase - view 2	2003	
	Uknown	reconstruction_01_rendering_05.jpg	Visualisations of the exterior of the synagogue in the Romanesque phase	2003	
Mainz - Worms - Speyer. Drei mittelalterliche Städte im Zentrum Europas als Linked Data	AI Mainz archive	reconstruction_02_model_01.pln	3D model of the synagogue reconstruction in Archicad format	2021	✗
		reconstruction_02_model_02.ifc	Model export to IFC format	2021	✗
		reconstruction_02_rendering_01.jpg	Screenshot of the synagogue model prepared for animation	2021	
		reconstruction_02_rendering_02.jpg	Screenshot of the synagogue model prepared for 3D printing	2021	

Tab. 35 Overview of the guidelines materials prepared by the authors of study (Igor Bajena & Irene Cazzaro).

Guidelines				
Name of the file	Used sources	Author	Description	Preview
guideline_01.jpg	reconstruction_01_rendering_02.jpg reconstruction_01_rendering_04.jpg reconstruction_01_rendering_05.jpg	Igor Bajena	Elements of the building, which should be skipped during the reconstruction	
guideline_02.jpg	reconstruction_01_rendering_02.jpg reconstruction_01_rendering_04.jpg reconstruction_01_rendering_05.jpg report_drawing_05.jpg	Igor Bajena	Identification of the structural elements of the building	
guideline_03.jpg	https://www.getty.edu/research/tools/vocabularies/aat/	Igor Bajena	Structure of identified elements based on the Art & Architecture Thesaurus® Online	
guideline_04.jpg	-	Igor Bajena	Scheme of the created hierarchy of structural elements of the building	
guideline_05.jpg	reconstruction_01_rendering_02.jpg reconstruction_01_rendering_04.jpg reconstruction_01_rendering_05.jpg report_drawing_05.jpg	Igor Bajena	Applying different structural categories to the building and identification of the types of structural elements	
guideline_06.jpg	-	Irene Cazzaro	General uncertainty scale according to the physical or mental operations we should do when dealing with different sources	
guideline_07.jpg	reconstruction_01_rendering_05.jpg	Irene Cazzaro	Application of the uncertainty scale to the synagogue exterior view	

Guidelines				
Name of the file	Used sources	Author	Description	Preview
guideline_08.jpg	reconstruction_01_rendering_02.jpg	Irene Cazzaro	Application of the uncertainty scale to the synagogue interior view	
guideline_09.jpg	report_drawing_03.jpg	Igor Bajena	Identification of photo sources from location on the plan view of Jewish Quarter	

Appendix 4: Workflows and documentation of Case Study SpSya1250

Below are materials provided by those modelling the case study of the reconstruction of Speyer Synagogue in the 13th century. Each person provided a short report about the time of each step with some comments and a documentation table and a table describing the workflow of the respective programme.

Blender

3D Model by Stefan Wetherington (Blender 3.0.0)

1) Modelling time: ~20 hours.

   The trial-and-error process of splitting the walls between certainty levels with a boolean modifier took a lot of time, and the correction passes also took quite some time.

2) Workflow documentation: <25 minutes.

   Taking screenshots during the modelling process quickend this documentation.

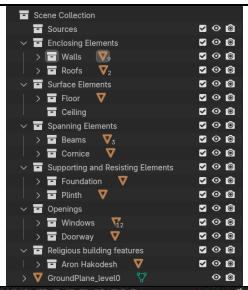
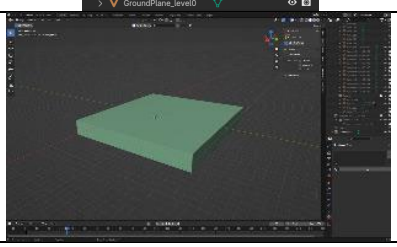
3) Objects documentation: >4 hours.

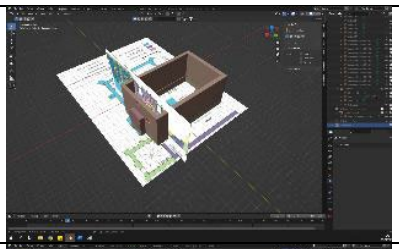
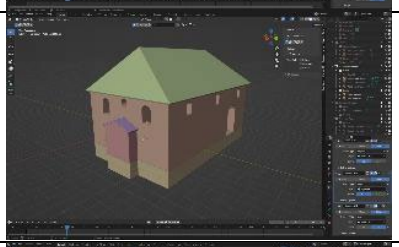
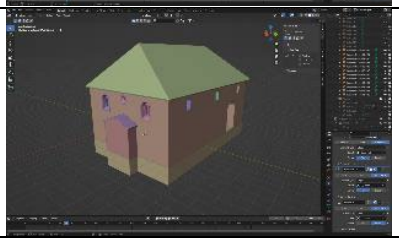
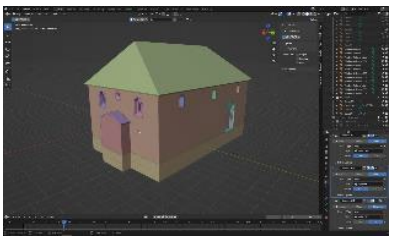
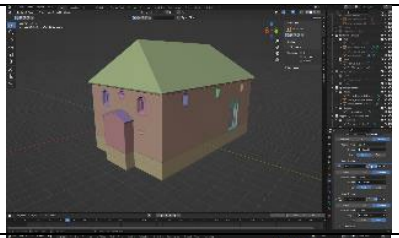
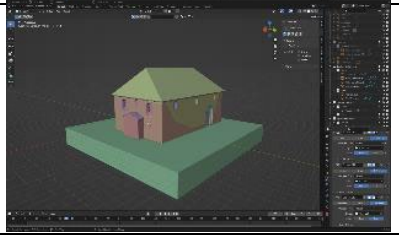
   Took quite long. Filling out all of the fields was time consuming. Multiple screenshots had to be made during the documentation.

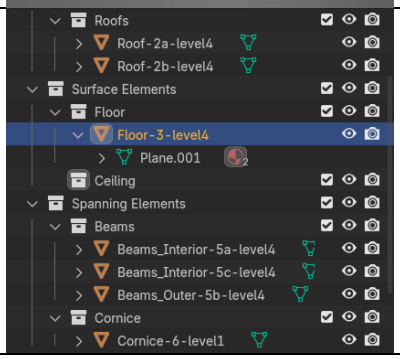
4) WissKI entry: First entry: ~20 mins, following entries: 4 mins.

   The first entry took quite a while, even though I had used a similar upload form before. Not all boxes were clearly defined, often there where multiple options of the same type when something was suggested (Multiple Variations of AI Mainz for example). It was also unclear why there was an upload for the model at the top, and further down a "native"-file upload. The following uploads were quicker, as I didn't have to fully fill out everything (for example my name showing up as an entity) and I then kind of knew what to input where.

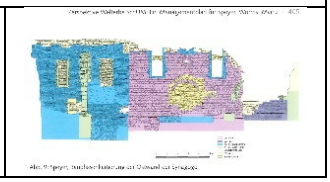
Tab. 36 Reconstruction workflow steps in Blender by Stefan Wetherington.

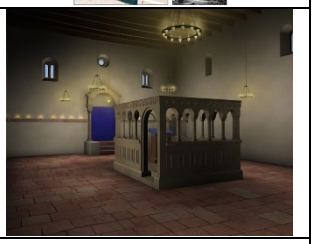
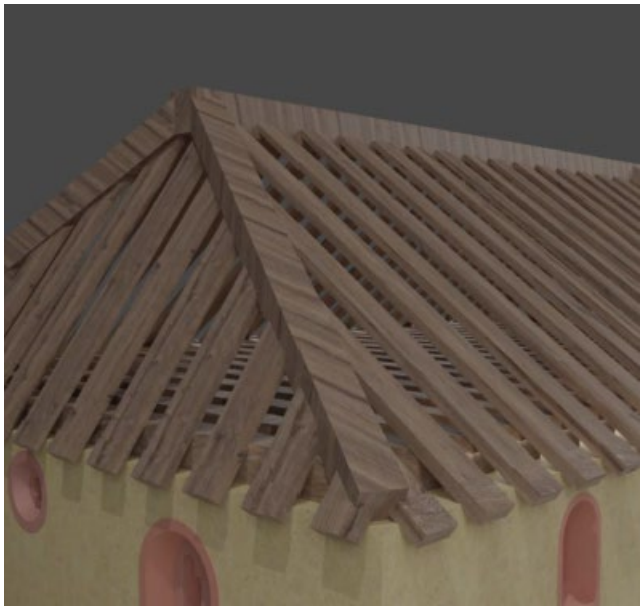
Workflow in Blender		
1	Implementation of the semantic components using named groups ['Collections' in Blender] that structured using the suggested hierarchy. The objects are then placed inside the innermost collections.	
2	The ground plane was created using a cube mesh, which was then enlarged to 25x25x3m by typing in those dimensions into its attributes.	

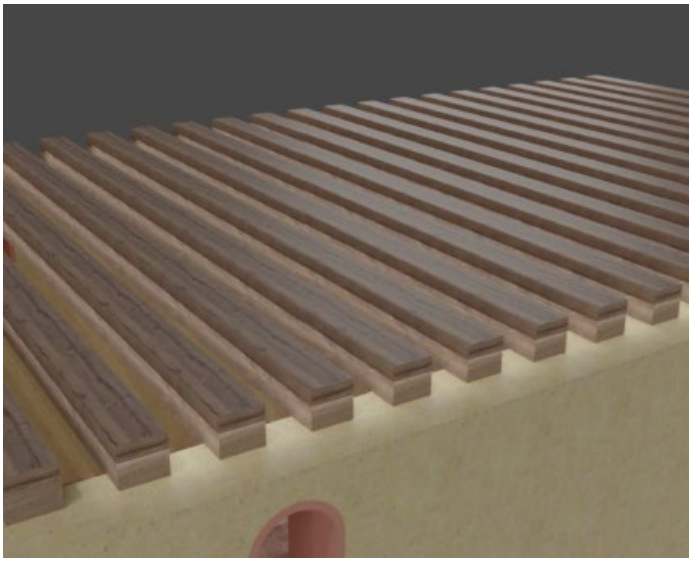
3	Same of the sources were added to the scene [here: floor plans] by simply importing them and scaling them to the correct size. The walls were modelled by extruding a cube mesh along the walls of the floor plan.	
4	The foundation was added by copying the bottom plane of the wall mesh and then extruding it to the correct depth. The openings were cut out from the wall mesh using a Boolean modifier, which made them non-destructive and easily modifiable at this stage.	
5	The largest roof was modelled using a cube mesh and merging its top edges to create a triangular prism. The smaller roof was created using a cube mesh for one side of the roof and then using a mirror modifier to mirror it onto the other side.	
6	The windows were created by tracing their outline using vertices from one of the provided sources. A cylinder mesh was later added to the mesh to create the column in the major windows.	
7	The doorway was created the same way as the windows - by tracing them from the sources. The columns, their bases and capitals were added using the Archimesh-Addon, which is already included in Blender. It lets you import a set of architectural elements and then lets you change them by changing in their attributes in a drop-down menu.	
8	The beams were added by using a cube mesh, which was modelled into a single beam and then copying it using the array modifier. This lets you specify how often you want an element repeated and what the distance between them should be.	
9	Parts of the Aaron Hakodesh was also modelled using the Archimesh-Addon [Columns, Arch, Capitals, Bases]. The gable was created using the Archimesh from the addon and then extruding and moving some vertices. The stairs were made using a simple cube mesh.	
10	The wall was separated by using a boolean modifier. The hole was then filled by adding a new mesh that fit the missing space perfectly.	

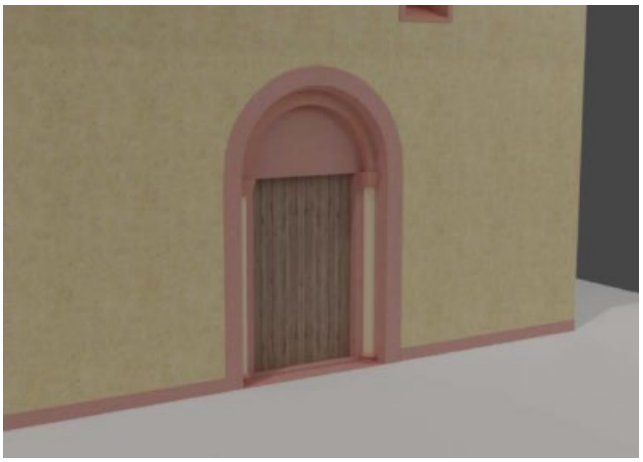
11	The texture tiles were added to the unwrapped UVs of the objects. They were then scaled and rotated.		
12	The uncertainty scale was implemented by including the level in the object name. The name also includes the ID from the semantic elements described in the handout.		

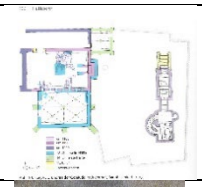
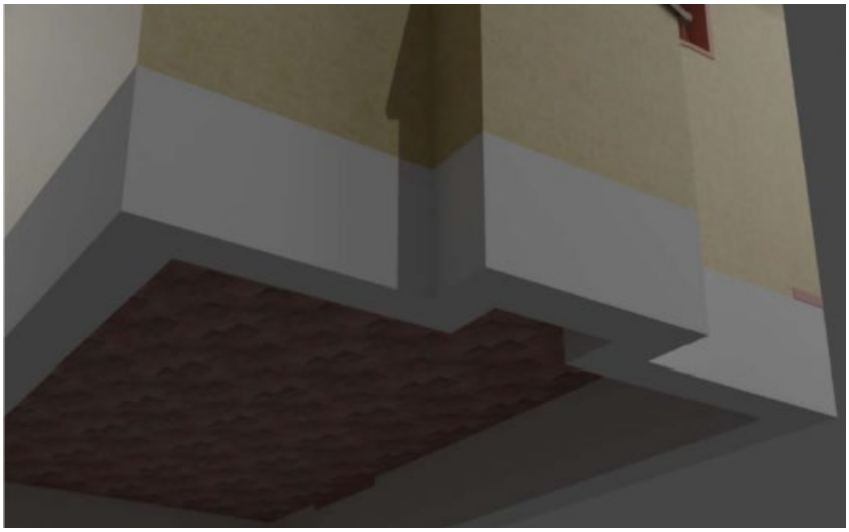
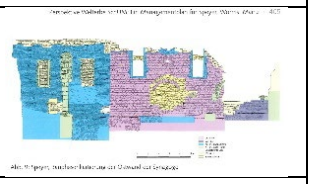
Tab. 37 Documentation of a 3D reconstruction of the semantic elements of Speyer Synagogue in the 13th century by Stefan Wetherington in Blender.

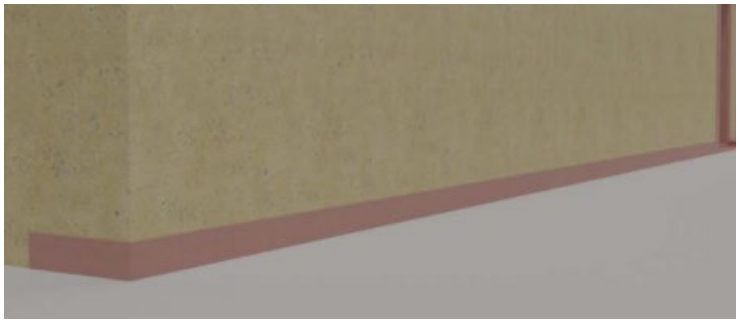
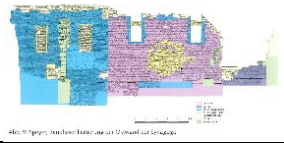
Aaron Hakodesh		
Reconstruction (1)		
Used sources	Report_05	

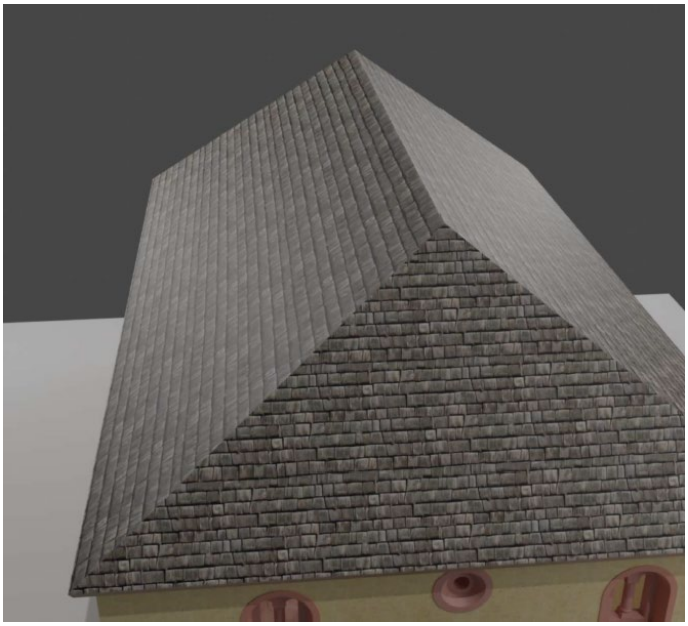
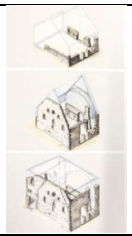
	Article_01	
	Reconstruction_01_rendering_02	
Uncertainty	The still standing wall shows remnants of the Aaron Hakodesh. The reconstruction has an Aaron Hakodesh which can be used as reference. There are some sources that show an Aaron Hakodesh from around a similar timeframe.	Level 2 (recess) Level 3 (columns, gabel, stairs)
Argumentation	The Aaron Hakodesh was modelled using the measurements provided in article_01 and the dimensions from the report_05. The overall shape was taken from the prior reconstruction.	
Beams 5a		
Reconstruction (2)		
Used sources	Reconstruction_01_rendering_05	
Uncertainty	Nothing is left of the original roof at the site. There are also no other surviving roofs from that period. That also true for the beams.	Level 2
Argumentation	Hip roof beams were modelled. An array modifier was used to duplicate the beams and then a mirror modifier to mirror them along an axis. At the end some supporting beams were added to connect them all to ether.	

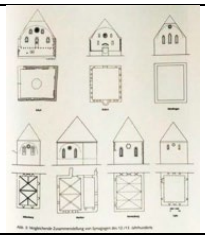
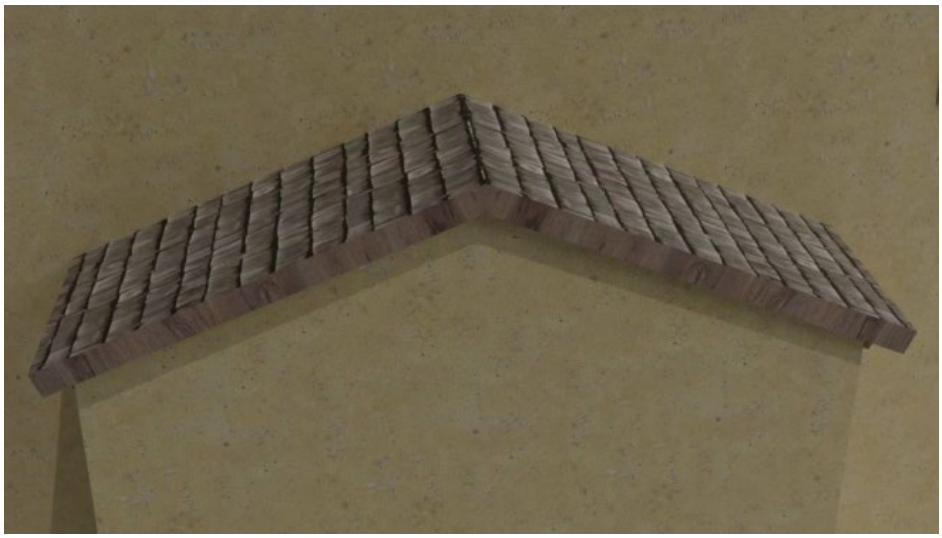
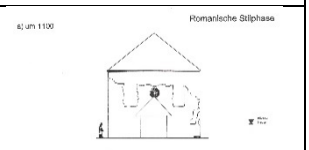
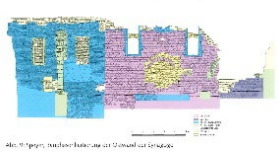
Beams 5b		
Reconstruction (3)		
Used sources	Reconstruction_01_rendering_05	
Uncertainty	Nothing is left of the original roof at the site. There are also no other surviving roofs from that period. That also true for the beams.	Level 4
Argumentation	Gable roof beams were modelled. An array modifier was used to duplicate the beams and then a mirror modifier to mirror them along an axis.	
Beams 5c		
Reconstruction (4)		

Used sources	Reconstruction_01_rendering_02	
Uncertainty	Nothing is left of the original roof at the site. There are also no other surviving roofs from that period. That also true for the beams.	Level 4
Argumentation	Overarching beams were modelled to span the room. One beam was modelled and then copied via an array modifier.	
Cornice		
Reconstruction (5)		
Used sources	Reconstruction_01_rendering_02	
Uncertainty	Parts of the cornice can still be found in the inside of the eastern wall.	Level 1
Argumentation	Added the cornice ledge at the appropriate height.	
Entrance		
Reconstruction (6)		

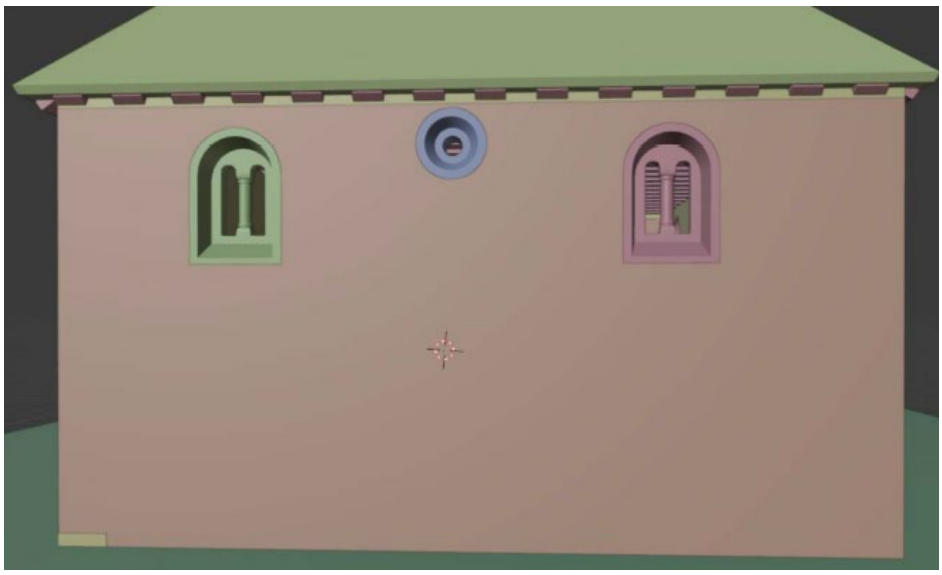
Used sources	Report_04	
	Analogy_02_01	
Uncertainty	The width of the entrance can still be found in the floor plan of report_04. There are analogies that can be referenced.	Level 3
Argumentation	A hole was cut out of the wall with a boolean. Then a cylinder was put in place and the bottom half removed. Pillars were added and the wooden door inserted.	
Foundation		
Reconstruction (7)		
Used sources	Report_05	
Uncertainty	Parts of the foundation were uncovered during the excavation and were recorded in report_05.	Level 1
Argumentation	Used the floor plan for the layout of the foundation. Sadly, the foundation is probably thicker than the walls, but there is no source showing this thickness.	

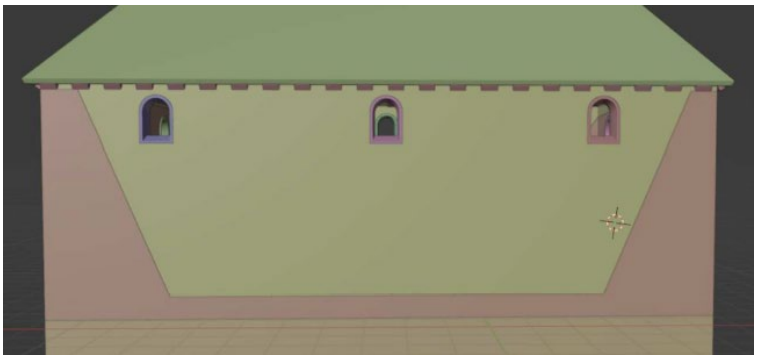
Plinth		
Reconstruction (8)		
Used sources	Reconstruction_01_rendering_05	
	Report_05	
Uncertainty	The plinth can be found at the site and is recorded in report_05.	Level 1
Argumentation	Was added later in the modelling process. A simple elongated cube.	

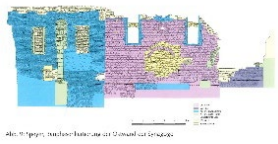
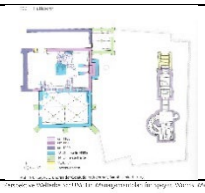
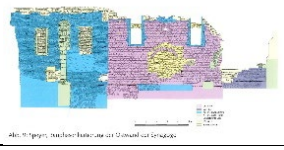
Roof 2a		
Reconstruction (9)		
Used sources	Analogy_05	

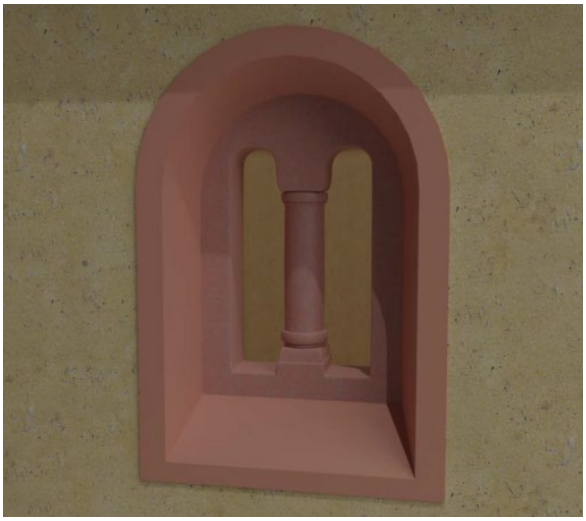
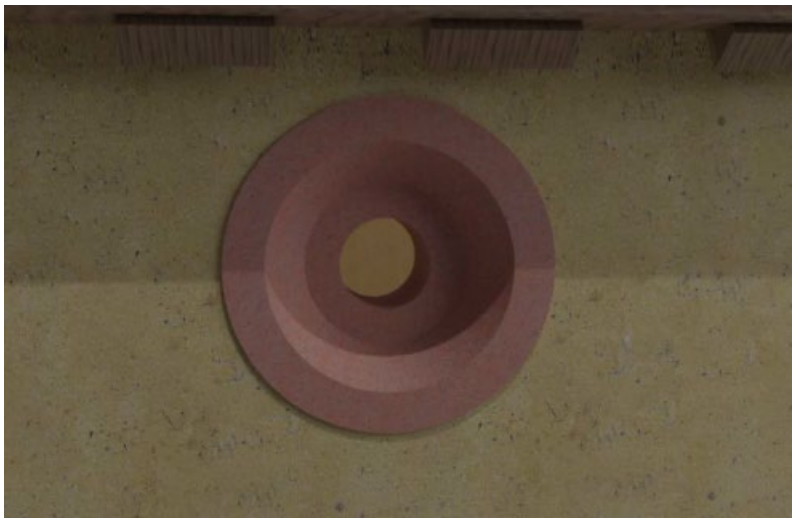
	Analogy_04	
	Reconstruction_02_rendering_01	
Uncertainty	Nothing is left of the original roof at the site. There are also no other surviving roofs from that period.	Level 4
Argumentation	A hip roof was modelled. It is the closest to the reconstructions.	
Roof 2b		
Reconstruction (10)		
Used sources	Drawing_01	
	Reconstruction_01_rendering_05	
	Report_05	
Uncertainty	Nothing is left of the original roof at the site. There are also no other surviving roofs from that period.	Level 4
Argumentation	A gable roof was modelled. It is the most likely covering of the extrusion.	

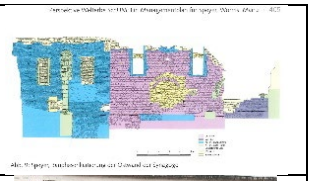
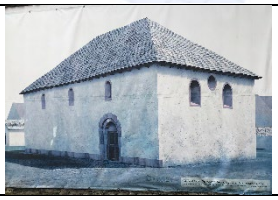
Wall 1a		
Reconstruction (11)		
Used sources	Photo_location_02	
Uncertainty	Parts of the wall can still be found at the location. The missing part of the wall needs to be reconstructed on that basis.	Level 1 [remaining walls] Level 2 [missing walls]
Argumentation	Most complicated part of the whole modelling process. The complete wall was modelled at the beginning. Later a boolean modifier was used to cut away the missing part of the wall and then filled up with a separate object.	

Wall 1b	
Reconstruction (12)	

Used sources	Photo_location_09	
Uncertainty	Parts of the wall can still be found at the location. The missing part of the wall needs to be reconstructed on that basis.	Level 1 [remaining walls] Level 2 [missing walls]
Argumentation	Most complicated part of the whole modelling process. The complete wall was modelled at the beginning. Later a boolean modifier was used to cut away the missing part of the wall and then filled up with a separate object.	
Wall 1c		
Reconstruction (13)		
Used sources	No source provided?	
Uncertainty	Parts of the wall can still be found at the location. The missing part of the wall needs to be reconstructed on that basis.	Level 1 [remaining walls] Level 2 [missing walls]
Argumentation	Most complicated part of the whole modelling process. The complete wall was modelled at the beginning. Later a boolean modifier was used to cut away the missing part of the wall and then filled up with a separate object.	
Wall 1d		
Reconstruction (14)		

Used sources	Photo_location_10	
	Report_05	
Uncertainty	Parts of the wall can still be found at the location. The missing part of the wall needs to be reconstructed on that basis.	Level 1 [remaining walls] Level 2 [missing walls]
Argumentation	Most complicated part of the whole modelling process. The complete wall was modelled at the beginning. Later a boolean modifier was used to cut away the missing part of the wall and then filled up with a separate object.	
Wall 1e		
Reconstruction (15)		
Used sources	Report_04	
	Report_05	
Uncertainty	The foundation of the extrusion still survives today. The dimensions can be gleaned from both the reports above.	Level 2
Argumentation	All the walls were extruded upwards from the dimensions of the report. The wall 1e was only extruded up to the height found in report_5 together with the estimated height of the Aaron Hakodesh.	

<table>
<tr><th colspan="4">Window 8a</th></tr>
<tr><td>Reconstruction (16)</td><td colspan="3">  </td></tr>
<tr><td rowspan="2">Used sources</td><td colspan="2">Photo_museum_02</td><td> </td></tr>
<tr><td colspan="2">Photo_location_10</td><td> </td></tr>
<tr><td>Uncertainty</td><td colspan="2">The windows are still embedded into the wall, and an additional set is displayed at the museum.</td><td>Level 1</td></tr>
<tr><td>Argumentation</td><td colspan="3">First the sources were added to Blender as reference pictures. To be able to get the form of the column and its Argumentation connection right, a subsurface modifier was added. This makes this the object with by fa~ the most vertices. Which also makes it the object that took the longest to model.</td></tr>
<tr><th colspan="4">Window 8b</th></tr>
<tr><td>Reconstruction (17)</td><td colspan="3">  </td></tr>
</table>

Used sources	Report_05	
	Photo_location_10	
Uncertainty	The windows can still be found in the walls.	Level 1
Argumentation		
Window 8c		
Reconstruction (18)		
Used sources	Reconstruction_02_rendering_01	
	Reconstruction_01_rendering_01	
Uncertainty	The windows cannot be found in the still standing walls, or in the archaeological report. The only source for this project are the prior made renders.	Level 4
Argumentation	For these windows the Ba windows were used, and then scaled down to fit the openings. The position and amount were taken from the reconstructions. No major problems during modelling.	

3D Model by Louise Tharandt (Blender 3.0.3)

1) Modelling time: ~26 hours.

   The reconstruction itself was pretty easy, as the models were reconstructed as an ideal version and not in their "natural" form. It was also easier, as the textures were already defined, which meant, that I could concentrate on each structural element. I also invested some time into trying to find the best method and easiest workflow to reconstruct each element, which led to a few tries to reconstruct some parts of the synagogue.

2) Research time: ~ 10 hours.

   The research was made much quicker, because of the access to the collected sources on the server. The photos from the location were a big help, as were some of the text documents. In a few cases, it took some time to find the right source, as I was trying not to use any of the other reconstruction, because I did not know, on what kind of sources these were based on.

3) Documentation time: ~6 hours.

   The documentation was done rather quickly, I had written some notes while reconstructing the synagogue. I had also written a short daily report of the work I had done, which made it easier to remember the workflow of the reconstructions.

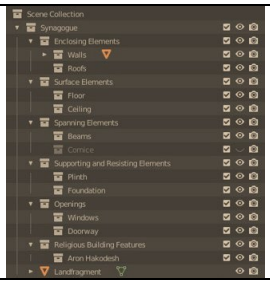
4) WissKI entry: First entry: ~ 1 hour, following entries: ~10mins.

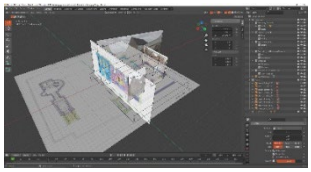
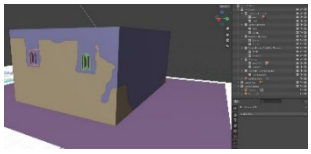
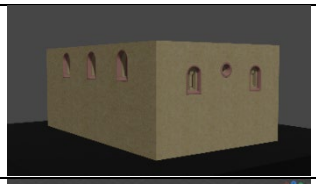
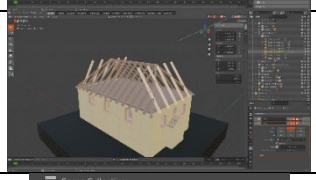
   I had some problems uploading my first export, as the file size was limited. Afterwards I managed to upload the correct files, but it took some time to fill out each section. It was especially confusing, as in some fields I had to create new entries, while the entry was already in the list of examples (e.g. organizations). I also notices to late, that I edited the wrong model, which I did not build or upload.

   The other uploads went quicker, as I was simply adding the same information every time, just a different export file with it, but adding the information sometimes resulted in the wrong entry that I did not put in there, this led to me having to start the process again. It was also taking longer, because most of the time the model did not show, which led to me trying to fix the export and upload without any luck.

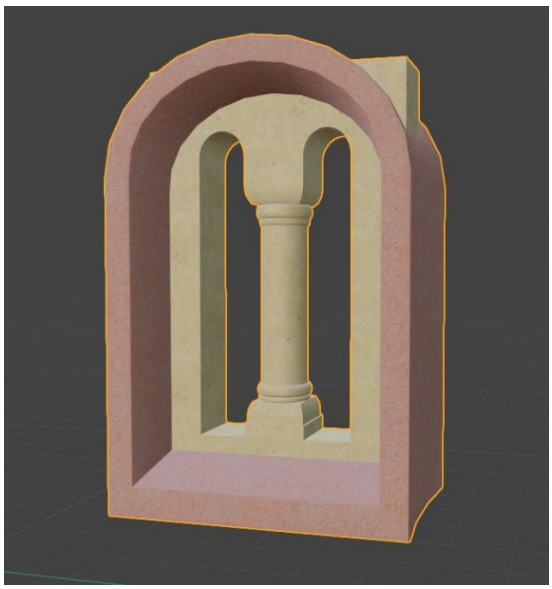
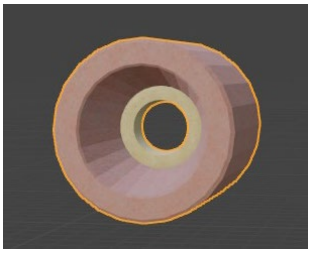
   Currently I have managed to upload a .glb and a .fbx file, no other file formats have worked.

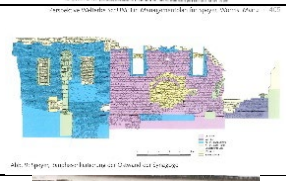
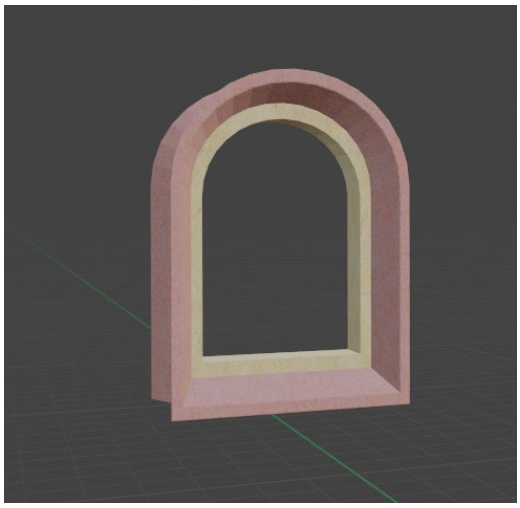
Tab. 38 Reconstruction workflow steps in Blender by Louise Tharandt.

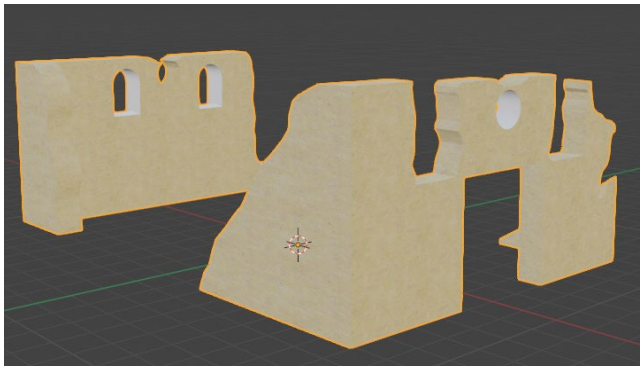
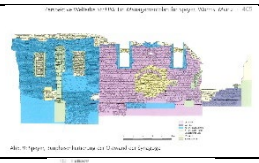
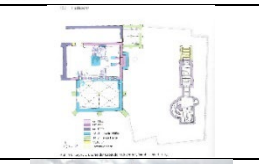
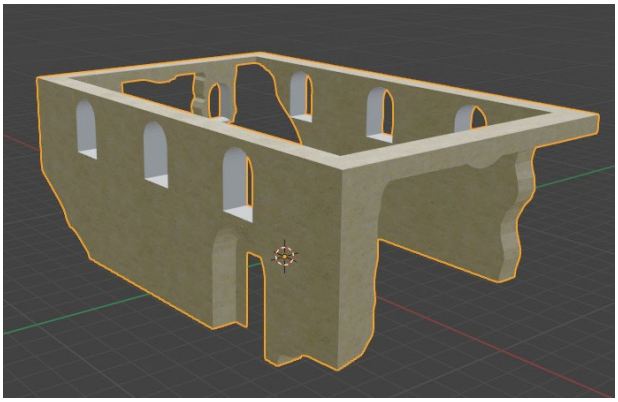
Workflow in Blender			
1	Set up the reconstruction and created the semantic architectural structure, by creating new collections and adding the corresponding elements into these "folders".		

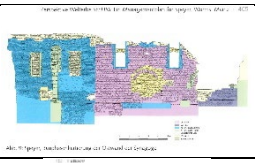
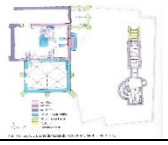
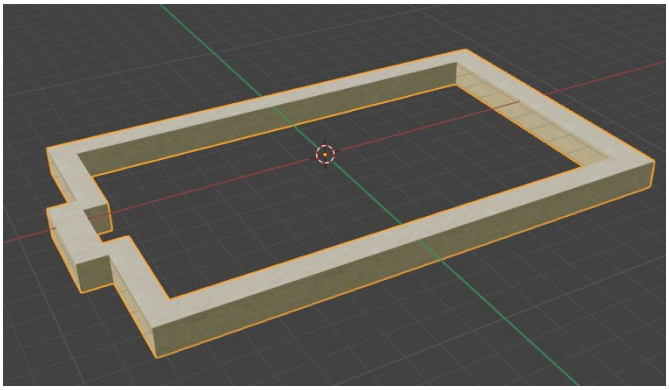
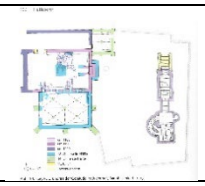
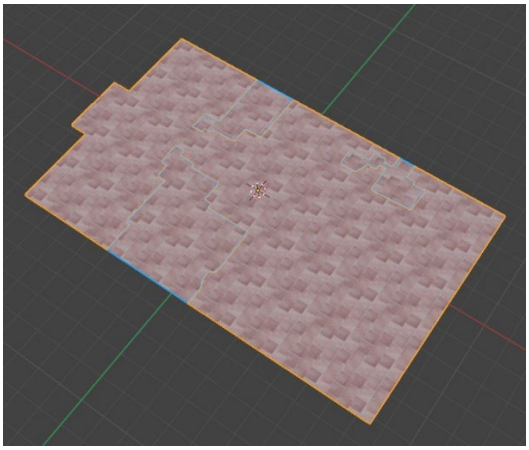
2	Started the basic groundwork for the reconstruction of the synagogue by adding and scaling all necessary reference images. The certainty of all elements was researched and written down, to add to the planned reconstructions.	
3	Reconstructed the still existing windows, the walls (which were separated after marking the still existing part with the knife tool) and foundation, as well as first experimentation on how to add the windows into the reconstructed walls (Booleans) and adding the correct textures.	
4	Reconstructed the rest of the windows by using text references and adding these with the correct textures into the reconstructed walls of the synagogue.	
5	Reconstructed all the elements of the doorway of the synagogue, researched and added the plinth, and reconstructed the floor on the inside of the building.	
6	Added the Aron HaKodesh space on the outside of the eastern façade and reconstructed the elements of the Aron HaKodesh on the inside of the synagogue.	
7	Reconstructed the cornice and all necessary beams as well as the roof of the synagogue. Textured all elements and checked for any errors or wrong names /certainty levels.	
8	Reviewed all reconstructed elements and added the correct names and certainty levels to the object properties. Checked the rotation, scale and location of all elements and set the location of all elements to the same coordinate.	

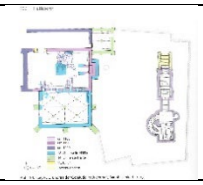
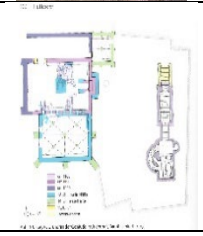
Tab. 39 Documentation of a 3D reconstruction of the semantic elements of Speyer Synagogue in the 13th century by Louise Tharandt in Blender.

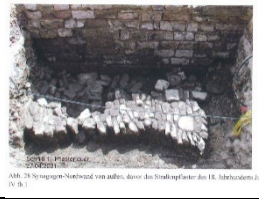
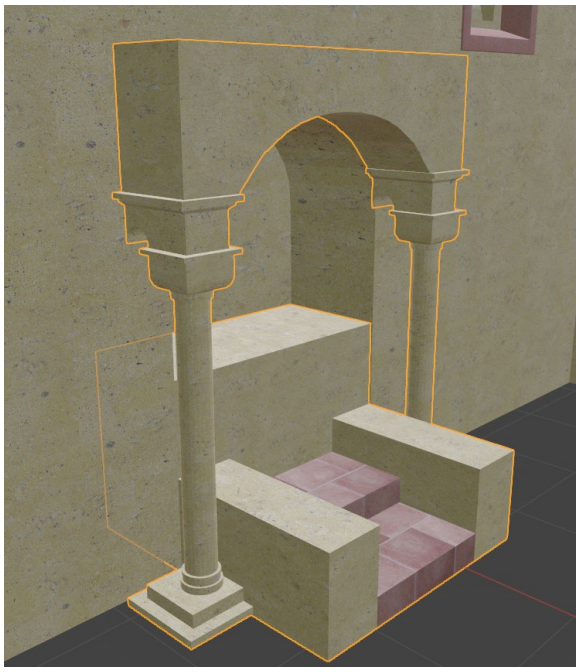
<table>
<tr><th colspan="3">Window_a</th></tr>
<tr><td>Reconstruction (1)</td><td colspan="2">  </td></tr>
<tr><td rowspan="2">Used sources</td><td>Report_text_page11</td><td> </td></tr>
<tr><td>Photo_museum_01</td><td> </td></tr>
<tr><td>Uncertainty</td><td>The windows on the western façade are still existing (now in museum) and are therefore level 4. The windows of the eastern wall were reconstructed based on the windows from the museum.</td><td>Windows West wall: Level 4
Windows East wall: Level 3</td></tr>
<tr><td>Argumentation</td><td colspan="2">On the basis of the museum photo, a simple cube was used in combination with two cylinders as Booleans to create the bifocal shape of the window. The dimensions were taken from the report text page 11 by Georg Litzel. The column of the window was added as an extra cylinder mesh, while the upper and lower parts of the columns were built from the leftovers of the Boolean in the cube.</td></tr>
<tr><th colspan="3">Window_b</th></tr>
<tr><td>Reconstruction (2)</td><td colspan="2">  </td></tr>
</table>

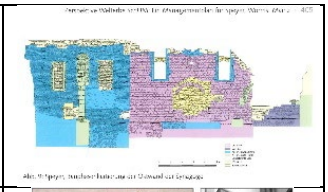
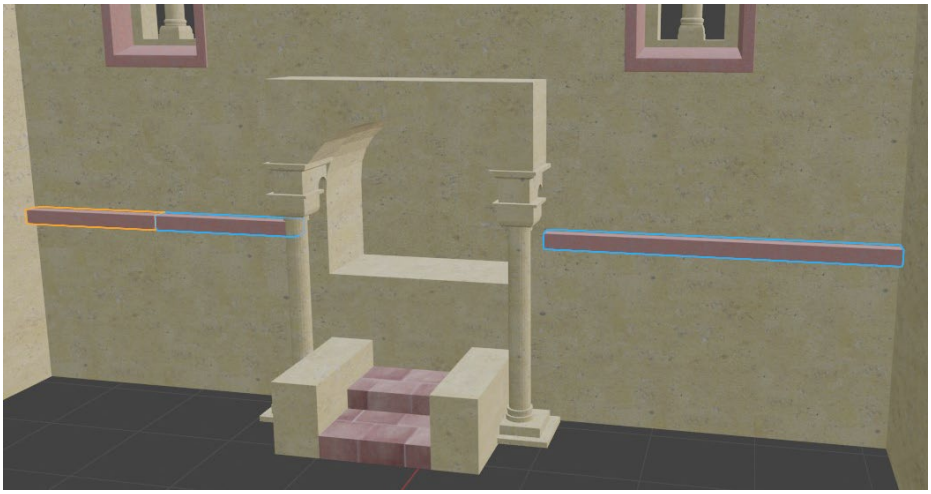
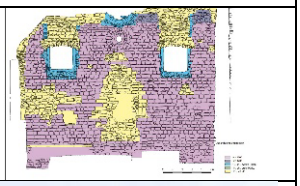
Used sources	Report_text_page11	
	Report_drawing_05	
	Photo_location_10	
Uncertainty	As there are still windows visible in each wall, the level of uncertainty is 4 = still existing	Level 4
Argumentation	The report drawing was taken as the basis for the reconstruction and dimension of the window, while the photo was used to see how deep the windows were set into the wall. The dimensions were compared to the report text page 11 by Georg Litzel. The windows were reconstructed with a cylinder, that was solidified and a cylinder as a Boolean.	
Window_c		
Reconstruction [3]		
Used sources	Report_text_page11	
Uncertainty	The windows don't exist any more and there are no visible markings in the walls to reconstruct the placement or dimensions of the windows.	Level 2
Argumentation	The dimensions, structure and placement were taken from the report text page 11 by Georg Litzel. The windows were reconstructed with a cylinder, which was cut in half and solidified, this was then copied and used as a Boolean.	

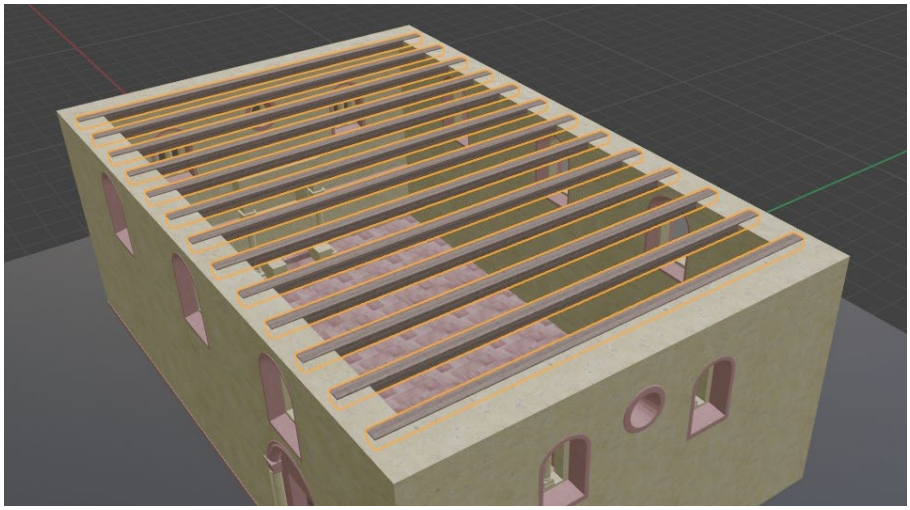
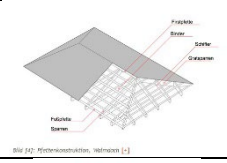
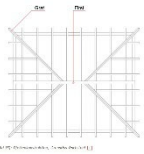
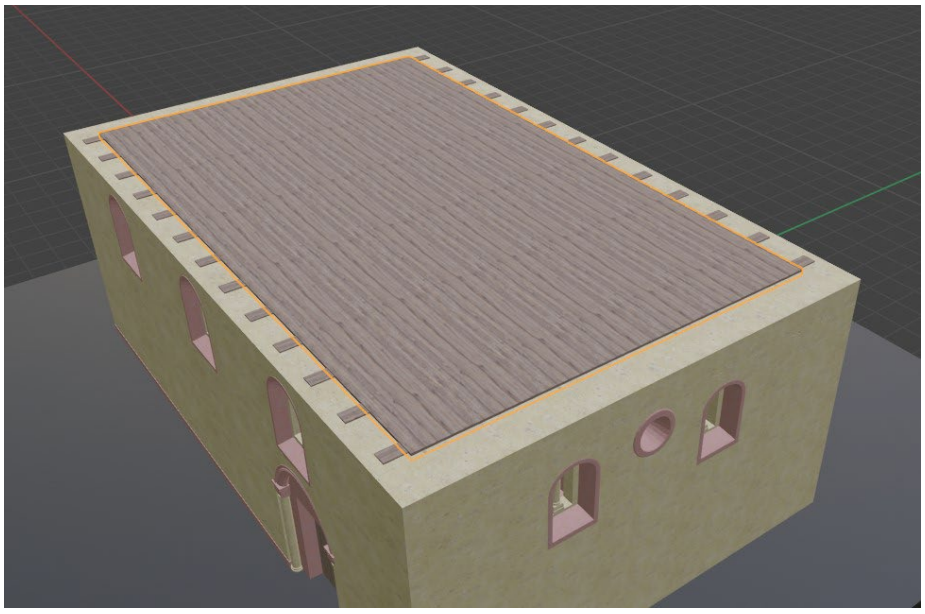
<table>
<tr><th colspan="3">Wall_a</th></tr>
<tr><td>Reconstruction (4)</td><td colspan="2">  </td></tr>
<tr><td rowspan="5">Used sources</td><td>Report_drawing_05</td><td>  </td></tr>
<tr><td>Report_drawing_03c</td><td>  </td></tr>
<tr><td>Photo_location_02</td><td> </td></tr>
<tr><td>Photo_location_03</td><td> </td></tr>
<tr><td>Photo_location_09</td><td> </td></tr>
<tr><td>Uncertainty</td><td>These wall are still existing and were examined and dated to specific time periods.</td><td>Level 4</td></tr>
<tr><td>Argumentation</td><td colspan="2">The dimensions of the wall were taken from report_drawing_03 and 05, with the difference to the reconstructed walls taken from the photographs.</td></tr>
<tr><th colspan="3">Wall_b</th></tr>
<tr><td>Reconstruction (5)</td><td colspan="2">  </td></tr>
</table>

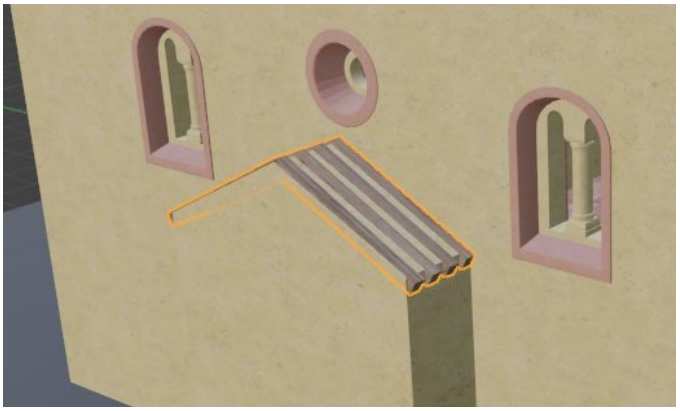
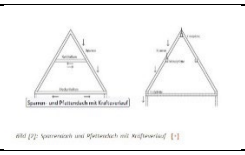
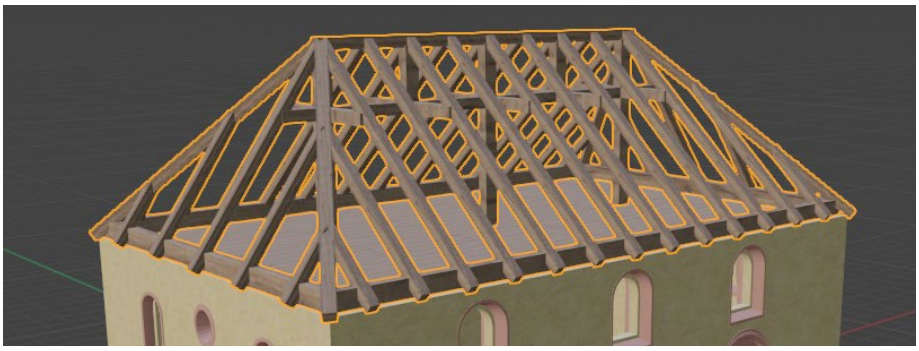
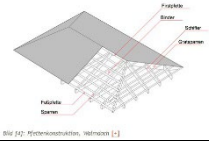
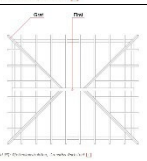
Used sources	Report_drawing_05	
	Report_drawing_03c	
Uncertainty	These walls were reconstructed based on the missing areas between the ruins of the walls, that can be still seen today.	Level 3
Argumentation	The dimensions of the wall were taken from report_drawing_03 and 05, with the difference to the reconstructed walls taken from the photographs. The walls were first created from a cube, with a different cube as a Boolean and then cut with the Knife tool to separate the still existing wall (a) and the reconstructed wall (b).	
Foundation		
Reconstruction (6)		
Used sources	Report_drawing_03	
Uncertainty	The foundation can still be found today and was examined in the archaeological excavation.	Level 4
Argumentation	The dimensions were taken from the report_drawing_03 and the height was defined at 1 Meter.	
Floor		
Reconstruction (7)		

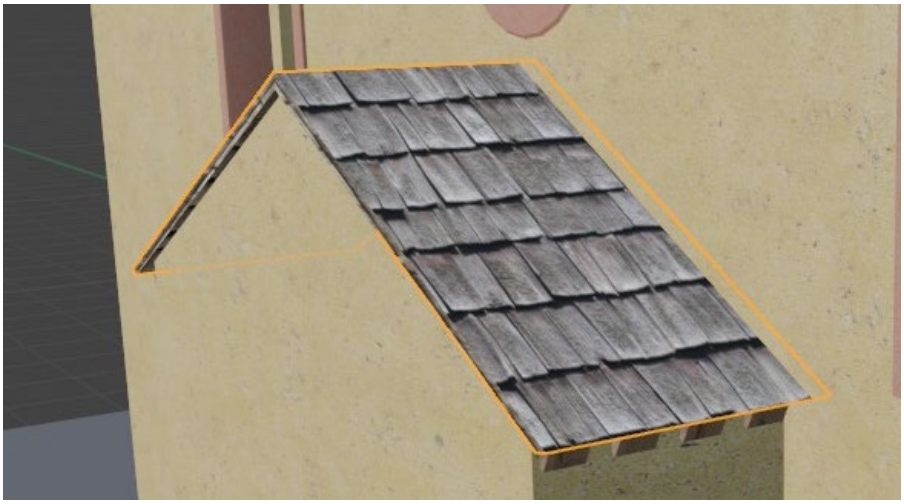
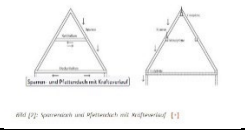
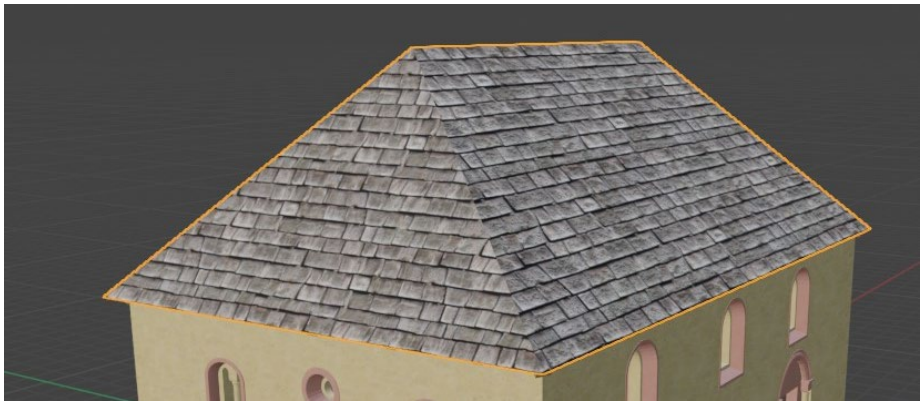
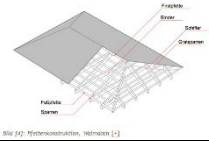
Used sources	Report_drawing_03	
Uncertainty	In the report drawing some of the floor parts are marked as still existing (level 4), the rest was deducted (level 3)	Level 4 Level 3
Argumentation	The floor was reconstructed with the report drawing as a basis. First a cube was modelled to fit the dimensions of the synagogue, with the Knife tool the still existing floor part were cut out and then separated.	
Doorway		
Reconstruction (8)		
Used sources	Analogy_02_01	
	Report_drawing_03	
Uncertainty	There is not much left of the doorway, so the doorway of analogy_02 was used.	Level 2
Argumentation	The basic structure of analogy_02 was used to recreate and reconstruct the doorway of the synagogue. The width was taken from the report_drawing_03. The doorway was modelled by combining cubes and cylinders and using Booleans to create the opening for the door.	

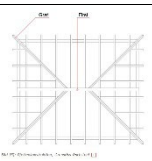
<table>
<tr><th colspan="4">Plinth</th></tr>
<tr><td>Reconstruction (9)</td><td colspan="3"> </td></tr>
<tr><td rowspan="2">Used sources</td><td colspan="2">Report_text_Page27</td><td> </td></tr>
<tr><td colspan="2">Report_text_Page95_Abb28</td><td>  </td></tr>
<tr><td>Uncertainty</td><td colspan="2">There are no definitive images of the plinth, but in the archaeological report it is mentioned, that the plinth was found in the excavation.</td><td>Level 4</td></tr>
<tr><td>Argumentation</td><td colspan="3">Based on the archaeological report the plinth was added with a simple cube, fitting with the dimensions of the northern façade.</td></tr>
<tr><th colspan="4">Aron HaKodesh</th></tr>
<tr><td>Reconstruction (10)</td><td colspan="3">  </td></tr>
</table>

Used sources	Report_drawing_05	
	article_01_Page183_Abb17_18	
Uncertainty	There is not much left of the Aron Hakodesh, which led to the use of analogies, mainly the text and images from article_01.	Level 2
Argumentation	The reconstruction was mainly based on article_01 and modelled to fit with the rest of the Aron Hakodesh, which was visible in the eastern wall. The reconstruction was created with cubes, cylinders and Booleans, which were modelled to fit the overall look found in article_01.	
Cornice		
Reconstruction (11)		
Used sources	Article_01_Page182_Abb14	
	Photo_location_11	
Uncertainty	There are still parts of the cornice visible (level 4) the rest of the cornice was reconstructed (level 3).	Level 4 Level 3
Argumentation	The drawing of the inner wall was mainly used to reconstruct the cornice and model the missing parts. A cube was used to build the cornice, which was then separated to the still existing and the reconstructed parts.	

Beams_c		
Reconstruction (12)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	
	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	
Uncertainty	The beams and roof of the synagogue don't exist anymore, there are no fitting analogy to use for the reconstruction.	Level 1
Argumentation	Without any analogies or similar structures, the beams were modelled after the architectural basics of the type of roof, that was defined for the synagogue. The beams were reconstructed from cubes, which were multiplied with the Array modifier.	
Ceiling		
Reconstruction (13)		

Used sources	There are no sources	
Uncertainty	The beams and roof of the synagogue don't exist anymore, and there is no source for a ceiling between the beams for the roof.	Level 1
Argumentation	A ceiling was added, which is also the floor of the attic. It was modelled from a cube and set on top of the beams c.	
Beams_b		
Reconstruction (14)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-s/satteldach.php?searchresult=1&sstring=satteldach#wb_460	
Uncertainty	The beams and roof of the synagogue don't exist anymore, there are no fitting analogy to use for the reconstruction.	Level 1
Argumentation	Without any analogies or similar structures, the beams were modelled after the architectural basics of the type of roof, that was defined for the synagogue. The beams were reconstructed from cubes, which were multiplied with the Array modifier.	
Beams_a		
Reconstruction (15)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	
	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	

Uncertainty	The beams and roof of the synagogue don't exist anymore, there are no fitting analogy to use for the reconstruction.	Level 1
Argumentation	Without any analogies or similar structures, the beams were modelled after the architectural basics of the type of roof, that was defined for the synagogue. The beams were reconstructed from cubes, which were multiplied with the Array modifier.	
Roof_b		
Reconstruction (16)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-s/satteldach.php?searchresult=1&sstring=satteldach#wb_460	
Uncertainty	The beams and roof of the synagogue don't exist anymore, there are no fitting analogy to use for the reconstruction.	Level 1
Argumentation	Without any analogies or similar structures, the roof was modelled to fit the structure of the beams.	
Roof_a		
Reconstruction (17)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	

	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	
Uncertainty	The beams and roof of the synagogue don't exist anymore, there are no fitting analogy to use for the reconstruction.	Level 1
Argumentation	Without any analogies or similar structures, the roof was modelled to fit the structure of the beams.	

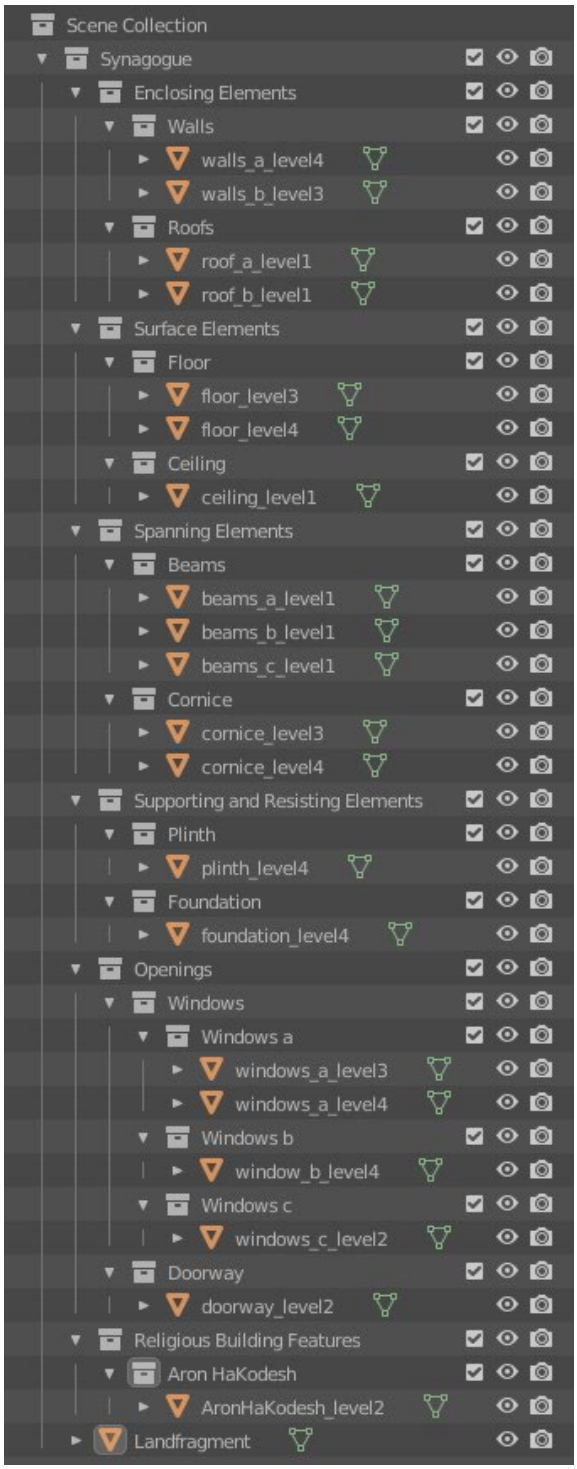


Figure 1

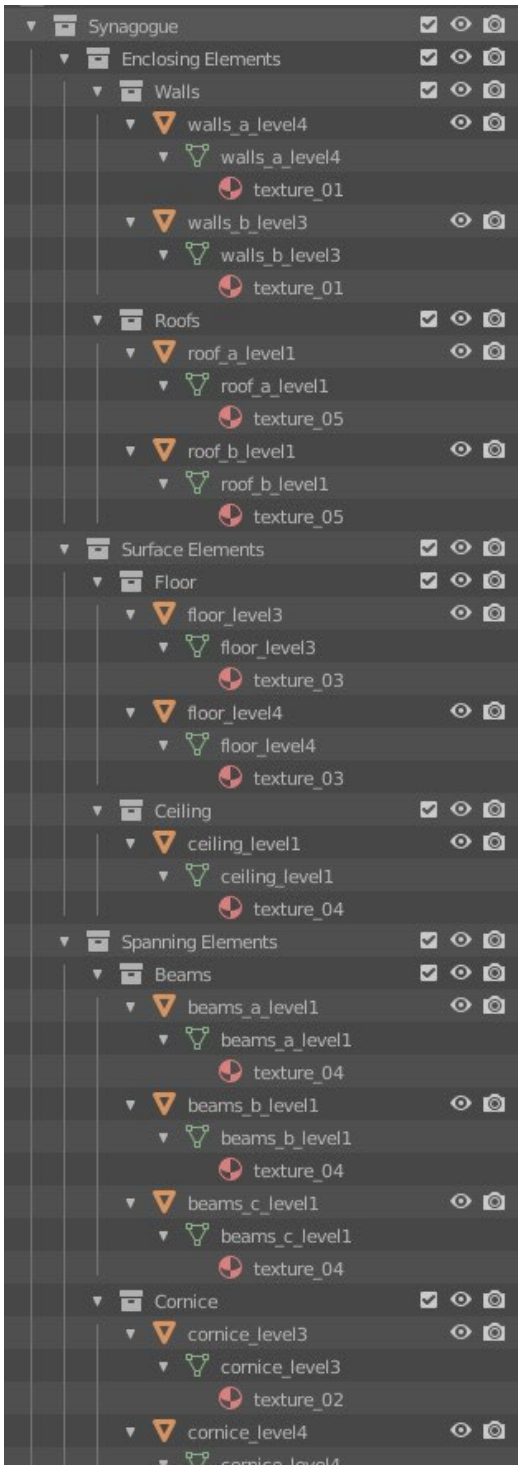


Figure 2

In the collections ( ) Figure 1, that were defined through the hierarchy in the handout, each element was placed, with the correct name as the object property ( ) as well as the correct object data property ( ) Figure 2.

Graphisoft Archicad

3D Model by Igor Bajena (Graphisoft Archicad 25 INT)

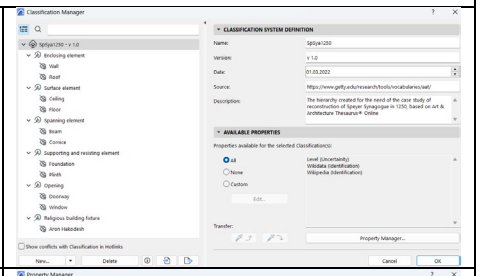
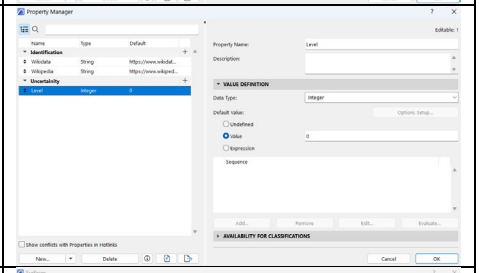
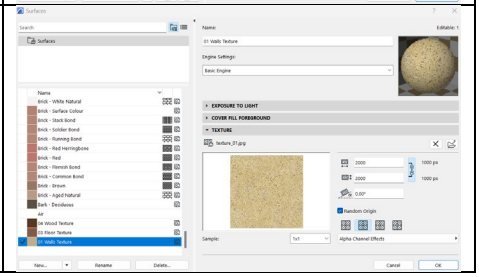
1) Modelling time: ~24 hours.

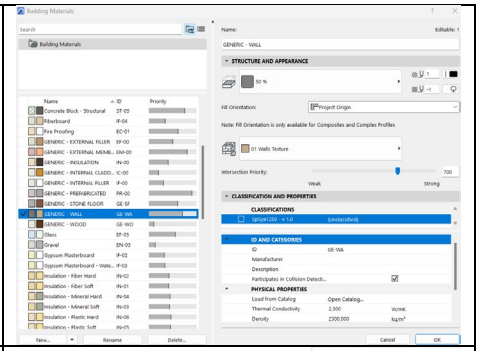
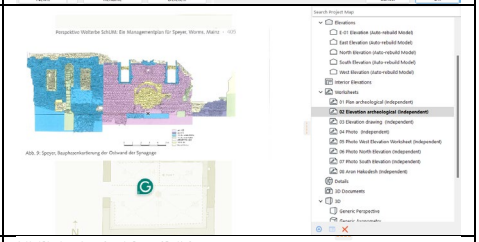
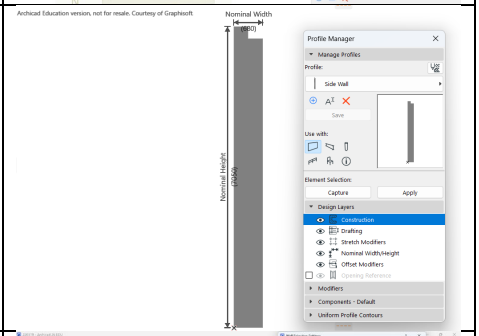
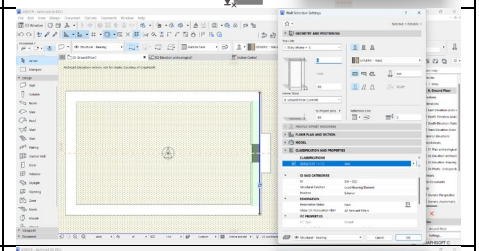
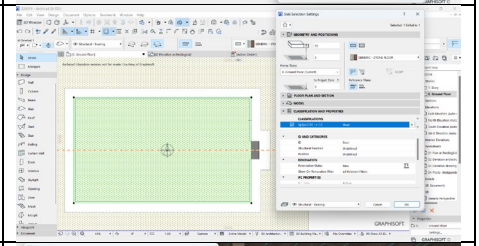
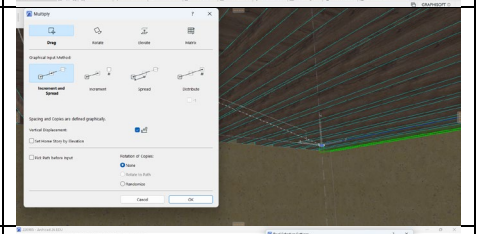
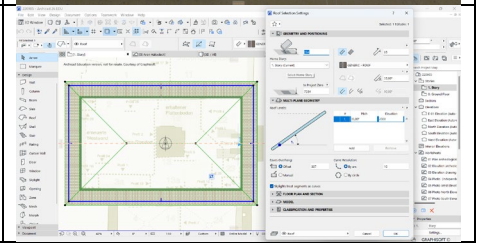
   Initially, a fair amount was devoted to organising the working environment, introducing custom parameters and classifications. The biggest challenge was to create a roof structure with carpentry joints without source material, using our own experience. The most time-consuming were detail-rich elements such as door windows and Aron Hakodesh. Additional time had to be spent on finalising the editable elements into library elements and assigning classifications and properties.

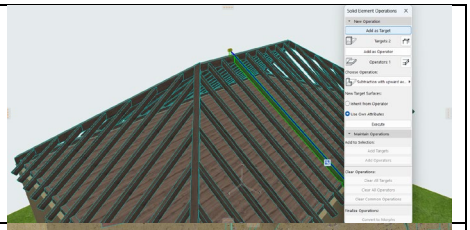
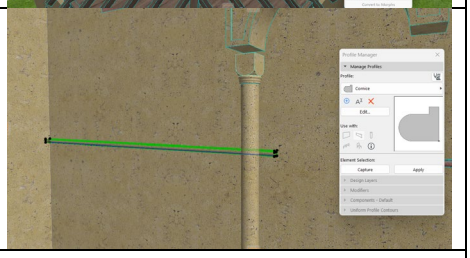
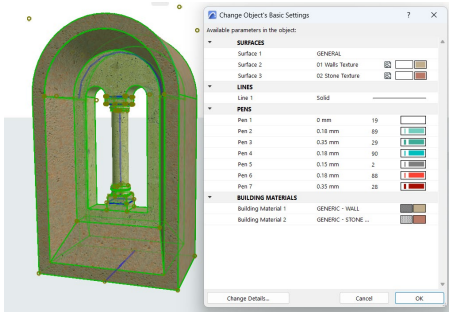
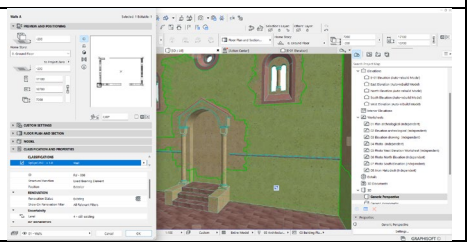
2) Workflow documentation: 1,5 hours

   Describing the workflow required careful consideration of every step, as Archicad tools are not typical for 3D modelling

Tab. 40 Reconstruction workflow steps in Archicad by Igor Bajena.

Workflow in Archicad		
1	Set up the organisation of the file by limiting the layers to 11 and setting up a new hierarchical classification of elements in the programme, following the guidelines. The classification will be added to each object as a selectable parameter. Each item in the classification has been given a reference link to the term definition in Getty AAT.	
2	Create a new property 'Uncertainty' in the property manager as an integer that can be assigned to an object.	
3	Creation of finishing materials using the textures attached in the initial materials and definition of scale and tiling methods.	

4	The foundation was added by copying the bottom plane of the wall mesh and then extruding it to the correct depth. The openings were cut out from the wall mesh using a Boolean modifier, which made them non-destructive and easily modifiable at this stage.	
5	Using a worksheet to upload source drawings and adjust them to the correct scale. Worksheets can be used as semi-transparent backgrounds in modelling in 2D plan views.	
6	Creation of a profile for the longitudinal walls of the building with a top-notch finish to allow for the placement of ceiling beams.	
7	Defining the properties of transverse walls with a simple rectangular profile, including thickness, height, and material. Selection of the classification parameter. Drawing of the wall perimeter on a 2D plan. Same process for foundation walls.	
8	Introducing the floor and ceiling by using a magic wand to fill the space between the walls. Adapting properties and materials.	
9	Use of the beam tool to create a floor beam with the appropriate section and material parameters. Then, use the option to duplicate elements every specified distance (‘spread’).	
10	Create roofs using the roof tool and by drawing the reference outline and using the hipped roof option. The pitch angle, materials and classification were adjusted by parameters.	

11	Creation of roof trusses for both canopies using beams with specific section parameters To create the carpentry connections, actions on the solid elements were used to properly trim the beams to each other.	
12	Using custom profile beams to create cornices and plinths.	
13	Creating the geometry of custom objects such as a door portal, windows or even Aron Hakodesh using combinations of various Archicad tools such as beam, column, slab. In the case of complex forms, the morph conversion option was used to allow free manipulation of the rows and edges of the geometry. Once the actual form had been created, all geometry was marked and saved as a library element, which is not editable but can be inserted multiple times with different sets of properties.	
14	Grouping elements into the semantic units defined in the guidelines and storing the marked elements as one object. This is followed by loading the new library elements as non-editable elements and adjusting the classification parameters and reconstruction uncertainty.	

SketchUp

3D Model by Stefan Wetherington (SketchUp Pro 2021)

1) Modelling time: ~15 hours.

   I needed about one day less (6 hours) with SketchUp than in Blender. The modelling process went quicker with SketchUp, mainly because I didn't have to lookup as much while modelling and I had already made most decisions while modelling with Blender. Splitting the walls by uncertainty, went alot quicker, as I didn't need to mess around with booleans. And I didn't have that many mistakes I had to clean up at the end. Initially, a fair amount was devoted to organising the working environment, introducing custom parameters and classifications. The biggest challenge was to create a roof structure with carpentry joints without source material, using our own experience. The most time-consuming were detail-rich elements such as door windows and Aron Hakodesh. Additional time had to be spent on finalising the editable elements into library elements and assigning classifications and properties.

2) Workflow documentation: 45 mins

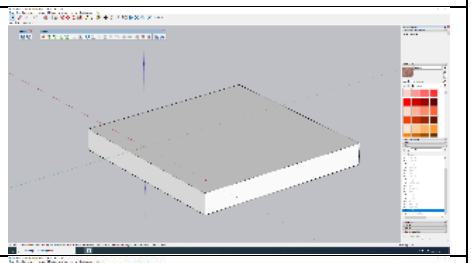
   As with Blender this went fairy quick.

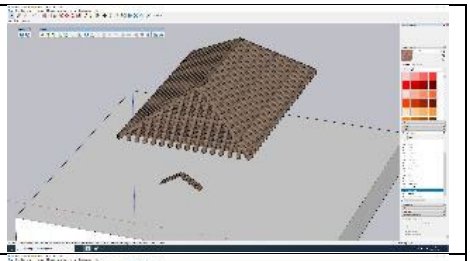
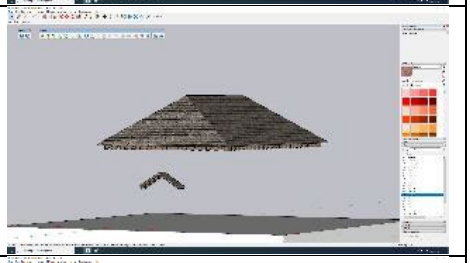
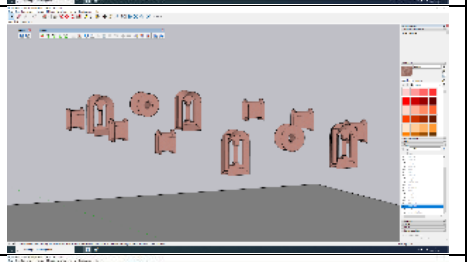
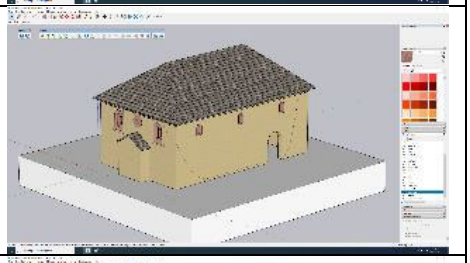
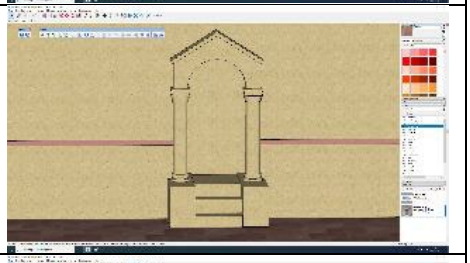
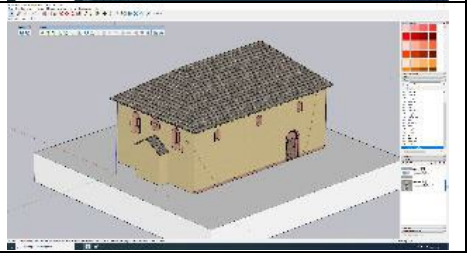
3) Objects documentation: 45 mins.

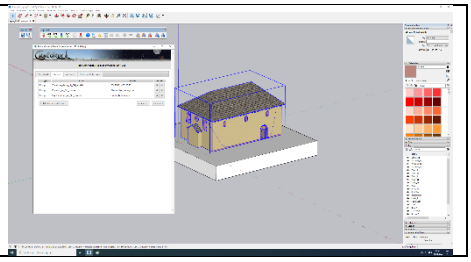
   This is not representative, because many of the entries did not change between the different softwares. Mainly the screenshots and the process had to be changed.

4) WissKI entry: see Blender entry (by Stefan Wetherington) above.

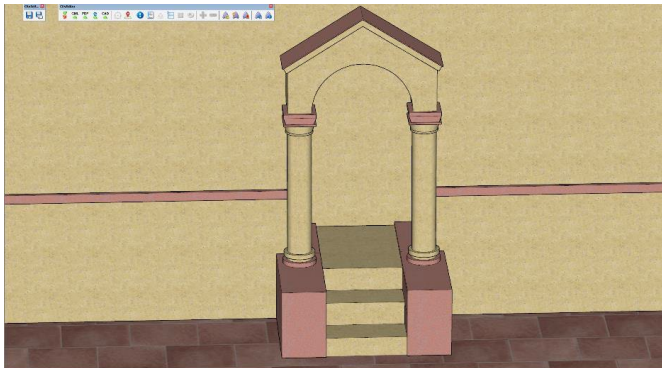
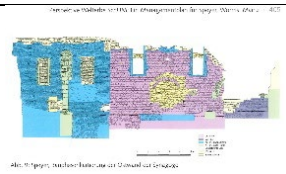
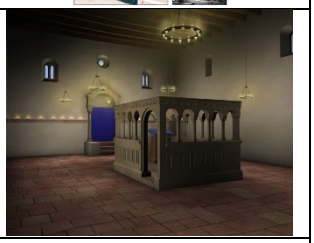
Tab. 41 Reconstruction workflow steps in SketchUp by Stefan Wetherington.

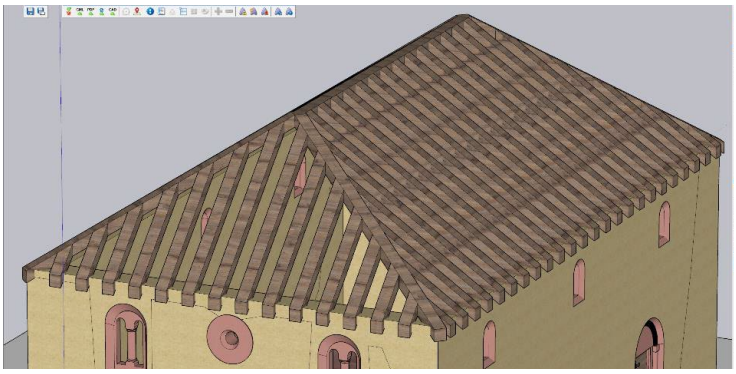
Workflow in SketchUp		
1	Added ground plane.	
2	Added arch. report and modelled walls using SketchUps scene option to line up photos/pictures. Openings for the windows and the door were cut right away into the model using the line tool.	

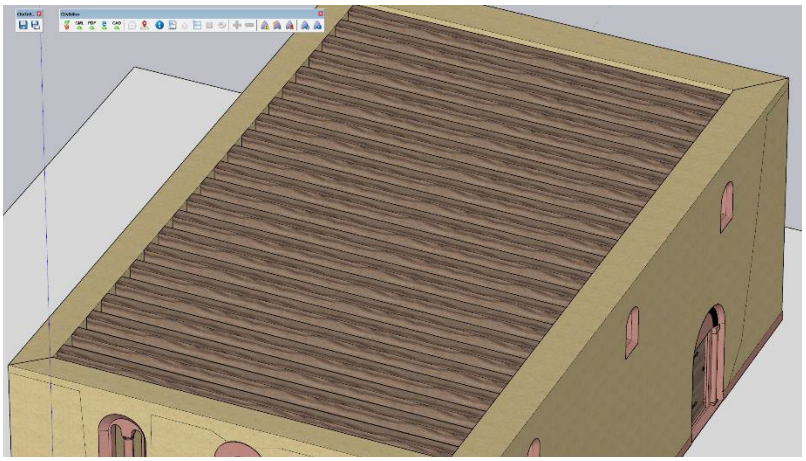
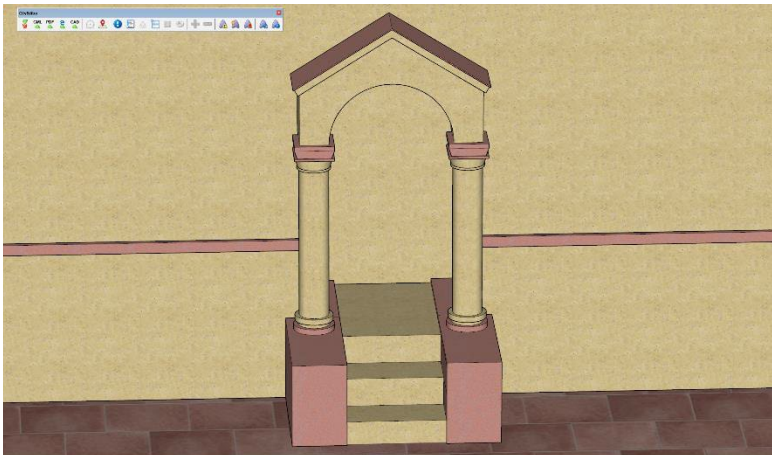
3	Modelled the beams next. Took very long to make. Every single beam had to be modelled and positioned manually. Maybe there is a plugin that could have made it a lot easier?	
4	Added roof on top of the beams. It started by stowing the roof plan from above and drawing the ridge to the desired height, copying and raising the roof plane and joining the two planes with lines. Went very quick.	
5	Added windows. The inner part made by rotating the profile and pulling it out with a push/pull tool. A column was created by using circle tool and pulling up the circle profile. Made similar windows into components so I could reuse them.	
6	The walls were split into different uncertainty groups. Went very fast. Used the line tool to just trace the separation line.	
7	Added doorway with columns using the scene option to line up the picture. Modelling process same like for windows.	
8	Added Aaron Hakodesh and floor. Floor done by drawing outline and pulling it up. Aron Hakodesh similar workflow like for windows. The stairs were done by drawing the plan for above and pulling up each step separately by different height.	
9	Finished model. The components were then grouped together, defined by the hierarchy (i.e. all the windows of the same type were grouped).	

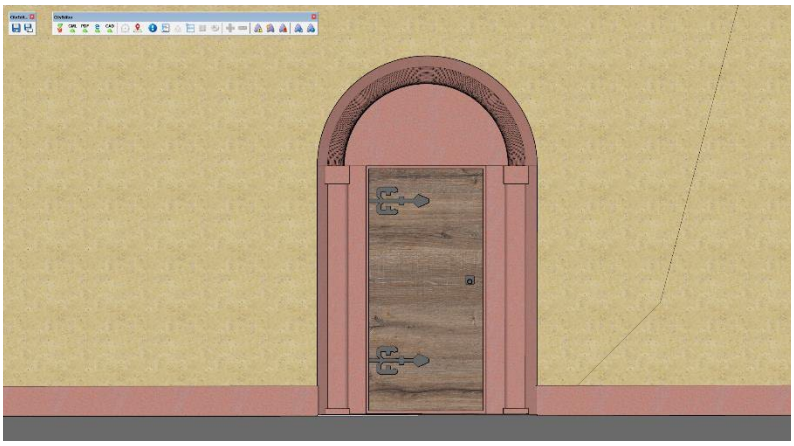
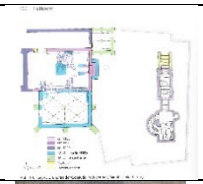
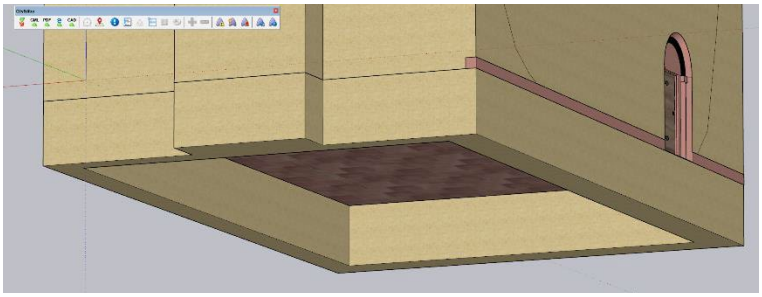
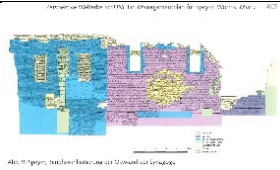
10	Then, using CityGML, groups were given attributes: Their name, id and the uncertainty level was added as well.	

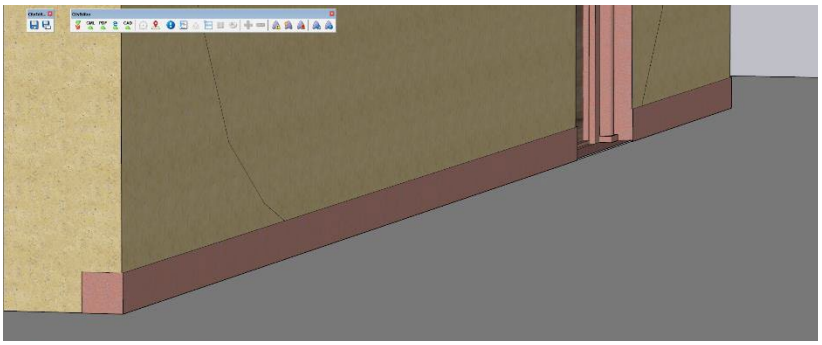
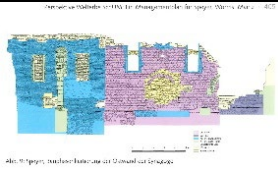
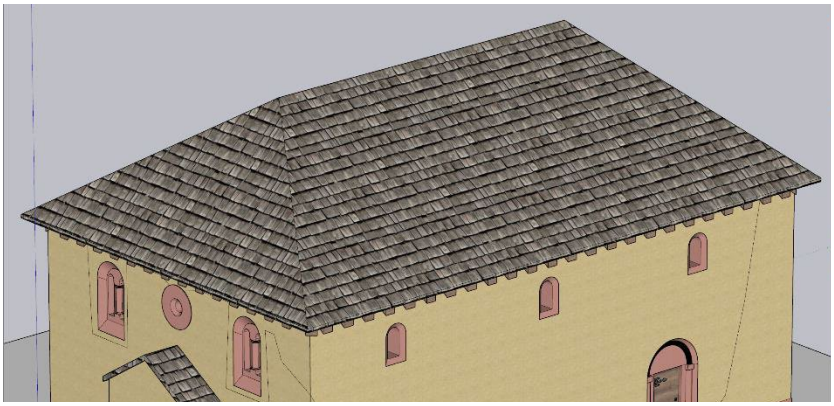
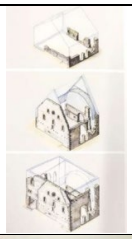
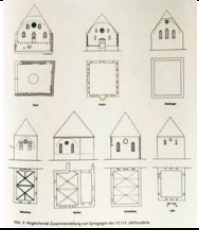
Tab. 42 Documentation of a 3D reconstruction of the semantic elements of Speyer Synagogue in the 13th century by Stefan Wetherington in SketchUp.

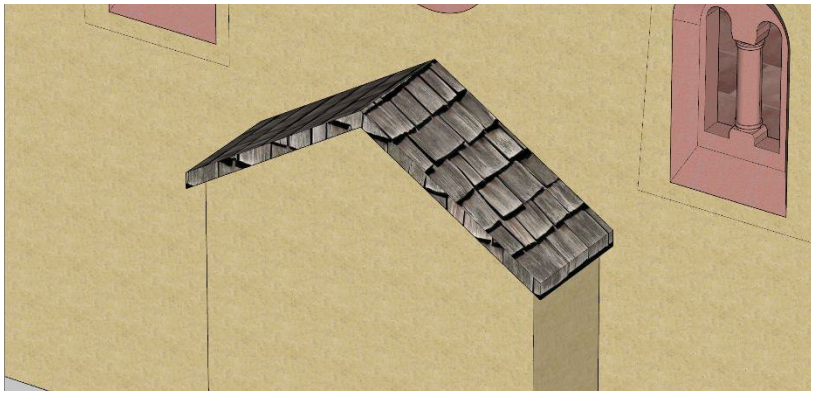
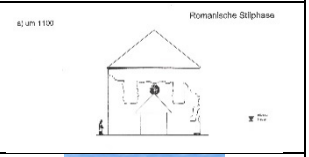
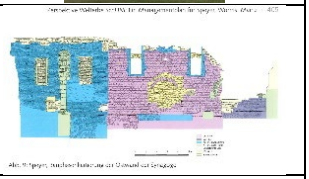
Aaron Hakodesh		
Reconstruction (1)		
Used sources	Report_05	
	Article_01	
	Reconstruction_01_rendering_02	
Uncertainty	The still standing wall shows remnants of the Aaron Hakodesh. The reconstruction has an Aaron Hakodesh which can be used as reference. There are some sources that show an Aaron Hakodesh from around a similar timeframe.	Level 2 (recess) Level 3 (columns, gabel, stairs)
Argumentation	The Aaron Hakodesh was modelled using the measurements provided in article_01 and the dimensions from the report_05. The overall shape was taken from the prior reconstruction.	
Beams 5a		

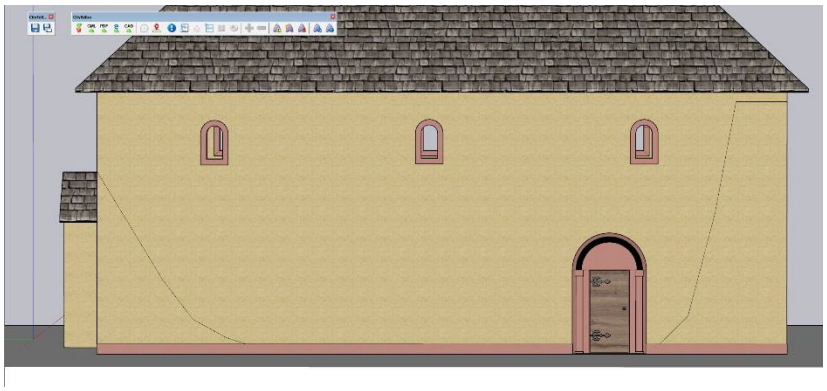
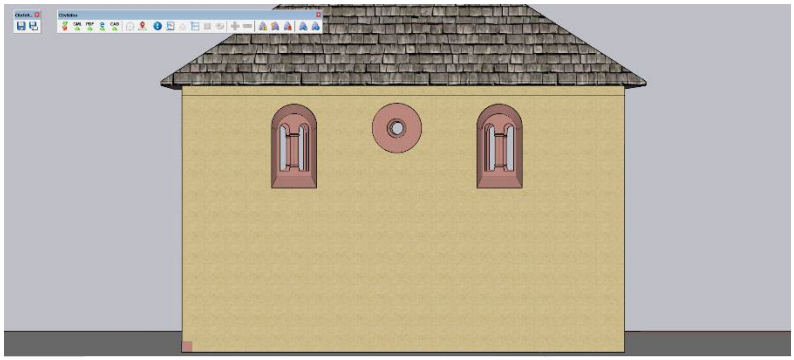
Reconstruction (2)		
Used sources	Reconstruction_01_rendering_05	
Uncertainty	Nothing is left of the original roof at the site. There are also no other surviving roofs from that period. That also true for the beams.	Level 2
Argumentation	Hip roof beams were modelled. the line tool was used to model every beam. The extent was sketched first, then the spine was modelled. After that the other beams were added. Took the longest to model.	
Beams 5b		
Reconstruction (3)		
Used sources	Reconstruction_01_rendering_05	
Uncertainty	Nothing is left of the original roof at the site. There are also no other surviving roofs from that period. That also true for the beams.	Level 4
Argumentation	Gable roof beams were modelled. Three beams were modelled on one side, and then flipped a duplicate onto the other side.	
Beams 5c		

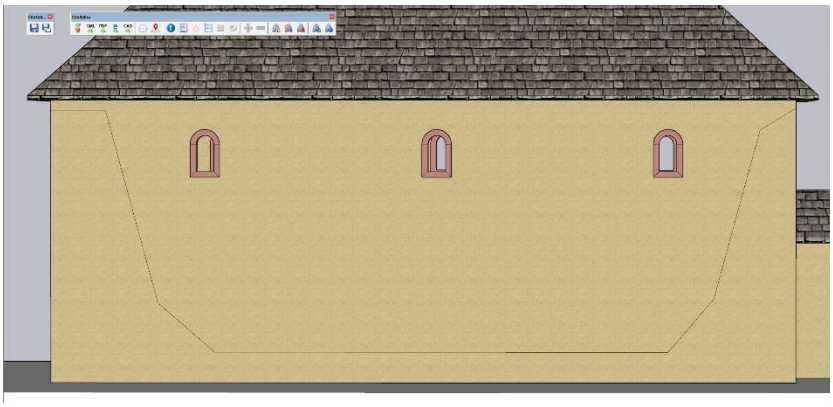
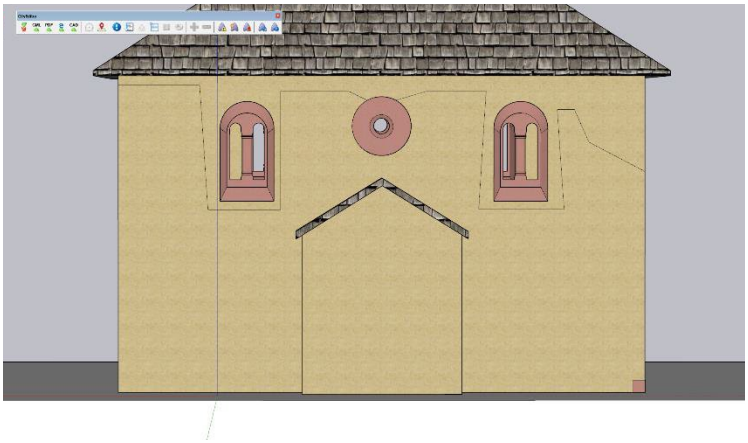
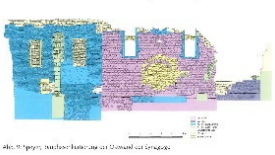
Reconstruction (4)		
Used sources	Reconstruction_01_rendering_02	
Uncertainty	Nothing is left of the original roof at the site. There are also no other surviving roofs from that period. That also true for the beams.	Level 4
Argumentation	Overarching beams were modelled to span the room. One beam was modelled and then copied via ctrl + the move tool.	
Cornice		
Reconstruction (5)		
Used sources	Reconstruction_01_rendering_02	
Uncertainty	Parts of the cornice can still be found in the inside of the eastern wall.	Level 1
Argumentation	Added the cornice ledge at the appropriate height.	
Entrance		

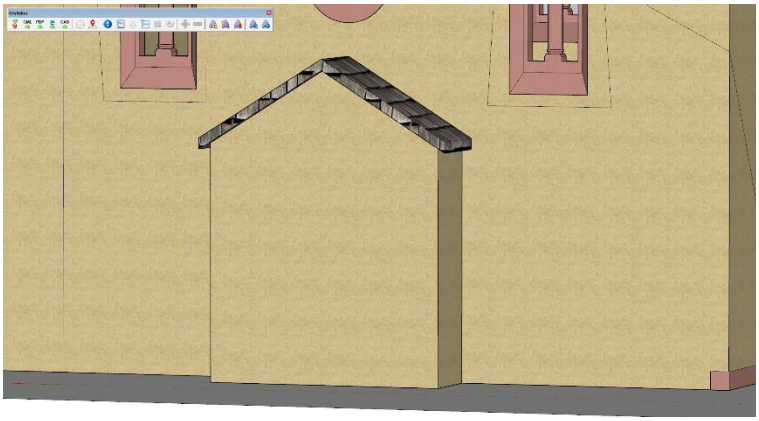
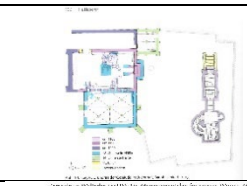
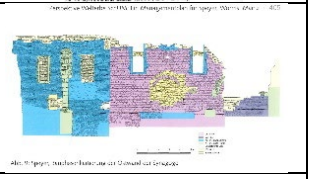
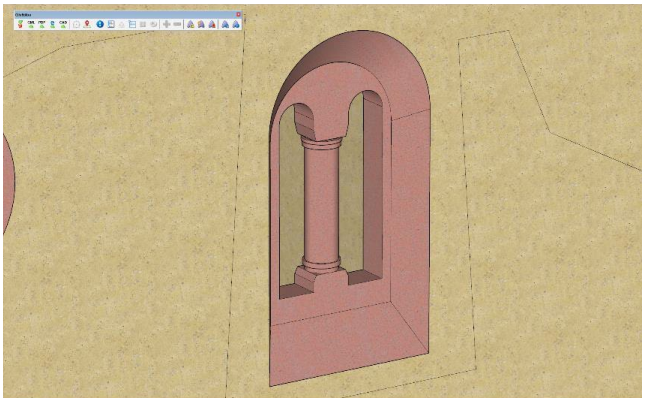
Reconstruction (6)		
Used sources	Report_04	
	Analogy_02_01	
Uncertainty	The width of the entrance can still be found in the floor plan of report_04. There are analogies that can be referenced.	Level 3
Argumentation	The door was traced using the reference photo. Then the circle tool was used to make the arch and the columns.	
Foundation		
Reconstruction (7)		
Used sources	Report_05	
Uncertainty	Parts of the foundation were uncovered during the excavation and were recorded in report_05.	Level 1
Argumentation	Used the floor plan for the layout of the foundation. Traced using the line tool.	
Plinth		

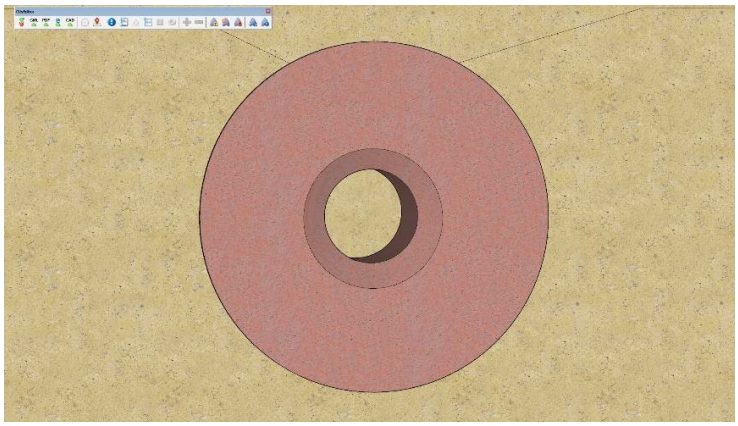
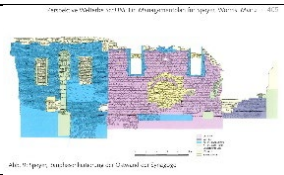
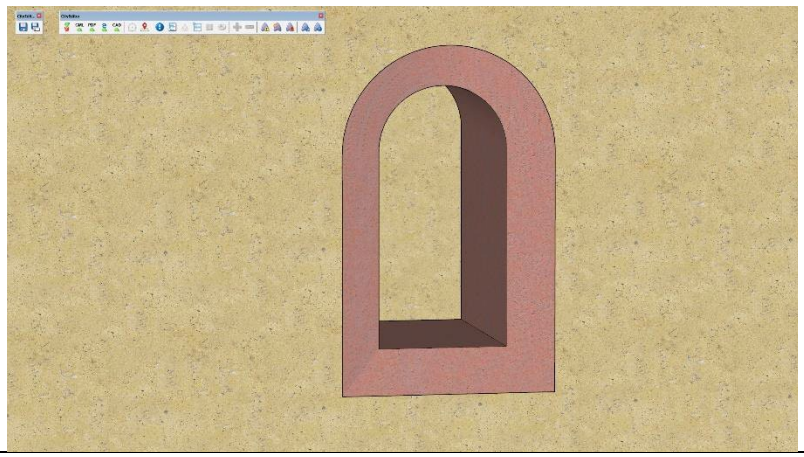
Reconstruction (8)		
Used sources	Reconstruction_01_rendering_05	
	Report_05	
Uncertainty	The plinth can be found at the site and is recorded in report_05.	Level 1
Argumentation	Was added later in the modelling process. A simple elongated cube.	
Roof 2a		
Reconstruction (9)		
Used sources	Analogy_05	
	Analogy_04	

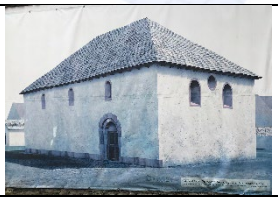
	Reconstruction_02_rendering_01	
Uncertainty	Nothing is left of the original roof at the site. There are also no other surviving roofs from that period.	Level 4
Argumentation	A hip roof was modelled. It is the closest to the reconstructions.	
Roof 2b		
Reconstruction (10)		
Used sources	Drawing_01	
	Reconstruction_01_rendering_05	
	Report_05	
Uncertainty	Nothing is left of the original roof at the site. There are also no other surviving roofs from that period.	Level 4
Argumentation	A gable roof was modelled. It is the most likely covering of the extrusion.	
Wall 1a		

Reconstruction (11)		
Used sources	Photo_location_02	
Uncertainty	Parts of the wall can still be found at the location. The missing part of the wall needs to be reconstructed on that basis.	Level 1 [remaining walls] Level 2 [missing walls]
Argumentation	Wall was modelled off the floor plan. Then the openings were traced onto the wall with the line tool and deleted. The separation of the uncertainty was accomplished by using the line tool to split the wall.	
Wall 1b		
Reconstruction (12)		
Used sources	Photo_location_09	
Uncertainty	Parts of the wall can still be found at the location. The missing part of the wall needs to be reconstructed on that basis.	Level 1 [remaining walls] Level 2 [missing walls]
Argumentation	Wall was modelled off the floor plan. Then the openings were traced onto the wall with the line tool and deleted. The separation of the uncertainty was accomplished by using the line tool to split the wall.	
Wall 1c		

Reconstruction (13)		
Used sources	No source provided?	
Uncertainty	Parts of the wall can still be found at the location. The missing part of the wall needs to be reconstructed on that basis.	Level 1 [remaining walls] Level 2 [missing walls]
Argumentation	Wall was modelled off the floor plan. Then the openings were traced onto the wall with the line tool and deleted. The separation of the uncertainty was accomplished by using the line tool to split the wall.	
Wall 1d		
Reconstruction (14)		
Used sources	Photo_location_10	
	Report_05	
Uncertainty	Parts of the wall can still be found at the location. The missing part of the wall needs to be reconstructed on that basis.	Level 1 [remaining walls] Level 2 [missing walls]
Argumentation	Wall was modelled off the floor plan. Then the openings were traced onto the wall with the line tool and deleted. The separation of the uncertainty was accomplished by using the line tool to split the wall.	

<table>
<tr><th colspan="3">Wall 1e</th></tr>
<tr><td>Reconstruction (15)</td><td colspan="2">  </td></tr>
<tr><td rowspan="2">Used sources</td><td>Report_04</td><td>  </td></tr>
<tr><td>Report_05</td><td>  </td></tr>
<tr><td>Uncertainty</td><td>The foundation of the extrusion still survives today. The dimensions can be gleaned from both the reports above.</td><td>Level 2</td></tr>
<tr><td>Argumentation</td><td colspan="2">All the walls were extruded upwards from the dimensions of the report. The wall 1e was only extruded up to the height found in report_5 together with the estimated height of the Aaron Hakodesh.</td></tr>
<tr><th colspan="3">Window 8a</th></tr>
<tr><td>Reconstruction (16)</td><td colspan="2">  </td></tr>
<tr><td>Used sources</td><td>Photo_museum_02</td><td> </td></tr>
</table>

	Photo_location_10	
Uncertainty	The windows are still embedded into the wall, and an additional set is displayed at the museum.	Level 1
Argumentation	First the sources were added to SketchUp as reference pictures. The line tool was used to trace the outline and the circle tool to create the column.	
Window 8b		
Reconstruction (17)		
Used sources	Report_05	
	Photo_location_10	
Uncertainty	The windows can still be found in the walls.	Level 1
Argumentation	First the sources were added to SketchUp as reference pictures. The circle tool was used multiple time to create this window.	
Window 8c		
Reconstruction (18)		

Used sources	Reconstruction_02_rendering_01	
	Reconstruction_01_rendering_01	
Uncertainty	The windows cannot be found in the still standing walls, or in the archaeological report. The only source for this project are the prior made renders.	Level 4
Argumentation	First the sources were added to SketchUp as reference pictures. The line tool was used to trace the outline and the circle tool to create the arch.	

Rhinoceros 3D

3D Model by Irene Cazzaro (Rhino 5)

1) Modelling time: ~25 hours.

   Modelling time includes also the initial time spent in deciding how to include different information into the model (application of object colour, object material and also layer colour for uncertainty visualisation). The division of the façades according to their uncertainty level generated some overlapping surfaces that needed to be removed at a later stage.

2) Workflow documentation: ~45 mins

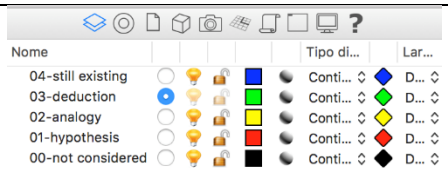
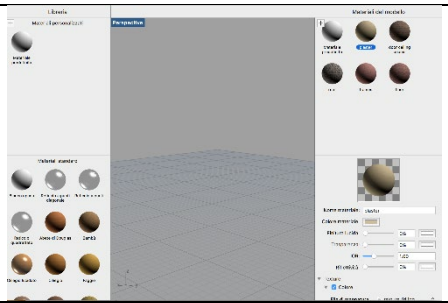
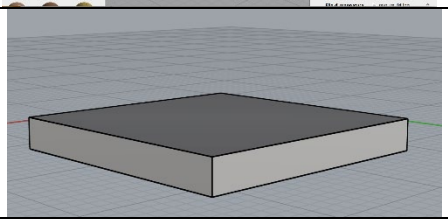
   The screenshots had been already taken during the modelling phase and just a brief description has been added for each one of them.

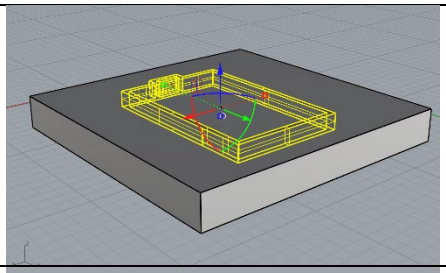
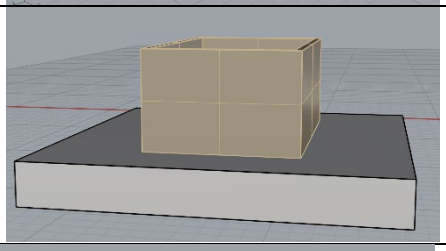
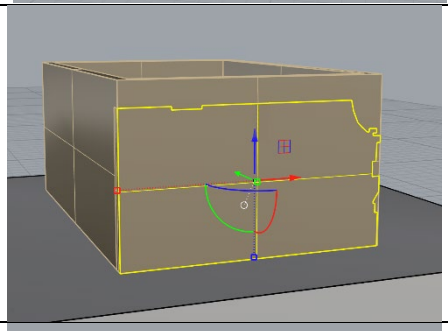
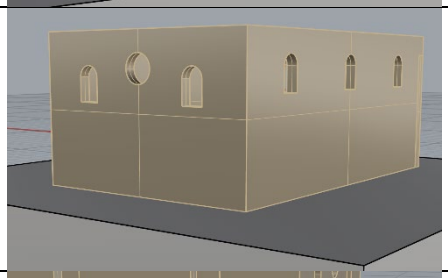
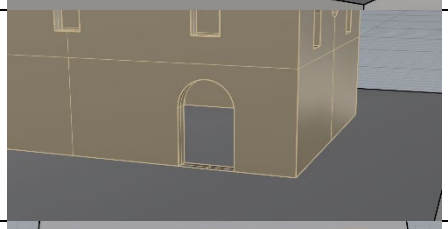
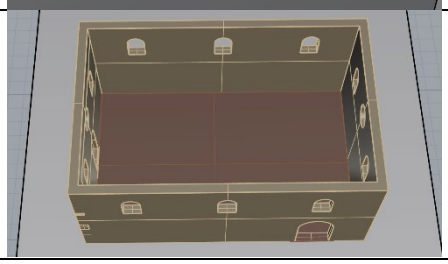
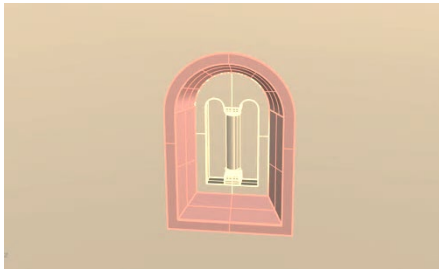
3) Objects documentation: ~5 hours.

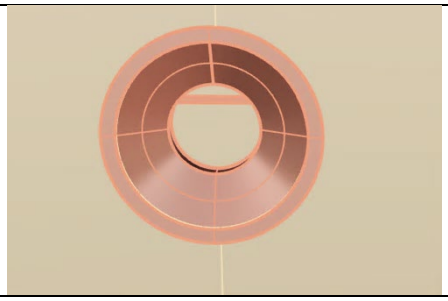
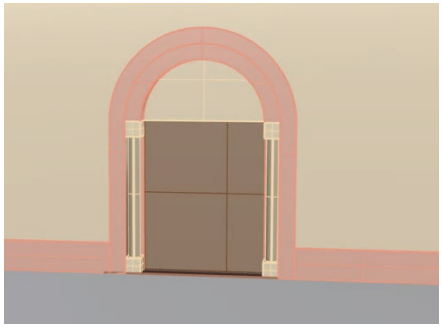
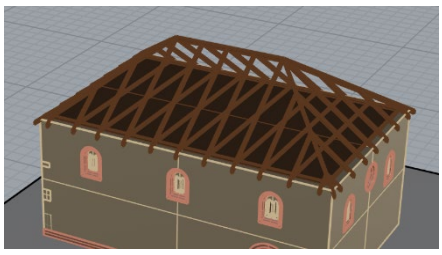
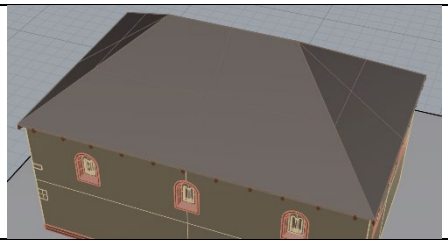
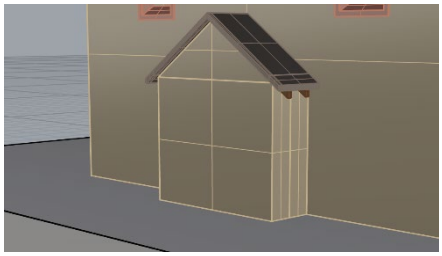
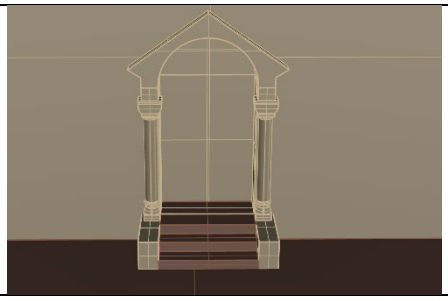
   This documentation process is more detailed and requires more time: a table has to be created for each element, with a description and a screenshot of it, then analogies have to be searched in the project folder and included into the table as screenshots. Choices related to uncertainty have to be documented as well. Of course, in my opinion, these tables are well structured and at the end the collected information turns out to be very useful. This is not representative, because many of the entries did not change between the different softwares. Mainly the screenshots and the process had to be changed.

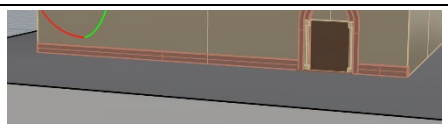
4) WissKI entry: no information provided.

Tab. 43 Reconstruction workflow steps in Rhinoceros by Irene Cazzaro.

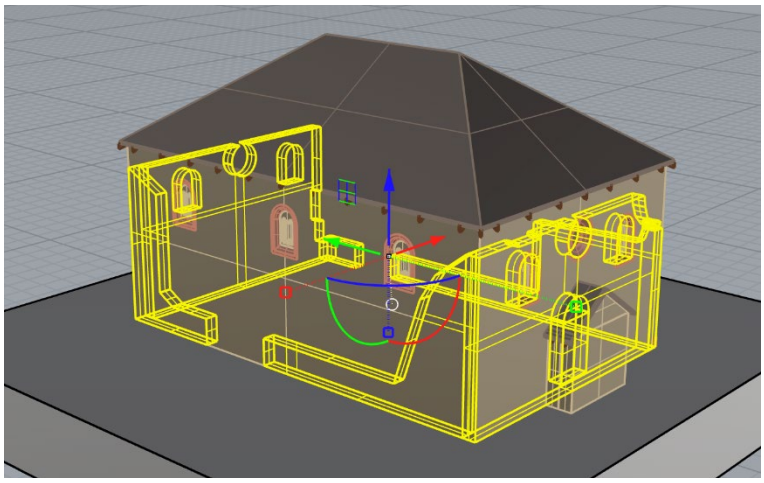
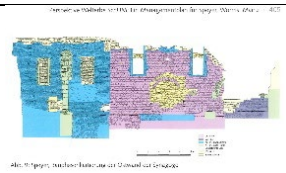
Workflow in Rhinoceros		
1	Creation of layers for uncertainty visualisation: “04-still existing” (blue); “03-deduction” (green); “02-analogy” (yellow); “01-hypothesis” (red); “00-not considered (black).	
2	Creation of **object materials** and related visualisation **colours** according to the handout. The materials have been called “plaster” (texture_01); “frames” (texture_02); “floor” (texture_03); “door ceiling beams” (texture_04); “roof” (texture_05).	
3	**Basement** Obtained by extrusion (3 m) of a 25x25 m square Object name: “basement” Layer: “00-not considered”; colour: “by layer” (black); material: not defined.	

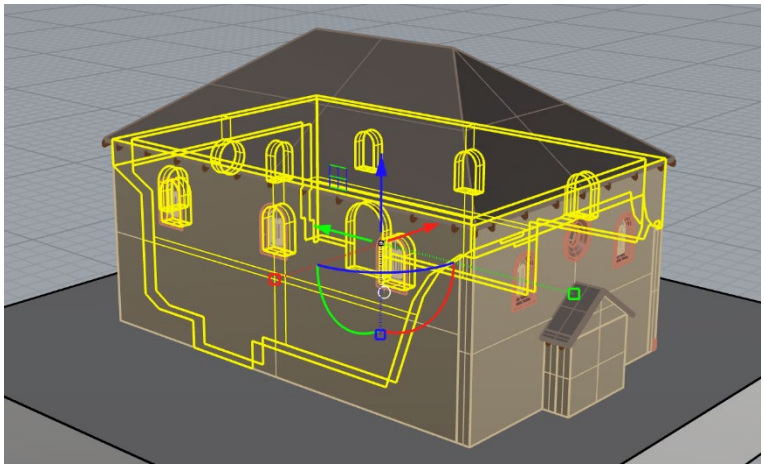
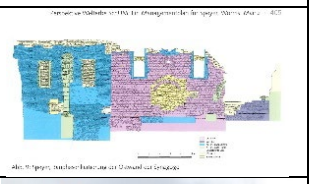
4	**Foundations** Obtained by extrusion of the related surface as in “report_03.jpg” Object name: “foundations” Layer: “04-still existing”; colour and material according to texture_01	
5	**Perimeter walls** Obtained by extrusion of the related surface Object name: “wall_2” Layer: “03-deduction”; colour and material according to texture_01	
6	**Subdivision of the eastern façade** **Obtained by cutting “wall_2” according to the information in “report_05.jpg”** **Object name: “wall_1”** Layer: “04-still existing”; colour and material according to texture_01	
7	**Holes for windows** Obtained by Boolean difference	
8	**Hole for portal** Obtained by Boolean difference	
9	**Floor** Obtained by extrusion of the area inside the perimeter walls. Object name: “floor” Layer: “01-hypothesis” Colour and material according to texture_03	
10	**Windows** Obtained by extrusion and by rotation (columns) Frames obtained by extrusion and loft Object names: “window_1” Layer: “04-still existing” for those in the western façade; “03-deduction for the other ones; colour and material according to texture_01 for the internal part and texture_02 for the frames	

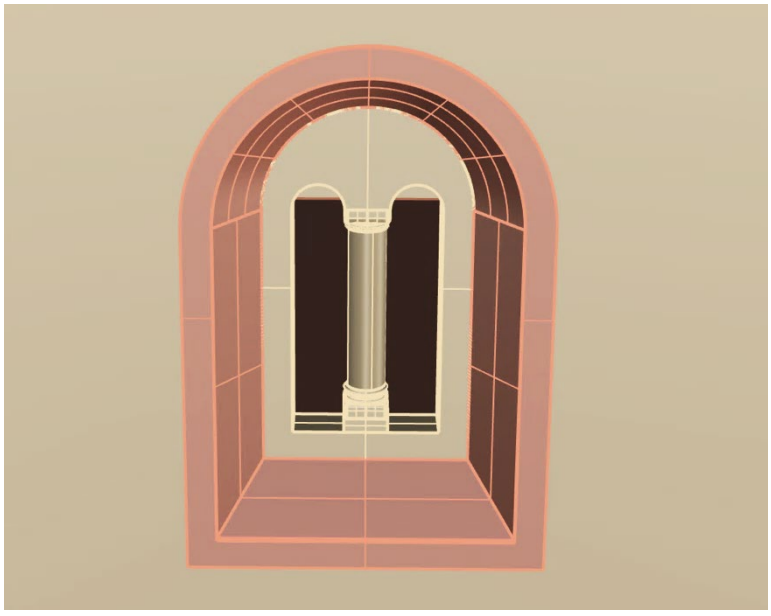
11	**Circular windows** Frame obtained by extrusion and loft around the circular hole Object name: “window_2” Layer: “03-deduction”; colour and material according to texture_02	
12	**Portal** Some details are still needed. Mainly obtained by extrusion. Object name: “portal”. Layer: “02-analogy” Colour and material according to texture_02 for the frames, texture_01 for columns and semi-circular wall above the door, texture_04 for the door.	
13	**Beams** Obtained by drawing the rectangular section, extruding it for all the length of the beam that was then copied many times (some are horizontal, for the others the angle is 35°; the length varies according to the construction scheme) Object name: “beams” Layer: “01-hypothesis”; colour and material according to texture_04	
14	**Roof** Four surfaces with a 35° angle were created above the beams, then they were extruded Object name: “roof” Layer: “01-hypothesis”; colour and material according to texture_05	
15	**Aron Hakodesh - exterior** The walls were extruded according to the foundation. The roof follows the traces of the arch on the eastern façade. Object name: “aron hakodesh_exterior” Layer: “02-analogy”; colour and material according to texture_01 for the wall, texture_04 for the beams and texture_05 for the roof	
16	**Aron Hakodesh** Basement, stairs and upper part modelled by extrusion, columns by rotation. Layer: “02-analogy”, colour and material according to texture_01 apart from the stairs, for which texture_03 is used	

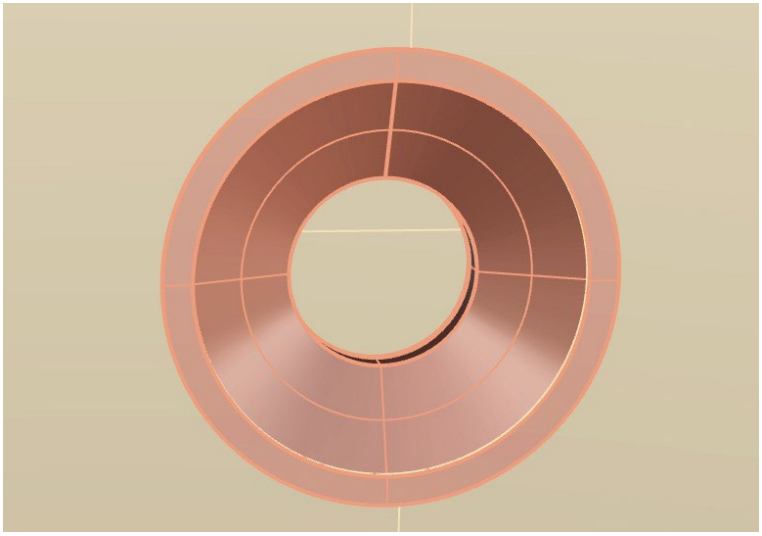
17	**Plinth** Obtained by extrusion of a part of the wall. Layer: “03-deduction” Colour and material according to texture_02	
18	**Cornice** Obtained by extrusion of a part of the wall. Layer: “03-deduction” Colour and material according to texture_02	

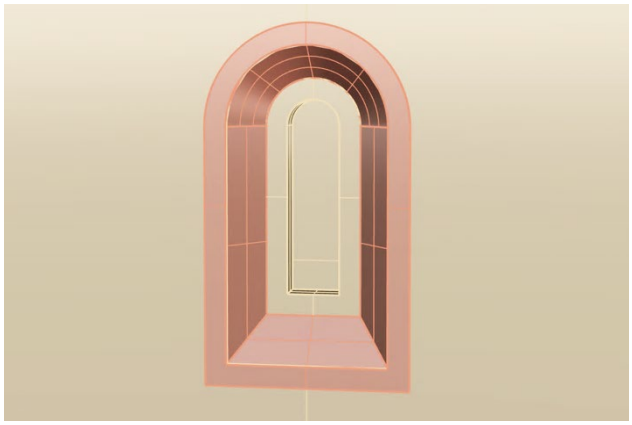
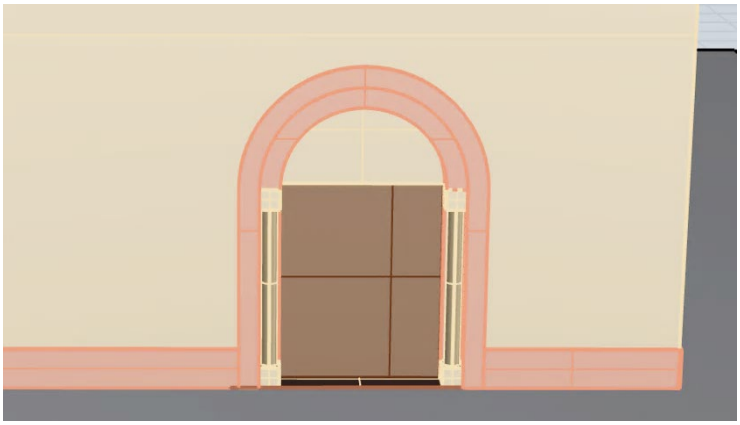
Tab. 44 Documentation of a 3D reconstruction of the semantic elements of Speyer Synagogue in the 13th century by Irene Cazzaro in Rhinoceros.

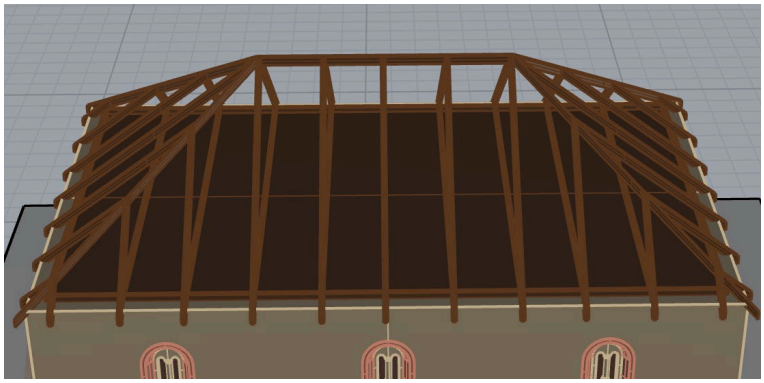
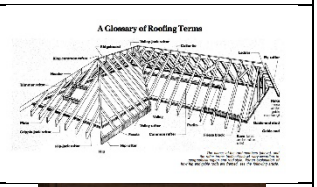
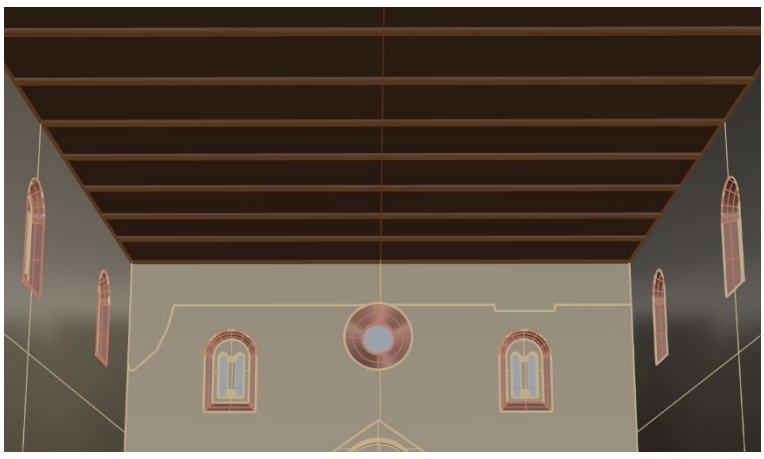
Wall type 1		
Reconstruction (1)		
Used sources	report_05.jpg	
	photo_location_01.jpg	
Uncertainty	This is the part of the wall that we can still see.	04-still existing

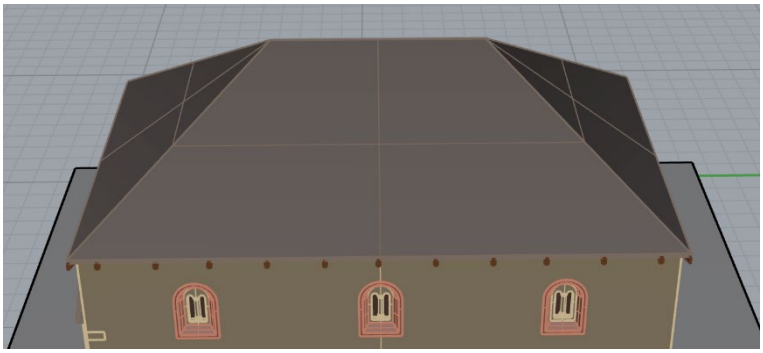
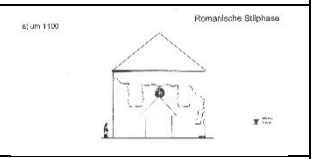
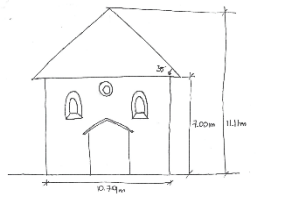
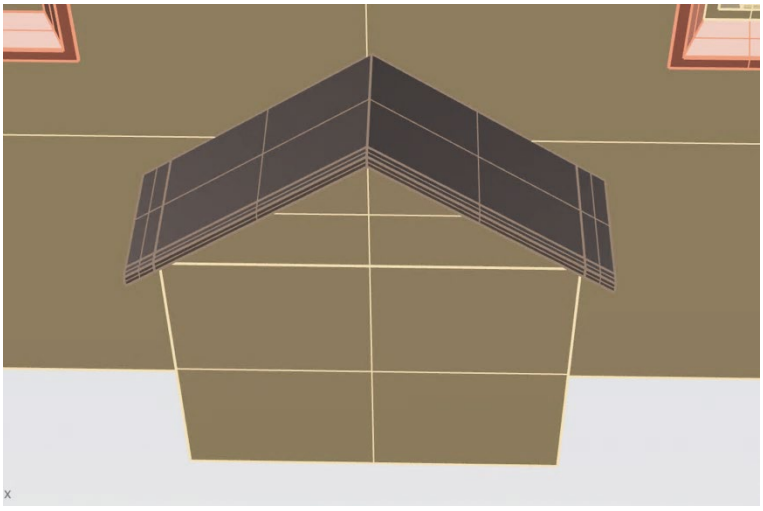
Wall type 2		
Reconstruction (2)		
Used sources	report_05.jpg	
	photo_location_01.jpg	
Uncertainty	This part of the wall was reconstructed by deduction, assuming that it was similar to the still existing part.	03-deduction

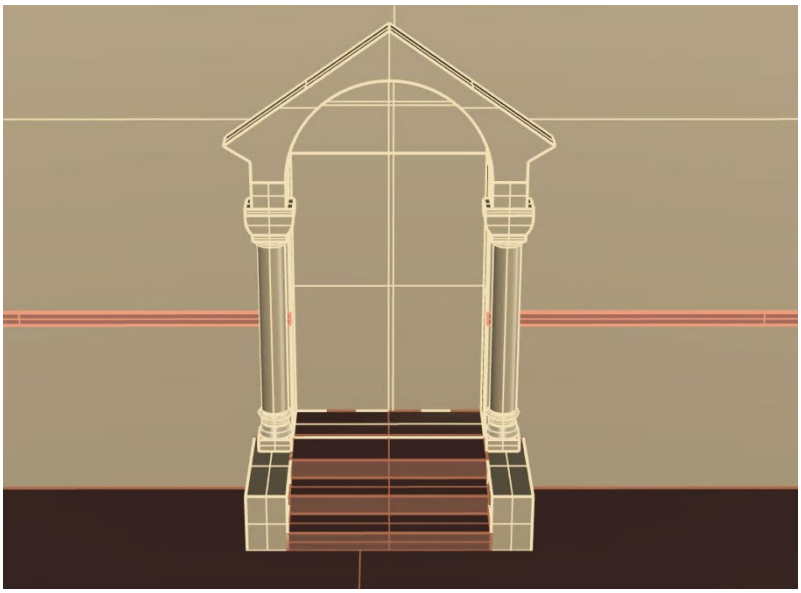
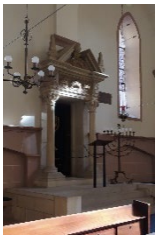
Window type 1	
Reconstruction (3)	

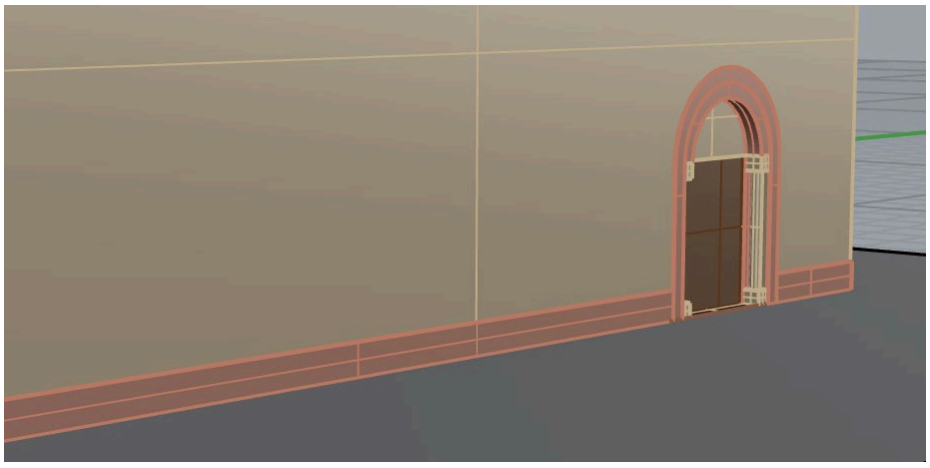
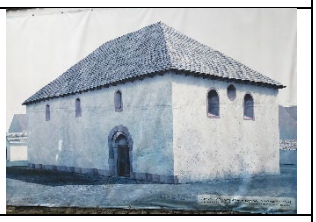
Used sources	photo_location_04.jpg	
	photo_museum_02.jpg	
Uncertainty	The windows on the western façade are copies of the original ones preserved in the Judenhof museum, thus in that case the uncertainty level is “04-still existing”. It is assumed that the other windows were similar and can be reconstructed by deduction.	**04-still existing** for those on the western façade; **03-deduction** for the other ones
Window type 2		
Reconstruction (4)		
Used sources	photo_location_01.jpg	
	photo_location_04.jpg	
Uncertainty	We can see the complete circular hole in the still existing part of the wall.	**04-still existing**

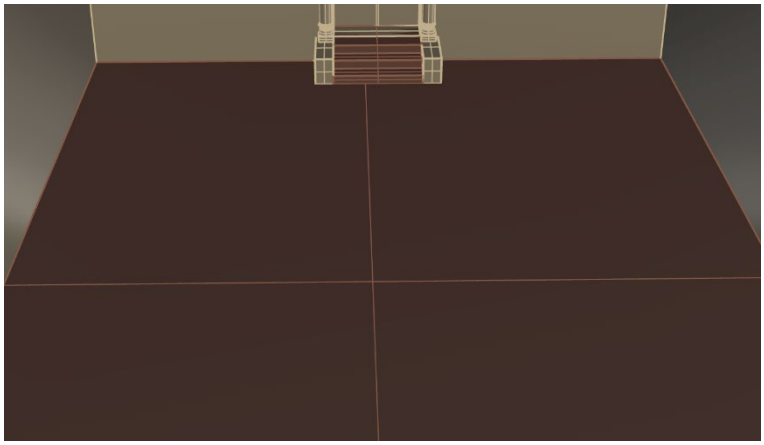
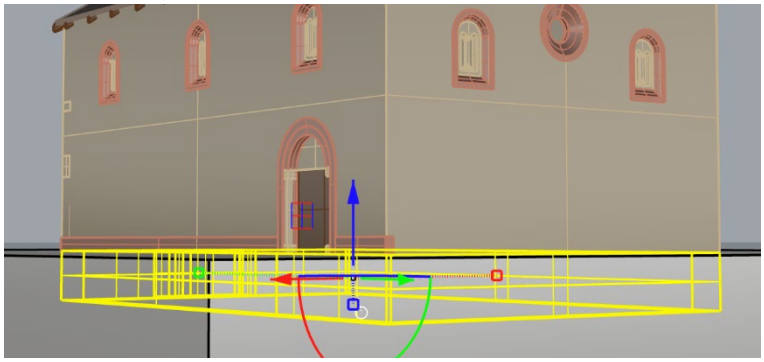
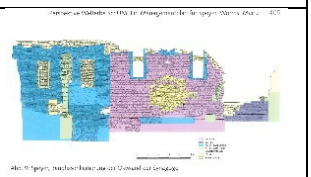
Window type 3		
Reconstruction (5)		
Used sources	reconstruction_01_rendering_02.jpg	
	reconstruction_01_rendering_05.jpg	
Uncertainty	We know nothing about the windows on the northern and southern façade, but there must be some source of natural light, maybe smaller than on the other walls.	01-hypothesis
Portal		
Reconstruction (6)		
Used sources	analogy_02_01.jpg	

	analogy_03.png	
Uncertainty	We do not have traces of the portal of the Speyer synagogue, but we can reconstruct it by analogy e.g. with the portal of the medieval synagogue in Worms.	03-analogy
Beams		
Reconstruction [7]		
Used sources	https://s3.amazonaws.com/finehomebuilding.s3.tauntoncloud.com/app/uploads/1982/09/29111349/roof-framing-terms.jpg (accessed April 4th, 2022)	
	reconstruction_01_rendering_03.jpg	
Uncertainty	We know nothing about the structure of the roof.	01-hypothesis
Ceiling		
Reconstruction [8]		

Used sources	reconstruction_01_rendering_02.jpg	
Uncertainty	We know nothing about the structure of the roof.	01-hypothesis
Roof type 1		
Reconstruction (9)		
Used sources	drawing_01.jpg	
	drawing_04.jpg	
Uncertainty	We know nothing about the structure of the roof.	01-hypothesis
Roof type 2		
Reconstruction (10)		

Used sources	reconstruction_01_rendering_05.jpg	
Uncertainty	We know nothing about the structure of the roof. The simplest thing to assume is that the slope of the roof is the same as the upper part of the Aron Hakodesh (this can be seen in the interior). The material is assumed to be the same as the main roof.	01-hypothesis
Aron Hakodesh		
Reconstruction (11)		
Used sources	reconstruction_01_rendering_02.png	
	Personal archive of Irene Cazzaro, who can make it accessible if required	
Uncertainty	It was modelled based on similar examples of the same historical period.	03-analogy

Cornice		
Reconstruction (12)		
Used sources	Personal archive of Irene Cazzaro, who can make it accessible if required	
Uncertainty	There are clear traces of it in the internal part of the wall.	04-still existing
Plinth		
Reconstruction (13)		
Used sources	reconstruction_01_rendering_01.jpg	
Uncertainty	There are some traces of the plinth, but they have to be mentally completed.	03-deduction

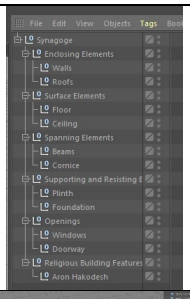
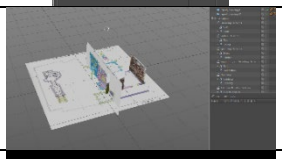
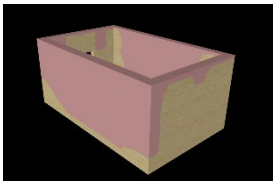
Floor		
Reconstruction (14)		
Used sources	reconstruction_01_rendering_02.png	
Uncertainty	There are no traces of the ancient floor.	01-hypothesis
Foundations		
Reconstruction (15)		
	report_05.jpg	
Uncertainty	The foundations are still there and they were analysed during the archaeological excavations.	04-still existing

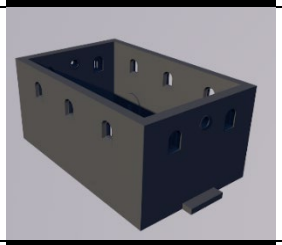
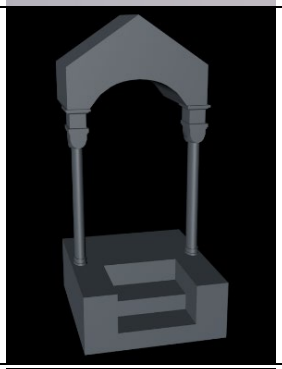
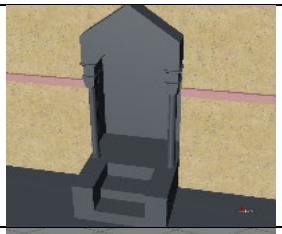
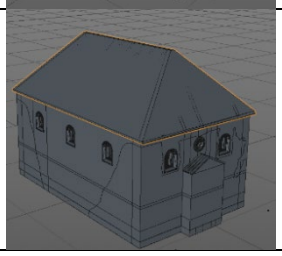
Cinema4D

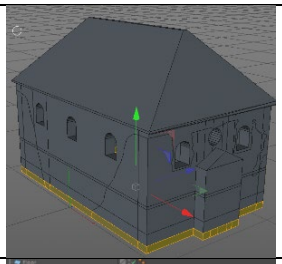
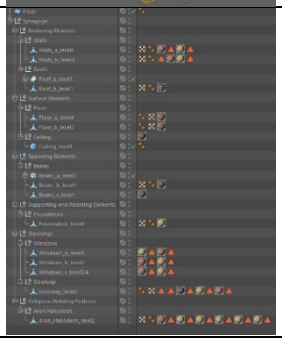
3D Model by Maryam Jäger (version unknown)

The modeller does not report the time of different tasks related to the study (modelling, documentation, etc.).

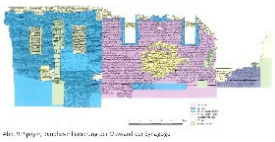
Tab. 45 Reconstruction workflow steps in Cinema4D by Maryam Jäger.

Workflow in Cinema4D		
1	Set up the reconstruction and created a structure using "null objects" to group the architectural elements. The structure follows the suggested hierarchy.	
2	Started to lay the basis for the reconstruction. For this, the reference images were inserted, placed and scaled.	
3	Reconstruction of the round windows. Use of the report, reconstruction drawing and photos for the dimensions. Reconstruction with the help of, cylinders and a cone shape.	
4	Reconstruction of the windows from the north and south sides. Here, only the report could be used for the dimensions because no remains are left today. Reconstruction with the help of Booleans, square and cylinder shapes.	
5	The western windows still exist, so the photo could be used as a reference. The window-shape from the north/south windows was used as a basis. The column was built with spline-modelling combined with primitive objects that are connected into one object.	
6	Reconstruction of the walls. The course of the walls was determined with help of the report and the reconstruction drawing. The walls were built with help of box-modelling. The Knife tool was then used to cut out the existing parts of the wall. They were split into two objects and the holes closed with the bridge tool. Photos and reconstruction drawings were used as references for cutting.	

7	Analogy_02 was used as reference. The doorway is built out of several objects that are connected into one. The columns were built with several cubes and cylinders that were connected into one object. The frame was built out of connected cubes. The arch was built with help of splines and two sweep generators.		
8	The openings for the windows and doors were cut out with the knife tool and the corresponding openings were inserted and scaled if necessary to match the dimensions of the walls. Photos and reconstruction drawings were used to place the windows and doorway.		
9	The Aron Hakodesh was reconstructed out of several parts. The base and roof were built with cubes and knife tool. The columns were reused from the doorway and scaled to fit the dimensions of the Aron Hakodesh. In the end, the parts were connected into one object.		
10	The floor was reconstructed on the basis of the report drawing. For this, a plane was placed on the floor level and cut out with the knife tool along the remains of the floor which are visible on the drawing. These parts were separated and made into two different objects.		
11	Parts of the cornice are still visible today. The rest could be reconstructed on the basis of the report drawing. The walls were cut with the knife tool and the new polygons extruded to create the cornice.		
12	There are no remains of the roof, so it was reconstructed according to the rules of a hipped roof. Several cubes were positioned 3to form a hipped roof. These cubes were then combined into one object.		
13	The roof was modelled to fit the beams. First a cube was fit to the desired size and placed according to the beams. With the knife tool the shape of a hipped roof was cut out. Lastly a boolen generator was used to hollow out the roof.		

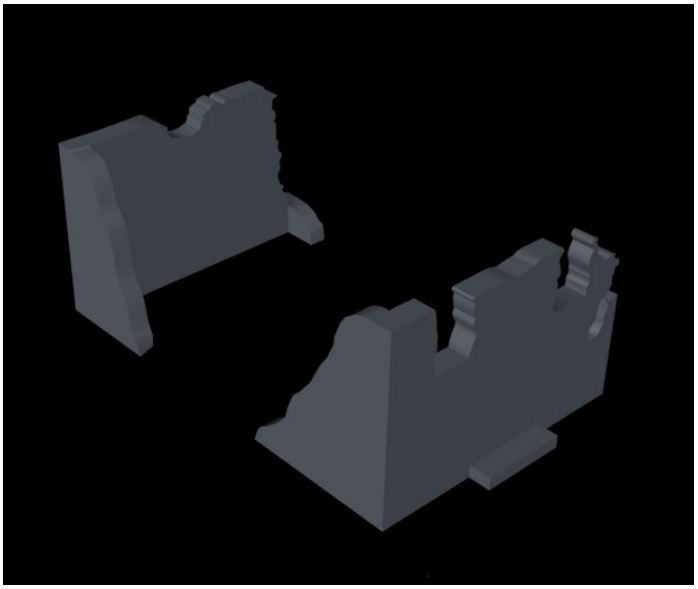
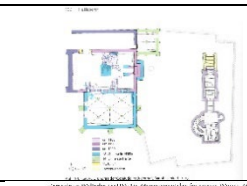
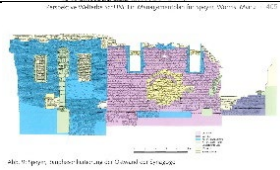
14	The modelling of the foundation was part of the reconstruction of the walls. This part was then detached from the walls (split tool) and renamed accordingly.	
15	Lastly the reconstruction structure was checked and the elements named according to their certainty levels.	

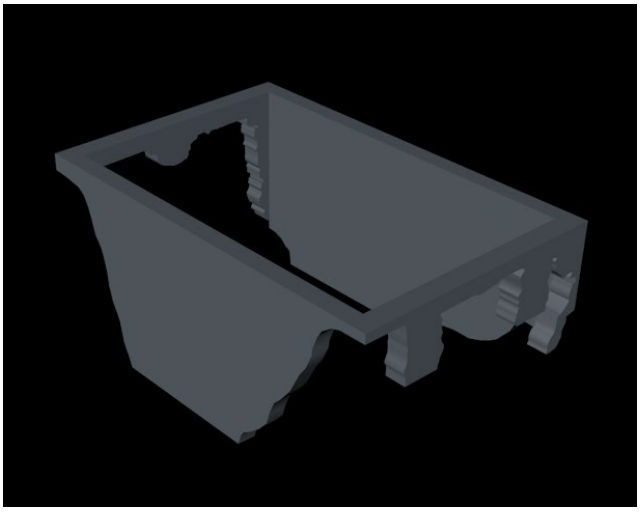
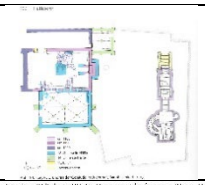
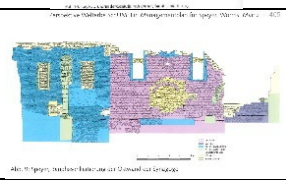
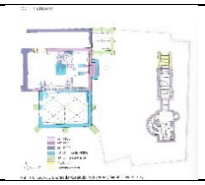
Tab. 46 Documentation of a 3D reconstruction of the semantic elements of Speyer Synagogue in the 13th century by Maryam Jäger in Cinema4D.

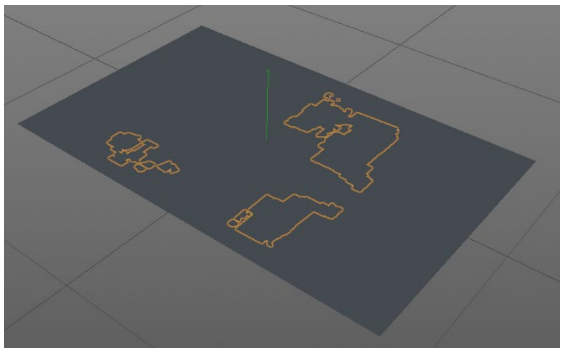
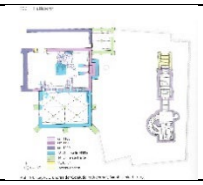
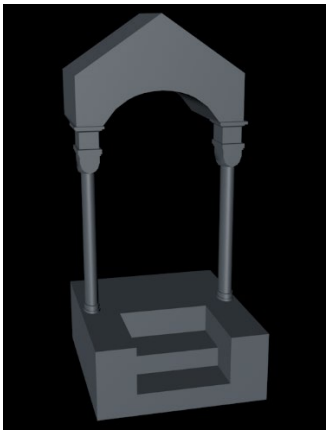
Window_a		
Reconstruction (1)		
Used sources	Report_text_page_11	
	Report_drawing_05	
	Photo_location_10	
Uncertainty	The Windows are still existing and therefore the level of certainty for the reconstruction is on the highest level.	Level 4
Argumentation	Report_drawing_05 as well as the description in the report (page 11) were used as the basis for the reconstruction. Drawing and report do not give information about all dimensions of the window. Therefore photo_location_10 was used as a reference.	

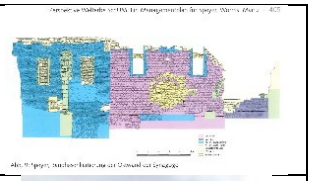
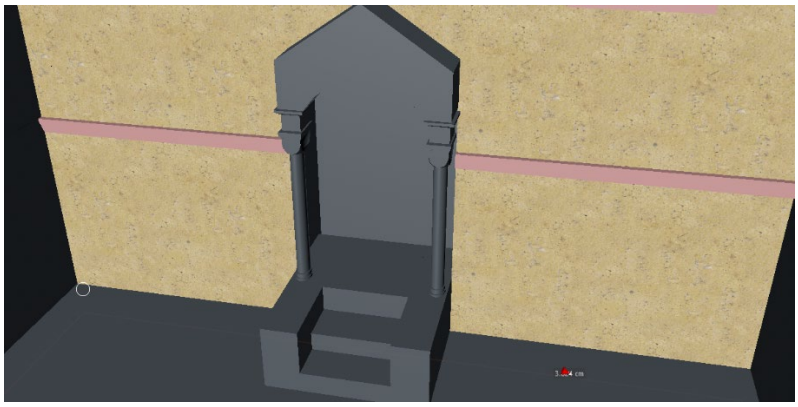
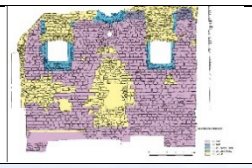
Window_b		
Reconstruction (2)		
Used sources	Report_text_page_11	
Uncertainty	These windows no longer exist. There are also no imprints or similar on the walls, so that their shape or position cannot be deducted.	Level 2
Argumentation	The dimensions were taken from the report.	

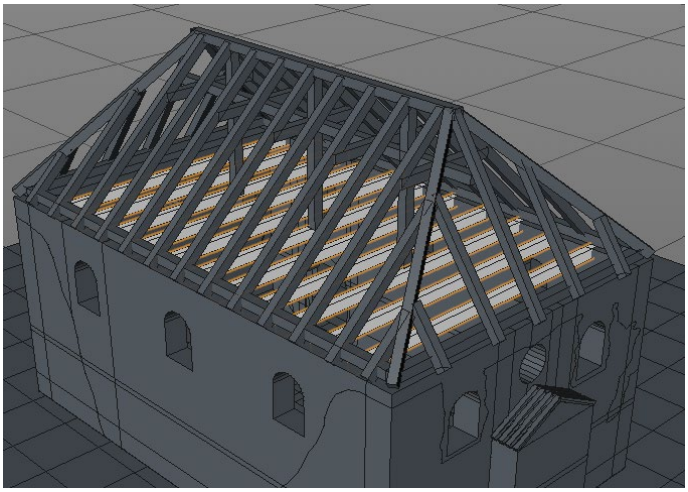
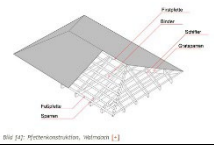
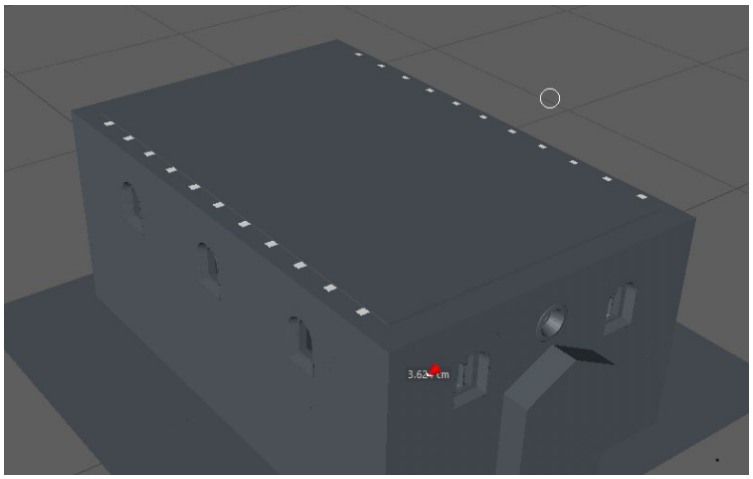
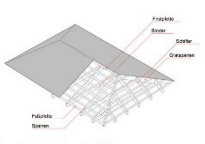
Window, east and west		
Reconstruction (3)		
Used sources	Report_text_page_11	
	photo_museum_01	
Uncertainty	The western windows are still existing. The windows on the eastern wall are reconstructed similarly and therefore only level 3 in certainty.	Level 3/4
Argumentation	The photo from the museum could be used for reconstructing the shape and the report could be used for the correct dimensions.	

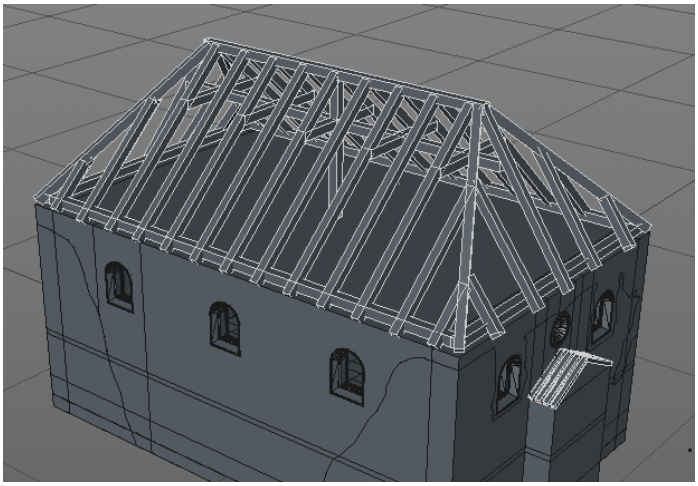
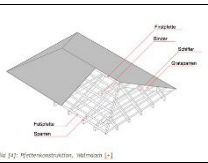
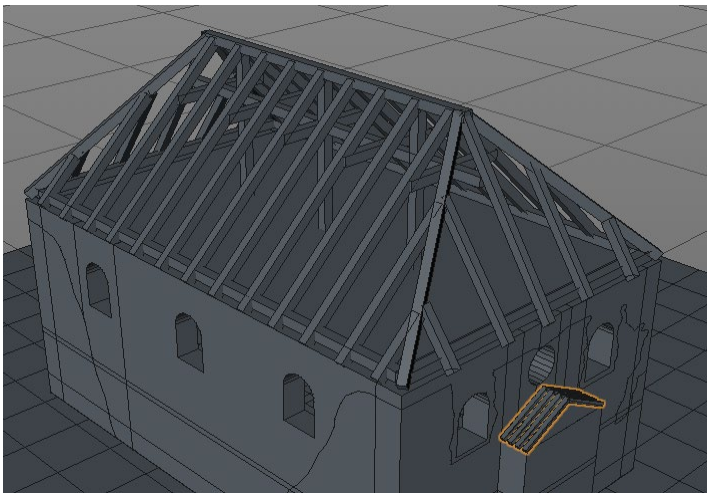
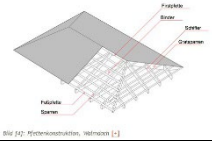
<table>
<tr><th colspan="3">Walls_a</th></tr>
<tr><td>Reconstruction (4)</td><td colspan="2">  </td></tr>
<tr><td rowspan="4">Used sources</td><td>report_drawing_03</td><td>  </td></tr>
<tr><td>report_drawing_05</td><td>  </td></tr>
<tr><td>photo_location_02</td><td> </td></tr>
<tr><td>photo_location_03</td><td> </td></tr>
<tr><td>Uncertainty</td><td>Still existing.</td><td>Level 4</td></tr>
<tr><td>Argumentation</td><td colspan="2">The dimensions were taken from the report and the photos.</td></tr>
</table>

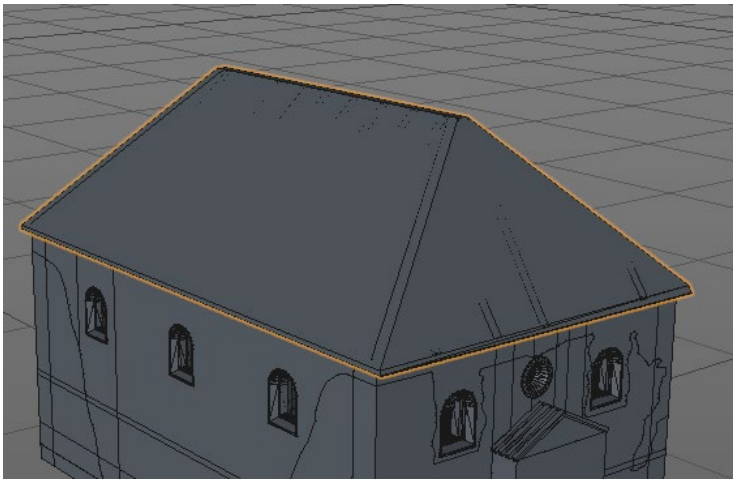
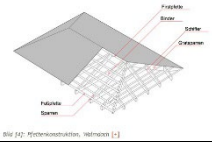
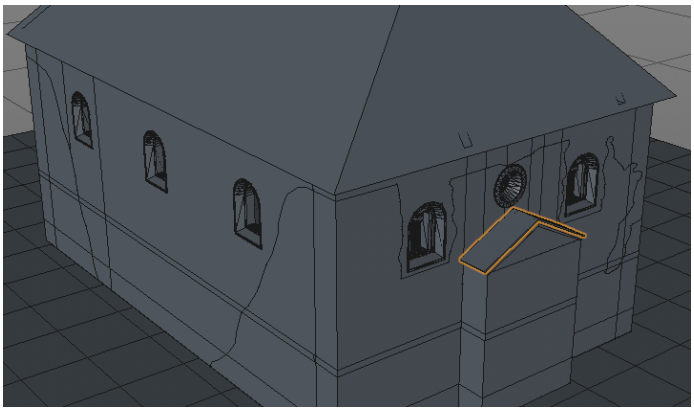
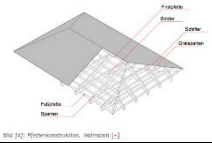
Walls_b		
Reconstruction (5)		
Used sources	report_drawing_03	
	report_drawing_05	
Uncertainty	Reconstruction on the basis of the still existing parts of the wall.	Level 3
Argumentation	The dimensions were taken from the report drawings and the photos.	
Door		
Reconstruction (6)		
Used sources	report_drawing_03	

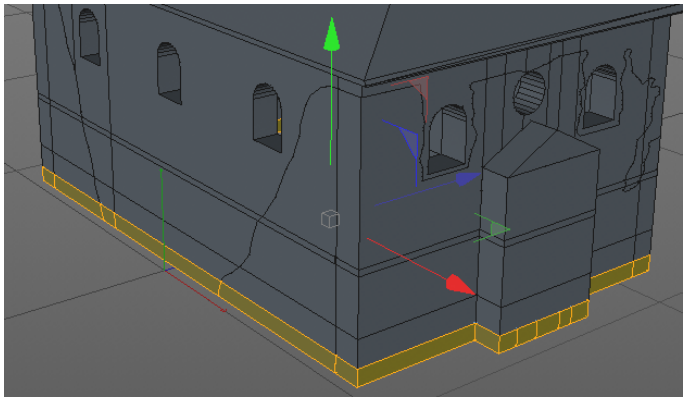
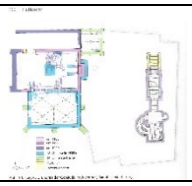
	analogy_02_01	
Uncertainty	The door does not exist anymore, therefore a analogie had to be used.	Level 2
Argumentation	Analogy_02 was used as reference because it has a relatively simple shape. The report drawing was used for the dimensions.	
Floor_a/b		
Reconstruction (7)		
Used sources	report_drawing_03	
Uncertainty	The report drawing shows the still existing parts of the floor. The rest could then easily be deducted	Level 4/3
Argumentation	The report drawing could be used to reconstruct the existing and missing part of the floor	
Aron Hakodesh		
Reconstruction (8)		

Used sources	report_05	
	photo_location_05	
	article_01_Page183_Abb18	
Uncertainty	Only the general shape and location is visible on the eastern wall. The rest had to be deducted from analogies.	Level 2
Argumentation	The reconstruction was based on analogies of similar structures from the defined time period. The dimensions were scaled to fit the niche which is visible on the report drawing and photo.	
Cornice		
Reconstruction (9)		
Used sources	article_01_Page182_Abb14	
	photo_location_11	
Uncertainty	Parts are still visible today, the rest can easily be deducted.	Level 3/4
Argumentation	Parts of the cornice are still visible today. The rest could be reconstructed on the basis of the report drawing .	

Beams_a		
Reconstruction (10)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	
Uncertainty	Nothing is left of the roof therefore analogy has to be used.	Level 1
Argumentation	There are no remains of the roof, so it was reconstructed according to the rules of a hipped roof.	
Ceiling		
Reconstruction (11)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	
Uncertainty	Nothing is left of the roof therefore analogy has to be used.	Level 1
Argumentation	The ceiling was reconstructed to provide a ceiling to the room and create an attic.	

Beams_b		
Reconstruction (12)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	
Uncertainty	Nothing is left of the roof therefore analogy has to be used.	Level 1
Argumentation	There are no remains of the roof, so it was reconstructed according to the rules of a hipped roof.	
Beams_c		
Reconstruction (13)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	
Uncertainty	Nothing is left of the roof therefore analogy has to be used.	Level 1
Argumentation	There are no remains of the roof, so it was reconstructed according to the rules of a hipped roof.	

Roof_a		
Reconstruction (14)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	
Uncertainty	Nothing is left of the roof therefore analogy has to be used.	Level 1
Argumentation	The roof was modelled according to the beams.	
Roof_b		
Reconstruction (15)		
Used sources	http://www.urbs-mediaevalis.de/pages/studienportal/bauteiltypologie/bauteile-w/walmdach.php	
Uncertainty	Nothing is left of the roof therefore analogy has to be used.	Level 1
Argumentation	The roof was modelled according to the beams.	

Foundation		
Reconstruction (16)		
Used sources	report_drawing_03	
Uncertainty	The foundation still exists and is recorded in the archaeological report.	Level 4
Argumentation	The foundation was modelled with the report drawing as reference.	

Appendix 5: Metadata sets in 3D Repositories

Report on documented metadata in selected 3D model repositories

In the following, an analysis of the metadata documented in selected repositories from institutional and commercial offerings based on screenshots of digital cultural heritage entries are collected. The following repositories were analysed:

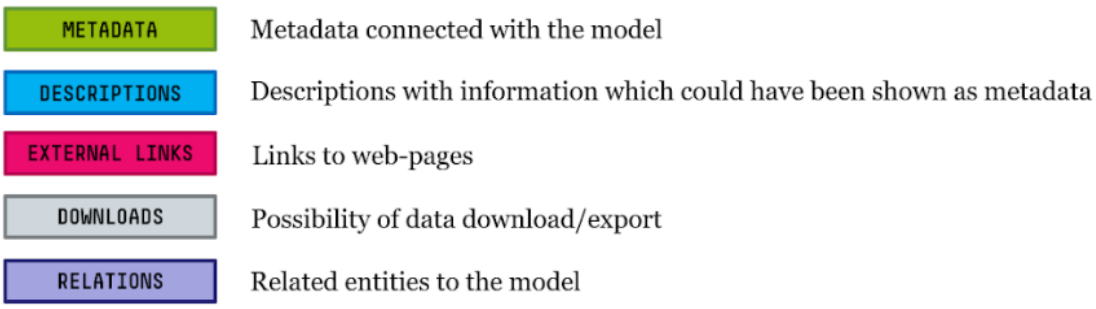
Commercial offer:

- 3D Warehouse
- Sketchfab
- Turbosquid
- Blend Swap

Institutional offer:

- Kompakkt
- Europeana
- Smithsonian 3D Digitization
- Open Heritage 3D

The following is a legend of the marking colours used to indicate the different types of available information:

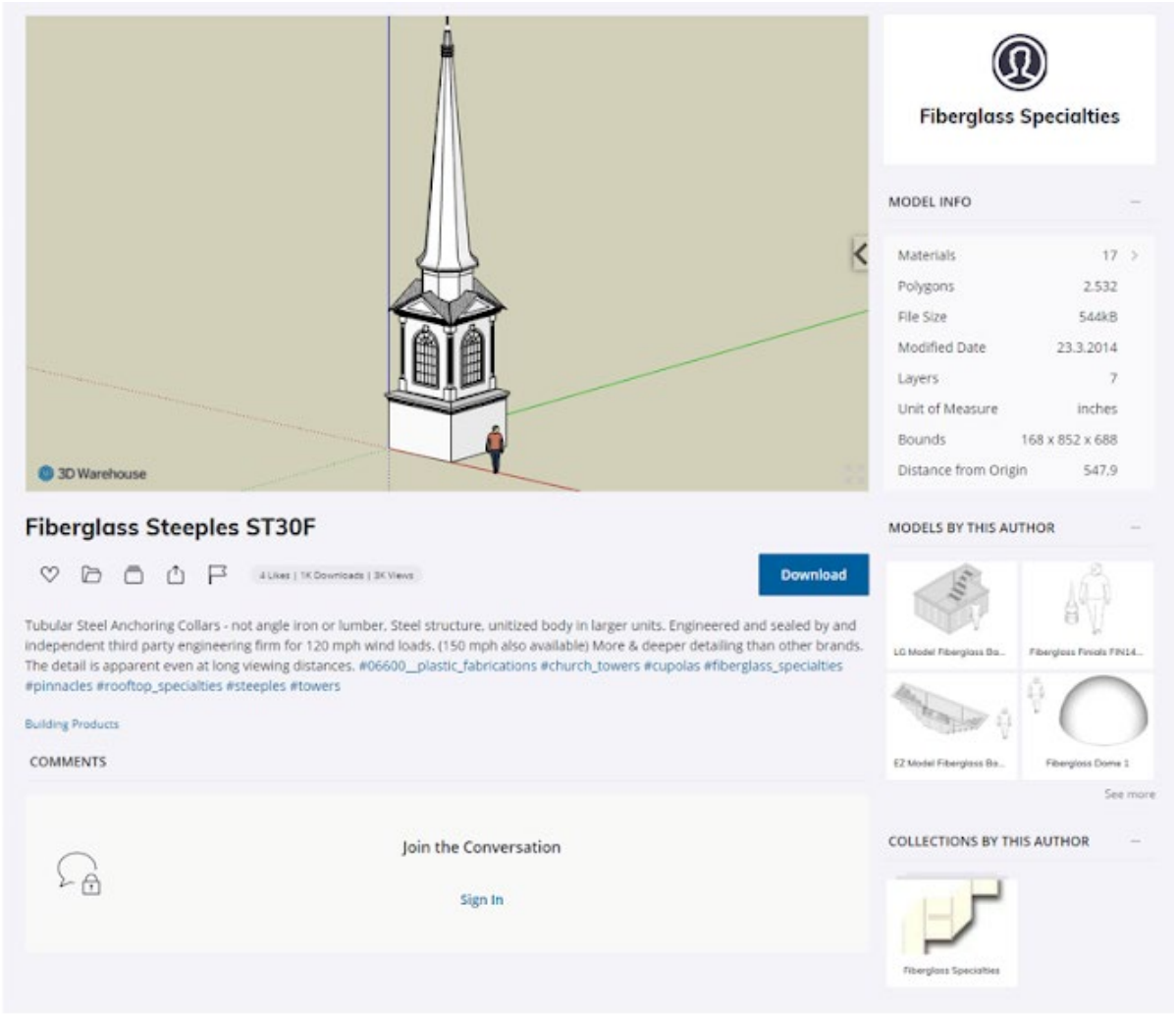


3D Warehouse

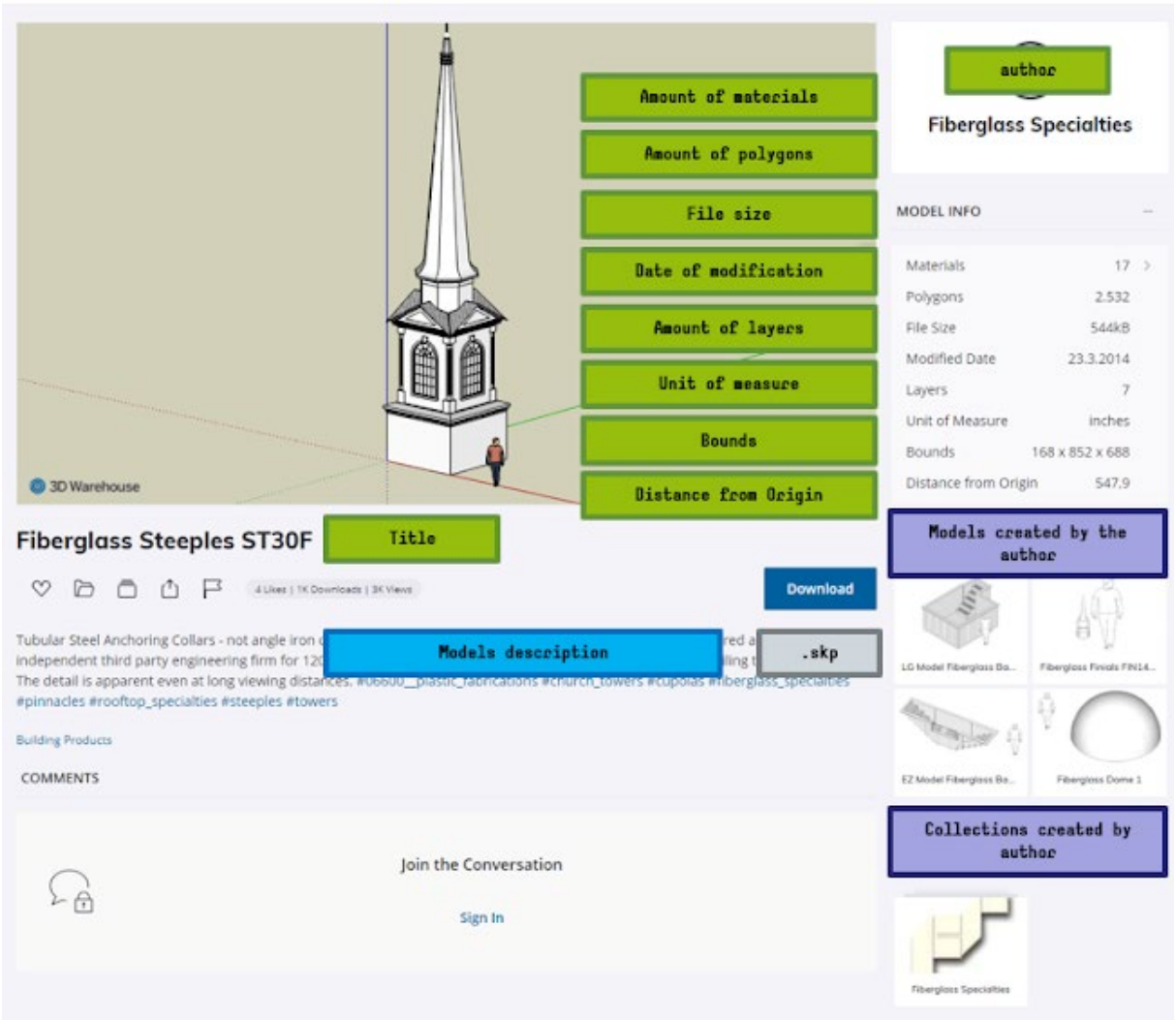
"3D Warehouse is a website of searchable, pre-made 3D models that works seamlessly with SketchUp. 3D Warehouse is a tremendous resource and online community for anyone who creates or uses 3D models."
https://3dwarehouse.SketchUp.com/

Reviewed entry:
https://3dwarehouse.SketchUp.com/model/f3b26a49739b20a08b7e02a440eafc36/Fiberglass-Steeples-ST30F

Screenshot:



Metadata analysis:



Sketchfab

Sketchfab

"Sketchfab is a platform to publish, share, discover, buy and sell 3D, VR and AR content. It provides a viewer based on the WebGL and WebXR technologies that allows users to display 3D models on the web, to be viewed on any mobile browser, desktop browser or Virtual Reality headset."
https://sketchfab.com/

Reviewed entry:
https://sketchfab.com/3d-models/cpdp-4a180e83961147b2bda7541b50ec8a2e

Screenshot (main entry):

CPDP
3D Model

AI_MAINZ PRO
FOLLOWING

76 258 12

Download 3D Model + Add To </> Embed Share Report

Triangles: 2.9M Vertices: 1.5M More model information

Realized within the project of the sourced-based reconstruction of the New Synagogue in Wroclaw/Breslau (Poland). Link to the 3D model documentation: http://www.vfu-oppler.hs-mainz.de/en/wisski/navigate/1480/view. Supported by »The German Federal Government Commissioner for Culture and the Media « (02/2018-11/2019) and »The Foundation for Polish-German Cooperation« (05/2018). Magnified by https://architekturinstitut.hs-mainz.de/. Published under CC-BY-NC-SA 4.0.

License: CC Attribution Learn more

Published 3 years ago

Architecture 3D Models | Cultural Heritage & History 3D Models

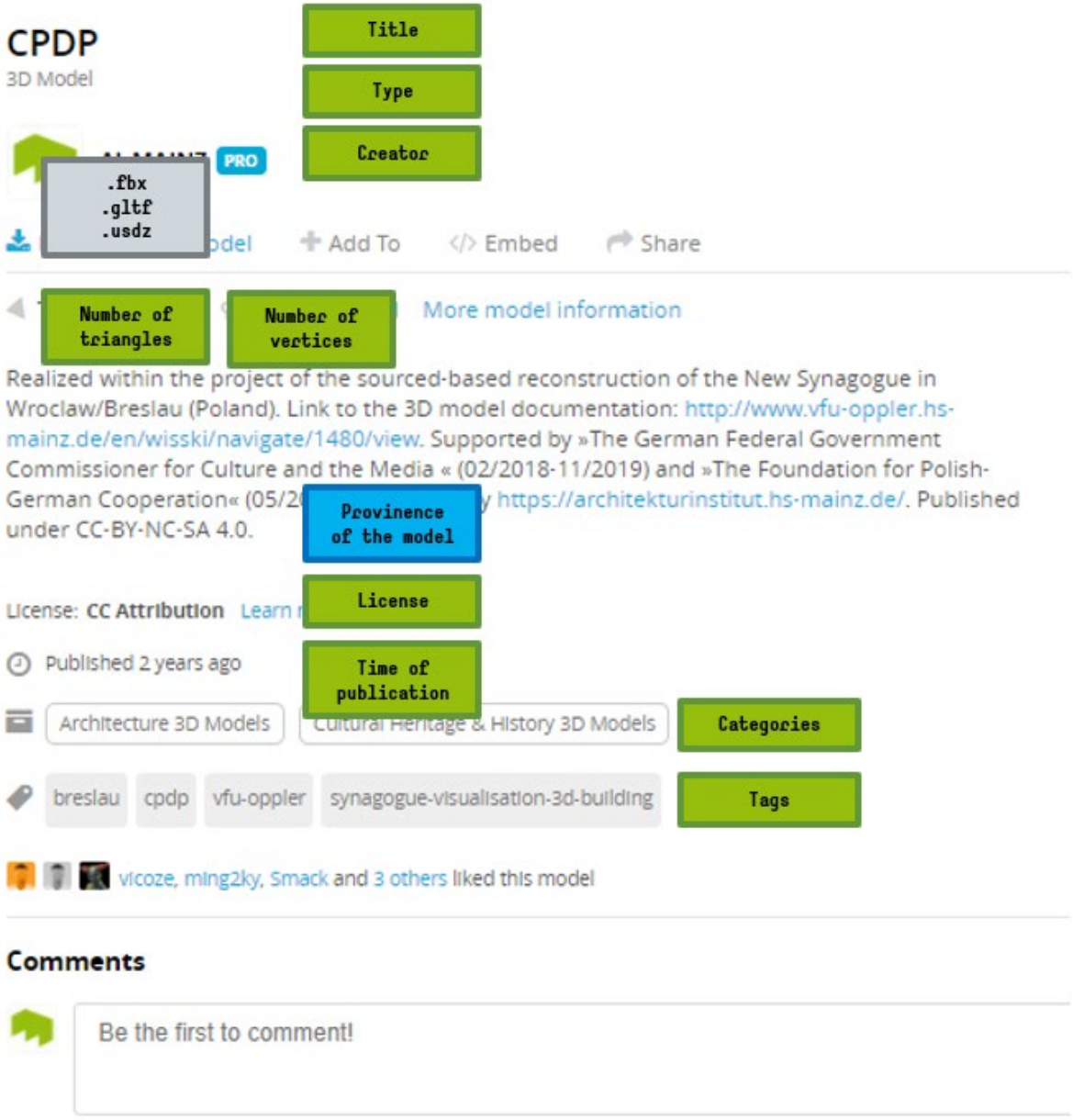
breslau | cpdp | vfu-oppler | synagogue-visualisation-3d-building

vicoze, ming2ky, Smack and 9 others liked this model

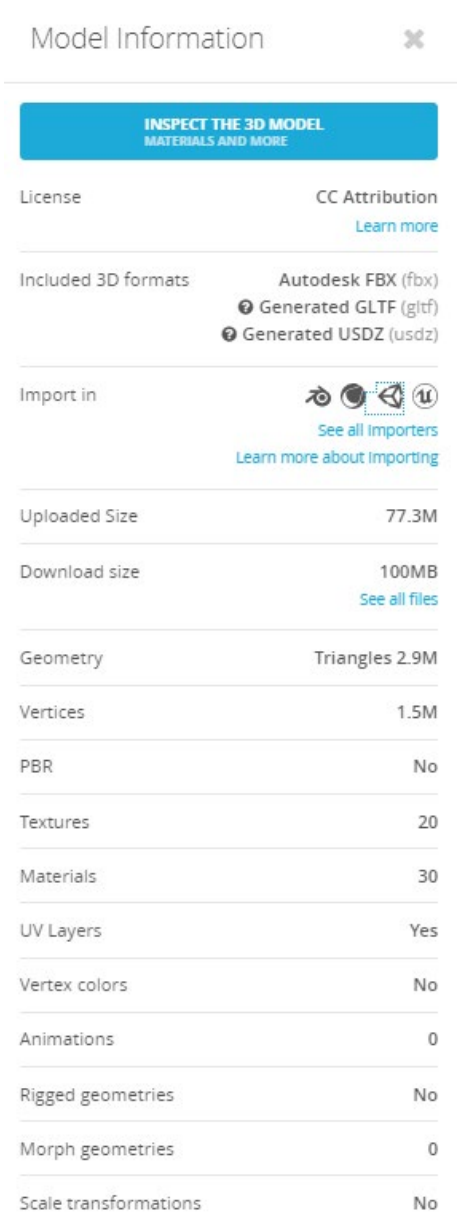
Comments

Be the first to comment!

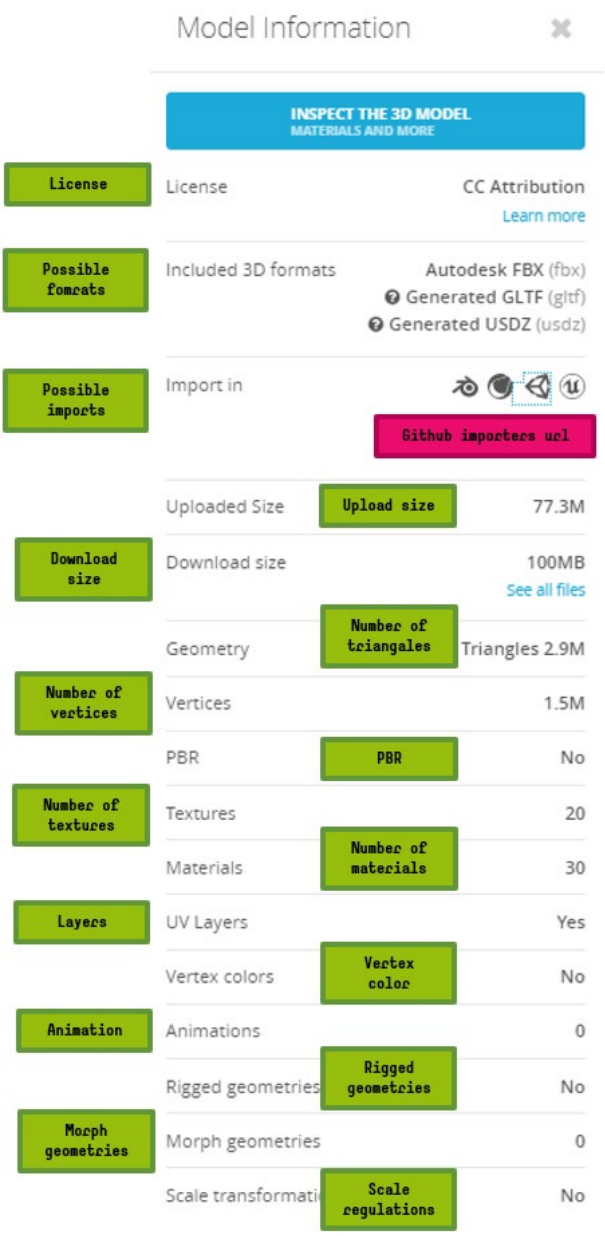
Metadata analysis:



Screenshot (More model information):



Metadata analysis (More model information):

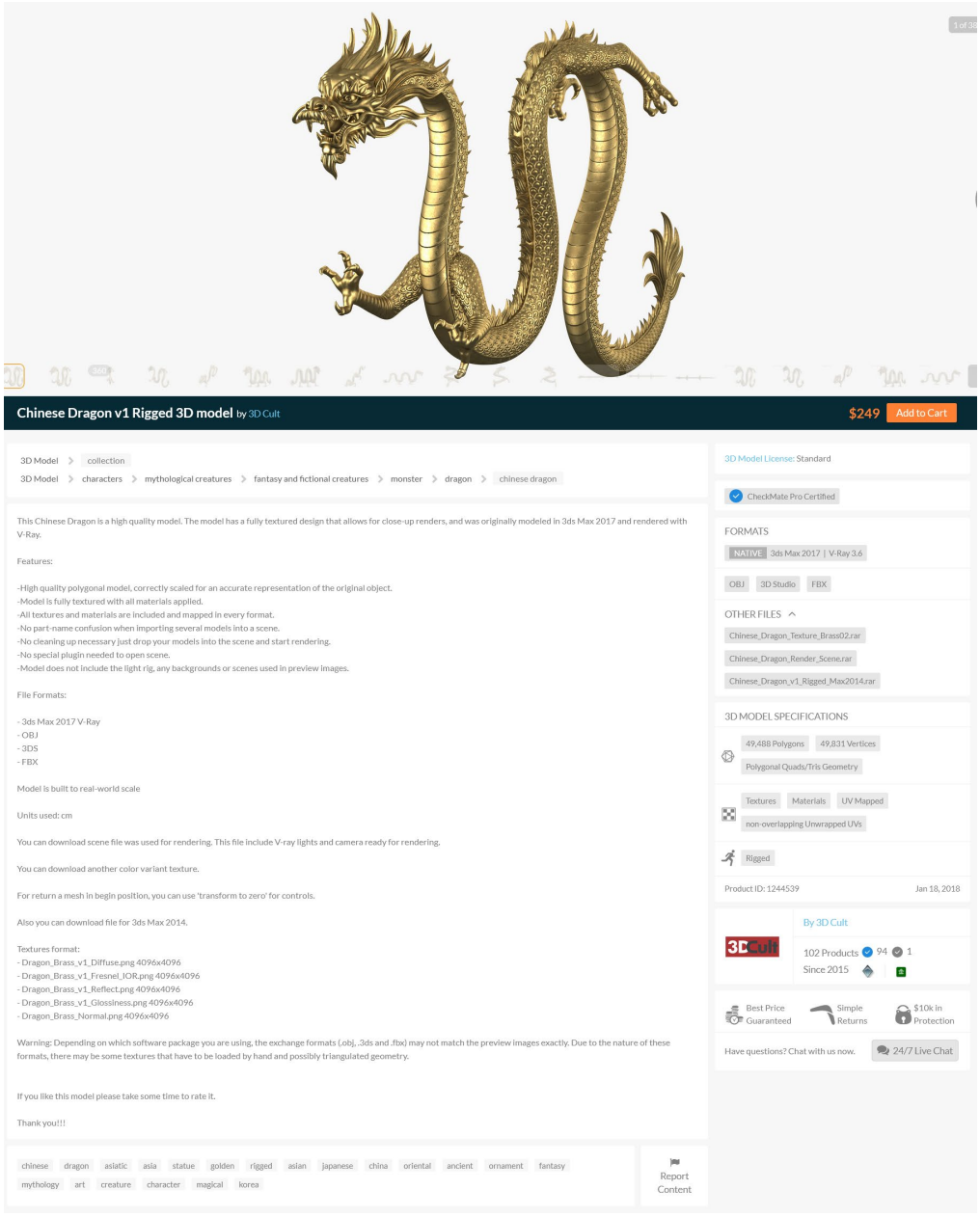


Turbosquid

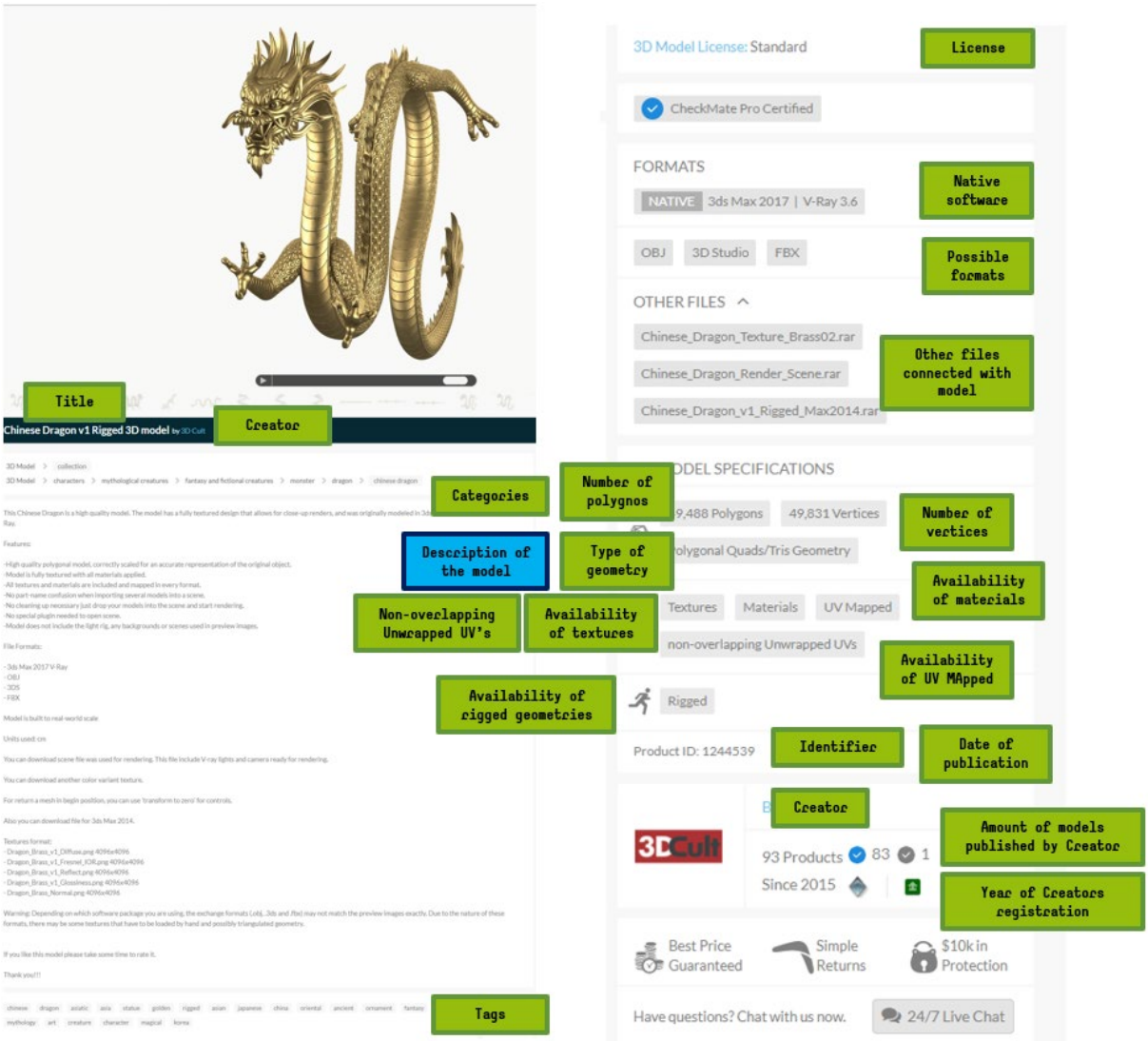
“ TurboSquid is a digital media company that sells stock 3D models used in 3D graphics to a variety of industries, including computer games, architecture, and interactive training. The company, headquartered in New Orleans, Louisiana in the United States, is most known for brokering the sale of 3D models in return for a percentage of the sales. As of 2019, TurboSquid has over 800,000 3D models in its library.”
https://www.turbosquid.com/

Reviewed entry:
https://www.turbosquid.com/3d-models/chinese-dragon-rig-v1-3d-model-1244539

Screenshot:



Metadata analysis:

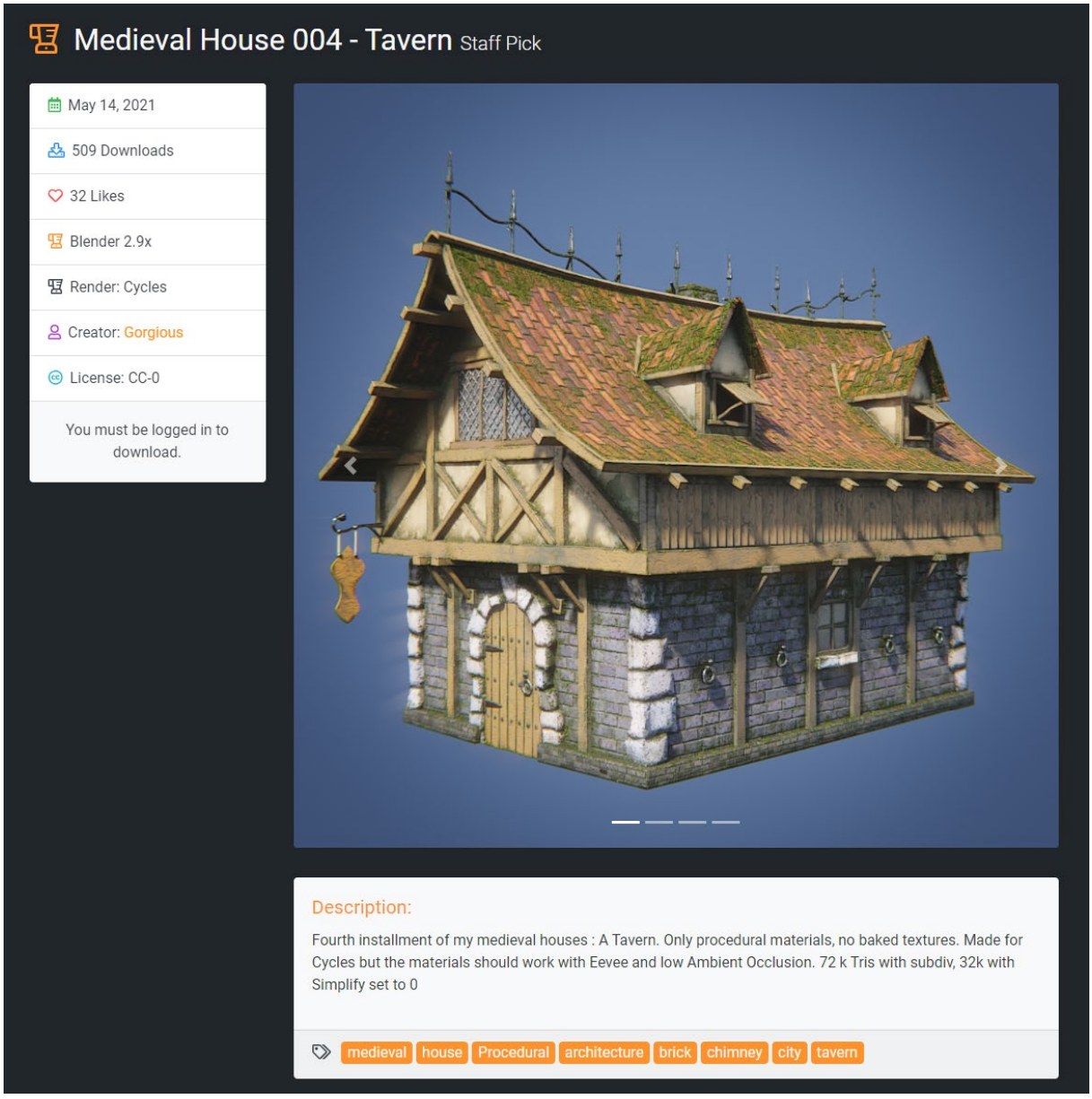


Blend Swap

“ Blend Swap's mission is to create a place where Blender-powered 3D artists can share, exchange, collaborate, and learn from other artists in the community. We strive to showcase and advance artists with staff picks and collaborations with other top Blender sites on the internet.”
https://www.blendswap.com/

Reviewed entry:
https://www.blendswap.com/blend/28068

Screenshot:



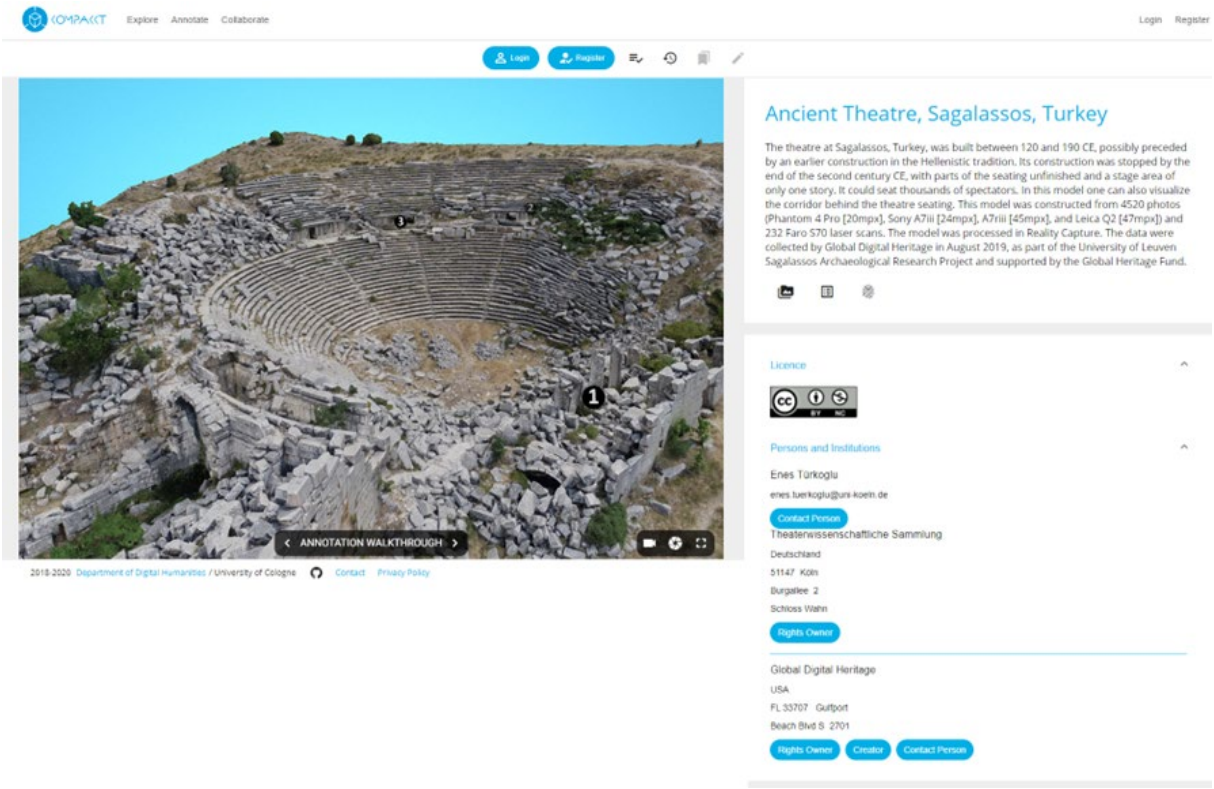
Metadata analysis:

Kompakkt

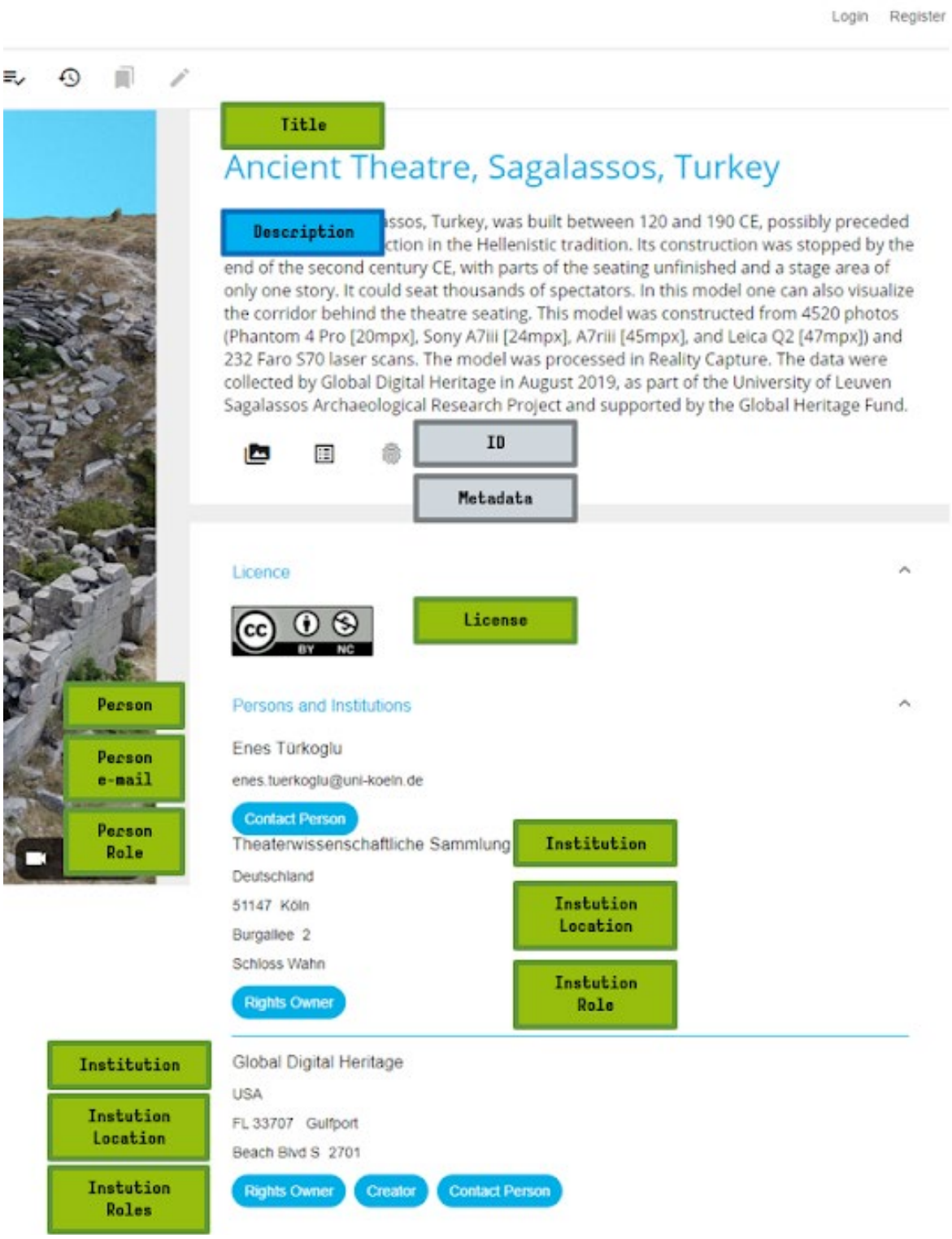
"The aim of Kompakkt project is to expand the e-learning software ILIAS, with which teachers can select, explore, annotate and manage 3D objects from collections. Thus, the students are given a lower-threshold access than before to research-relevant 3D objects as teaching material."
https://kompakkt.de/home

Reviewed entry:
https://kompakkt.de/entity/5e55381fea740b0a95515b46

Screenshot:



Metadata analysis:

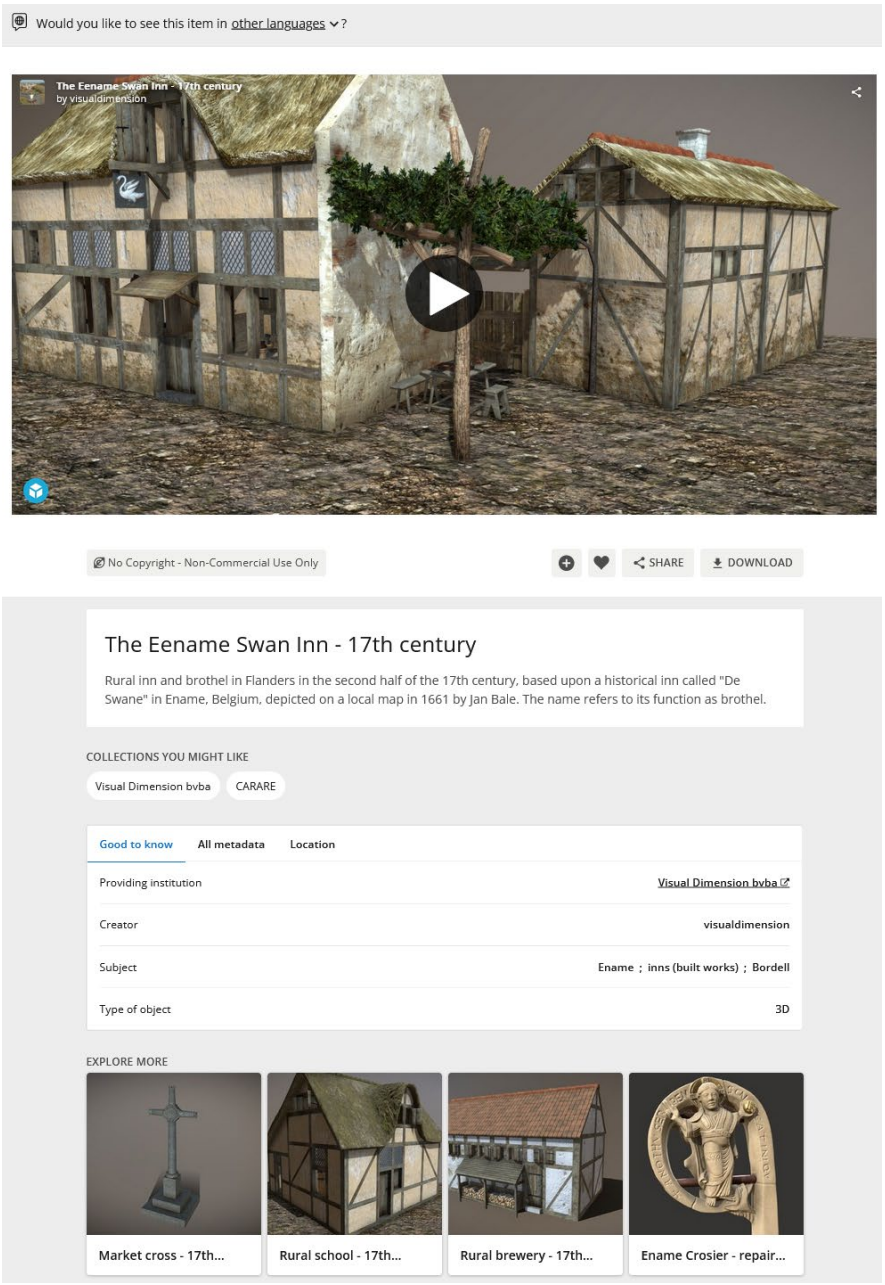


Europeana

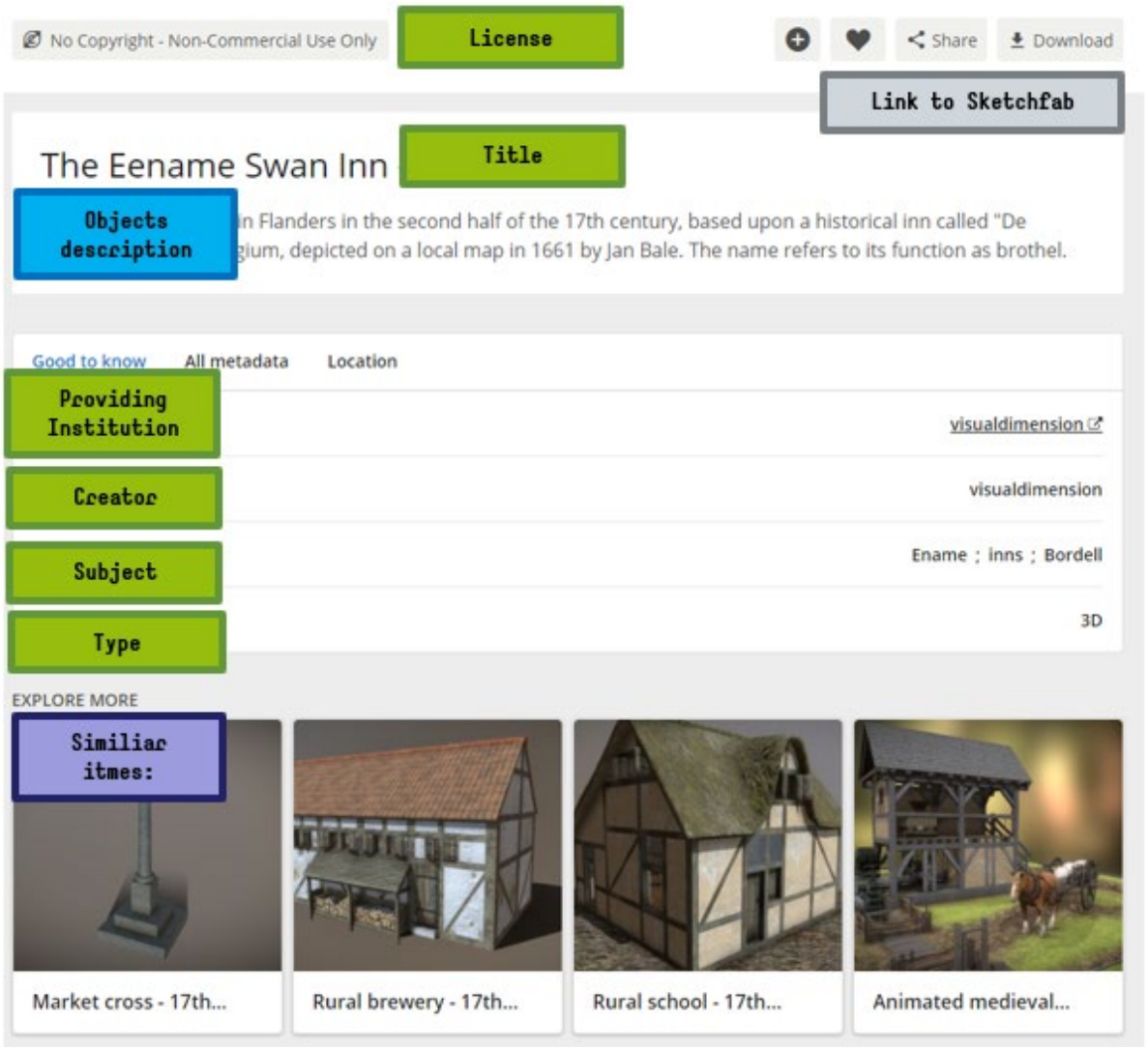
"Europeana empowers the cultural heritage sector in its digital transformation. We develop expertise, tools and policies to embrace digital change and encourage partnerships that foster innovation. We make it easier for people to use cultural heritage for education, research, creation and recreation. Our work contributes to an open, knowledgeable and creative society."
https://www.europeana.eu/

Reviewed entry:
https://www.europeana.eu/en/item/181/share3d_129

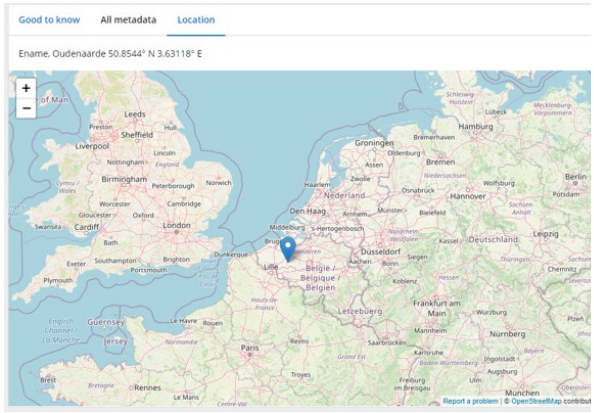
Screenshot:



Metadata analysis:

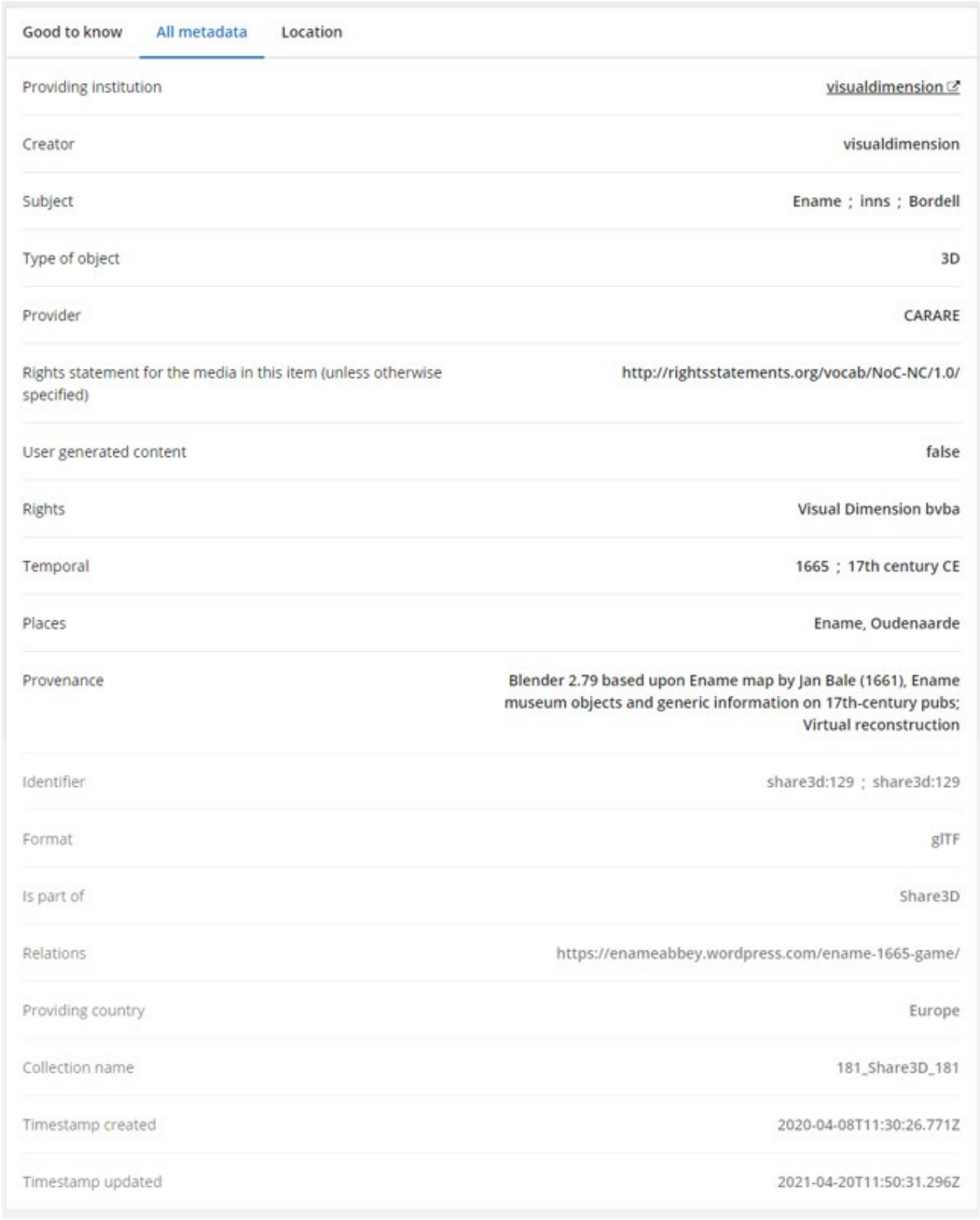


Screenshot (Location):



Metadata analysis (location):

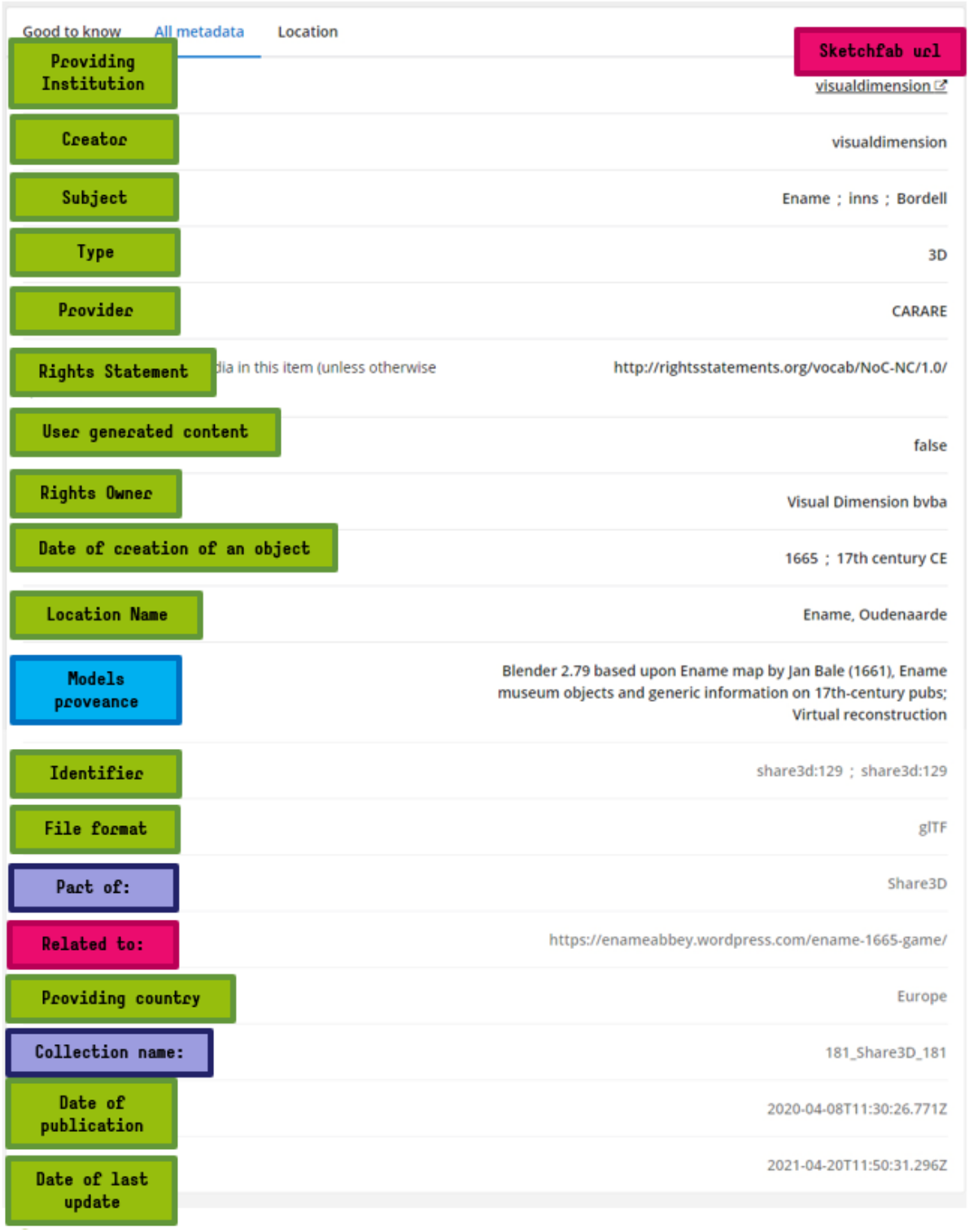
Screenshot (All metadata):



Good to know | All metadata | Location

Providing institution	visualdimension
Creator	visualdimension
Subject	Ename ; inns ; Bordell
Type of object	3D
Provider	CARARE
Rights statement for the media in this item (unless otherwise specified)	http://rightsstatements.org/vocab/NoC-NC/1.0/
User generated content	false
Rights	Visual Dimension bvba
Temporal	1665 ; 17th century CE
Places	Ename, Oudenaarde
Provenance	Blender 2.79 based upon Ename map by Jan Bale (1661), Ename museum objects and generic information on 17th-century pubs; Virtual reconstruction
Identifier	share3d:129 ; share3d:129
Format	glTF
Is part of	Share3D
Relations	https://enameabbey.wordpress.com/ename-1665-game/
Providing country	Europe
Collection name	181_Share3D_181
Timestamp created	2020-04-08T11:30:26.771Z
Timestamp updated	2021-04-20T11:50:31.296Z

Metadata analysis (All metadata):



Smithsonian 3D Digitization

Smithsonian | 3D DIGITIZATION

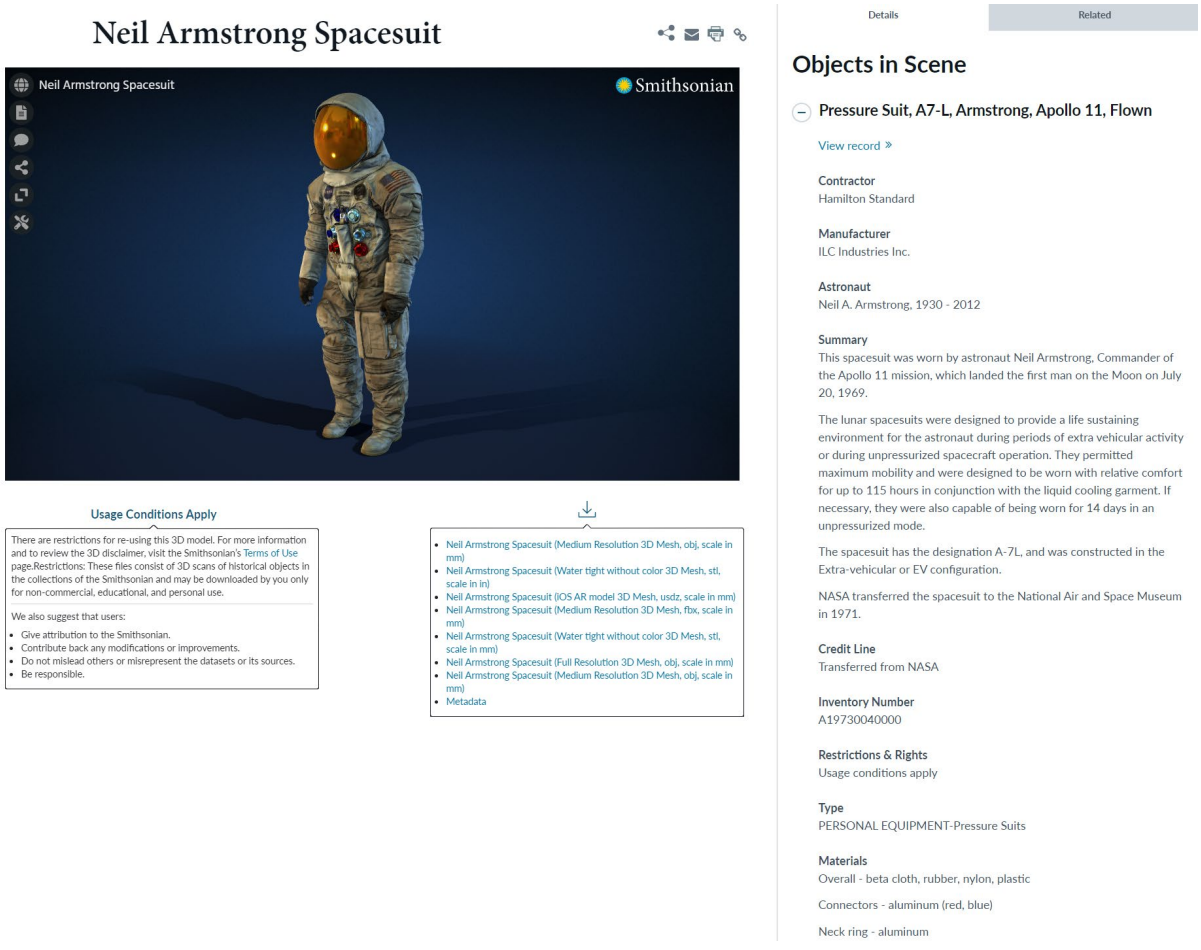
"The 3D Program is a small group of technologists working within the Smithsonian Institution Digitization Program Office. We focus on developing solutions to further the Smithsonian's mission of "the increase and diffusion of knowledge" through the use of three-dimensional capture technology, analysis tools, and our distribution platform"

https://3d.si.edu/

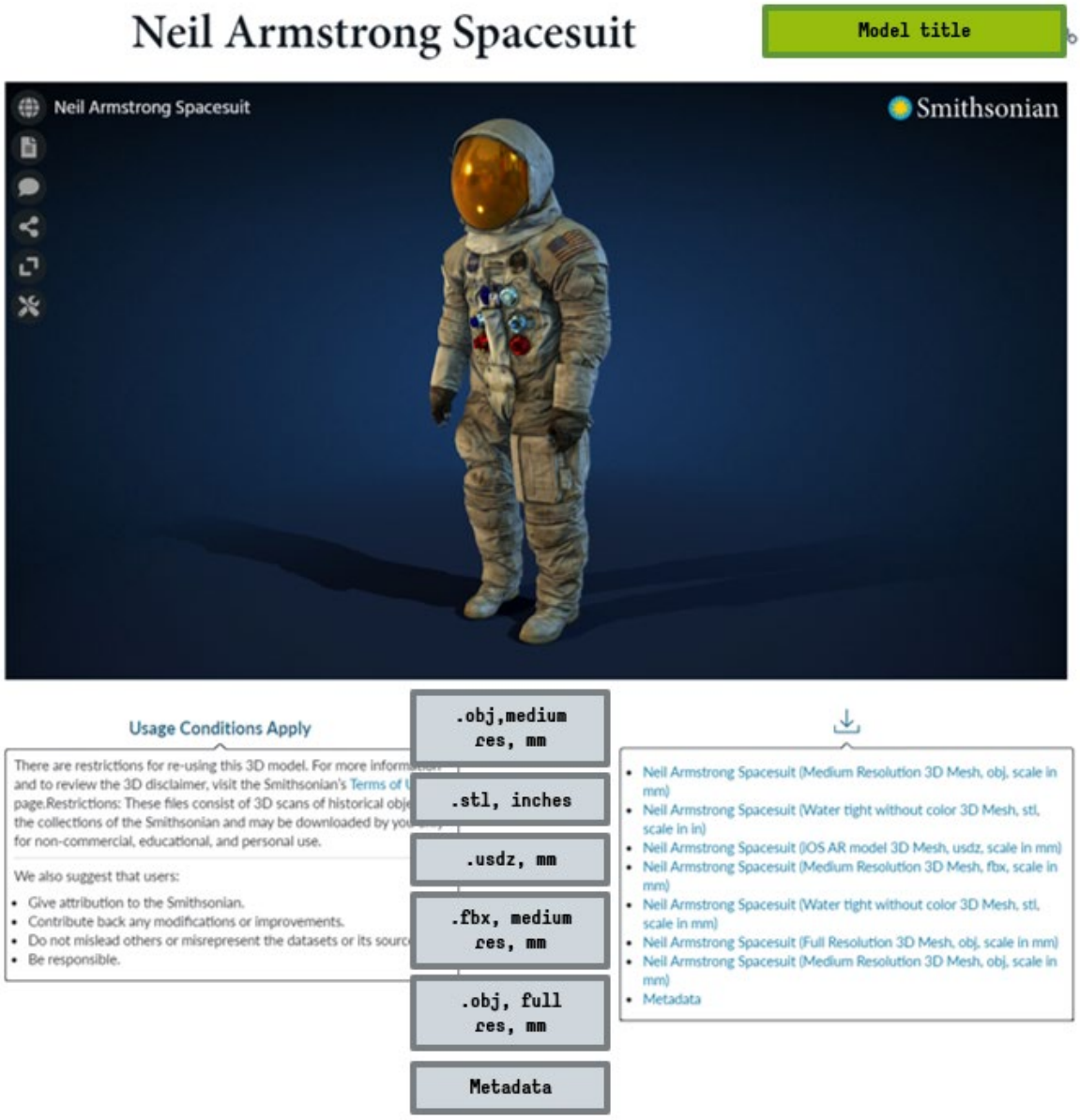
Reviewed entry:

https://3d.si.edu/object/3d/neil-armstrong-spacesuit:d8c63ba6-4ebc-11ea-b77f-2e728ce88125

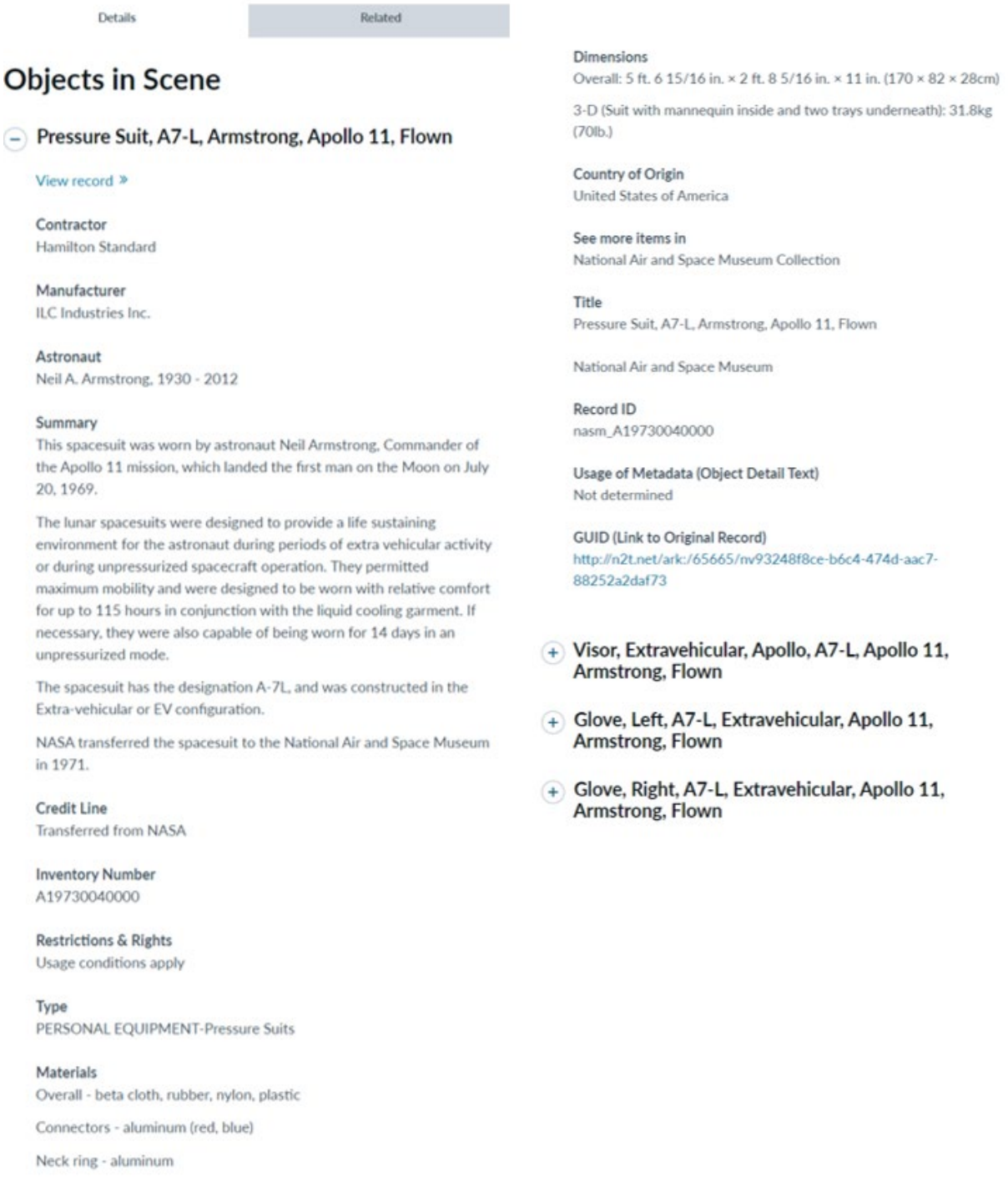
Screenshot:



Metadata analysis:



Screenshot (Pressure Suit, A7-L, Armstrong, Apollo 11, Flown):



Details | Related

Objects in Scene

Pressure Suit, A7-L, Armstrong, Apollo 11, Flown

View record »

Contractor
Hamilton Standard

Manufacturer
ILC Industries Inc.

Astronaut
Neil A. Armstrong, 1930 - 2012

Summary
This spacesuit was worn by astronaut Neil Armstrong, Commander of the Apollo 11 mission, which landed the first man on the Moon on July 20, 1969.

The lunar spacesuits were designed to provide a life sustaining environment for the astronaut during periods of extra vehicular activity or during unpressurized spacecraft operation. They permitted maximum mobility and were designed to be worn with relative comfort for up to 115 hours in conjunction with the liquid cooling garment. If necessary, they were also capable of being worn for 14 days in an unpressurized mode.

The spacesuit has the designation A-7L, and was constructed in the Extra-vehicular or EV configuration.

NASA transferred the spacesuit to the National Air and Space Museum in 1971.

Credit Line
Transferred from NASA

Inventory Number
A19730040000

Restrictions & Rights
Usage conditions apply

Type
PERSONAL EQUIPMENT-Pressure Suits

Materials
Overall - beta cloth, rubber, nylon, plastic

Connectors - aluminum (red, blue)

Neck ring - aluminum

Dimensions
Overall: 5 ft. 6 15/16 in. × 2 ft. 8 5/16 in. × 11 in. (170 × 82 × 28cm)

3-D (Suit with mannequin inside and two trays underneath): 31.8kg (70lb.)

Country of Origin
United States of America

See more items in
National Air and Space Museum Collection

Title
Pressure Suit, A7-L, Armstrong, Apollo 11, Flown

National Air and Space Museum

Record ID
nasm_A19730040000

Usage of Metadata (Object Detail Text)
Not determined

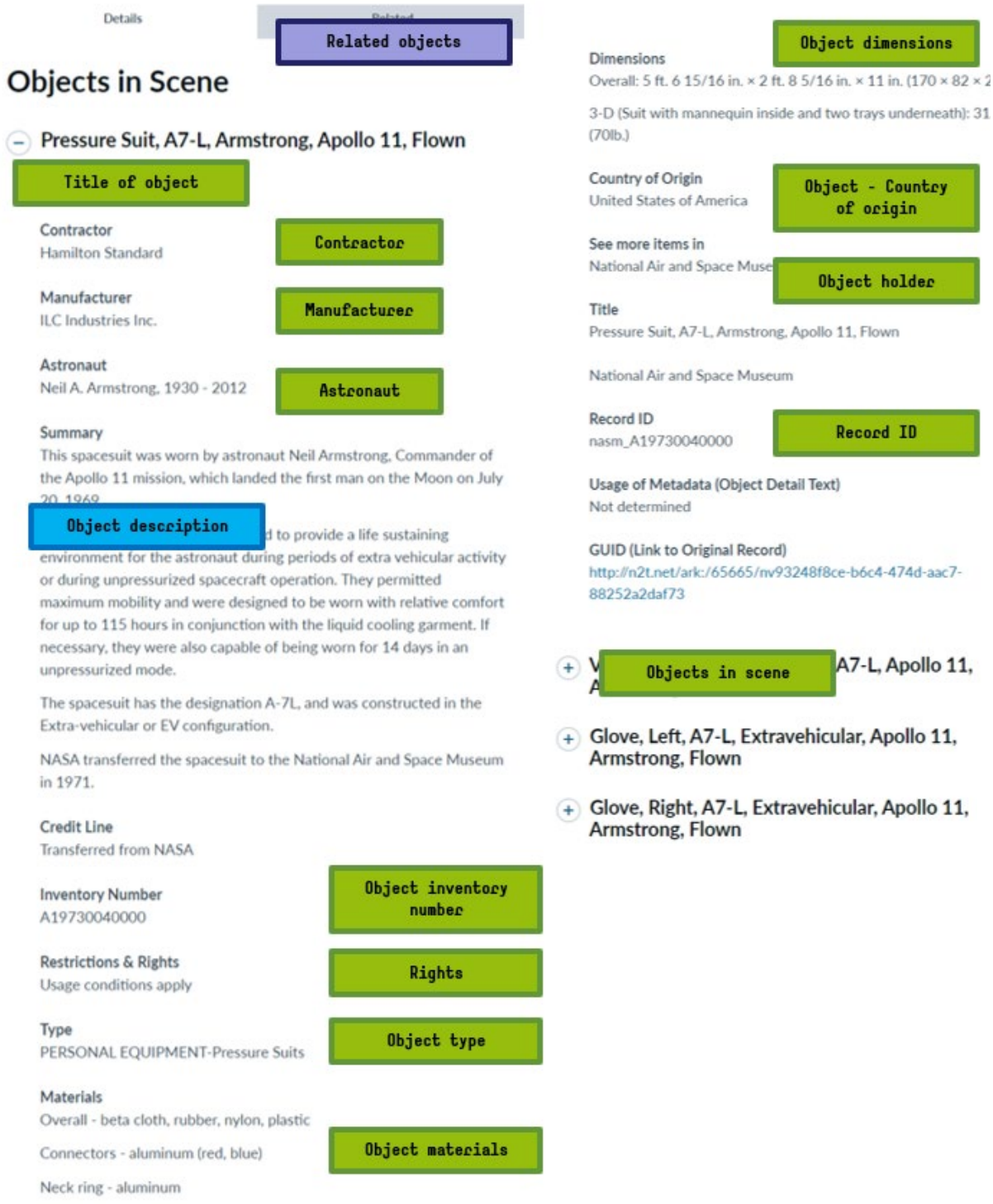
GUID (Link to Original Record)
http://n2t.net/ark:/65665/nv93248f8ce-b6c4-474d-aac7-88252a2daf73

Visor, Extravehicular, Apollo, A7-L, Apollo 11, Armstrong, Flown

Glove, Left, A7-L, Extravehicular, Apollo 11, Armstrong, Flown

Glove, Right, A7-L, Extravehicular, Apollo 11, Armstrong, Flown

Metadata analysis (Pressure Suit, A7-L, Armstrong, Apollo 11, Flown):

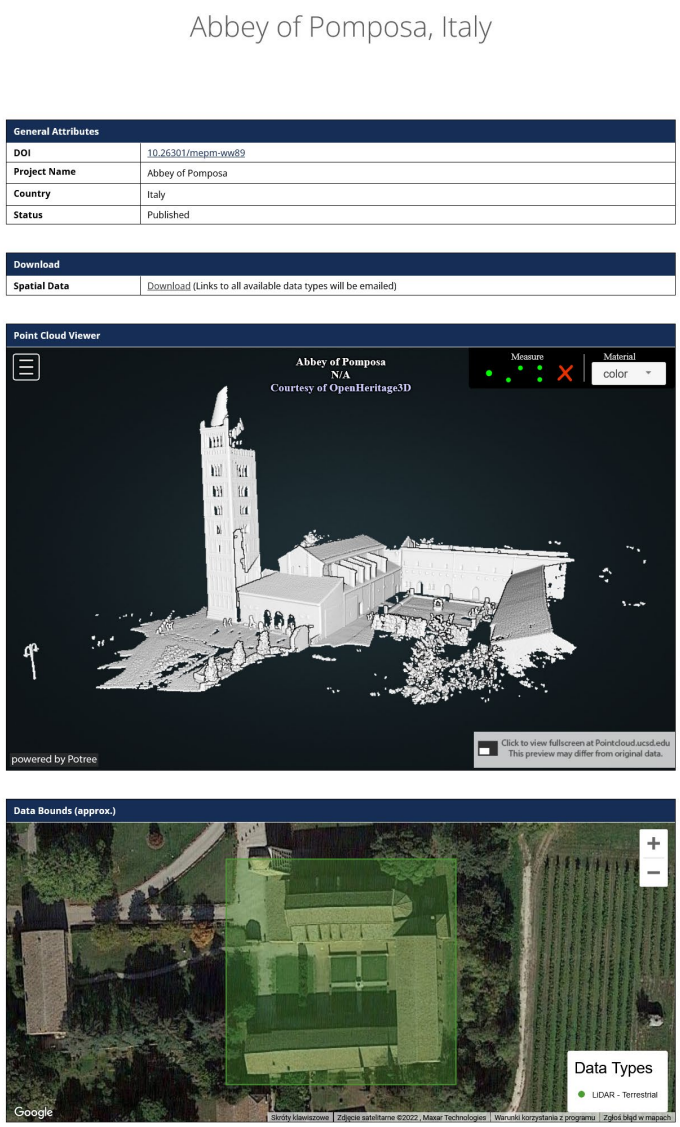


Open Heritage 3D

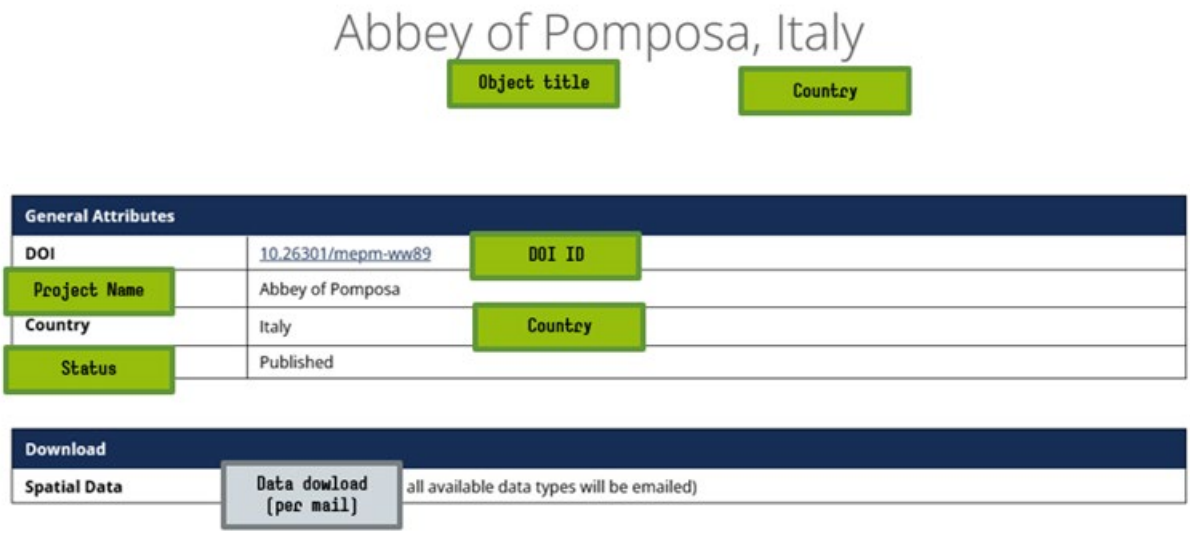
"As 3D data capture becomes an increasingly common method for the documentation of cultural heritage there has emerged a growing need to assist with the distribution and open access of this growing library of 3D data while maintaining scientific rigor, respecting cultural and ethical sensitivities, enhancing discoverability, and addressing data longevity and archival standards. In response to these areas of need, the Open Heritage 3D project was developed to make primary 3D cultural heritage data open and accessible and remove the barriers for content producers to publish their data."
https://openheritage3d.org/

Reviewed entry:
https://openheritage3d.org/project.php?id=mepm-ww89

Screenshot:



Metadata analysis :



Screenshot (documentation):

Data Type	Size	Device Name	Device Type
LiDAR - Terrestrial	0.643 GB	Not available	Not available

Background	
Site Description	Pomposa Abbey is a Benedictine monastery in the comune of Codigoro near Ferrara, Italy. It was one of the most important in northern Italy, famous for the Carolingian manuscripts preserved in its rich library, one of the wealthiest of Carolingian repositories and for the Romanesque buildings. Begun in the late in the late 700's the building was enlarged significantly in the tenth and eleventh centuries, with the addition of the bell tower dating to 1063. The Abbey was at one time the governmental seat for a good portion of Northern Italy, but fell into decline due to an impoverished turn in the local economy and the presence of malaria.
Collection Date	0000-00-00 to 0000-00-00
Publication Date	2020-06-22
License Type	N/A

Entities	
Contributors	N/A
Collectors	N/A
Funders	N/A
Partners	N/A
Site Authority	N/A

Citation
2020: Abbey of Pomposa - LiDAR - Terrestrial . Collected by . Distributed by Open Heritage 3D. https://doi.org/10.26301/mepm-ww89

Metadata analysis (documentation):

Data Type	Size	Device Name	Device Type
LiDAR - Terrestrial	0.643 GB	Not available	Not available

Type of model | File size | Used device name | Used device type

Background	
Site Description	Pomposa Abbey is a Benedictine monastery in the comune of Codigoro near Ferrara, Italy. It was one of the most … in northern Italy, famous for the Carolingian manuscripts preserved in its rich library, one of the wealthiest of … repositories and for the Romanesque buildings. Begun in the late in the late 700's the building was enlarged … in the tenth and eleventh centuries, with the addition of the bell tower dating to 1063. The Abbey was at one … governmental seat for a good portion of Northern Italy, but fell into decline due to an impoverished turn in the … omy and the presence of malaria.
Collection Date	… to 0000-00-00
Publication Date	… 2
License Type	…

Description of entry | Acqusition time span | Publication date | License

Entities	
Contributors	
Collectors	
Funders	
Partners	
Site Authority	

Contributor | Collector | Funder | Partner | Local Authority

Citation
2020: Abbey of Pomposa - LiDAR - Terrestrial . Collected by . Distributed by Open Heritage 3D. https://doi.org/10.26301/mepm-ww89

How to cite | DOI

Appendix 6: Documentation scenarios for digital 3D reconstruction

The documentation scenarios for 3D digital reconstruction models for different cases are outlined below. Each scenario focuses on including only the essential information needed to convey the basic details of the reconstruction. Four main scenarios were developed: the reconstruction of a physical building, the reconstruction of a past phase of a city, the reconstruction of the current state of a historical sculpture, and the reconstruction of a never-completed historical project. Additionally, conditions related to file size (whether suitable for web viewing or not) and various options for referencing existing resources were applied to these scenarios. Fields requiring manual text entry are highlighted in black, while fields in grey indicate that a selection must be made from a drop-down menu or a tick box. For each scenario, the total number of fields requiring completion is also provided.

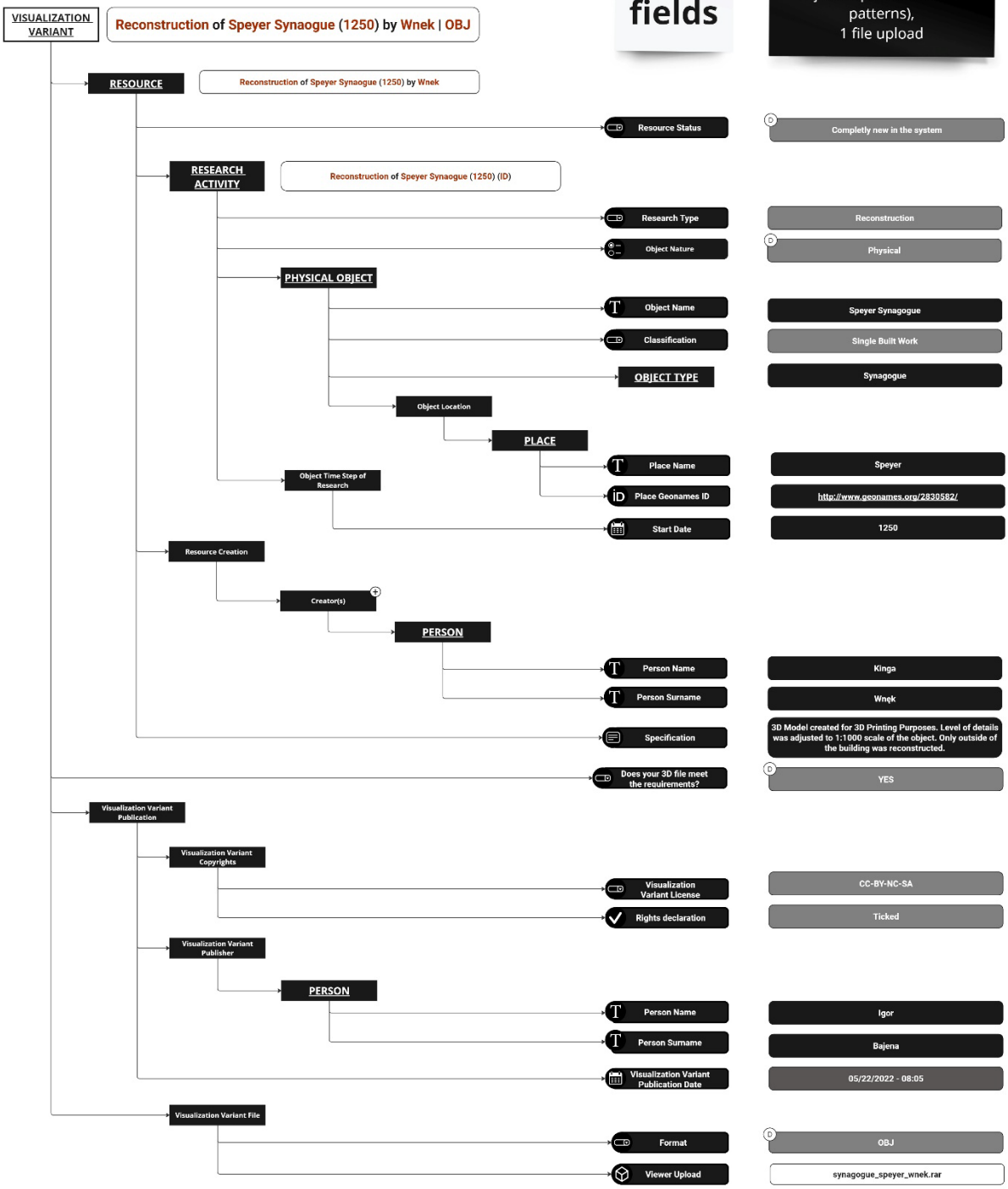
The data forms displayed also offer the ability to generate title patterns, which are automatically created names based on user-provided data. These titles are generated for entire documentation units and are not directly entered by the user but are dependent on their input. For instance, in the 'Person' documentation unit, a title pattern is generated by combining the inputs from the ‘First name’ and ‘Last name’ text fields. These fields are highlighted in white, with text in two font colours: black for fixed, unchangeable text elements, and red for parts that adapt based on user input.

The input fields are also identified with small icons that indicate the type of field. In addition to the standard short text field (marked with a "T"), there are long text fields (denoted by a paragraph symbol), date fields (with a calendar icon), drop-down menu fields, tick boxes (marked with a tick), ID fields (indicated by an "ID"), image upload fields (represented by an image symbol), and 3D file upload fields (marked with a cube). These icons provide a visual guide to the type of input required, making the form easier to navigate.

Scenario 1.1:
3D Reconstruction of Physical Building - New Entry

20 fields

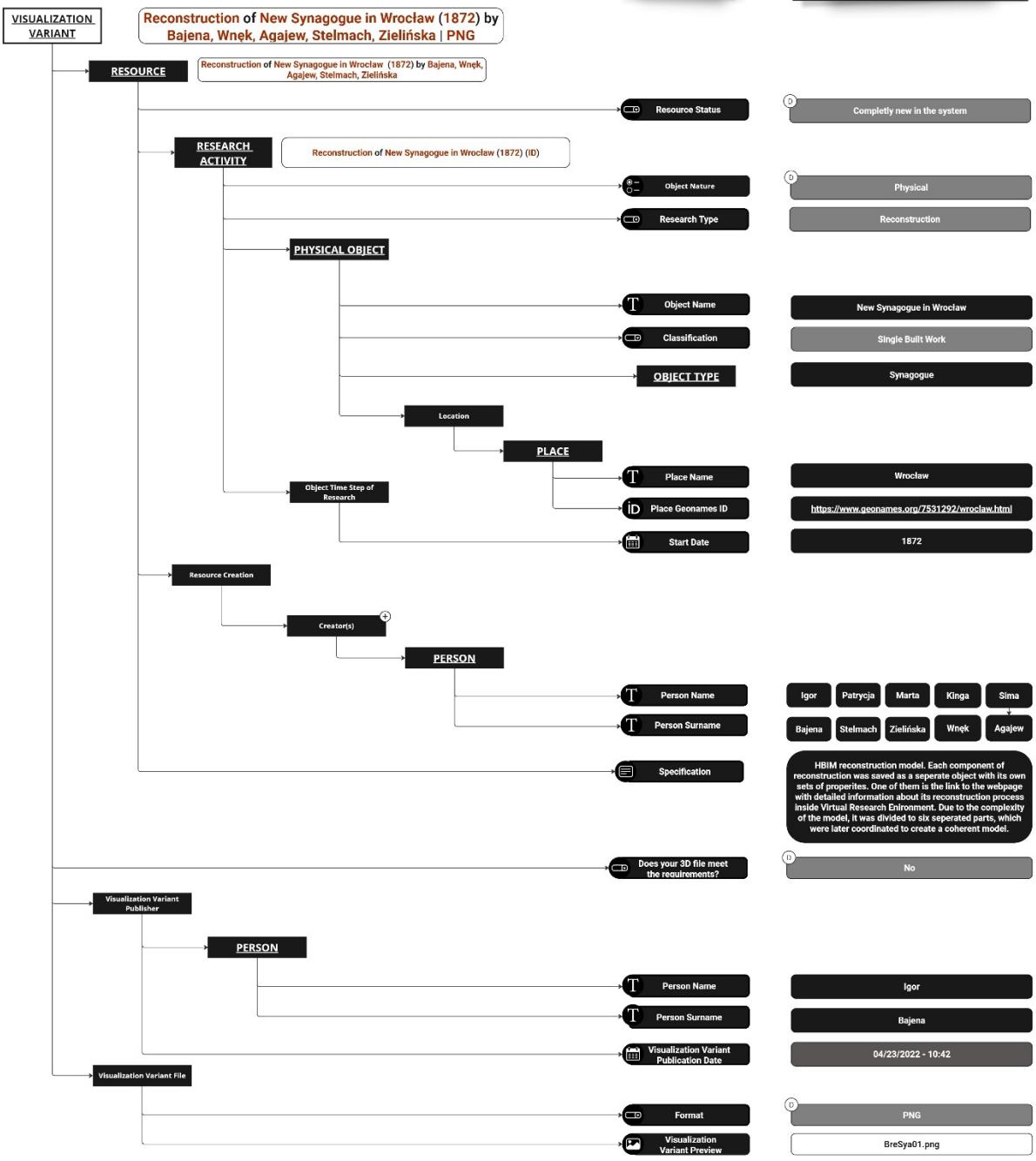
11 fields types by hand,
8 fields from the list (4 out of 8 just dependecies/title patterns),
1 file upload



Scenario 1.2:
3D Reconstruction of Physical Building - New Entry (too big file)

18 (26) fields

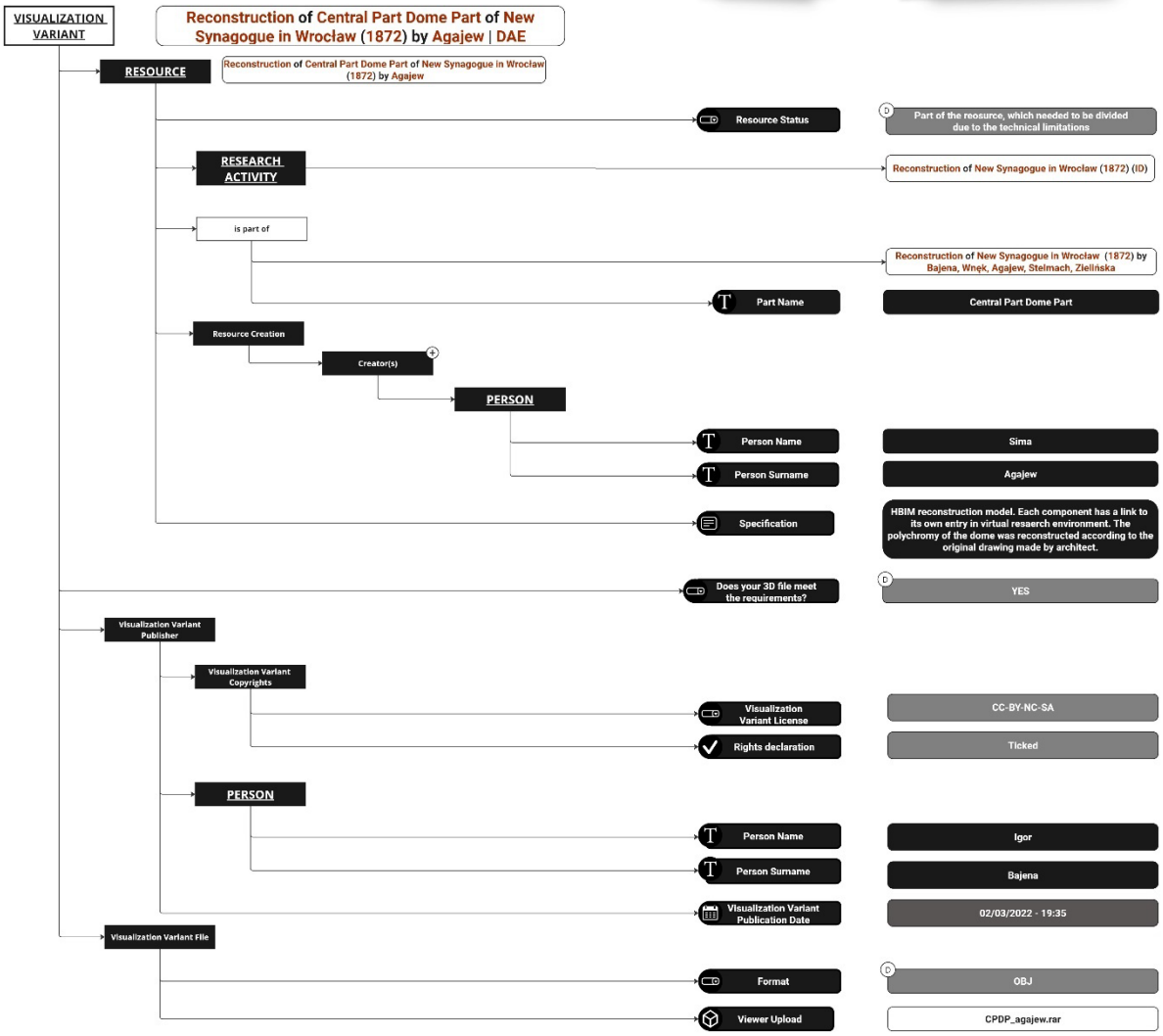
11 fields by hand (19 by hand in total),
6 fields from the list (4 out of 6 just dependecies/title patterns),
1 file upload



Scenario 1.3:
3D Reconstruction of Physical Building - Part of the 3D file, which was too big

15 fields

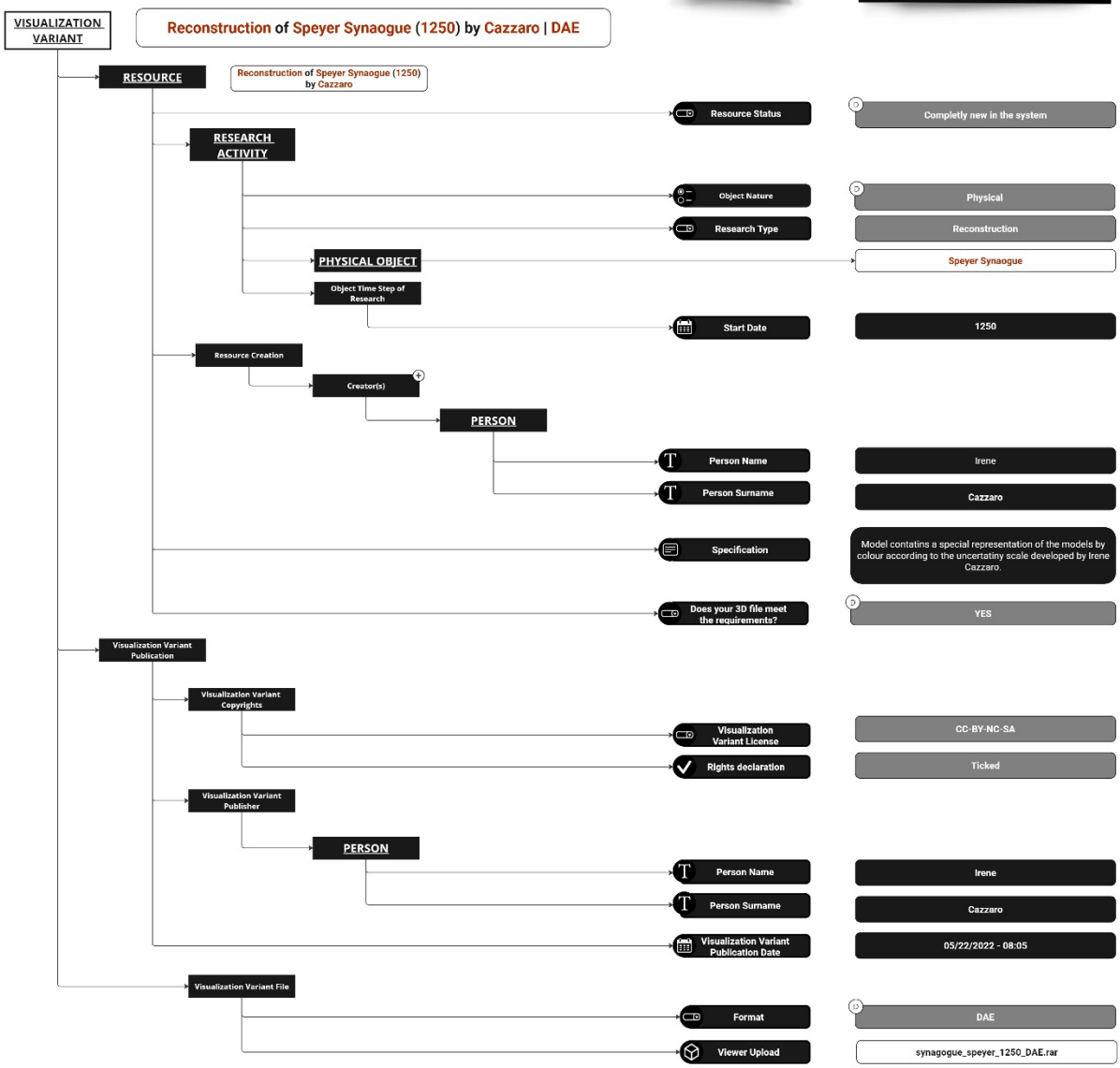
9 fields by hand
5 fields from the list (3 out of 5 just dependecies/title patterns),
1 file upload



Scenario 1.4:
3D Reconstruction of Physical Building - Reffering to the object in the system

16 fields

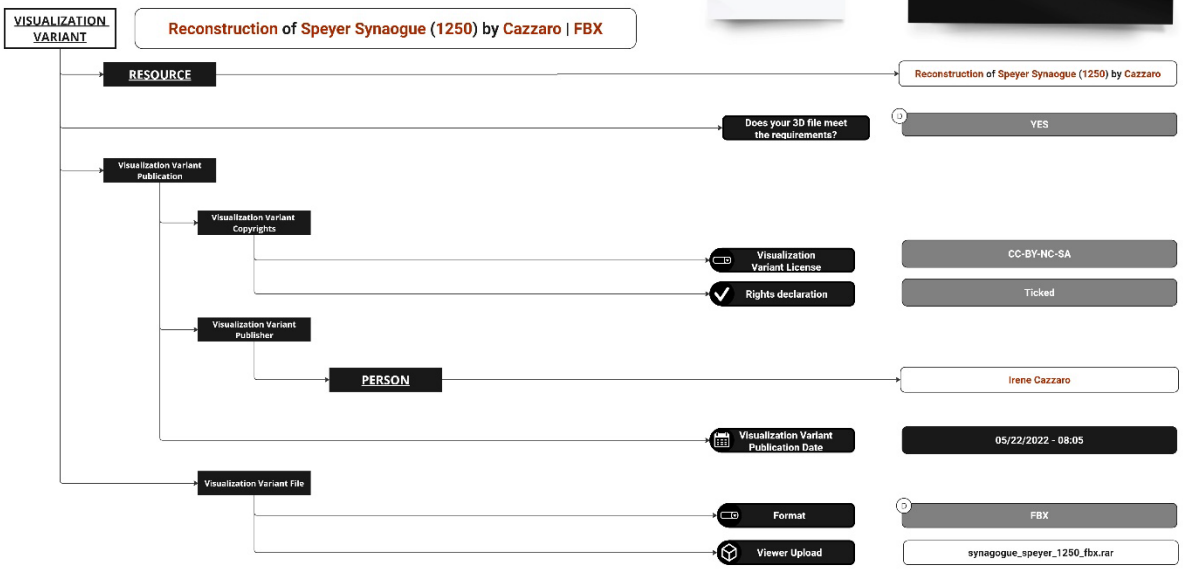
8 fields by hand
7 (4 out of 7 just dependecies/title patterns),
1 file upload



Scenario 1.5:
3D Reconstruction of Physical Building - New visualization variant of the same resource

8 fields

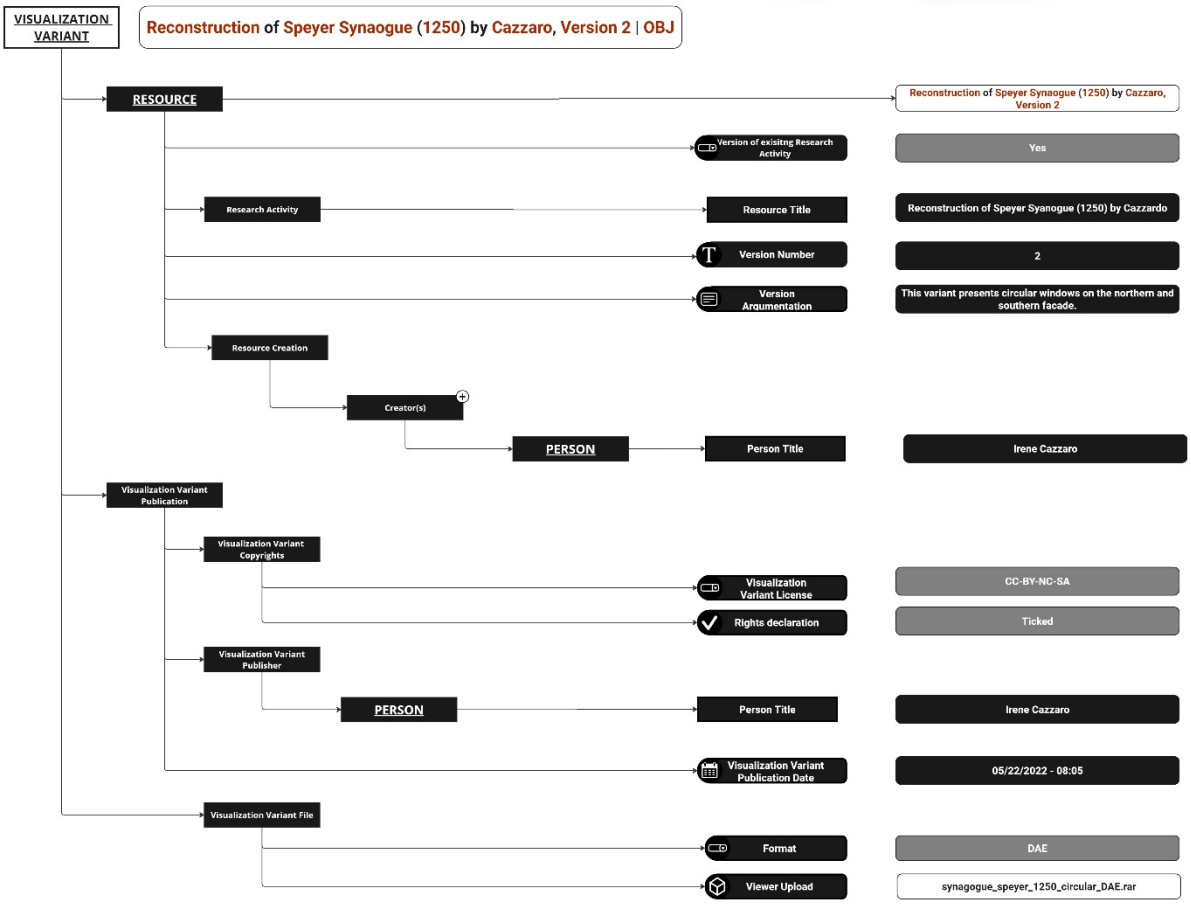
3 fields by hand
4 (2 out of 4 just dependecies/title patterns),
1 file upload



Scenario 1.6:
3D Reconstruction of Physical Building - New Version of the model (change of geometry)

12 fields

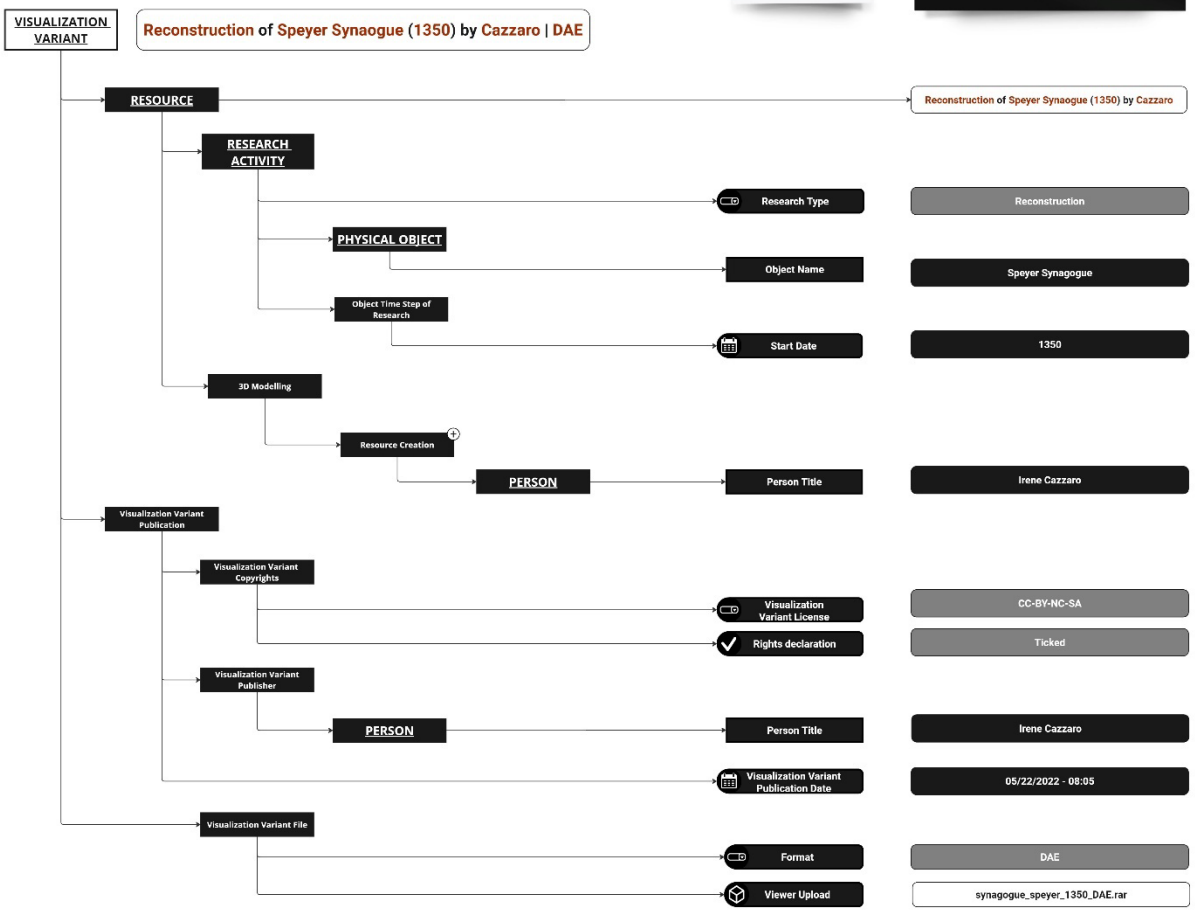
6 fields by hand,
4 fields from the list,
1 file upload



Scenario 1.7:
3D Reconstruction of Physical Building - New Time Step for the object (New Research acitvity)

10 fields

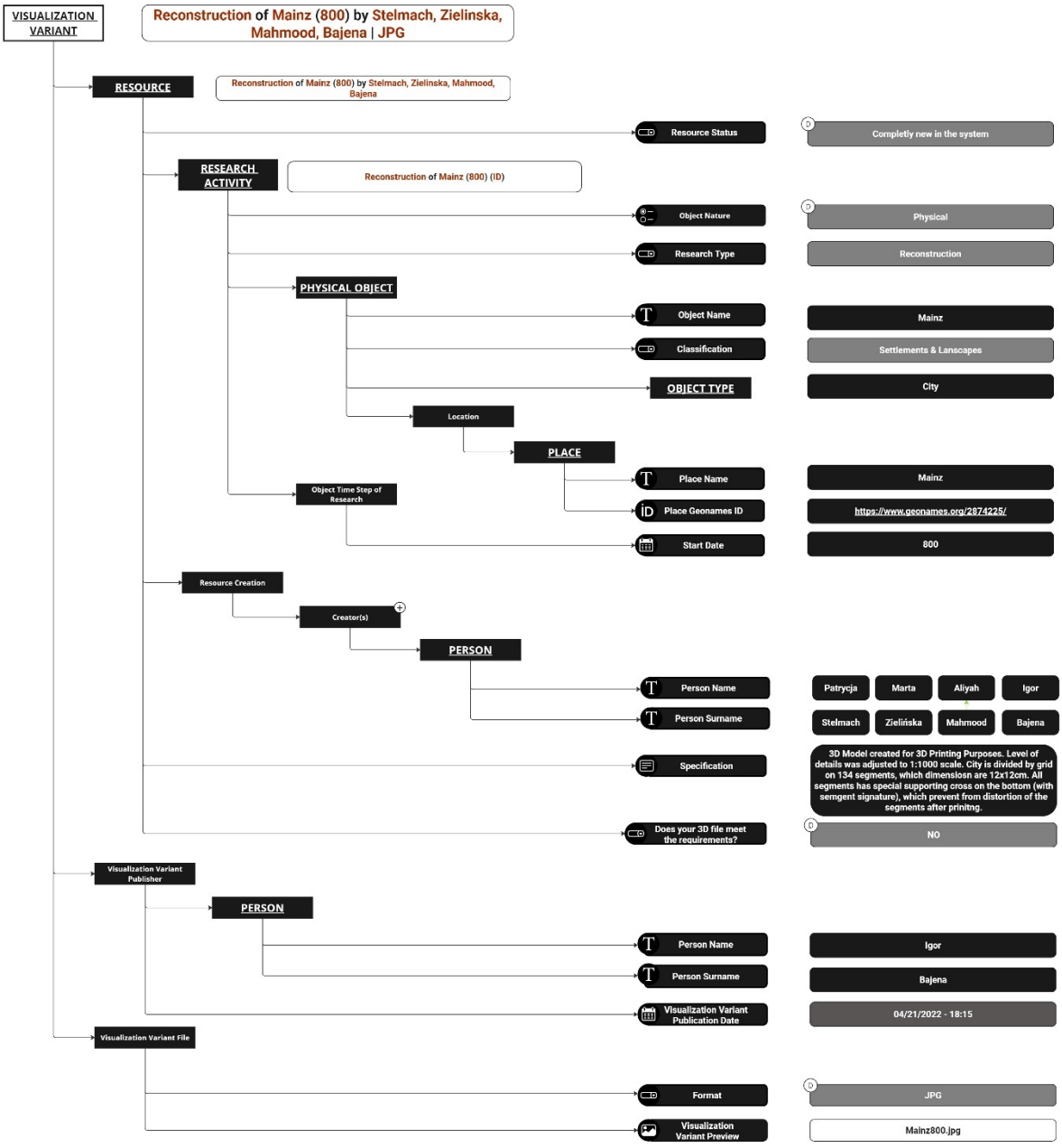
5 fields by hand,
4 fields from the list,
1 file upload



Scenario 2.1:
3D Reconstruction of Physical City - New Entry (too big file)

18 (24) fields

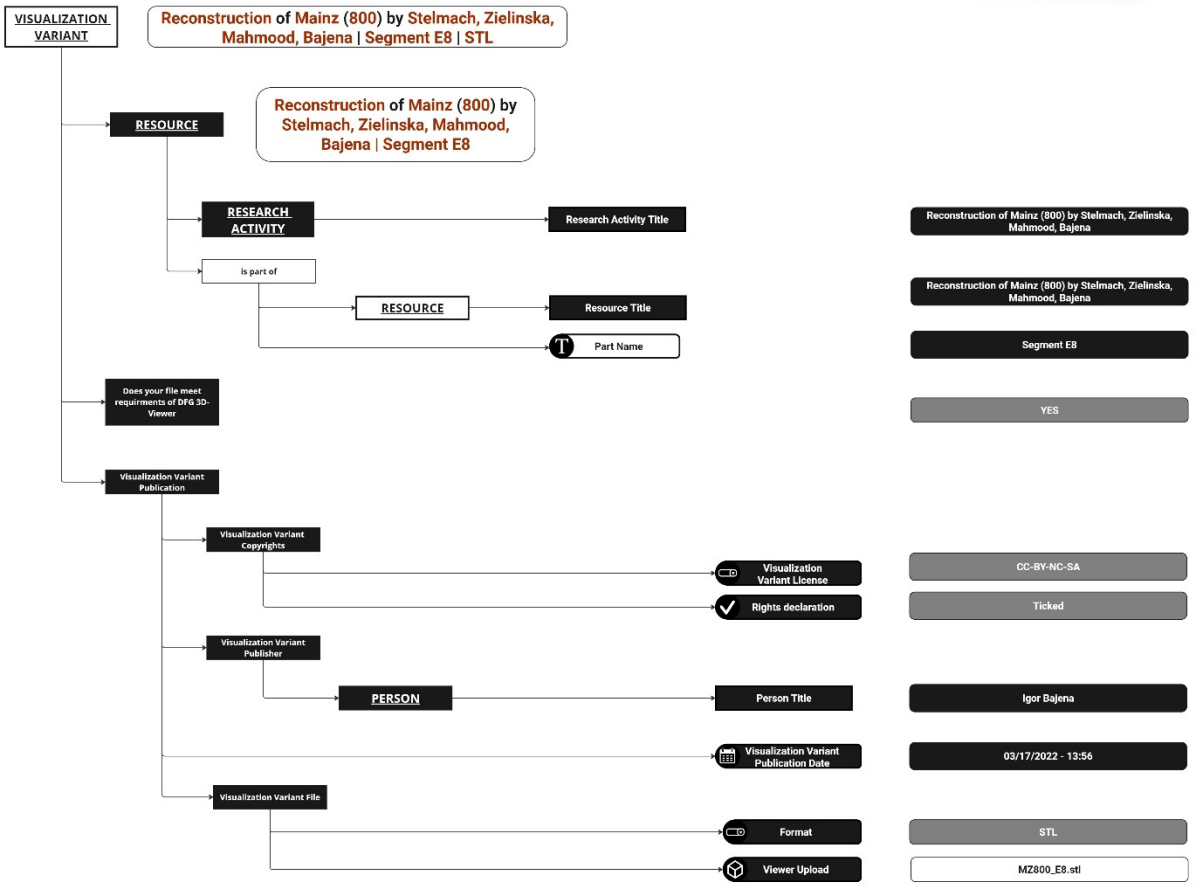
11 fields types by hand (17 by hand in total),
6 fields from the list (4 out of 6 just dependecies/title patterns),
1 file upload



Scenario 2.2:
3D Reconstruction of Physical City - Part of the model, which could be display

10 fields

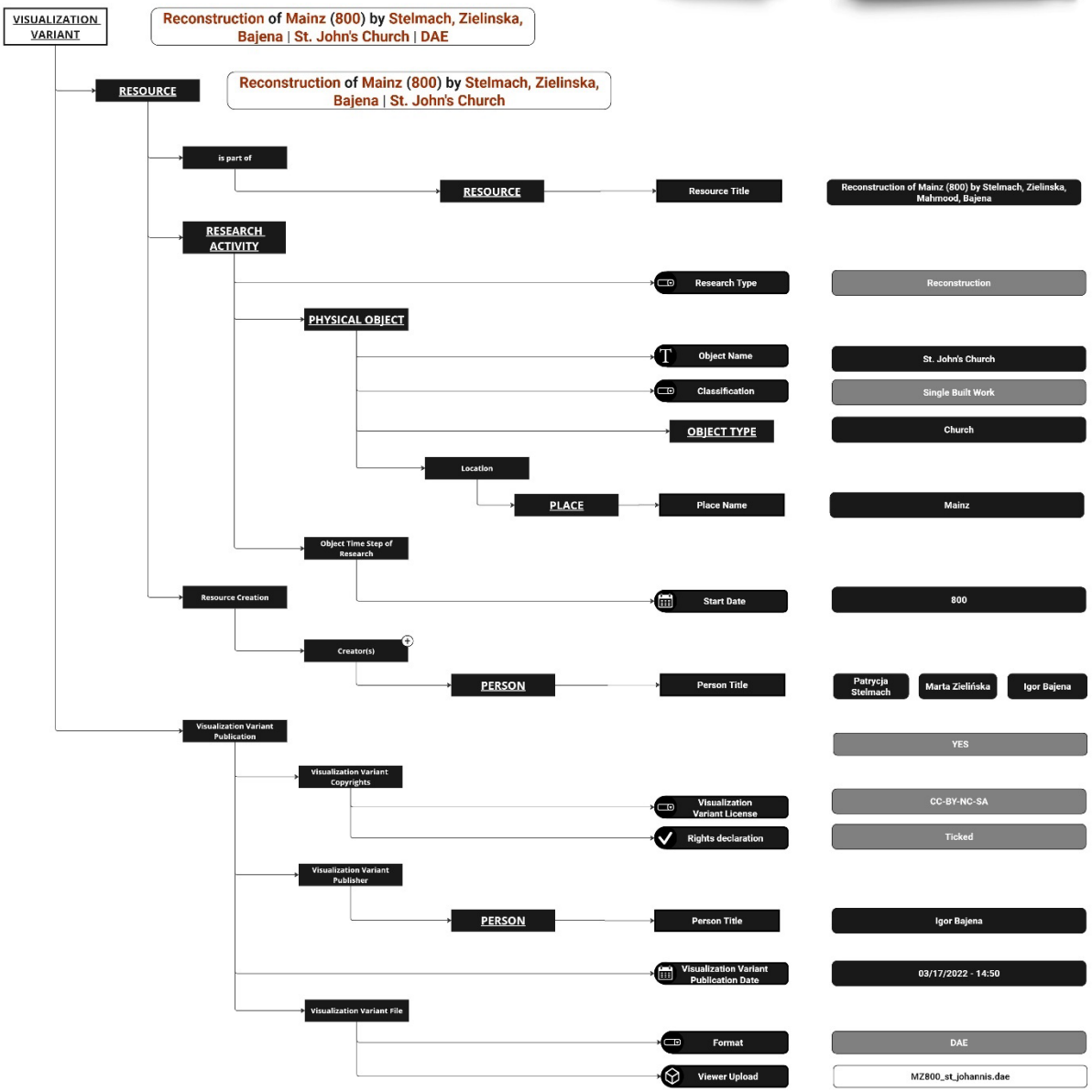
5 fields by hand,
4 fields from the list,
1 file upload



Scenario 2.3:
3D Reconstruction of Physical City - Significant object, which is a part of larger model

15 (17) fields

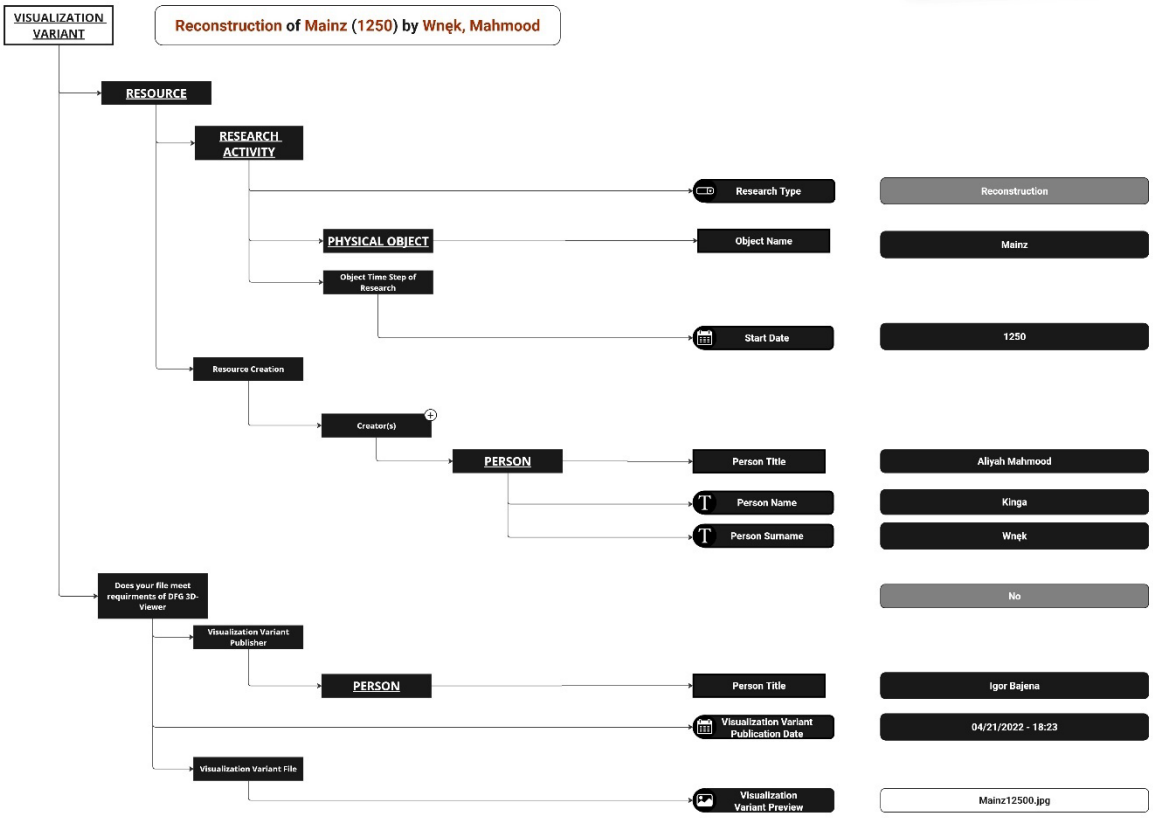
8 fields by hand (10 for 3 authors),
6 fields from the list,
1 file upload



Scenario 2.4:
3D Reconstruction of Physical City - New Time Step to exisitng City (too big file)

10 fields

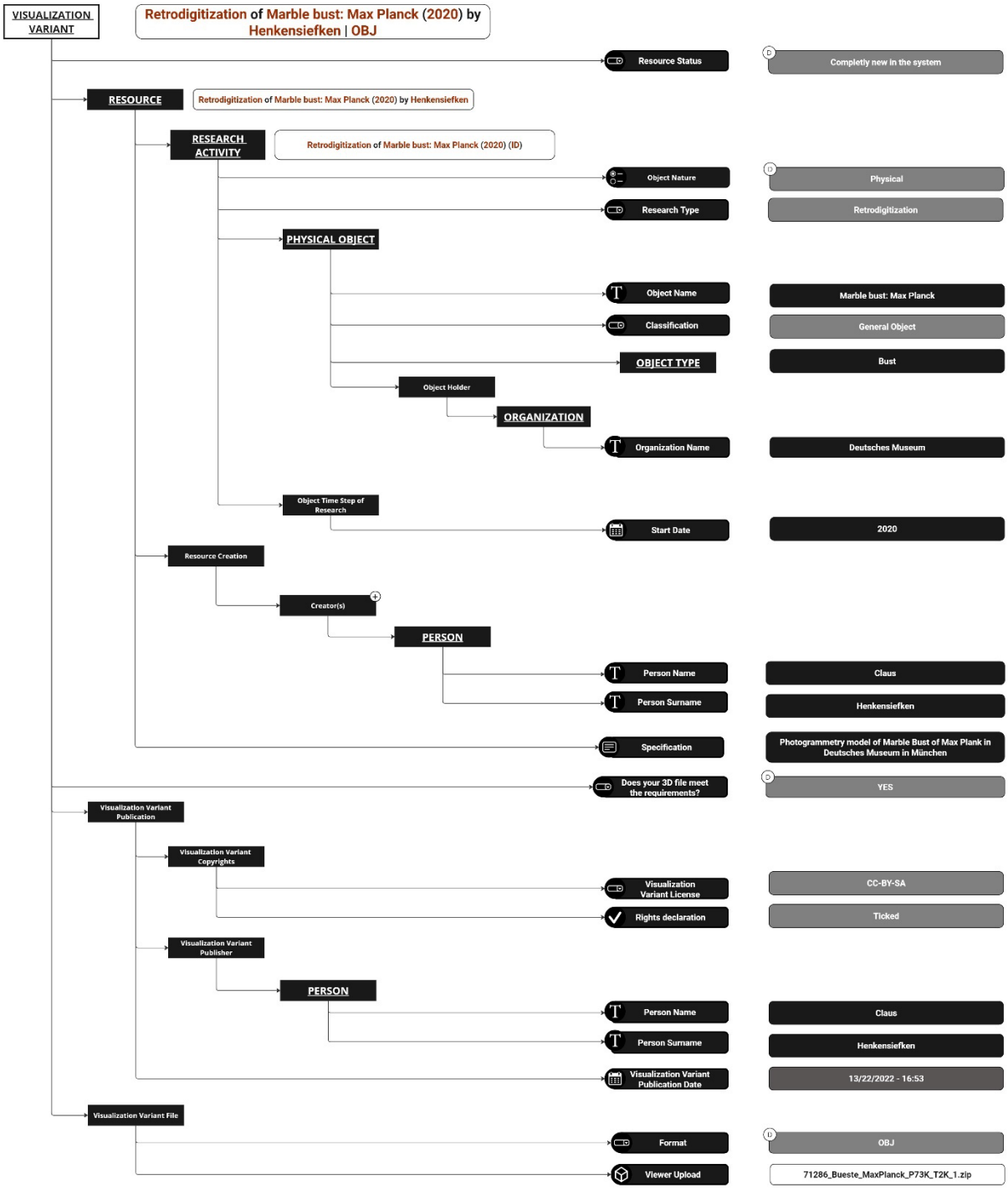
7 fields by hand (7 for 2 authors),
2 fields from the list,
1 file upload



Scenario 3.1:
3D Reconstruction of Physical Object/Artefact - New Entry

19 fields

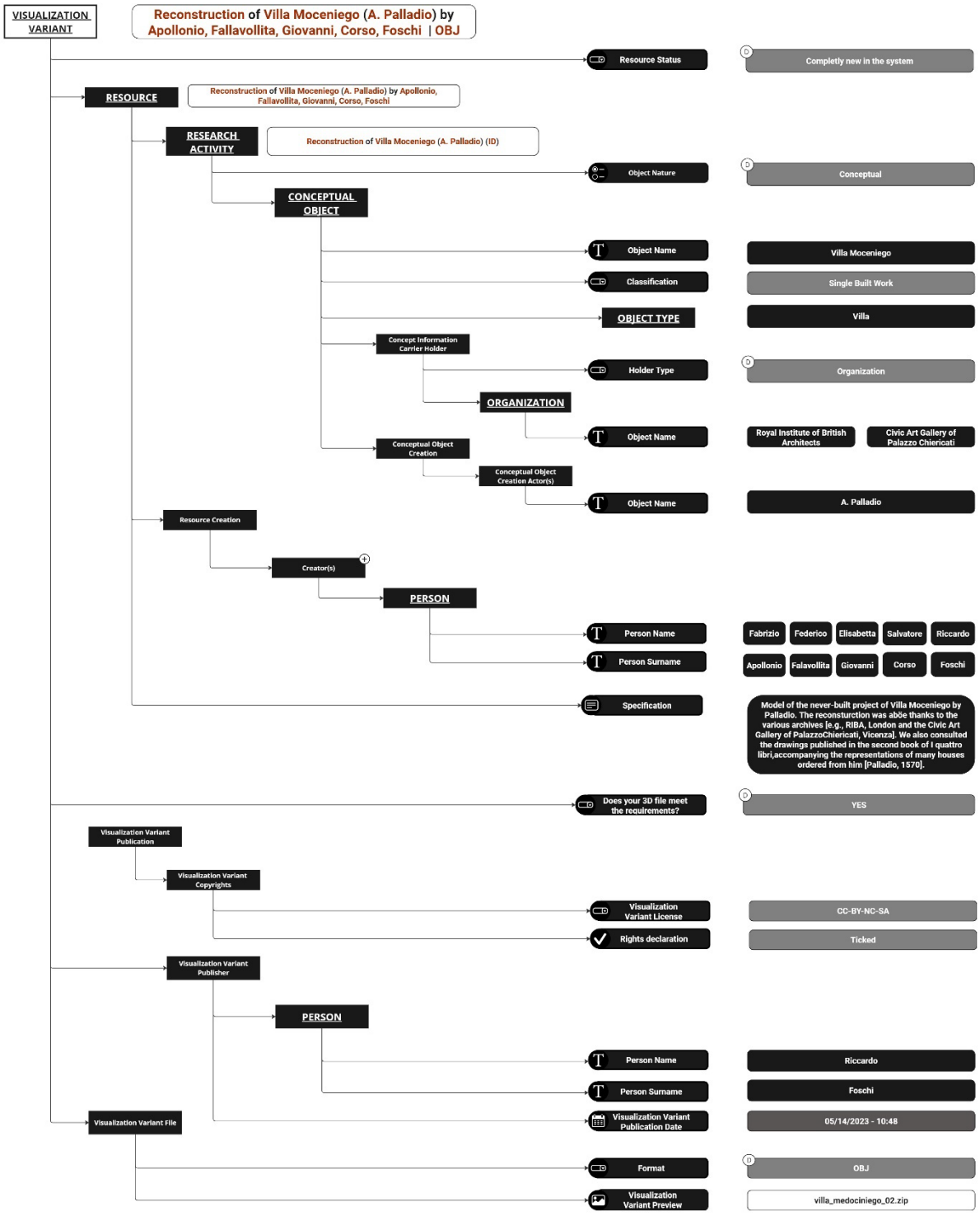
10 fields by hand,
8 fields from the list (4 out of 8 just dependecies/title patterns),
1 file upload



Scenario 4.1:
3D Reconstruction of Conceptual Object
New Entry

19 (28) fields

10 fields by hand (19 by hand in total),
8 fields from the list (5 out of 8 just dependecies/title patterns),
1 file upload



Appendix 7: OntSciDoc 3D evaluation and data model

The Appendix contains a study related to the use of the OntSciDoc3D ontology[156] in the context of the documentation of 3D models of cultural heritage. The first part presents a revision of the ontology against a more recent version of CIDOC CRM, which included significant changes in the approach to data modelling (see Tab. 47). The second part presents the data model developed using OntSciDoc3D and CIDOC CRM for the flat hierarchy used in the WissKI-based 3D repository for the DFG 3D-Viewer project.

Tab. 47 Revision of the OntSciDoc3D ontology for harmonisation with the CIDOC CRM vversion 7.2.2. from September 2022.

Class	Comment	Decision
osd_5a Historical Event	-	Preserved
osd_7a Research Activity	-	Preserved
osd_7b Membership	-	Preserved
osd_7c Documentation	-	Preserved
osd_11a Modification	Class repetition, use E11 Modification instead.	Deprecated
osd_12a Production	Class repetition, use E12 Production instead.	Deprecated
osd_13a Topic Assignment	-	Preserved
osd_13c Location Assignment	-	Preserved
osd_13d Role Assignment	-	Preserved
osd_13e Date Assignment	-	Preserved
osd_13f Documentation Assignment	-	Preserved
osd_13g Alternative Title Assignment	-	Preserved
osd_13h Right Status Assignment	-	Preserved
osd_21a Person	Class repetition, use E21 Person instead.	Deprecated
osd_22a Object	-	Preserved
osd_24a Physical Source	-	Preserved
osd_30a Copy Right	-	Preserved
osd_31a Annotation	-	Preserved
osd_31b Source	-	Preserved
osd_31c Comment	-	Preserved
osd_31d Note	-	Preserved
osd_31e Article	-	Preserved
osd_32a Authority Document	Class repetition, use E32 Authority Document instead.	Deprecated
osd_35a Object Title	Specification classes of E35 Title were deprecated in CRM version 7.2.2. use E35 Title instead.	Deprecated
osd_35b Source Title	Specification classes of E35 Title were deprecated in CRM version 7.2.2. use E35 Title instead.	Deprecated
osd_35c Source Subtitle	Specification classes of E35 Title were deprecated in CRM version 7.2.2. use E35 Title instead.	Deprecated
osd_35d Object Subtitle	Specification classes of E35 Title were deprecated in CRM version 7.2.2. use E35 Title instead.	Deprecated
osd_35e Object Alternative Title	-	Preserved
osd_41a Research Activity Appellation	Specification classes of E41 Appellation were deprecated in CRM version 7.2.2. use E41 Appellation instead.	Deprecated

[156] See: https://www.ontscidoc3d.hs-mainz.de/ontology/ (accessed 24 October 2024).

Class	Comment	Decision
osd_41b Sub Research Activity Appellation	Specification classes of E41 Appellation were deprecated in CRM version 7.2.2. use E41 Appellation instead.	Deprecated
osd_41c Historical Event Appellation	Specification classes of E41 Appellation were deprecated in CRM version 7.2.2. use E41 Appellation instead.	Deprecated
osd_42a Authority Document Identifier	Specification classes of E42 Identifier were deprecated in CRM version 7.2.2. use E42 Identifer instead.	Deprecated
osd_42b Type ID	Specification classes of E42 Identifier were deprecated in CRM version 7.2.2. use E42 Identifer instead.	Deprecated
osd_42c Actor ID	Specification classes of E42 Identifier were deprecated in CRM version 7.2.2. use E42 Identifer instead.	Deprecated
osd_42d Corporate Body ID	Specification classes of E42 Identifier were deprecated in CRM version 7.2.2. use E42 Identifer instead.	Deprecated
osd_42e Place ID	Specification classes of E42 Identifier were deprecated in CRM version 7.2.2. use E42 Identifer instead.	Deprecated
osd_42f Inventory Number	Specification classes of E42 Identifier were deprecated in CRM version 7.2.2. use E42 Identifer instead.	Deprecated
osd_42g Language Identifier	Specification classes of E42 Identifier were deprecated in CRM version 7.2.2. use E42 Identifer instead.	Deprecated
osd_44a Place Appellation	Specification classes of E41 Appellation were deprecated in CRM version 7.2.2. use E41 Appellation instead.	Deprecated
osd_44b Alternative Place Appellation	Specification classes of E41 Appellation were deprecated in CRM version 7.2.2. use E41 Appellation instead.	Deprecated
osd_44c Location Appellation	Specification classes of E41 Appellation were deprecated in CRM version 7.2.2. use E41 Appellation instead.	Deprecated
osd_47a Spatial Coordinates	Parent class was deprecated in CRM version 7.2.2., use E94 Space Primitive.	Deprecated
osd_50a Verbal Date	Parent class was deprecated in CRM version 7.2.2. , use E61 Time Primitive.	Deprecated
osd_50b Editorial Date	Parent class was deprecated in CRM version 7.2.2., use E61 Time Primitive.	Deprecated
osd_51a Authority File Url	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation.	Deprecated
osd_51b Sketchfab Url	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation .	Deprecated
osd_51c Preview Image Url	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation.	Deprecated
osd_51d Image Url	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation.	Deprecated
osd_51e File Url	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation.	Deprecated
osd_51f Source Url	Parent class was deprecated in CRM version 7.2.2. , use E41 Appellation.	Deprecated
osd_51g Corporate Body Url	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation.	Deprecated

Class	Comment	Decision
osd_51h Annotation Url	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation.	Deprecated
osd_52a Time Span	Class repetition, use E52 Time Span instead.	Deprecated
osd_52b Editorial Timespan	-	Preserved
osd_53a Place	-	Preserved
osd_53b Location	-	Preserved
osd_53c Source Section	-	Preserved
osd_55a Type	Class repetition, use E52 Time Span instead.	Deprecated
osd_55b Broader Type	-	Preserved
osd_55c Research Activity Type	Specification classes of E55 Type were deprecated in CRM version 7.2.2. use E55 Type instead.	Deprecated
osd_55d Object Type	Specification classes of E55 Type were deprecated in CRM version 7.2.2. use E55 Type instead.	Deprecated
osd_55e Source Type	Specification classes of E55 Type were deprecated in CRM version 7.2.2. use E55 Type instead.	Deprecated
osd_55f Historical Event Type	Specification classes of E55 Type were deprecated in CRM version 7.2.2. use E55 Type instead.	Deprecated
osd_55g Person Type	Specification classes of E55 Type were deprecated in CRM version 7.2.2. use E55 Type instead.	Deprecated
osd_55h Corporate Body Type	Specification classes of E55 Type were deprecated in CRM version 7.2.2. use E55 Type instead.	Deprecated
osd_55i 3D Reconstruction Type	Specification classes of E55 Type were deprecated in CRM version 7.2.2. use E55 Type instead.	Deprecated
osd_55j Certainty Value Type	-	Preserved
osd_55k Primary Source Type	Specification classes of E55 Type were deprecated in CRM version 7.2.2. use E55 Type instead.	Deprecated
osd_55l Historical Actor Type	Specification classes of E55 Type were deprecated in CRM version 7.2.2. use E55 Type instead.	Deprecated
osd_55m Editing Status	-	Preserved
osd_55n Right Status	-	Preserved
osd_55o Religion	-	Preserved
osd_55p Technique	-	Preserved
osd_55q Detail Level Type	-	Preserved
osd_55r Property Type	Specification classes of E55 Type were deprecated in CRM version 7.2.2. use E55 Type instead.	Deprecated
osd_56a Language	-	Preserved
osd_57a Material	-	Preserved
osd_65a Production	Class repetition, use E65 Production instead.	Deprecated
osd_67a Birth	Class repetition, use E67 Birth instead.	Deprecated
osd_69a Death	Class repetition, use E69 Death instead.	Deprecated
osd_73a 3D Reconstruction	-	Preserved
osd_73b 3D Reconstruction Version	Class parent changed to osd_73a 3D Reconsturction	Preserved
osd_73c 3D Reconstruction Variation	Class parent changed to osd_73a 3D Reconsturction	Preserved
osd_74a Corporate Body	Class repetition, use E74 Group instead.	Deprecated
osd_75a Type Apellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75b Broader Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated

Class	Comment	Decision
osd_75c Topic Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75d Context Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75e Certainty Value Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75f Primary Source Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75g Person Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75h Historical Actor Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75i Editing Status Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75j Right Status Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75k Material Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75l Religion Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75m Technique Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75n Research Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75o Object Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75p Source Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75q Historical Event Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75r 3D Reconstruction Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75s Corporate Body Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75t Detail Level Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75u Alternative Type Appellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_75v Property Type Apellation	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_82a Person Name	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_82b Corporate Body Name	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_82c Person Alternative Name	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated
osd_82d Corporate Body Alternative Name	Parent class was deprecated in CRM version 7.2.2., use E41 Appellation instead.	Deprecated

Class	Comment	Decision
osd_84a Source Part	Parent class was deprecated in CRM version 7.2.2., use E22 Human-Made Object instead.	Deprecated
osd_89a Topic	Class parent changed to osd_73a 3D Reconsturction	Preserved
osd_89b Context	Class parent changed to osd_73a 3D Reconsturction	Preserved

Scheme below shows how to read hierarchy in the first column of the table:

○ Main bundle group
├● Field, which parent is the main bundle
├○ Sub-bundle group
│ └● Field, which parent is the sub-bundle
└⊙ Sub-bundle reference group (loads the entire metadata package connected to groups that were previously entered by the administrator)

Group bundle (structural value)
Field (user input)

Tab. 48 Data model for documentation of digital 3D cultural heritage based on the OntSciDoc3D application ontology of CIDOC CRM.

Main Path: 3D Model		
Hierarchy	Name	Path
○	3D Model	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction]
│ ├● │	Preview	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_51d_Image_Url
│ ├○ │ └● │	Referencing	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm: P2_has_type -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_55b_Broader_Type -> ecrm:P1_is_identified_by -> ecrm: E41_Appellation
│ ├● │	is part of	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P106i_forms_part_of -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction
│ ├○ │ └● │	Part Name	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P2_has_type -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_55a_Type -> ecrm: P1_is_identified_by -> ecrm: E41_Appellation
│ ├● │	has part	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P106_is_composed_of -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction
│ ├● │	is derivative of	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> https://www.ontscidoc3d.hs-mainz.de/ontology/P130.2i_is_equal_to -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction
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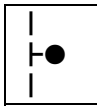
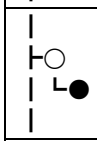
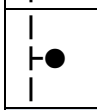
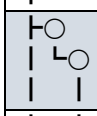
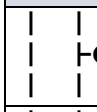
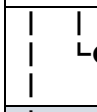
│ ├● │	is version of	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P165_incorporates -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction
│ ├○ │ └● │	Version Name	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P2_has_type -> ecrm: E55_Type -> ecrm: P1_is_identified_by -> ecrm: E41_Appellation

	has version	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P165i_is_incorporated_in -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction
	Model Representation	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm,:P2_has_type -> https://www.ontscidoc3d.hs-mainz.de/osd_55a_Type-> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_75a_Type_Appellation
	Model Description	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P129i_is_subject_of -> https://www.ontscidoc3d.hs-mainz.de/osd_31a_Annotation
	Reconstructed Period	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P141i_was_assigned_by -> ecrm:E13_Attribute_Assignment -> ecrm:P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan]
	Start Date	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P141i_was_assigned_by -> ecrm:E13_Attribute_Assignment -> ecrm:P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan
	End Date	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P141i_was_assigned_by -> ecrm:E13_Attribute_Assignment -> ecrm:P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan
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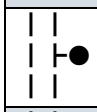	Model License	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P104_is_subject_to -> https://www.ontscidoc3d.hs-mainz.de/osd_30a_Copy_Right
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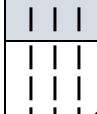
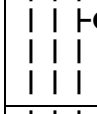
	Author Name	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P104_is_subject_to -> https://www.ontscidoc3d.hs-mainz.de/osd_30a_Copy_Right -> ecrm:P75i_is_possessed_by -> https://www.ontscidoc3d.hs-mainz.de/osd_21a_Person -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_82a_Person_Name
	Author ORCID ID	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ercm:P104_is_subject_to -> https://www.ontscidoc3d.hs-mainz.de/osd_30a_Copy_Right -> ecrm:P75i_is_possessed_by -> https://www.ontscidoc3d.hs-mainz.de/osd_21a_Person -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_42c_Actor_ID
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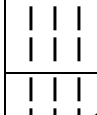
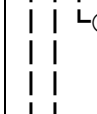
	Holder (Organization)	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P104_is_subject_to -> https://www.ontscidoc3d.hs-mainz.de/osd_30a_Copy_Right -> ecrm:P75i_is_possessed_by -> https://www.ontscidoc3d.hs-mainz.de/osd_74a_Corporate_Body]
	Holder Name	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ercm:P104_is_subject_to -> https://www.ontscidoc3d.hs-mainz.de/osd_30a_Copy_Right -> ecrm:P75i_is_possessed_by -> https://www.ontscidoc3d.hs-mainz.de/osd_74a_Corporate_Body ->

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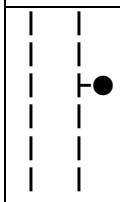
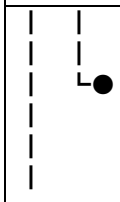
	Holder VIAF ID	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P104_is_subject_to -> https://www.ontscidoc3d.hs-mainz.de/osd_30a_Copy_Right -> ecrm:P75i_is_possessed_by -> https://www.ontscidoc3d.hs-mainz.de/osd_74a_Corporate_Body -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_42d_Corporate_Body_ID
	Holder Website	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P104_is_subject_to -> https://www.ontscidoc3d.hs-mainz.de/osd_30a_Copy_Right -> ecrm:P75i_is_possessed_by -> https://www.ontscidoc3d.hs-mainz.de/osd_74a_Corporate_Body -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_51g_Coroprate_Body_Url
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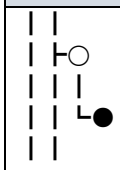
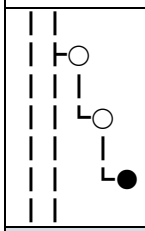
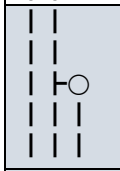
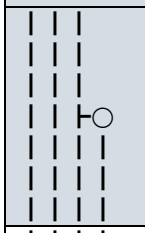
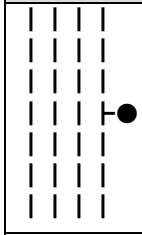
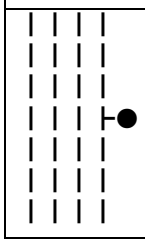
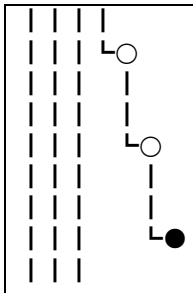
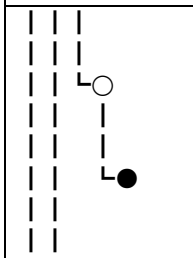
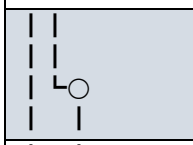
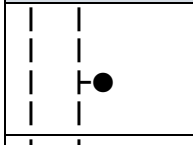
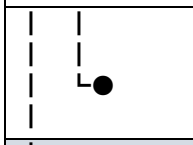
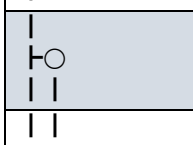
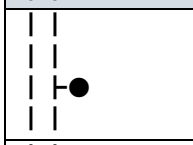
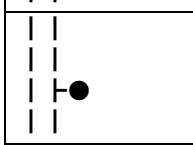
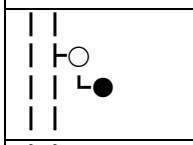
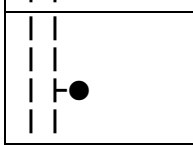
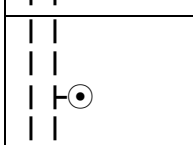
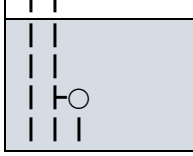
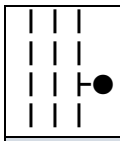
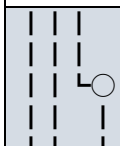
	Used software	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by-> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity-> ecrm:P16_used_specific_object -> ecrm:E73_Information_Object -> ecrm:P1_is_identified_by -> ecrm:E35_Title
	Modeling Techinque	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by-> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity-> ecrm:P141i_was_assigned_by -> ecrm:E17_Type_Assignment -> ecrm:P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_55a_Type-> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_75a_Type_Appellation
	Creation Participant(s)	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by-> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity -> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment]
	Creation Person	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by-> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity-> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm: P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_21a_Person]
	Creation Participant(s) Name	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by-> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity-> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm: P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_21a_Person -> ecrm: P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_82a_Person_Name
	Creation Participant(s) ORCID ID	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by-> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity-> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm: P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_21a_Person -> ecrm: P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_42c_Actor_ID

	Creation Participant(s) Affiliation	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by-> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity-> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm: P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_21a_Person -> ecrm: P11i_participated_in -> https://www.ontscidoc3d.hs-mainz.de/osd_7b_Membership -> ecrm:P11_had_participant -> ecrm:E74_Group -> ecrm:P1_is_identified_by -> ecrm:E35_Title
	Creation Participant(s) Role	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by-> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity-> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm: P141_assigned ->https://www.ontscidoc3d.hs-mainz.de/osd_55g_Person_Type -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_75g_Person_Type_Appellation
	Creation Time Span	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by -> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity -> ecrm:P4_has_time-span -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan]
	Start Date	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by -> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity -> ecrm:P4_has_time-span -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan
	End Date	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> https://www.ontscidoc3d.hs-mainz.de/P12.1i_was_created_by -> https://www.ontscidoc3d.hs-mainz.de/osd_7a_Research_Activity -> ecrm:P4_has_time-span -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan
	Object	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object]
	Object Name	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P102_has_title -> https://www.ontscidoc3d.hs-mainz.de/osd_35a_Object_Title
	Object Alternative Name(s)	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P102_has_title -> https://www.ontscidoc3d.hs-mainz.de/osd_35e_Object_Alternative_Title
	Object GND	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_22a_Object -> ecrm: P141i_was_assigned_by -> ecrm: E15_Identifier_Assignment -> ecrm: P141_assigned -> ecrm: E42_Identifier
	Object Category	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_22a_Object -> ecrm: P2_has_type -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_55b_Broader_Type
	Object Type	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P2_has_type -> https://www.ontscidoc3d.hs-mainz.de/osd_55d_Object_Type
	Object Location	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P53_has_former_or_current_location -> ecrm: E53_Place]

	Object Specific Location	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_22a_Object -> ecrm: P53_has_former_or_current_location -> ecrm: E53_Place -> ecrm: P1_is_identified_by -> ecrm: E41_Appellation
	Object City	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_22a_Object -> ecrm: P53_has_former_or_current_location -> ecrm: E53_Place -> ecrm: P89_falls_within -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53a_Place
	Object City Name	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_22a_Object -> ecrm: P53_has_former_or_current_location -> ecrm: E53_Place -> ecrm: P89_falls_within -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53a_Place -> ecrm: P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_44a_Place_Appellation
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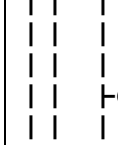
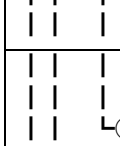
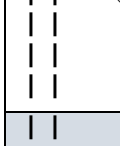
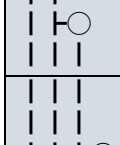
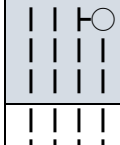
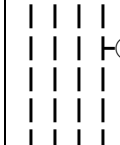
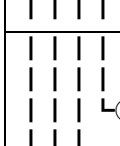
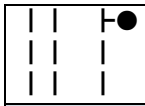
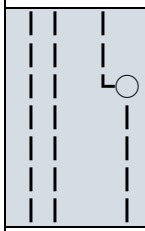
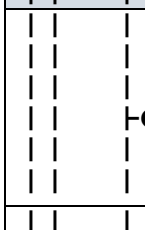
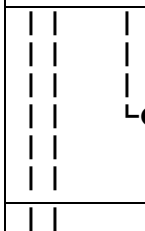
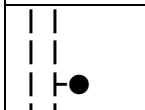
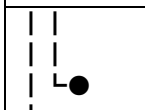
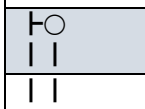
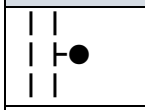
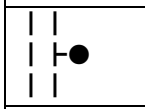
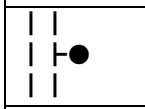
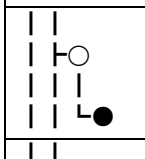
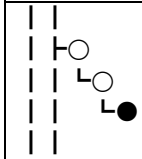
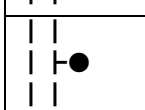
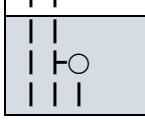
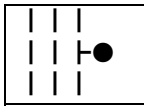
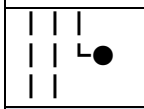
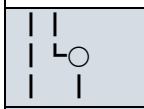
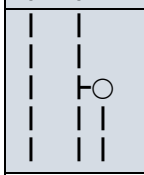
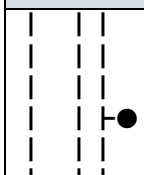
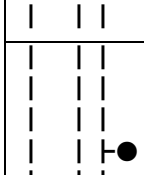
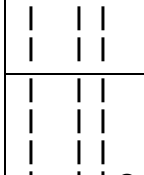
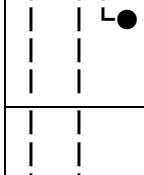
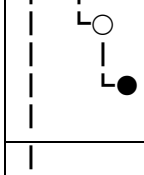
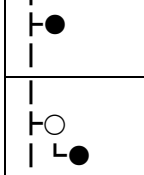
	City GND	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_73a_3D_Reconstruction -> ecrm: P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_22a_Object -> ecrm: P53_has_former_or_current_location -> ecrm: E53_Place -> ecrm: P89_falls_within -> https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53a_Place -> ecrm: P1_is_identified_by -> ecrm: E42_Identifier -> ecrm: P1_is_identified_by -> ecrm: E41_Appellation
	Historical Relations	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P10_falls_within -> ecrm:E93_Presence]
	Related Actor(s)	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P10_falls_within -> ecrm:E93_Presence -> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment]
	Actor Name	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P10_falls_within -> ecrm:E93_Presence -> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm:P141_assigned -> ecrm:E39_Actor -> ecrm:P1_is_identified_by -> ecrm:E41_Appellation
	Actor Role	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction-> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P10_falls_within -> ecrm:E93_Presence -> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm:P141_assigned -> ecrm:E55_Type -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_75a_Type_Appellation
	Historical Events	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P10_falls_within -> ecrm:E93_Presence -> ecrm:P9_consists_of -> https://www.ontscidoc3d.hs-mainz.de/osd_5a_Historical_Event]
	Event Title	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P10_falls_within -> ecrm:E93_Presence ->

		ecrm:P9_consists_of -> https://www.ontscidoc3d.hs-mainz.de/osd_5a_Historical_Event -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_41c_Historical_Event_Appellation
	Event Time Span	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P10_falls_within -> ecrm:E93_Presence -> ecrm:P9_consists_of -> https://www.ontscidoc3d.hs-mainz.de/osd_5a_Historical_Event -> ecrm:P4_has_time-span -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan]
	Start Date	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P10_falls_within -> ecrm:E93_Presence -> ecrm:P9_consists_of -> https://www.ontscidoc3d.hs-mainz.de/osd_5a_Historical_Event -> ecrm:P4_has_time-span -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan
	End Date	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P10_falls_within -> ecrm:E93_Presence -> ecrm:P9_consists_of -> https://www.ontscidoc3d.hs-mainz.de/osd_5a_Historical_Event -> ecrm:P4_has_time-span -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan
	Wikidata ID	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_42b_Type_ID
	Wikipedia link	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P130_shows_features_of -> https://www.ontscidoc3d.hs-mainz.de/osd_22a_Object -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_51h_Annotation_URL
	Project	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity]
	Project Title	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P1_is_identified_by -> ecrm:E35_Title
	Project Acronym	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P1_is_identified_by -> ecrm:E41_Appellation
	Project Website	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_51h_Annotation_URL
	Project Purpose(s)	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P141i_was_assigned_by -> ecrm:E17_Type_Assignment -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_75a_Type_Appellation
	Project Outcome(s)	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P20i_was_purpose_of -> ecrm:E65_Creation -> ecrm:P141i_was_assigned_by -> ecrm:E17_Type_Assignment -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_75a_Type_Appellation
	Project Description	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P129i_is_subject_of -> https://www.ontscidoc3d.hs-mainz.de/osd_31a_Annotation
	Project Time Span	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P4_has_time-span -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan]

	Start date	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P4_has_time-span -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan
	End Date	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P4_has_time-span -> https://www.ontscidoc3d.hs-mainz.de/osd_52a_Timespan
	Project Participant(s) (Organization)	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment]
	Project Organization	Group [https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm:P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_74a_Corporate_Body]
	Organization Name	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm:P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_74a_Corporate_Body -> P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_82b_Corporate_Body_Name
	Organization VIAF ID	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm:P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_74a_Corporate_Body -> P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_42d_Corporate_Body_ID
	Organization Website	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm:P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_74a_Corporate_Body -> P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_51g_Coroprate_Body_Url
	Organization Role	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P19i_was_made_for -> ecrm:E7_Activity -> ecrm:P141i_was_assigned_by -> https://www.ontscidoc3d.hs-mainz.de/osd_13d_Role_Assignment -> ecrm:P141_assigned -> https://www.ontscidoc3d.hs-mainz.de/osd_55a_Type -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_75a_Type_Appellation
	Native File	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_51h_Annotation_URL
	Documentation Upload	https://www.ontscidoc3d.hs-mainz.de/osd_73a_3D_Reconstruction -> ecrm:P70i_is_documented_in -> ecrm:E31_Document -> ecrm:P1_is_identified_by -> https://www.ontscidoc3d.hs-mainz.de/osd_51e_File_Url
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Hierarchy	Name	Path
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Appendix 8: OntPreHer3D – classes and properties

Ontology for Preservation of Cultural Heritage 3D Models (OntPreHer3D), version 2.2

External Ontologies Used

List of external ontologies used for data model:

- CIDOC CRM v 7.1.3.
- OntSciDoc3D v 2.0
- CRMdig v 4.0
- CRMinf v 1.0

List of external ontologies used for class hierarchy reference:

- LRMoo v 0.9.6

Classes declaration

M1 3D Object

Subclass of: D1 Digital Object

E26 Visual Item

Scope note:

This class comprises a virtual three-dimensional simulation of E70 Thing of a conceptual or physical nature that can be considered as a single digital unit. M1 3D Object can be described through a set of M15 Digital Features, which simulates their physical equivalents of E26 Physical Feature observed directly on the E70 Thing or its carrier of information (osd31b Source). This class can constitute a collection of points in a virtual space unconnected to each other (point cloud) or connected through lines, curves or planes, which form a specific M23 Digital Shape consisting of M16 Digital Material.

M1 3D Object can only be visually perceived by E39 Actor within the context of E17 Digital Environment. M1 3D Object, together with M17 Digital Environment, creates a digital spatial or spatiotemporal simulation saved as a file with a specific format (D1 Digital Object). M1 3D Object does not depend on a specific physical carrier and can exist simultaneously on one or more carriers. It can also be transferred to another instance of M17 Digital Environment through a process of D7 Digital Machine Event. However, this process can change its perception due to the differences in geometrical, morphological and materials simulations specifications, which are highly dependent on characteristics of M17 Digital Environment.

Examples:

- Manually created (M23) digital 3D model (M1) of hypothetical reconstruction (M25) of heritage object (M26)
- Raw point cloud (M1) acquired from laser scanning (osd7a)
- Processed 3D mesh (M1) acquired from the photogrammetry process (osd7a)

Properties:

- R4 is preceding version of (has preceding version): M1 3D Object
- R5 is following version of (has following): M1 3D Object
- R6 is alternation of (has alternation): M1 3D Object
- R7 has position (is position of): M18 Digital Position
- R12 is located within (locates): M17 Digital Environment

Same as:

- CRMvr: V8 3D Object (https://github.com/elisabettacaterina/CRMvr)

M2 Versioning (deprecated)

M3 Variation (deprecated)

M4 Division (deprecated)

M5 Digital Publication Event

Subclass of: D7 Digital Machine Event

Scope note:

This class comprises the activities of selecting, arranging and presenting one or more instances of D1 Digital Object available in electronic form on a public network to communicate it to some public audience. This event happens on physical digital devices following a human activity that intentionally caused its immediate or delayed initiation. This results in the creation of an instance of an M6 Digital Record with published instances of a D1 Digital Object on behalf of the human actor.

Examples:

- Process of publication of a video (D1) titled "Digital Reconstruction – New Synagogue in Breslau" on the Vimeo (https://vimeo.com/417172262)
- Process of uploading a 3D model of the "Central Part Dome Part (CPDP)" (M1) of the digital reconstruction (M25) of the Synagogue in Breslau (M26) to the public viewer in the Sketchfab Repository (https://sketchfab.com/3d-models/cpdp-4a180e83961147b2bda7541b50ec8a2e)
- Process of publication of the article "Digital Reconstruction of the New Synagogue in Breslau: New Approaches to Object-Oriented Research" (E73) by Springer publisher (E39) on the website (https://doi.org/10.1007/978-3-030-93186-5_2)

Properties:

- R1 published (was published by): D1 Digital Object
- R8 digitally created (was digitally created through): M5 Digital Publication Event

M6 Digital Record

Subclass of: D1 Digital Object

E31 Document

E33 Linguistic Object

F3 Manifestation

Scope note:

This class comprises a publicly available and identifiable digital set of items that make propositions about part of reality, constituting a specific subject. M6 Digital Record can be created only as a result of the M5 Digital Publication Event conducted by E39 Actor. Each M6 Digital Record has its own E42 Identifier as a URI web address of a digital resource on the web. The M6 Digital Record includes the published set of D1 Digital Object instances with any metadata, allowing a better understanding of the published resource. The M6 Digital Record is intended to disseminate the resource with first-hand information in a linguistic manner that humans understand. Therefore, it also constitutes an instance of the E33 Linguistic Object.

Examples:

- Wikipedia Article titled "Nowa Synagoga we Wrocławiu" (E35) in Polish (E56) translation by Wikipedia Editors Community (E39) available at https://pl.wikipedia.org/wiki/Nowa_Synagoga_we_Wroc%C5%82awiuv (E42)
- Record of a protected area "ShUM Sites of Speyer, Worms and Mainz" (E35) on the UNESCO (E39) list in English (E56) available at https://whc.unesco.org/en/list/1636 (E42)
- Entry "Mainz – Worms – Speyer. Drei mittelalterliche Städte im ZentrumEuropas als Linked Data" (E35) in German (E56) on the AI MAINZ (E39) website available at https://architekturinstitut.hs-mainz.de/projekte/historische_stadtmodelle_mainz_worms_speyer/ (E42)
- YouTube Video "What was the Role of Synagogues during the Second Temple Period? | Spotlight on History | Synagogues" (E35) in English (E56), published by Bible Discovery TV (E39) available at https://www.youtube.com/watch?v=M_44yS_Fgj4 (E42)

M7 Visualization (deprecated)

M8 Web Document (deprecated)

M9 Research Publication (deprecated)

M10 Area (deprecated)

M11 Single Built Work (deprecated)

M13 Component (deprecated)

M14 Research Project

Subclass of: E7 Activity

Scope note:

This class comprises a series of activities to find answers to scientific questions conducted by instances of E39 Actor, which are most often research institutions or universities. It commonly requires external funding and interdisciplinary consultation. It involves the preparation of adequate documentation of conducted instances of E7 Activities following academic work ethics and their discipline's internal requirements. The M14 Research Project is always motivated by specific objectives and has predetermined goals to be achieved in a defined E52 Time Span.

Examples:

- Project (M14) of hypothetical source-based digital 3D reconstruction (M25) of the New Synagogue in Breslau (M26) by AI MAINZ (E39) (https://www.new-synagogue-breslau-3d.hs-mainz.de/)
- Project (M14) "Computer-based Visualization of Architectural Cultural Heritage (CoVHer)" (E35) co-funded by the Erasmus+ Programme of the European Union (E74) (https://covher.eu/project/)
- Student seminar (M14) on digital reconstruction (M25) of wooden synagogues (M26) held at the Faculty of Architecture of Warsaw University of Technology (E39) in the summer semester of the academic year 2022/23 (E52)

M15 3D Feature

Subclass of: M1 3D Object

Scope note:

This class comprises identifiable features that are digitally attached in an integral way to particular digital objects. M15 Digital Feature refers only to the specific part of an M1 Digital Object, which the physical equivalent would not constitute a separate physical unit. Instances of M15 Digital Feature share many of the attributes of instances of M1 3D Object. They may have a one-, two- or three-dimensional geometric extent. The instances of M15 Digital Feature represent instances of the E26 Physical Feature, which could be observed directly on the E71 Man-Made Thing or its carrier of information (osd31b Source) and which are transferred to the M17 Digital Environment in the process of M25 Digital Reconstruction.

The M15 3D Feature consists of two components that simulate the shape of an object (M22 Digital Shape) and a surface finish that simulates reactions of materials to light (M16 Digital Material). In the vast majority of cases, both components have their counterparts, instances of which can exist in the physical world and are defined as E57 Material for surface finishes and M21 Shape for geometric shapes that can be measured and expressed in mathematical coordinates and functions.

Examples:

- CAD drawing of the profile of the cornice crowning (E26) St. Peter's Basilica in Rome (M26)

- Digitally reconstructed proportions of the dome (E26) of the demolished (E3) New Synagogue in Wroclaw (M26)
- Digital reconstruction of the rosette (E26) of Notre Dame Cathedral (M26)

Properties:

- R13 consists of (is incorporated in): M16 Digital Material

M16 Digital Material

Subclass of: E55 Type

Scope note:

This class is a specialisation of E55 Type and comprises the concepts of digital representations of E57 Materials. It consists of attributes encoded in a 3D file containing information about the material's colour, roughness, light emission, reflexivity, or transparency. The material can also be simulated by applying an image (E36, D1) to the surface of an M1 3D Object through an M24 Texture Mapping. Images can affect the surface's colour and pattern or create the illusion of depth or irregularity. Connecting several images to represent the same material is possible, but each image will be responsible for simulating a different property of the material's surface.

This type is used categorically in the model without reference to instances of it, i.e., the model does not foresee the description of instances of M16 Digital Material, e.g., "instances of gold".

Examples:

- Old Abandoned Building Wood Plank Flooring PBR Material (M16) #3 for Blender (D14) (https://freepbr.com/materials/old-wooden-flooring-3/)
- Seamless (tileable) Dirty Glass PBR Texture (M16) with eight maps (M20): albedo/diffuse, reflection, glossiness, height/displacement, roughness, metalness, ambient occlusion and normal map (https://cgaxis.com/product/dirty-glass-pbr-texture/)

M17 Digital Environment

Subclass of: D1 Digital Object

E92 Spacetime Volume

Scope note:

This class comprises a 4-dimensional environment in digital spacetime simulation in D14 Software, programmed for creating and displaying instances of M1 3D Objects. The program associated with 3D models always has an individual coordination system to locate the position of M1 3D Object in digital space. The fourth dimension is a characteristic of animated models only and, in most cases, is not considered. M17 Digital Environment has individual features that affect the perception of the placed M1 3D Object, such as the light or the camera through which the object is observed.

The central point (0,0,0) is an integral part of the M17 Digital Environment. Each M1 3D Object placed in the space has its own M18 Digital Position, which is described in relation to the central point of the space. The

object's position is determined by its pivot, the relative point to which all operations on the 3D object are performed. The pivot should be approximately at the centre of gravity of the object.

Examples:

- Modelling space (M17) inside the scene of the Blender program (D14)
- Interaction space (M17) with 3D model (M1) in Sketchfab online repository

Properties:

- R10 is simulated by (simulates): D13 Software

M18 Digital Position

Subclass of: D1 Digital Object

E53 Place

Scope note:

This class comprises the location of M1 3D Object in digital space expressed by set of E59 Primitive Values that should be implemented with appropriate validation, precision and references to spatial coordinate or relative to central point of M17 Digital Environment. In the same time, it serves as a declaration of E53 Place, but in digital world for M1 3D Object. M18 Digital Position of M1 3D Object may not have anything to do with the location of the actual equivalent of the 3D object in the real world expressed by E53 Place.

Examples:

- x = 4.07625 m, y = 1.00545 m, z = 6.35832 m (in Blender coordination metric system)

Properties:

- R11 refers to coordinate system within (has coordinate system referred to): M17 Digital Environment

M19 Simulation

Subclass of: D10 Software Execution

E13 Attribute Assignemnt

Scope note:

This class comprises events that happen on physical digital devices following a human activity that intentionally caused its immediate or delayed initiation and results in the creation of a virtual 3D representation simulating a certain E3 Condition State of instance of M26 Cultural Heritage Thing.

The input of a D7 Digital Machine Event is a three-dimensional digital model, an instance of an M1 3D Object in a specified M17 Digital Environment. Due to technological limitations or lack of sufficient source material, it should be borne in mind that M20 Simulation most often does not represent a perfect copy of the simulated object state but is rather an attempt to interpret the output, the end result of which is subject to a certain level of guesswork expressed by the M28 Uncertainty Value. Assumptions regarding the technology limitation can be expressed by the M27 Accuracy Value and limitations to the source material by the M29 Reliability Value.

Examples:

- Hypothetical realistic simulation (M20) of the reconstruction (M25) of the destroyed (E3) New Synagogue in Wroclaw (M26) via the Sketchfab viewer (M17) (Kuroczyński et al., 2019)
- Non-photorealistic visualisation (M20) Maison d'un employè, Cité idéale de Chaux by Ledoux with use of texture projection and procedural mapping based on original architect drawings (Apollonio et al., 2022)

M20 Property Set

Subclass of: E73 Information Object

Scope note:

This class comprises the intrinsic knowledge about how M16 Digital Material representing instances of E57 Material are simulated on surfaces of M1 3D Object. It consists of attributes encoded in a 3D file about the colour, roughness, light emission, reflexivity, transparency or any other property of the material. The material can also be simulated by applying an image (E36, D1) to the surface of a M1 3D Object through a texturing process. Images can affect the colour and pattern of the surface or create the illusion of depth or irregularity on the surface. The method of mapping images to the M15 Digital Feature surface is determined by M24 Texture Mapping.

Examples:

- Node graph (E73) for material (M16) setup with parameters (E59) in Blender (D14)
- Material (M16) property manager (E73) setup with parameters (E59) in ArchiCAD (D14)

M21 Shape

Subclass of: E55 Type

Scope note:

This class is a specialisation of E55 Type. It comprises the concepts of shapes and forms of conceptual and physical in two- and three-dimensional space. According to Getty Art&Architecture Thesaurus it is the outline, form, or characteristic configuration of an object, including its contours, which define the external form or outer boundary of the object.

Examples:

- Biforia window shape
- Cylinder
- Outline of the city's skyline

M22 Digital Shape

Subclass of: E55 Type

Scope note:

This class is a specialisation of E55 Type. It comprises the concept of digital interpretations of the M22 Shape. M22 Digital Shape most often does not accurately reflect the actual form of the M21 Shape. Its digital representation adopting certain simplifications allowing an appropriate perception of the target form or shape.

Examples:

- triangulated mesh of building model
- segmented arc
- idealised plan of a historical building based on right angles
- NURBS-based ideal semisphere

M23 3D Modelling Technique

Subclass of: osd75p Technique

Scope note:

This class is a specialisation of osd75p Technique . It comprises the classification of activities of constructing the M22 Digital Shape of M1 3D Object (e.g., algorithmic 3D modelling can be used to generate 3D models that are defined with NURBS or mesh representation methods).

Examples:

- algorithmic modelling
- digital sculpting
- direct hand-made 3D modelling
- semi-automatic reality-based 3D modelling

M24 Texture Mapping

Subclass of: D10 Software Execution

Scope note:

This class comprises events by which a digital device runs a series of computing operations on an M1 3D Object as a single task to apply an image to the surfaces of the 3D object to simulate a material. M24 Texture Mapping is predefined by a series of decisions regarding the material properties, texture image selection, and mapping method selection by the human.

Examples:

- UV Mapping
- Planar Mapping
- Box Mapping
- Cylinder Mapping
- Sphere Mapping
- Node Mapping

Source:

- https://manual.keyshot.com/manual/textures/mapping-types/

M25 Digital Reconstruction

Subclass of: Osd7a Research Activity

D7 Digital Machine Event

Scope note:

This class comprises actions intentionally carried out by instances of E39 Actor that result in digital reconstruction of a specific E3 Condition State of M26 Cultural Heritage Thing as a new instance of M1 3D Object. The reconstruction of a cultural object's past states is always subject to a certain degree of uncertainty, so M25 Digital Reconstruction can result in multiple instances of the M1 3D Object showing different stages of the reconstruction work or different versions of the final reconstruction.

This class encompasses not only the process of creating the model itself but all instances of E7 Activities that support this process, such as collecting source materials, digitising source materials, critically analysing the collected materials, or searching for analogies to fill gaps in building knowledge.

Examples:

- Hypothetical source-based digital 3D reconstruction (M25) of the New Synagogue in Breslau (M26) as it looked in 1872 (E3) by AI MAINZ (E39) (https://www.new-synagogue-breslau-3d.hs-mainz.de/wisski/navigate/1164/view)
- Hypothetical reconstruction (M25) of the church of Santa Margherita in Bologna (M26) by University of Bologna - Department of Architecture (E39), variant as designed by Angelo Venturoli in 1792 (E3) (https://doi.org/10.1007/s00004-023-00707-2)
- Digital documentation (M25) of Synagogue in Przysucha (M26) through laser scanning (osd7a) in 2022 (E3)

M26 Cultural Heritage Thing

Subclass of: E71 Human-Made Thing

Superclasss of: E24 Physical Human-Made Thing

E28 Conceptual Object

Scope note:

This class comprises discrete, identifiable human-made items that hold the legacy of the past generation and are documented as single units. These items are either intellectual products (intangible heritage) or human-made physical things (tangible heritage), characterised by relative stability. M26 Cultural Heritage Thing offers a bridge between the past and the future by applying particular approaches in the present. Due to its attached values for groups or societies inherited from the past, cultural heritage is maintained in the present and bestowed for the benefit of future generations.

Examples:

- Michelangelo's David sculpture (E22)
- Destroyed (E3) New Synagogue in Wroclaw (E22)
- Design of never-realized (E3)Volkshalle by Albert Speer (E29)
- Ruins (E3) of Acropolis of Athens (E22)
- Treatise on Architecture by Vitruvius (E89)

M27 Accuracy Value

Subclass of: E55 Type

Osd55q Detail Level Type

Scope note:

This class is a specialisation of E55 Type and comprises the precision of the representation of the M1 3D Object in relation to the collected source materials (osd31b Source) and their provenance used in the M25 Digital Reconstruction process. It can also be understood as the level of detail of the reconstruction and explains what margin of error was assumed by the E39 Actor performing the M25 Digital Reconstruction. It can be expressed in terms of scale (e.g., 1:500). In the case of digital reconstructions based on the process of digitisation, the model's accuracy corresponds to the measurement accuracy of the M8 Digital Device.

Examples:

- 1:50
- 1 cm
- 0,5 mm

M28 Uncertainty Value

Subclass of: E55 Type

Scope note:

This class is a specialisation of E55 Type and comprises reconstructed parts of M1 3D Object that are historically uncertain in comparison to its equivalent of M26 Cultural Heritage Thing in certain E3 Condition State that they represent. The more hypothetical the reconstitution, the more its level of uncertainty increases. Due to the subjective value and hypothesis burden, the M28 Uncertainty Value instance should be assigned by using I5 Inference Making expressing fuzziness of logic statements. M28 Uncertainty Value can be expressed as numerical or string value on a specific Uncertainty Scale (I3 Inference Logic), or be calculated by a mathematical formula (I3 Inference Logic) that takes into account the values estimated for different semantic parts of the object. as a percentage value, or through a string indicating the level of uncertainty.

Examples:

- "03" (E60) in 5-level uncertainty scale of Irene Cazzaro (I3) for portal reconstruction (M25) of the Speyer Synagogue (M26) which stands for deduction (E55) (2022, https://doi.org/doi.or/10.48676/unibo/amsdottorato/10817)

- 28% (E60) of uncertainty in digital reconstruction (I5) of Piazza delle Erbe calculated with formula of Average Uncertainty Weighted on the Volume with Relevance factor (AU_VR) (I3) published by Apollonio et al. (2023, https://doi.org/10.3390/heritage7010023)
- "low" (E59) uncertainty value of the reconstruction (I5) of the dome of the New Synagogue in Wroclaw (M26) in a 3-level scale (low-medium-high) (I3) by Kuroczyński et al. (2021, https://doi.org/10.1007/978-3-030-93186-5_2)

Same as:

- CRMvr: V21 Uncertainty Grade (https://github.com/elisabettacaterina/CRMvr)

M29 Reliability Value

Subclass of: E55 Type

Scope note:

This class is a specialisation of E55 Type and comprises the degree of confidence and trustworthiness associated with the osd31b Source and credibility associated with the reconstructed scenario or interpretation of historical events. It pertains to the consistency, coherence, and robustness of the reconstructed narrative, evidence, and arguments presented. The correct level of reliability of source materials allows to reduce the value of uncertainty for M25 Digital Reconstruction.

Examples:

- Inconsistent
- Damaged
- Readable

Same as:

- CRMvr: V22 Accuracy Grade (https://github.com/elisabettacaterina/CRMvr)

Properties declaration

R1 published (was published by)

Domain: M5 Digital Publication Event

Range: D1 Digital Object

Subproperty of:

dig: D7 Digital Machine Event -> dig: L11 had output (was output of) -> dig: D1 Digital Object

Quantification: one to many, necessary, dependent (1,n:1,1)

Scope note:

This property describes the process of a publication of a digital object (picture, document, video, 3D model, etc.) on the web resulting in creation of URI.

R2 has name (is name of) (deprecated)

R3 has surname (is surname of) (deprecated)

R4 is preceding version of (has preceding version)

Domain: D1 Digital Object

Range: D1 Digital Object

Subproperty of: crm:

E70 Thing -> crm: P130 shows features of (features are also found on)-> crm: E70 Thing

Quantification: one to one, necessary (1,1:0,1)

Scope note:

This property associates two instances of D1 Digital Object, indicating the progression of the state of work on the content they contain. The property allows the progression of work on versions to be tracked in the order in which they occur, pointing to the preceding working state. It can assign only one version the D1 Digital Object, which was a record of the previous work state.

R5 is following version of (has following version)

Domain: D1 Digital Object

Range: D1 Digital Object

Subproperty of:

crm: E70 Thing -> crm: P130 shows features of (features are also found on)-> crm: E70 Thing

Quantification: one to one, necessary (1,1:0,1)

Scope note:

This property associates two instances of D1 Digital Object, indicating the progression of the state of work on the content they contain. The property allows the progression of work on versions to be tracked in the order in which they occur, pointing directly to the following working state. It can assign only one version preceding it to the D1 Digital Object, which was a record of the following work state.

R6 is alternation of (has alternation)

Domain: M1 3D Object

Range: M1 3D Object

Subproperty of:

crm: E70 Thing -> crm: P130 shows features of (features are also found on)-> crm: E70 Thing

Quantification: many to many (0,n:0,n)

Scope note:

This property associates an instance of M1 3D Object with another instance of M1 3D Object that constitutes a variant of the former and that may also be used for identifying results of M25 Digital Reconstruction identified by the former, in suitable contexts, independent from the particular item to be identified. It is important to note that both M1 3D Object depict the same M26 Cultural Heritage Thing in the same E3 Condition State and were prepared based on the same body of knowledge. If the research on the object is progressing and the scope of the starting material for reconstruction has been changed, this should be expressed not by a variant but by creating an entirely new instance of M25 Digital Reconstruction.

It is a directed relationship where the range expresses the variant and the domain is the source of original form of variation if such a direction can be established. Otherwise, the relationship is symmetric. This property is not transitive. This property is irreflexive.

R7 has position (is position of)

Domain: M1 3D Object

Range: M18 Digital Position

Subproperty of:

crm: E19 Physical Object -> crm: P55 has current location (currently holds) -> crm:E53 Place

Quantification: many to many (0,n:0,n)

Scope note:

This property identifies an instance of M18 Digital Position, which determines the position of an M1 3D Object through a set of coordinates between the centre point of the M17 Digital Environment and the reference point of the 3D object.

R8 digitally created (was digitally created through)

Domain: M5 Digital Publication Event

Range: M6 Digital Record

Subproperty of:

lrmoo: F30 Manifestation Creation -> lrmoo: R24 created (was created through) -> lrmoo: F3 Manifestation

Quantification: one to many, necessary, dependent (1,n:1,1)

Scope note:

This property associates the instance of M6 Digital Record that was created digitally during a particular instance of M5 Digital Publication Event.

R9 simulates feature (is feature simulated by)

Domain: M19 Simulation

Range: E55 Type

Subproperty of:

crm: E7 Activity -> crm: P125 used object of type (was type of object used in) -> crm: E55 Type

Quantification: one to one, necessary (1,1:0,1)

Scope note:

This property associates the instance of M19 Simulation with the feature represented by the instance of E55 Type, which is digitally reconstructed on the M1 3D Object. The feature is related to material (E56 Material) or shape (M21 Shape).

R10 simulates (is simulated by)

Domain: M19 Simulation

Range: M26 Cultural Heritage Thing

Subproperty of:

crm: E7 Activity -> crm: P16 used specific object (was used for) -> crm: E70 Thing

Quantification: one to one, necessary (1,1:0,1)

Scope note:

This property associates the instance of M19 Simulation with the simulated object represented by the instance of M26 Cultural Heritage Thing, which is digitally reconstructed on the M1 3D Object.

R11 simulates object (is object simulated by)

Domain: M1 3D Object

Range: M26 Cultural Heritage Thing

Subproperty of:

crm: E70 Thing -> crm: P130 shows features of (features are also found on) -> crm: E70 Thing

Quantification: many to one, necessary (1,1:0,n)

Scope note:

This property identifies an instance of M26 Cultural Heritage Thing that is simulated by M1 3D Object. Simulating is meant in the sense that an instance of M26 Cultural Heritage Thing intentionally shows, through its optical qualities or form, a representation of the entity simulated. Digital 3D scans are, by default, regarded as being intentional in this sense.

This property is a shortcut of the more fully developed path from M26 Cultural Heritage Thing through R10 is simulated by, M19 Simulation, L11 had an output to M1 3D Object.

R12 refers to coordinate system within (has coordinate system referred to)

Domain: M18 Digital Position

Range: M17 Digital Environment

Subproperty of:

crm: E89 Propositional Object -> crm: P67 refers to (is referred to) -> crm: E1 CRM Entity

Quantification: many to one, necessary (1,1:0,n)

Scope note:

This property associates the instance of M18 Digital Position in relation to the coordinate system of the instance of M1 Digital Environment to which it refers to.

R12 embeds (is embedded in)

Domain: M17 Digital Environment

Range: M1 3D Object

Quantification: many to many (0,n:0,n)

Scope note:

This property associates the instance of M1 3D Object with an instance of M17 Digital Environment, where the 3D model is embedded. Creating a derived 3D Object by exporting to other file formats (D1 Digital Object) also creates new instances of D17 Digital Environment based on the specification of the exported file format, where the M1 3D Object is embedded.

R13 consists of (is incorporated in)

Domain: M1 3D Object

Range: M16 Digital Material, M23 Digital Shape

Quantification: many to many, necessary (1,n:0,n)

Scope note:

This property identifies the instance of M1 3D Object or M15 Digital Feature with its attributes of shape (M22 Digital Shape) and material (M16 Digital Material). All digital 3D things simulate visually 2D or 3D shapes and volumes with a surface-specific perception expressed by digital materials. R12 consists of (is incorporated in) allows the different digital materials and different shapes to be recorded.

R14 has reconstructed (is reconstructed by)

Domain: M25 Digital Reconstruction

Range: M26 Cultural Heritage Thing

Subproperty of:

crm: E13 Attribute Assignment -> crm: P140 assigned attribute to (was attributed by) -> crm: E1 CRM Entity

Quantification: many to many (0,n:0,n)

Scope note:

This property associates an instance of M25 Digital Reconstruction with the instance of M26 Cultural Heritage Thing about which it made a reconstruction. One cultural object can be the subject of multiple instances of digital reconstructions conducted by different actors in different times and environments.

R15 simulates time (is time simulated by)

Domain: M25 Digital Reconstruction

Range: E52 Time Span

Quantification: one to one, necessary (1,1:0,1)

Scope note:

This property associates an instance of M25 Digital Reconstruction with the instance of E52 Time Span about which it made a reconstruction. Each digital reconstruction of an object matches only a certain time span from the object's lifespan, which this property allows to document.

R16 has shape (is shape of)

Domain: M26 Cultural Heritage Thing

Range: M21 Shape

Subproperty of:

crm: E1 CRM Entity -> crm: P2 has type (is type of) -> crm: E55 Type

Quantification: many to many, necessary (1,n:0,n)

Scope note:

This property identifies the instances of M21 Shape that match the outline of an instance of M26 Cultural Heritage Thing. In the case of physical things, this property describes the physical boundaries of the object. In the case of conceptual objects, this property refers to the boundaries deduced from the interpretation of the carriers of a given concept.

R17 has representation type (is representation type of)

Domain: M1 3D Object

Range: E55 Type

Subproperty of:

crm: E1 CRM Entity -> crm: P2 has type (is type of) -> crm: E55 Type

Quantification: many to many (0,n:0,n)

Scope note:

This property allows the categorisation of M1 3D Object instances according to the type of 3D model representation, which should be understood as the intrinsic mathematical/geometrical digital representation. Possible classifications are continuous representation (e.g., NURBS, Bézier, spline) and discrete representation (e.g., mesh, point clouds, voxels), mathematical representation (equations with parameters) and the numerical representation (coordinates), or implicit representation and explicit representation. It should be kept in mind that this class refers to general categories defining the geometric representation method.

R18 has accuracy value (is accuracy value of)

Domain: M19 Simulation

Range: M27 Accuracy Value

Subproperty of:

crm: E13 Attribute Assignment -> crm: P141 assigned (was assigned by)-> crm: E1 CRM Entity

Quantification: many to many (0,n:0,n)

Scope note:

This property indicates the value of accuracy of object simulation in digital space that was assigned to M19 Simulation event.

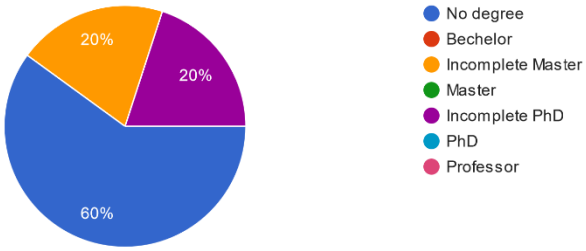
Appendix 9: Student Survey 1 (DFG 3D-Viewer Repository)

Survey with students of architecture of 8th semester at the Faculty of Architecture at the Warsaw University of Technology after seminar about digital 3D reconstruction of wooden synagogues during summer semester of academic year 2021/2022 - 5 responses.

PERSONAL DATA

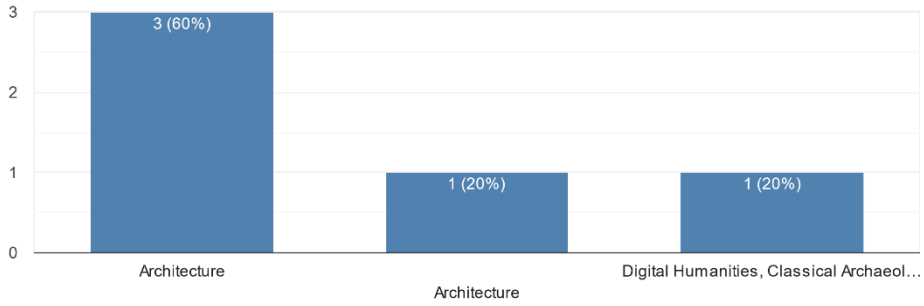
Indicate your current level of education

5 responses



Indicate your area of study

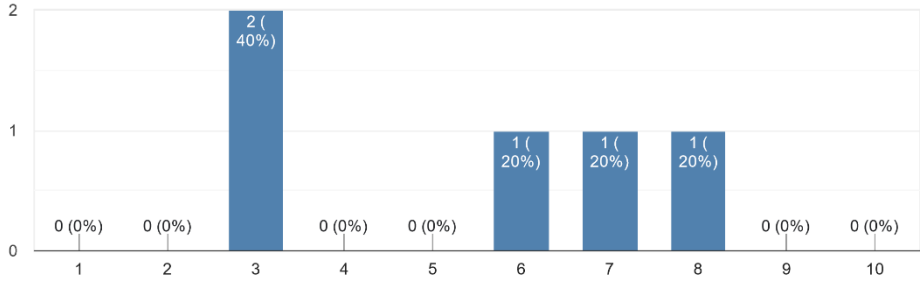
5 responses



METADATA FORM IN 3D REPOSITORY

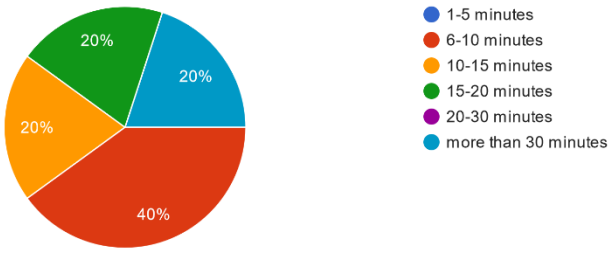
Rate the difficulty of filling in the form, taking 1 as very easy and 10 as very difficult

5 responses



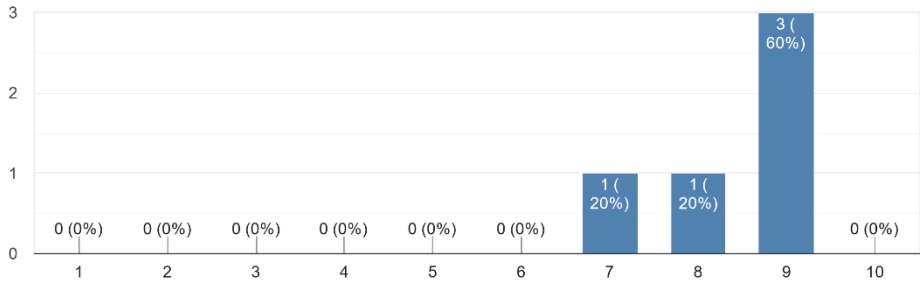
Estimate the time needed to complete the form

5 responses



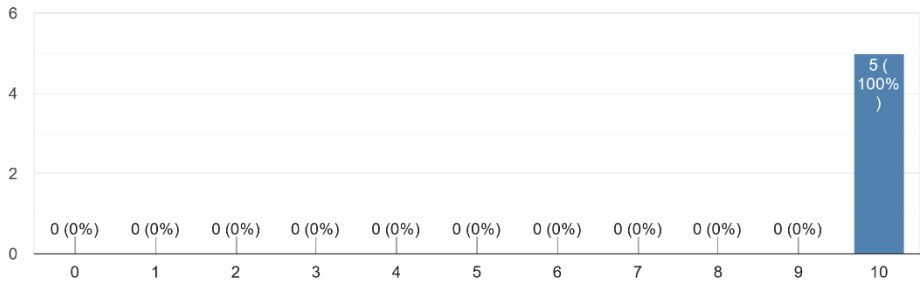
Evaluate if the field names and attached instructions were clear to you. Take 1 for unclear and 10 for perfectly clear.

5 responses



Assess the completeness of the necessary information collected in the form about the identification of the object to be reconstructed, t...t or the project under which the model was created.

5 responses



Did any of the fields cause you particular difficulty? Which one and why?

2 responses

For example in "Historical Relations" Add New Wisski Entity button was easily confused with Update Wisski Entity. Also every time I added a new entry, its name disappeared in preview.

No

Was any important information missing in the form?

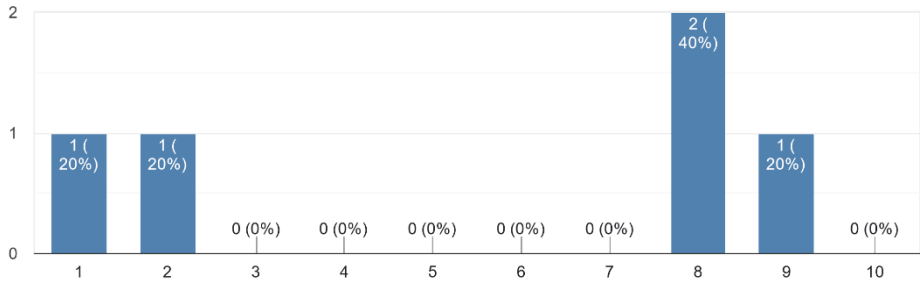
1 response

-

FILE UPLOAD & 3D VIEWER

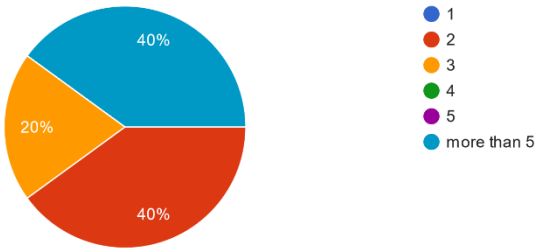
Rate the difficulty of the 3D model upload, taking 1 as very easy and 10 as very difficult

5 responses



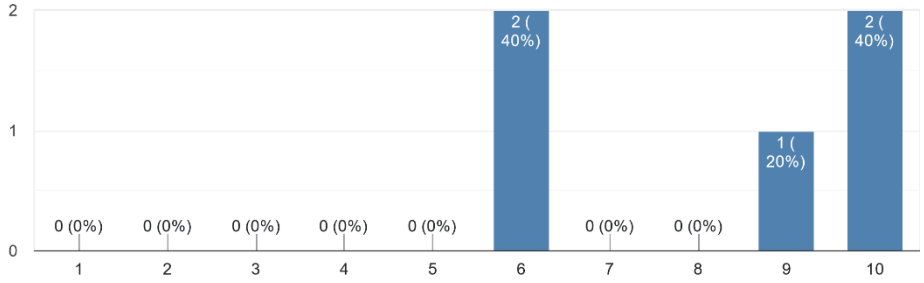
How many attempts did it take to get your file to display correctly with the creation of automatic renders?

5 responses



Were the instructions for preparing the model clear to you? Rate on a scale of 1-10 with 1 being completely unclear and 10 being completely clear

5 responses



Were the instructions for preparing the model included in the repository sufficient? What was missing?

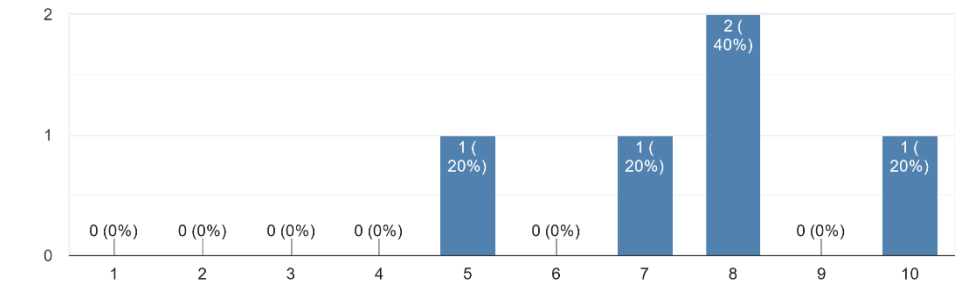
2 responses

In my case: I had to export from the native file. Also I think that it would be better if the information was more clearly emphasised, for exaple as bullet points instead of plain text that written in long lines of text.

I had a problem with textures used in SketchUp after i loaded file on repository, if i knew ealier how to manager that It would save my time

Assess the functionality of the viewer. Assume 1 for non-functional and 10 for fully functional

5 responses



What do you think should be improved about the viewer's functionality?

2 responses

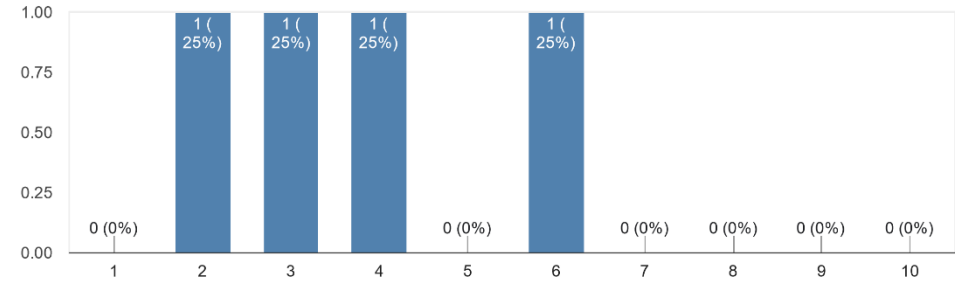
In my case: the textures were overscaled

... uncertainty visualisation, hopefully!! (in my case a function that shows the different layers would be enough)

DOCUMENATATION: SEMANTIC DIVISON

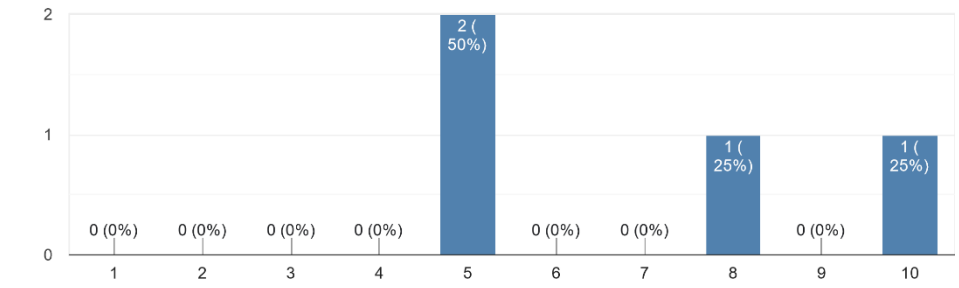
Rate the difficulty of creation of a semantic division of the object? Take 1 as very easy and 10 as very difficult

4 responses



Were the instructions about semantic division? Rate on a scale of 1-10 with 1 being completely unclear and 10 being completely clear

4 responses



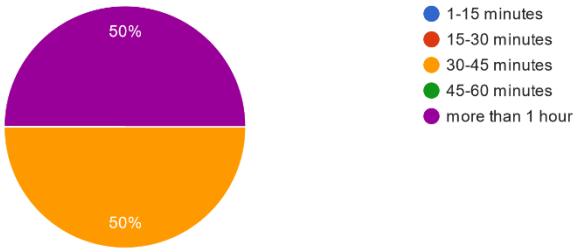
What in the semantic division of the object did you find difficult?

1 response

It takes a lot of time and it is unclear what the outcome is supposed to look like. Also I wasn't sure for example if I should name types of windows or mark every single one of them.

Estimate the time needed to create semantic division of the object

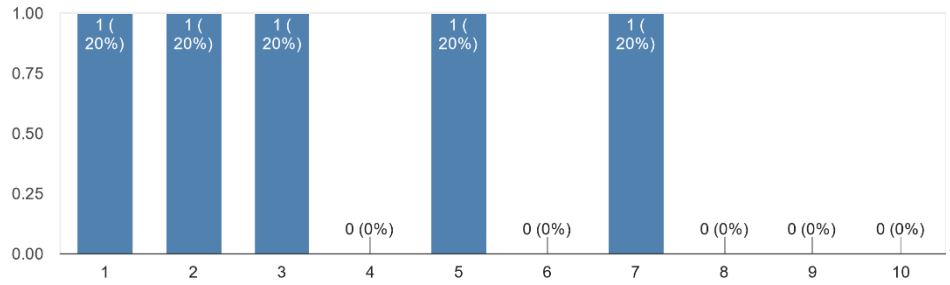
4 responses



DOCUMENTATION: TEMPLATES

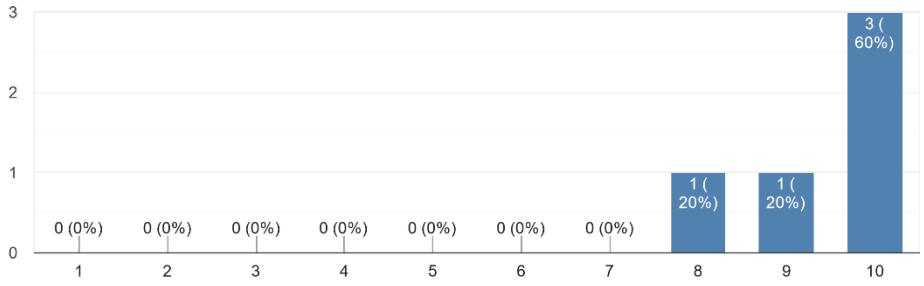
Rate the difficulty of filling in the documentation template? Take 1 as very easy and 10 as very difficult

5 responses



Were the instructions about filling in the documentation template? Rate on a scale of 1-10 with 1 being completely unclear and 10 being completely clear

5 responses



What in the filling in the documentation template did you find difficult?

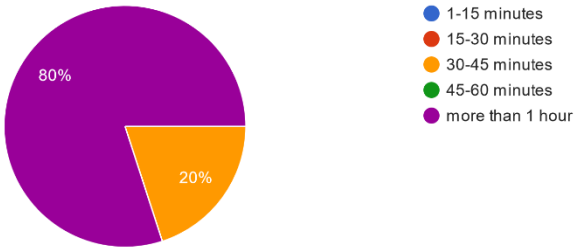
2 responses

It takes a lot of time

Cetrtainty of reconstruction

Estimate the time needed to fill in the documentation template of the object

5 responses



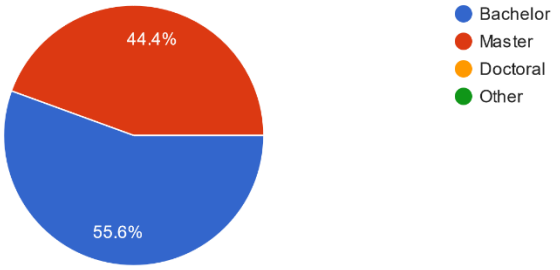
Appendix 10: Student Survey 2 (DFG 3D-Viewer Repository)

Survey with students of architecture of 8th semestrer at the Faculty of Architecture at the Warsaw Univeristy of Technology and Master Program in Architecture at the Łódź University of Technology after joint seminar about digital 3D reconstruction of wooden synagogues during summer semester of acadmeic year 2022/2023 – 9 responses.

PERSONAL DATA

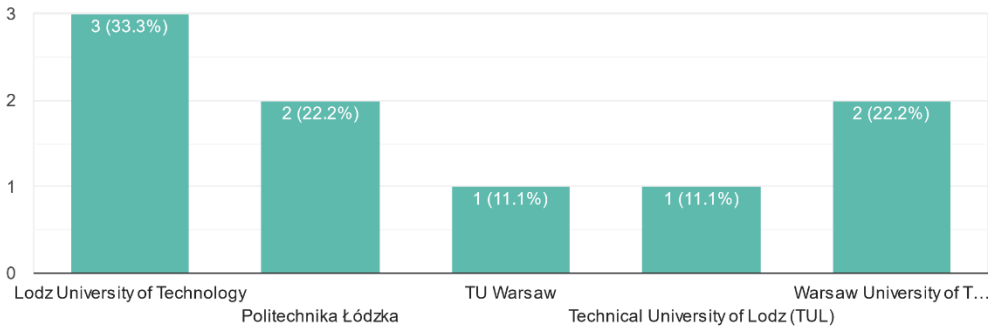
What is your level of current studies?

9 responses

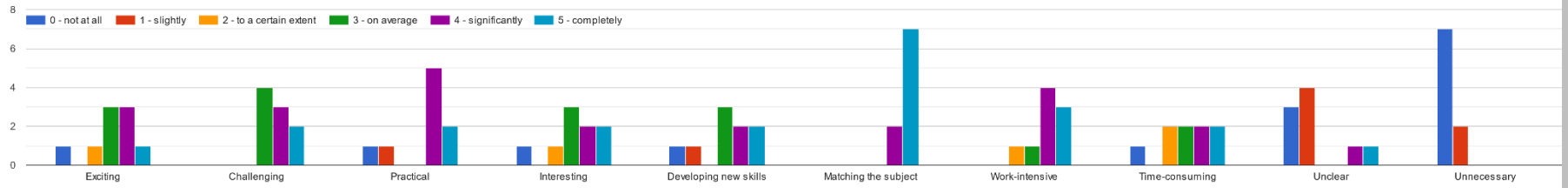


What is your university?

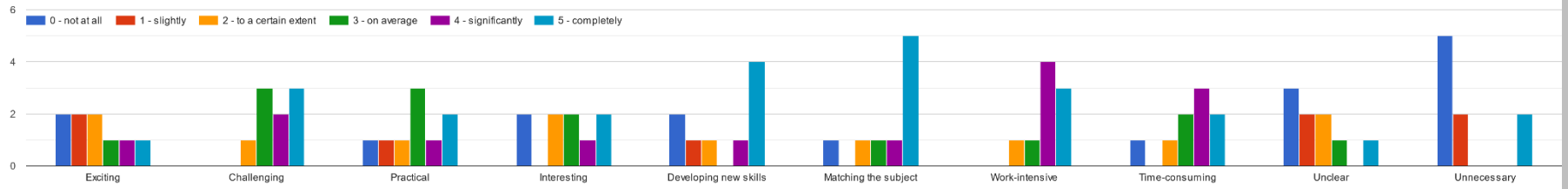
9 responses



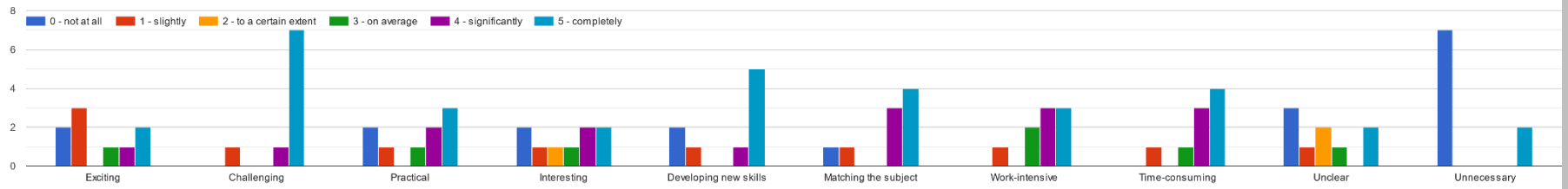
Initial survey of the building and available historical sources



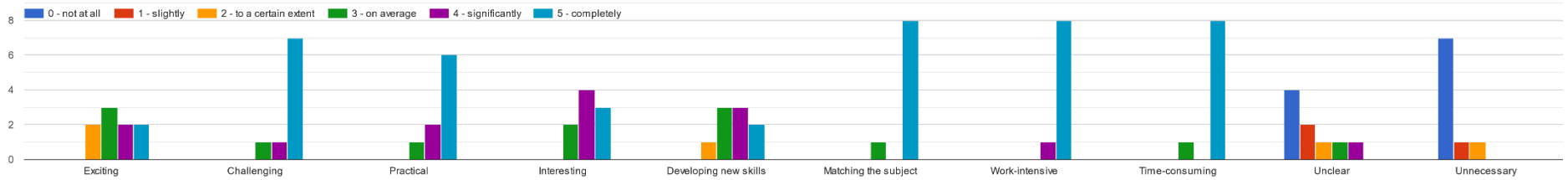
Object segmentation according to the Getty AAT hierarchy



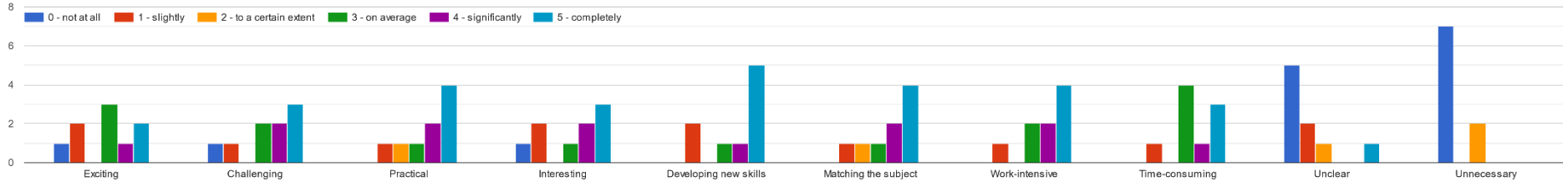
Matrix for evaluating sources and the reconstitution process



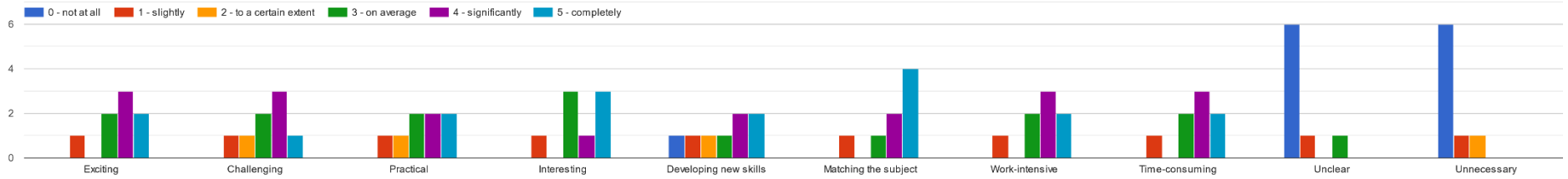
Creation of a 3D source-based reconstruction model



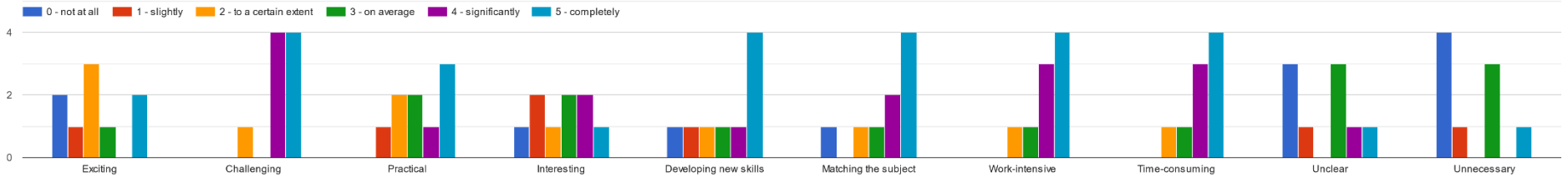
Wikipedia entry (article review and digitisation of technical drawings)



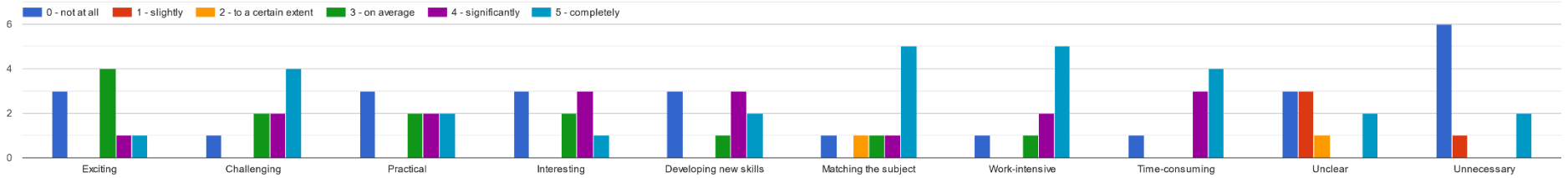
Creating a postcard for an AR application



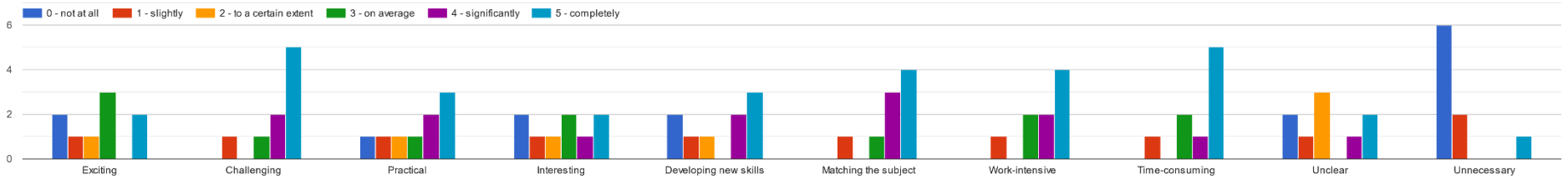
Documentation based on data exchange format standards (CityGML/IFC)



Project documentation on the IDOVIR platform



Entry in the 3D model repository



Which task was the most challenging and why?

9 responses

Creation of the 3D model, because the course was half a semester too short for such a demanding task.

3D model- im traumatised

stworzenie matrycy i systemu oceny i wiarygodności modeli, na początku niezrozumiałe, dużo znaków zapytania i nieścisłości z uwagi na charakter zagadnienia, potem już neutralne

Preparing the model for a specific function - AR or 3D Print.

Preparing model for a 3D print. It is almost impossible for some modelling softwares to fix some mistakes made when creating a model for a different purpose (like AR), thus in some cases a 3d model of a synagogue is almost impossible to adapt to a 3D print.
Also, we learned way too late about many changes regarding the final assignment which meant even more problems when converting the models and cutting them.

Adaptation of the 3D model for the AR application and Adaptation of the 3D model for the 3D print. Time consuming and super challenging.

Export model with textures that work in 3drepository

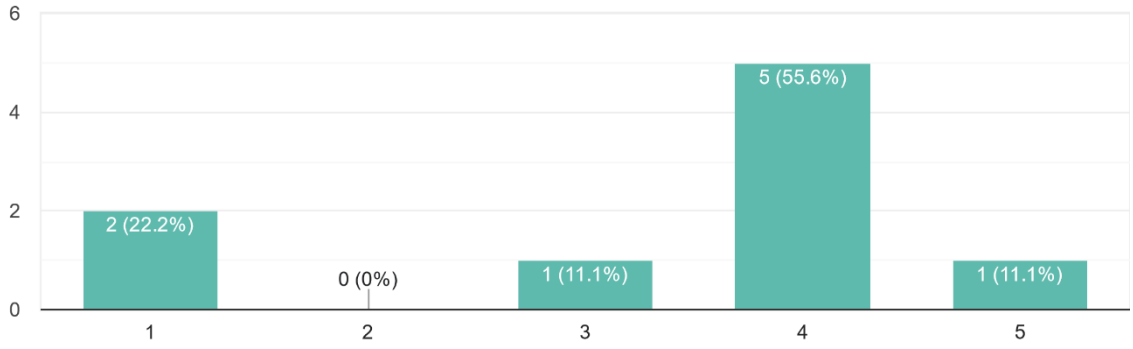
For me, the most difficult tasks were those that were not entirely clear to me. Especially creating a model in CityGML or IFC format. In my case, I was creating a model in SketchUp 2020, but I couldn't find a way to make CityGML work in it. And I've already used trial versions.

IDOVIR, because of ceratain lack of possibilities

IDOVIR

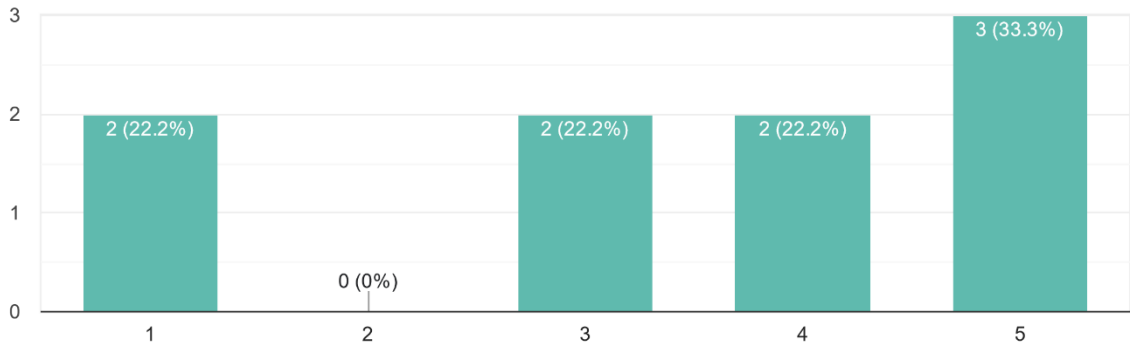
How do you assess the intuitiveness of the IDOVIR system?

9 responses



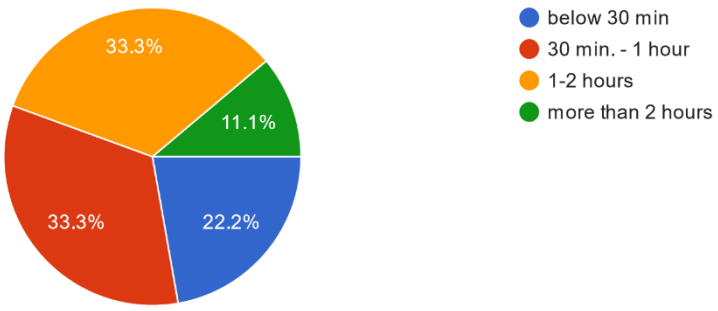
Rate the difficulty of using the tool to create a "Project structure". Take 1 as very difficult and 5 as very easy.

9 responses



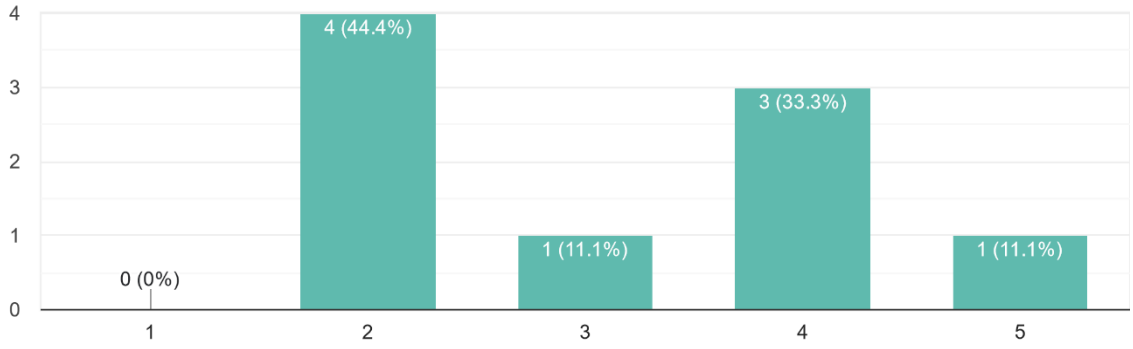
Approximately how much time did you need to enter the "Project structure" into the system?

9 responses



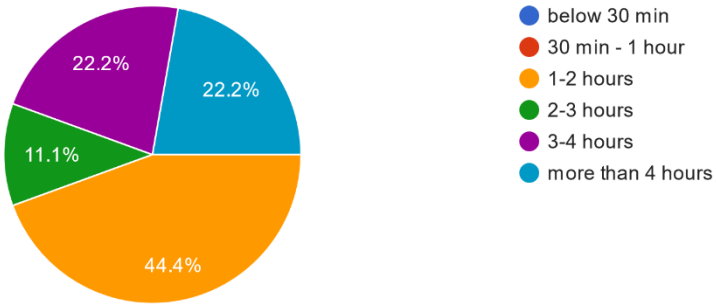
Rate the difficulty of uploading and describing sources to the system. Take 1 as very difficult and 5 as very easy.

9 responses



Approximately how much time did you need to upload and describe all the sources into the system?

9 responses



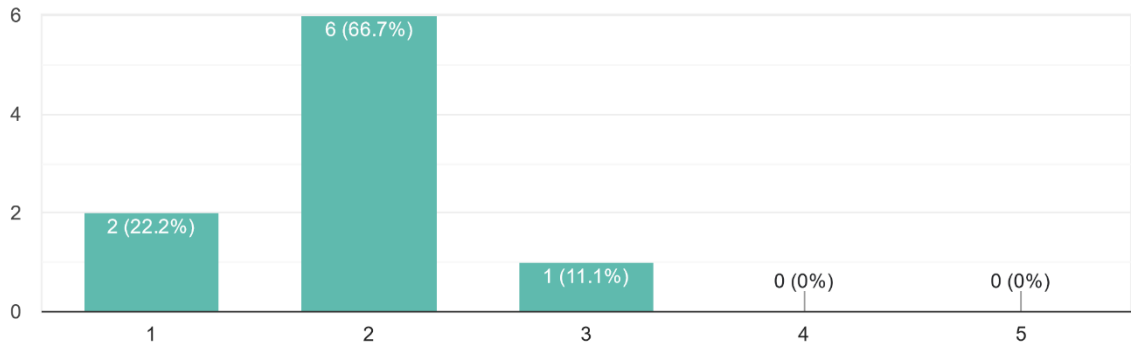
Did anything cause you particular difficulty when uploading and describing sources in the system?

4 responses

no
Not really, it's just time-consuming describing everything
can't change source figure number
Some bugs

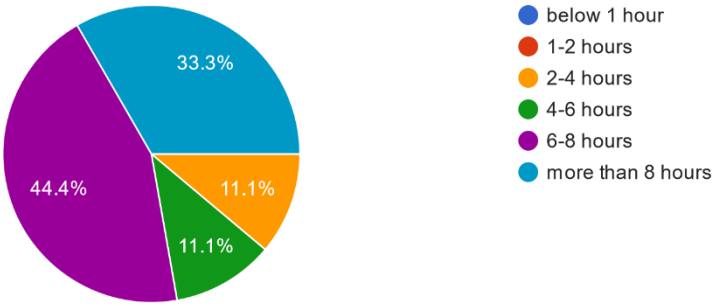
Rate the difficulty of documentation of the reconstruction (reasoning of the decision, upload and description of the reconstruction material, descripti...object). Take 1 as very difficult and 5 as very easy.

9 responses



Approximately how much time did prepare whole documentation about reconstruction (excluding uploading and describing sources) into the system?

9 responses



Whether the methods of evaluation of the reconstruction met your expectations (breakdown into geometry, material and colour with the possibility of changing the evaluation criteria). If not, what would you change?

9 responses

I liked the methods of evaluation, they were really clear.

-

no idea

still evaluating

They are completely unnecessary, models should have information regarding their location and history but breaking them down to each individual material seems pointless.

i would change the structure of evaluation and made it more simple and understandable for avarage person

add option to create own group of criteria - would allow to use different methods of evaluation accoring to own matrix

I didn't find a place where I could evaluate the elements as mentioned in the question. For me, it was a great difficulty to create descriptions of project structure elements. I missed a place where I could mark which source materials I used (in Idovir you can only add one photo and if it is a screen of the model, you can't attach source photos). There was also a lack of specific elements/parts in the description, e.g. space for a verbal description, a score from the matrix or a number from Getty ATT. But maybe I didn't find it.

No, it should have more categories.

Do you think that creating this type of documentation is important for digital reconstructions? Why?

9 responses

It is very important, but for the course purposes, the introduction should be longer and more thorough.

super important

I think so, it's easier for non architecture students and other people to learn and understand history from 3d objects

This is one solution. A way to detail archival objects that may one day see the light of day again

Yes, defintiely, it paves a road for a great digital storage of human achievements in architecture, the way we do documentation should be even more simple and straightforward, making the documentation needs to be as easy as reading it by a viewer in the future.

It is important to certain extend, key is to not overload with information.

yes - it allows to support crediblity of reconstruction

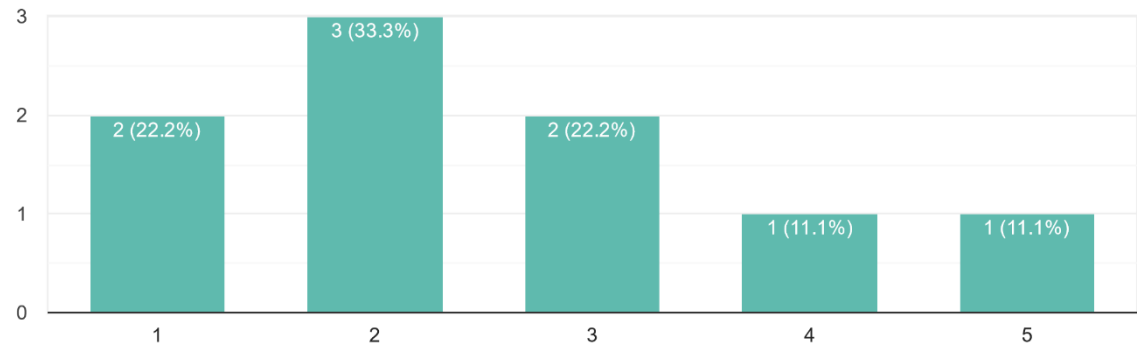
I think it is important, but rather impractical. Rarely will there be a person who actually wants or needs to analyze such documentation.

It is important in certain situations

3D REPOSITORY

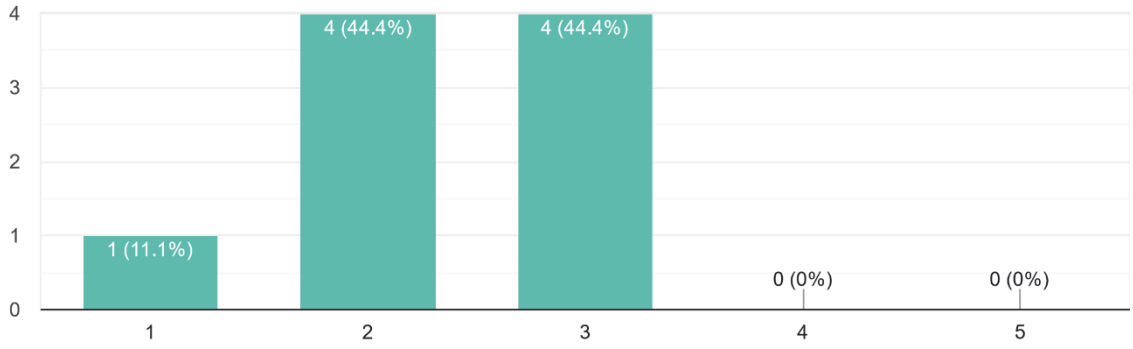
How do you assess the intuitiveness of the 3D Repository?

9 responses



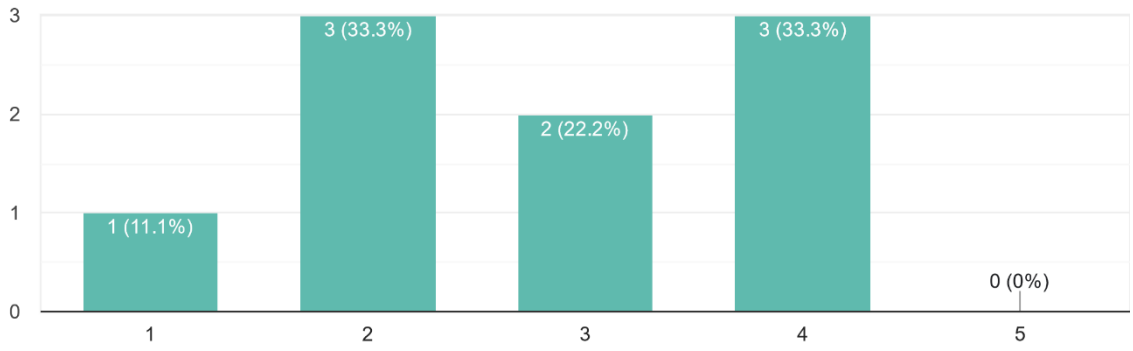
Rate the level of difficulty of filling in the fields in the metadata form.

9 responses



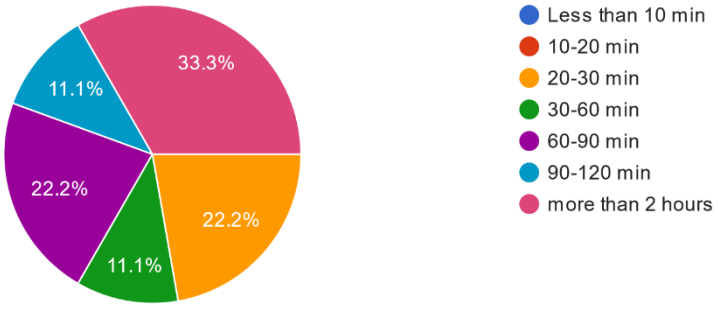
Were the field names and their descriptions clear and understandable?

9 responses



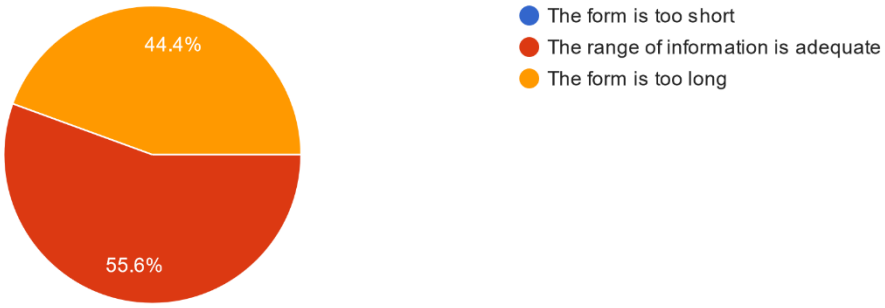
How much time did you need to complete the entire metadata form?

9 responses



Assess the scope of the information in the metadata form

9 responses



Did any elements of the form cause you particular difficulty? Which ones and why?

4 responses

Plenty of time to type repetitive data

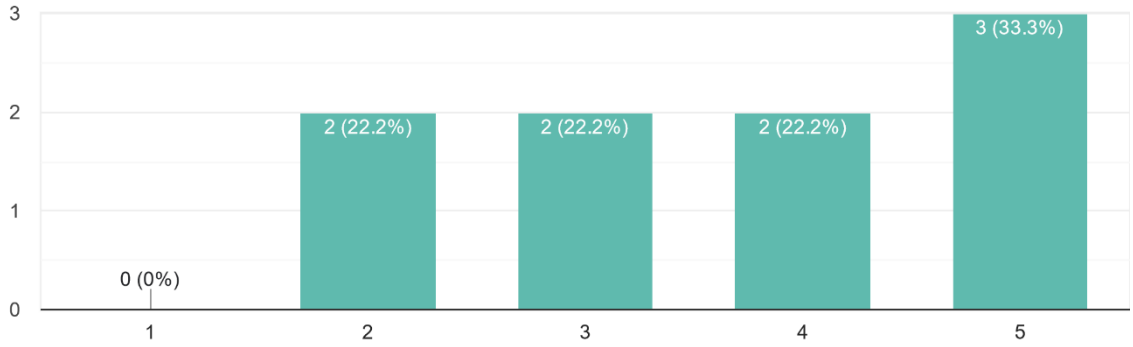
System don't see names that were created before so it's hard to complete whole thing with proper name of subject or even author.

model preview

Many bugs in wisski system

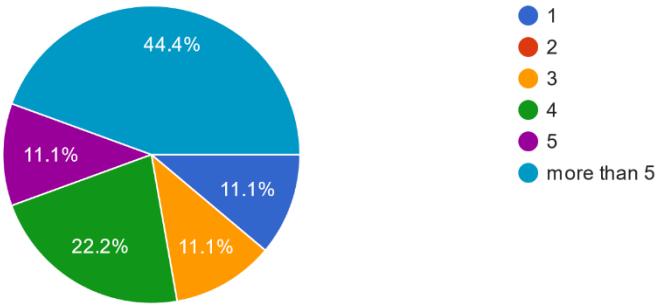
Were the instructions for preparing the file for upload clear to you?

9 responses



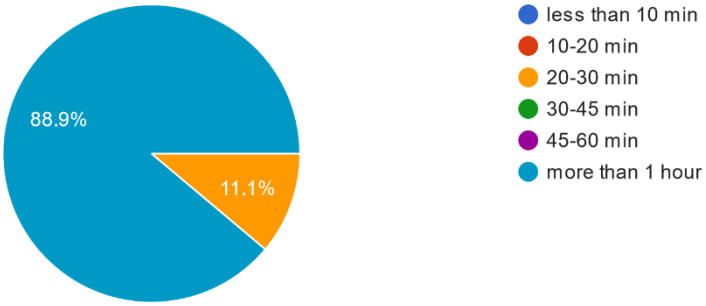
How many approaches did you need to make your model display correctly in the 3D viewer?

9 responses



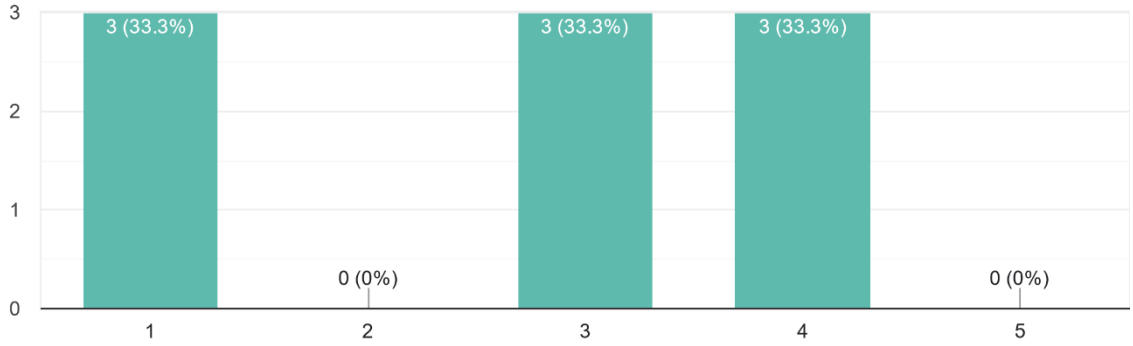
How much time did you have to spend preparing the model under the 3D Repository (Counting from the start of the first file export until the file was correctly loaded in the viewer)?

9 responses



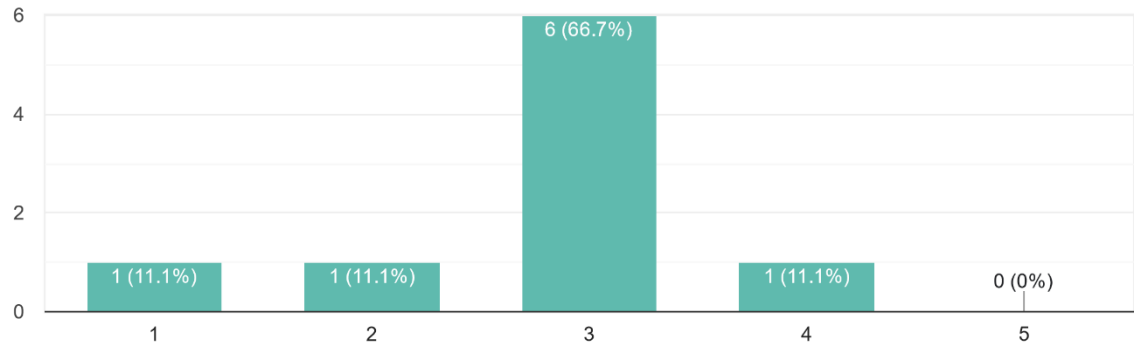
How would you rate the quality of the model visualisation in the viewer?

9 responses



Evaluate the functionality of the repository and viewer (automatic renders, 3D section, scene and model editor in the viewer, number of errors encountered).

9 responses



Do you have any additional thoughts on the 3D Repository?

4 responses

no comments

Please add information that all models must have a triangles as a poly structure, importing models that have polygons based around 4 and more vertexes creates errors and does not display the model properly.

A lot of lacks, it's hard to write them here, but it took several attempts to make right documentation.

I think this site is a great idea. Unfortunately, in the case of my model of the synagogue, the website changed the colors of the textures quite a lot. Despite many attempts, I was unable to fix it.

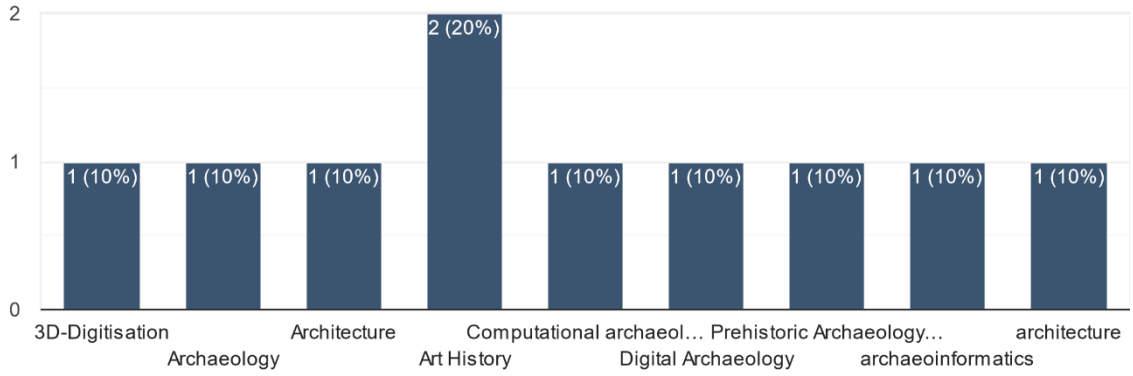
Appendix 11: Cultural Institutions Survey (DFG 3D-Viewer Repository)

First survey with DFG 3D-Viewer project partners: University of Cologne (archaeology), Ludwig Maximilian University of Munich (art history), Brandenburg University of Technology Cottbus-Senftenberg (architecture), and the Deutsches Museum (technology history) – 10 responses.

GENERAL INFORMATION

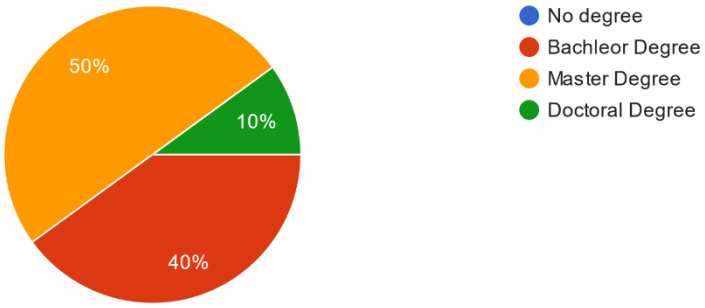
What is your area of study?

10 responses



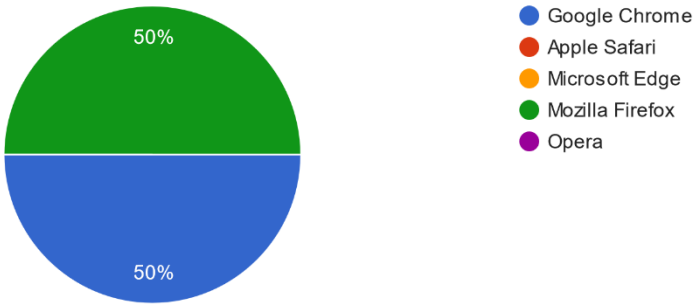
What is the highest degree you have obtained?

10 responses



What kind of web browser do you use?

10 responses



MODEL DISPLAY IN THE VIEWER

What was the result of your first upload to the repository?

10 responses

If you had any problems uploading or displaying the 3D model, please describe them.

9 responses

The file size was too low and the model appears to be black although I uploaded it without textures

Aside from the file size limit being incredibly restrictive, no real problems were encountered.

erlaubte Datenmenge viel zu klein. Außerdem wäre es gut, wenn es einen Upload und einen Save Button gäbe, sodass man auch zu einem späteren Zeitpunkt, zb wenn mehr Informationen gesammelt werden konnten, zum Uploadprozess des Modells zurückkehren kann und das Modell nicht verfrüht veröffentlicht wird

There are several problems.
First of all, there are to few possibilities to select the "object type" from. There are only architectural types and a lot of archaeological modells are from an other categorie.
In the flied "reconstructed period" it is sometimes difficult to give specific information to the day and month. It would be more logical to give only the year here.
Another big Problem ist the fact, that the file upload only allows 2MB. That ist very small and almost impossible to reach in many cases. In the end I couldn't upload a file that is small enough and shows the whole model with its texture.

The limit for upload files were just 2mb. My files were much larger even as a zip-folder and with other downsizing tools.

the 2MB limit was really a problem; besides, error messages appeared even if the file was in a format that has to be accepted and uploaded.

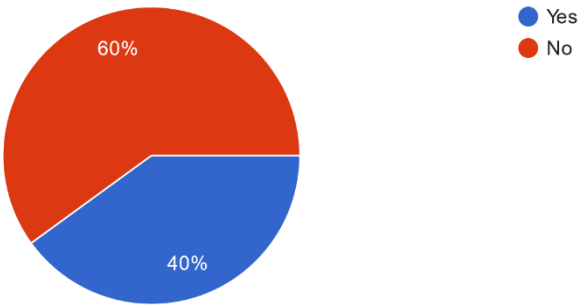
the model did not show in obj, with glTF the textures were not showing properly, after mapping the UV again and deleting the bump map and roughness map , the textures showed correctly.

After the uplade the displayed Metadata next to my model was that of another model.
The quality of the displayed texture on the model was not as it should look like.
After deleting the files I tried the upload process again. Same result. This time the preview renders didn't show up

A majority of the textures isn't showing and the model is oriented incorrectly.

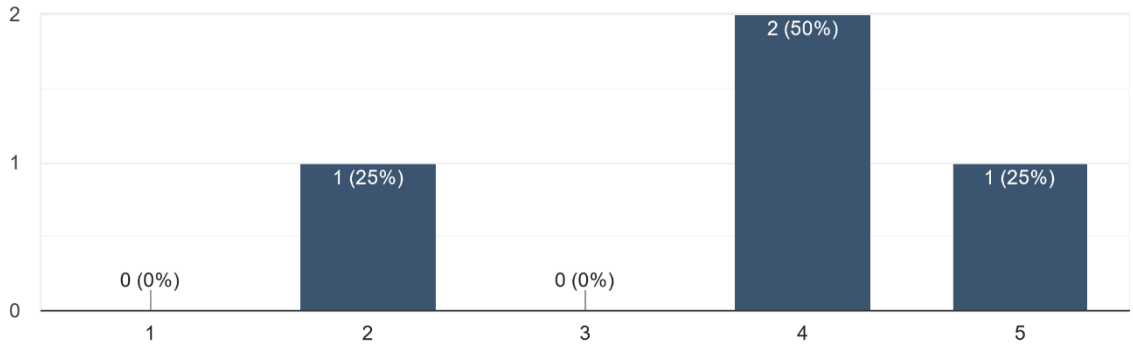
Have the nine automatic renders been created? (They should appear above the 3D viewer window)

10 responses



If automatic rendering has been created, please rate the layout and quality of the automatic rendering on a scale of 1-5.

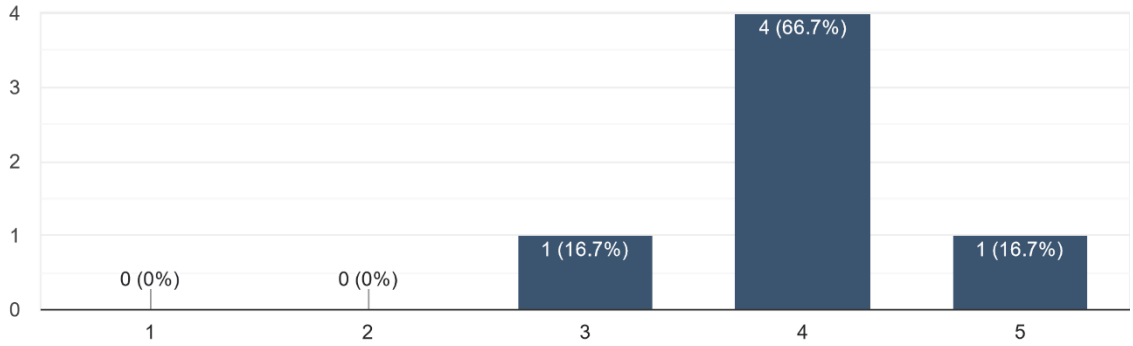
4 responses



METADATA FORM – GENERAL IMPRESSION

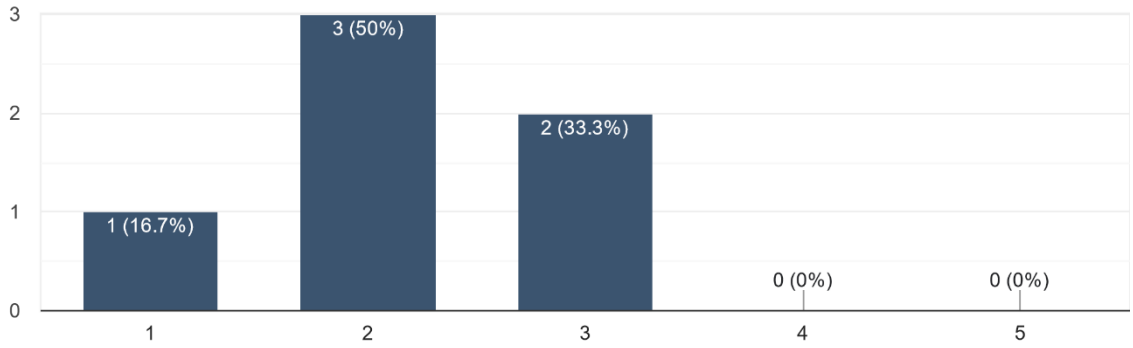
Please rate your impression of the length of the form on a scale of 1-5. A value of 3 indicates a perfectly balanced length of the form.

6 responses



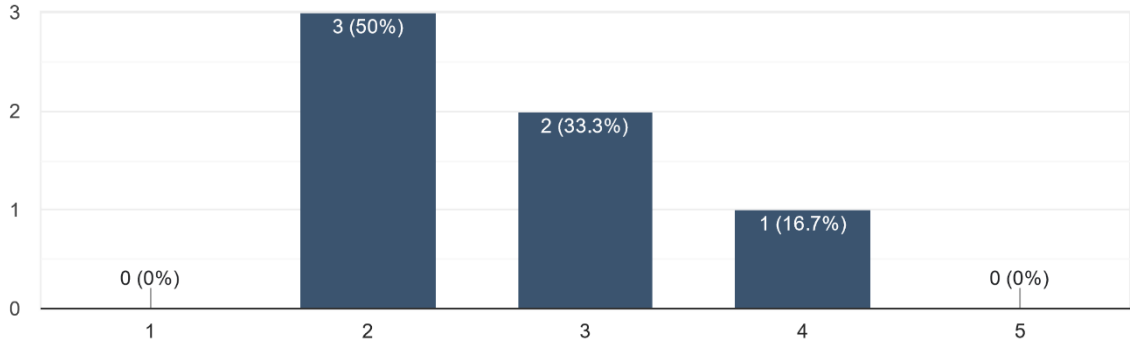
Please rate the level of difficulty in handling the form on a scale of 1-5. Pay attention to its intuitiveness and functionality.

6 responses



Please rate the clarity of the form structure on a scale of 1-5.

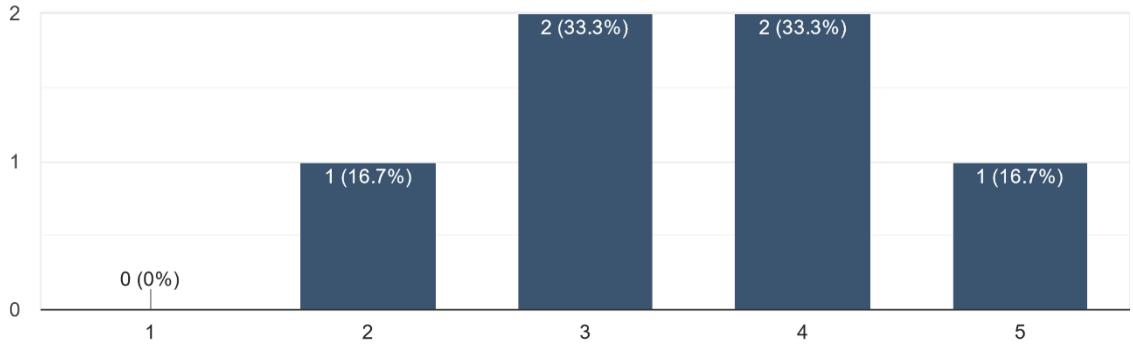
6 responses



FIRST SECTION – 3D MODEL

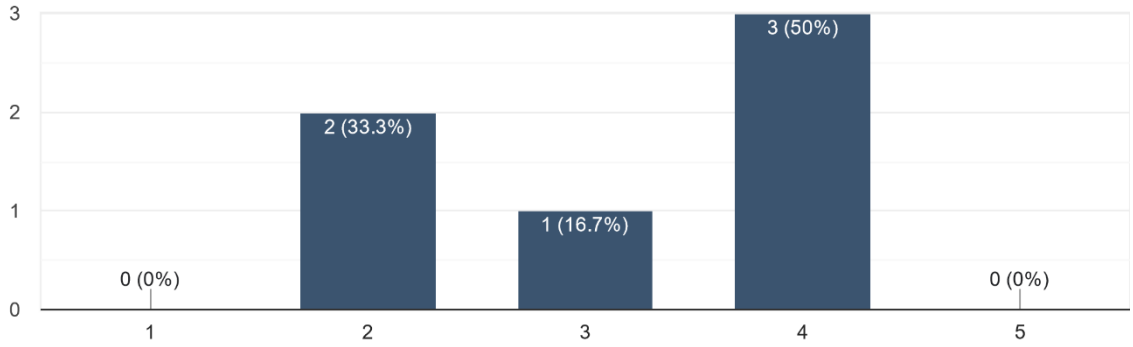
Please rate the comprehensibility of the field names, requirements and descriptions of individual fields on a scale of 1-5.

6 responses



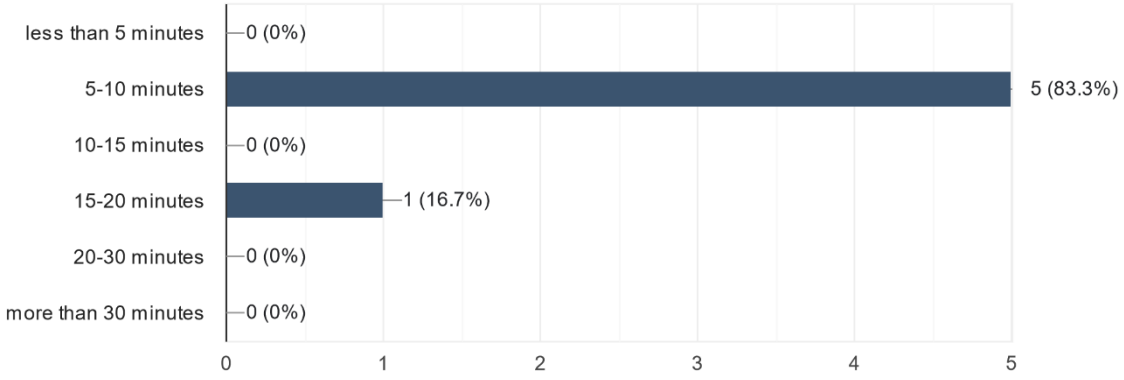
Please rate the difficulty in finding the data necessary to complete the fields on a scale of 1-5.

6 responses



Please estimate the time it took you to complete this section of the form in the repository.

6 responses



Describe what caused you difficulties and problems in completing the section?

3 responses

The field reconstruction period is not really clear. What does it refer to? Dating of the object? Dating of the reconstruction period? What if the object was "reconstructed" via Structure from Motion?

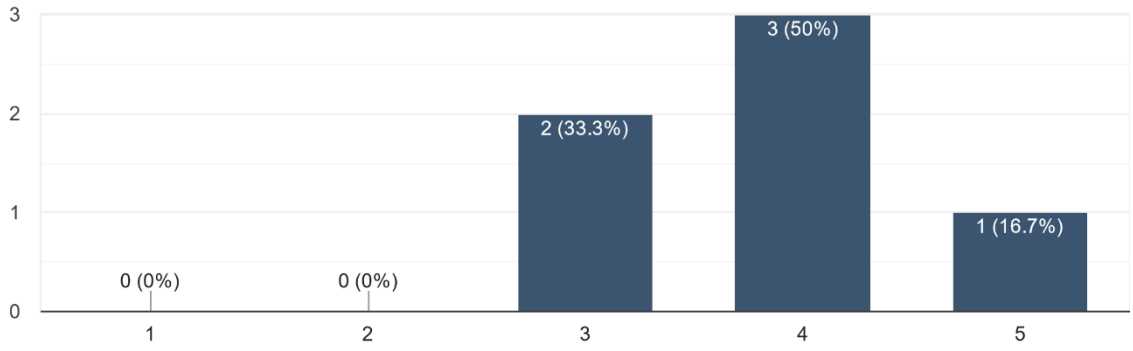
After entering my name as an entity, I wasn't able to reuse that entity in other entries but had to create a new entitie with my name. After the entries were created, they didn't show up as a confirmation that they were recieved correctly. It just said "Wisski-entity" and you had to click on edit to see what was in there.

I had some slight confusion with a colegue of mine about the reconstruction period. There was debate about whether or not the reconstruction period was referring to the model itself or the real life object.

SECOND SECTION – COPYRIGHTS

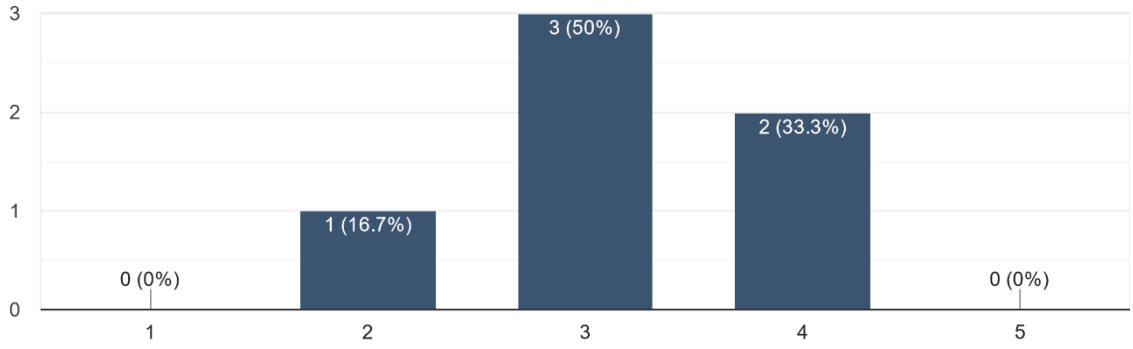
Please rate the comprehensibility of the field names, requirements and descriptions of individual fields on a scale of 1-5.

6 responses



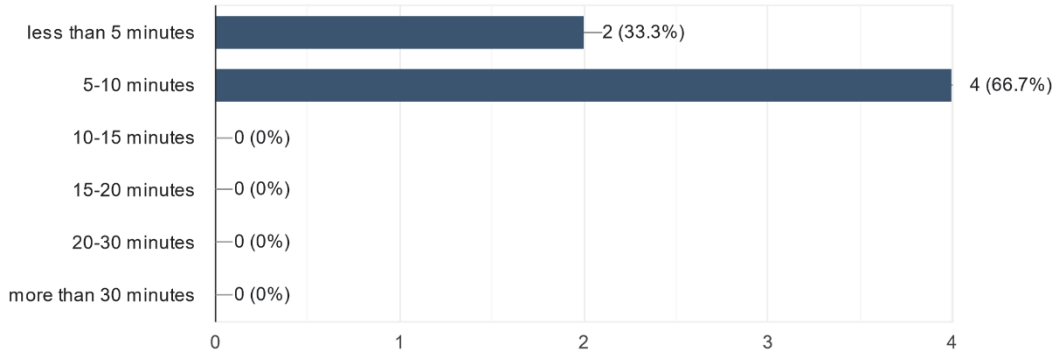
Please rate the difficulty in finding the data necessary to complete the fields on a scale of 1-5.

6 responses



Please estimate the time it took you to complete this section of the form in the repository.

6 responses



Describe what caused you difficulties and problems in completing the section?

5 responses

No difficulties, but it would be helpful if authors can be affiliated with different roles (photographer, sfm, supervisor, etc...).. But I see that is in the participants section.. Still confusing...

Getting the information required me to coordinate with someone else as I am not the person responsible for managing our own model repository.
Upon filling out the information on authors I noticed that when adding more than one author the textbox showing the name of the wisski entry showed up blank on the overview menu. The information is still saved when going to edit an individual entry and is transferred properly upon finishing the form, however.

man kann nicht unbedingt bei jedem Modell ohne Weiteres auf diese Information zugreifen, manchmal muss man sich über mehrere Ecken danach erkundigen

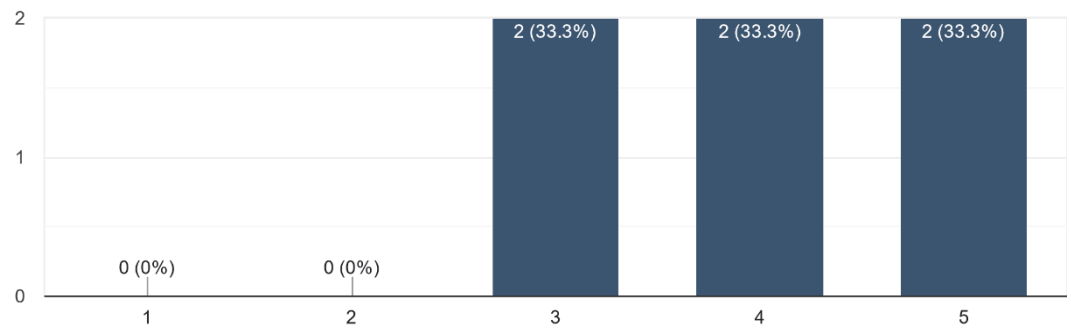
to find out about Viaf and Orcid

I was not familiar with WissKI beforehand so the concept of adding new entities took some getting used to. Especially the “Add existing wisski entity” field was a bit daunting, since I had no reference of what I should be looking for. I eventually stumbled across the wisski entry for the “Brandenburg University of Technology Cottbus-Senftenberg” when I had previously manually filled in “Brandenburgische Technische Universität Cottbus-Senftenberg”, which gave me the clue as to what I was supposed to be doing.

THIRD SECTION – MODEL CREATION

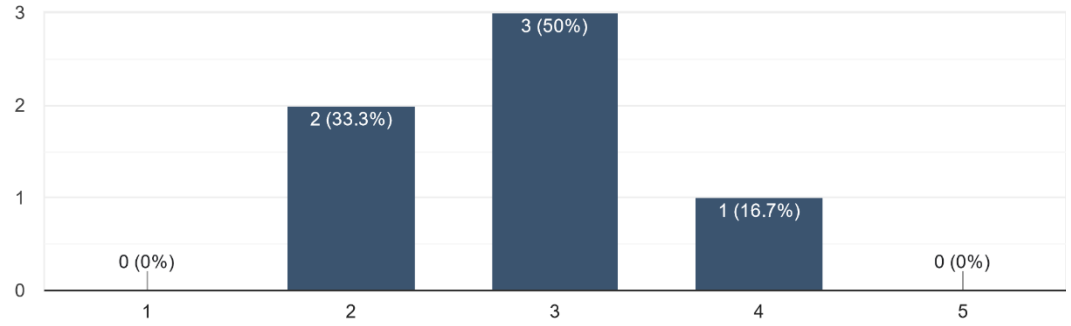
Please rate the comprehensibility of the field names, requirements and descriptions of individual fields on a scale of 1-5.

6 responses



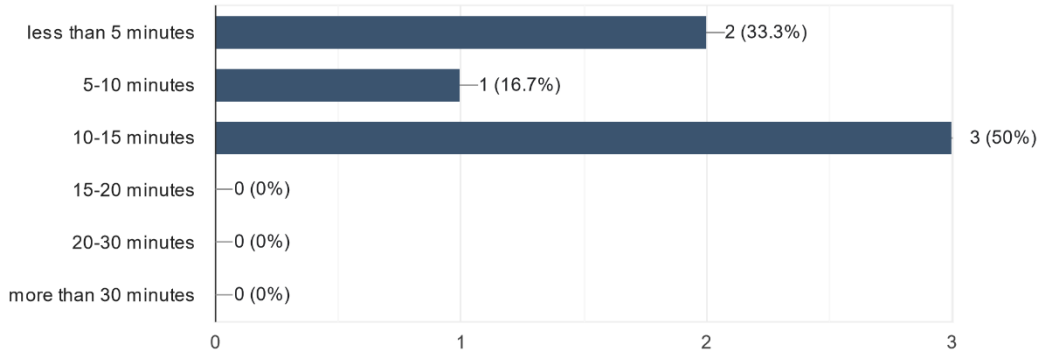
Please rate the difficulty in finding the data necessary to complete the fields on a scale of 1-5.

6 responses



Please estimate the time it took you to complete this section of the form in the repository.

6 responses



Describe what caused you difficulties and problems in completing the section.

5 responses

Here I find the creation timespan... That contradicts the "reconstruction timespan" if we talk about sfm no?

While some of the information, specifically which software was used and who created the model, were easy to find, how long the creation of the model took and who was responsible for what was not documented in our archives. This subsection of the form also slipped my attention after finishing the previous one, as the page scrolled right past it upon collapsing the one above.
Upon editing this section to include the information I discovered a problem with the wisski entry function. While trying to add the participants in the creation of the model I wanted to reference the names added in the previous section, but they didn't show up when clicking on "add existing wisski entry". Neither were they available in the "person" tab when clicking on "add new wisski entry", requiring the entries to be created completely from scratch.

dadurch, dass das Format unübersichtlich ist (sehr viele Untermenüs, die sich immer wieder öffnen), werden leicht einzelne Punkte übersehen. Hilfreich wäre es eventuell, wenn jedes "Unterthema" eine eigene Seite bekommt und am Ende nochmal auf einer ganzen Seite überprüft werden kann, ob alles richtig ausgefüllt wurde

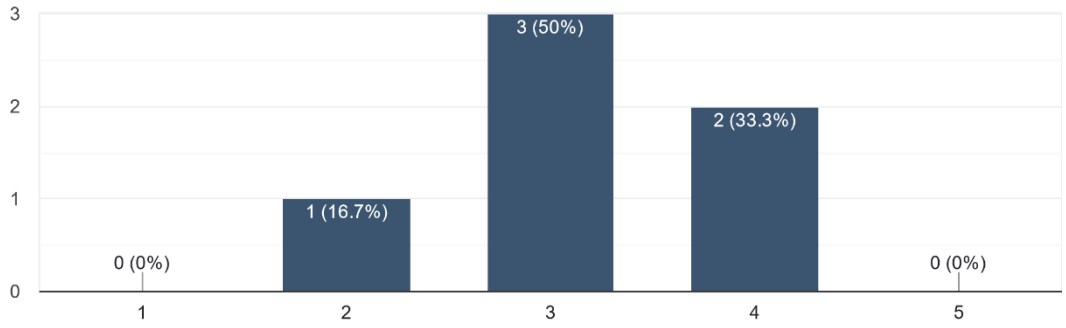
my scan technique wasn't on the list (structured light)

The nesting of different wisski entries gets a bit overbearing at this point and is hard to keep track of. It's hard to intuitively understand that 'Creator(s)' and 'Creator' are different wisski entries with different requirenments.

FOURTH SECTION – OBJECT

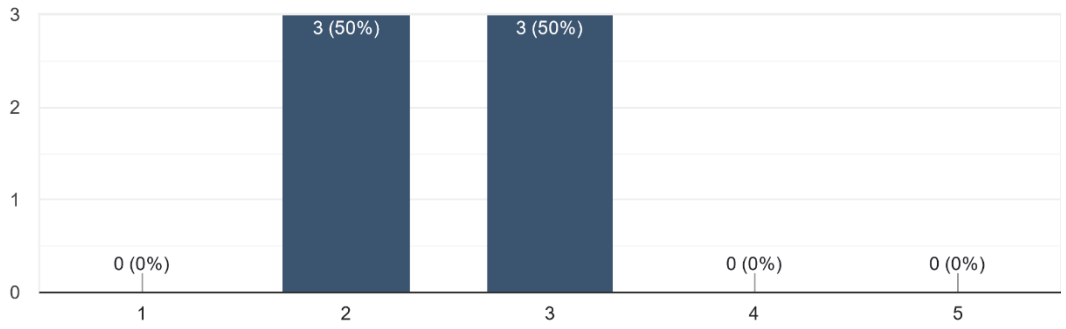
Please rate the comprehensibility of the field names, requirements and descriptions of individual fields on a scale of 1-5.

6 responses



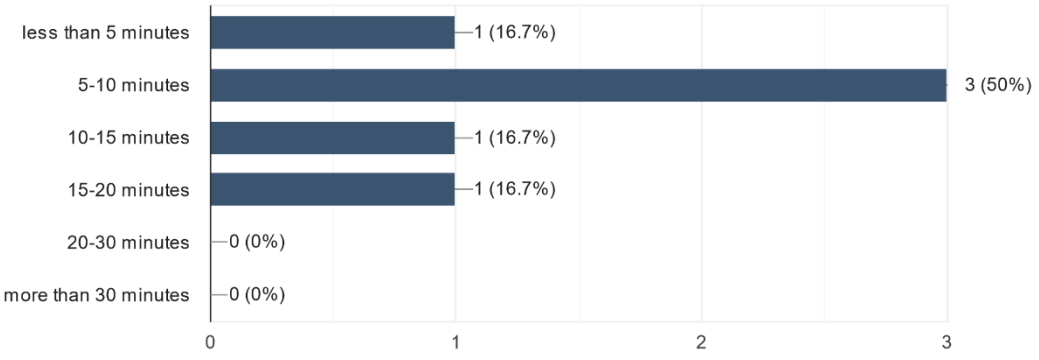
Please rate the difficulty in finding the data necessary to complete the fields on a scale of 1-5.

6 responses



Please estimate the time it took you to complete this section of the form in the repository.

6 responses



Describe what caused you difficulties and problems in completing the section.

4 responses

In the Object/Type section, there seems to be only architectural selections, but my object was not. I therefore selected "Single Built Works" for a terracotta figurine

Some information simply wasn't available, which did cut down on the time required to complete this section. While filling out this section I also initially assumed that the "alternate names" section was intended as a tag system.

This dataset should hold information about when the original objekt was created and by whom

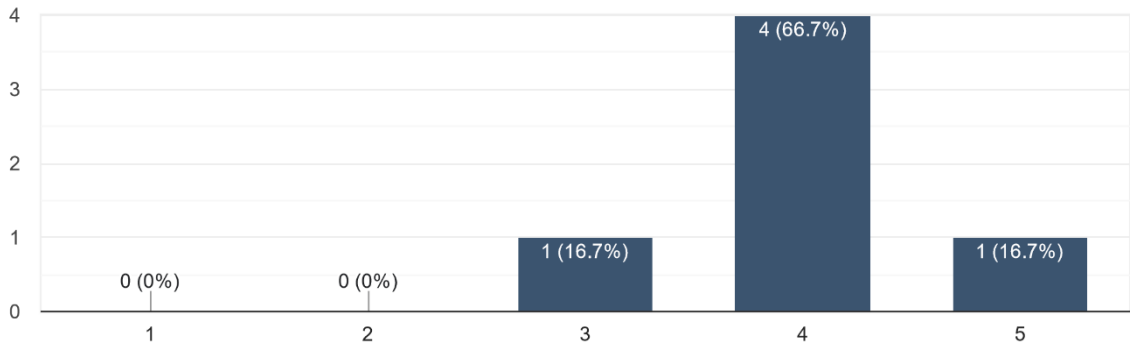
Finding all the relevant data is quite an undertaking, but the links are mostly helpful. I was not able to find a GND, even though there should be one.

When clicking on a hyperlink, it loads a new webpage and I'm forced to go back to the upload form by going back in my browser. This resulted in nearly all of my progress up to this point being lost(!). Please make it so that the linked page opens in a new tab instead.

FIFTH SECTION – OBJECT

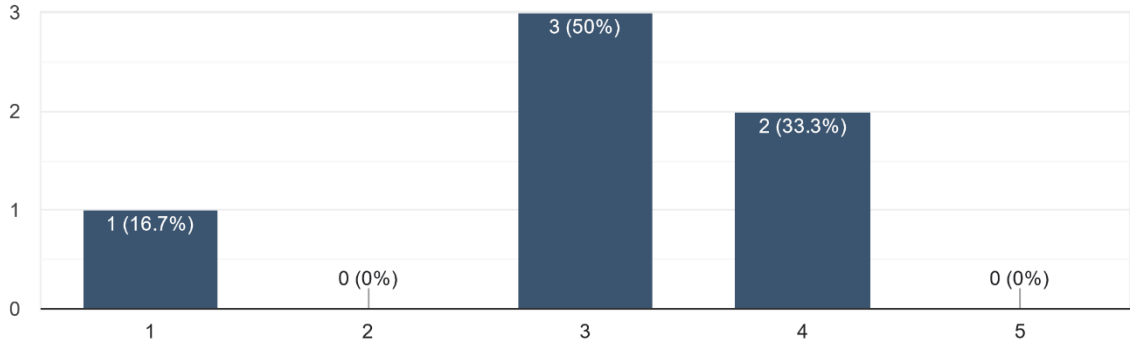
Please rate the comprehensibility of the field names, requirements and descriptions of individual fields on a scale of 1-5.

6 responses



Please rate the difficulty in finding the data necessary to complete the fields on a scale of 1-5.

6 responses



Describe what caused you difficulties and problems in completing the section.

4 responses

This information was sadly not documented with the model, so I had to skip this section. I could have made some guesses due to the context of the specific model used, but did not want to be untruthful.

Information war nicht vorhanden, deshalb konnte dieses Unterthema nicht ausgefüllt werden

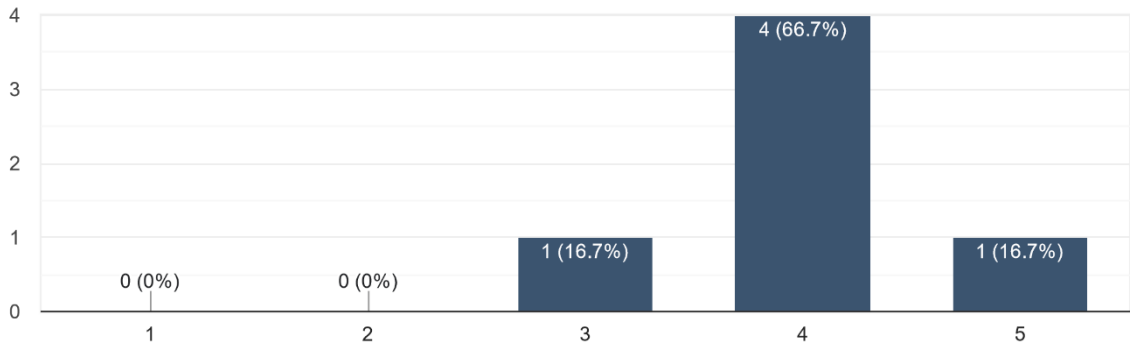
didn't apply

I wasn't sure what the project I was working on is called, as I was only responsible for modeling and uploading different objects. This is probably more of an internal issue.

SIXTH SECTION – UPLOAD

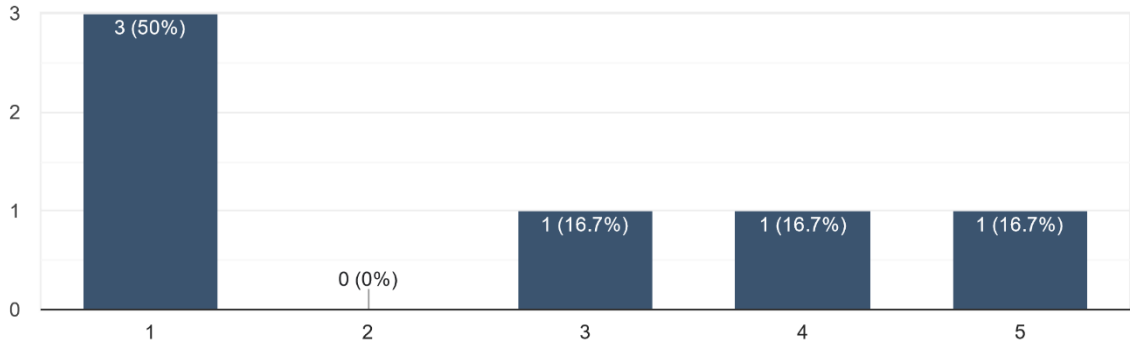
Please rate the comprehensibility of the field names, requirements and descriptions of individual fields on a scale of 1-5.

6 responses



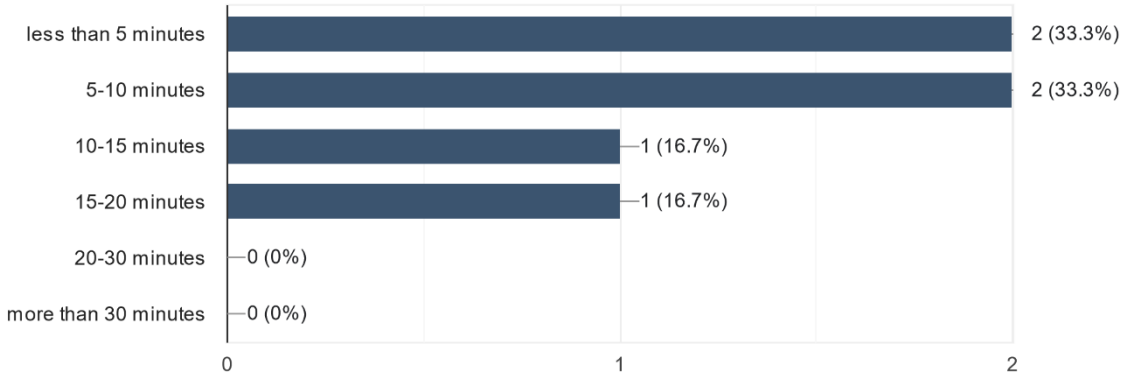
Please rate the difficulty in finding the data necessary to complete the fields on a scale of 1-5.

6 responses



Please estimate the time it took you to complete this section of the form in the repository.

6 responses



Describe what caused you difficulties and problems in completing the section.

4 responses

The file size limit of 2MB is just ridiculous, as I had to upload my model reduced in polygons and without texture to just make it work. This is really a problem. Usual models can easily get over 20MB and more...

The big problem with this section is the file size limit. 2 MB simply isn't enough to upload a model of any sort of complexity, let alone models with textures.
A much higher file size limit is needed in order to properly work with the repository and document models long-term.

erlaubte Datenmenge des Uploads viel zu gering!!! Mind 2GB wären notwendig, nicht 2MB!

Most of the time in completing this was taken up by preparing the viewer file for export. It might be a good idea to emphasize that .glb files are the most straight forward solution when it comes to textured models.

As the model files were on the larger end, the upload took around 10 minutes. To gauge the wait time, an upload progress bar would be a helpful addition.

Appendix 12: CoVHer Survey 1 (DFG 3D-Viewer Repository)

Survey with students specialising in cultural heritage fields (architecture, archaeology, digital humanities) from five European countries: Italy (University of Bologna), Germany (Hochschule Mainz - University of Applied Sciences), Poland (WUT and TUL), Spain (Universitat Autònoma de Barcelona), and Portugal (University of Porto) during 1st CoVHer Workshop about digital 3D heritage in Mainz[157] – 18 responses. The survey focuses on the documentation and publication of 3D models and two specific tools for this purpose: IDOVIR and 3D Repository.

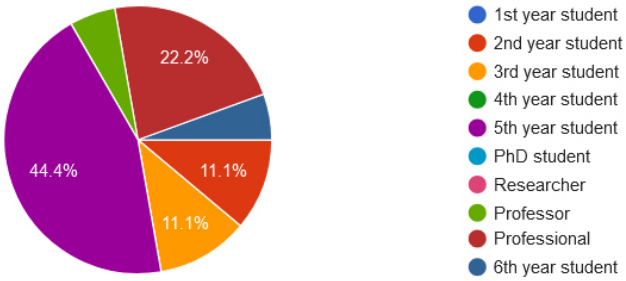
IDOVIR: https://idovir.com/

3D Repository: https://3d-repository.hs-mainz.de/

PERSONAL DATA

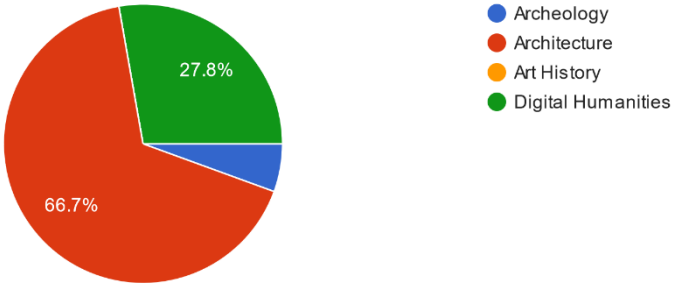
Who are you?

18 responses



What is your area of study?

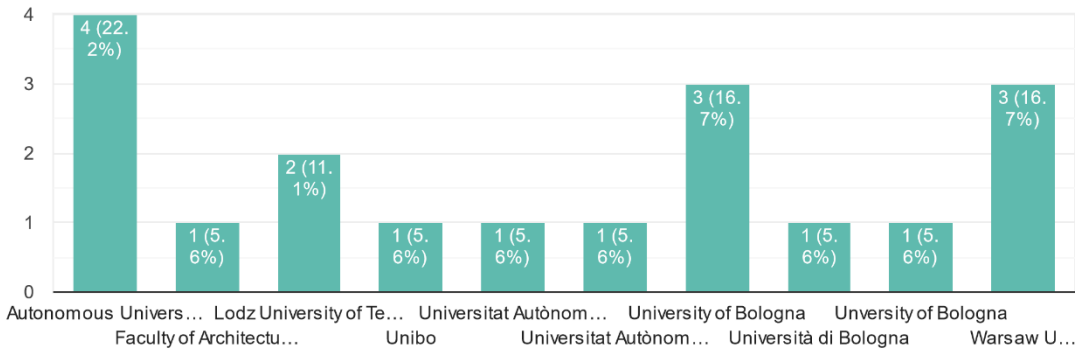
18 responses



[157] See: https://covher.eu/international-workshop-on-digital-3d-heritage-exploring-3d-modelling-in-education-documentation-and-dissemination-learning-teaching-and-training-activities-covher-mainz-meeting-6-13-s/ (accessed 28 October 2024).

What is the name of your organization/university?

18 responses



DOCUMENTATION

Do you think that documentation of digital reconstruction models is necessary?

18 responses

Why do you think the documentation is important/not important?

18 responses

Important

For verification and validation. The documentations of the decisions made warrantees the scientifical transparency of the created model. This allows any user to criticize the any decission made and to further improve the quality of the model, as the reasons behind every decission are stated.

Yes, people can understand reconstruction better

When we develop a reconstruction hypothesis it's important to documentate every step of the process to ensure that we are working with a good methodology and good practices

The Documentation is important for keeping right order of upcoming information in simple and easy way for future interaction.

I think the documentation is crucial if we want the model to be reused in the future by other people, and also for general workflow organization when working in a team

Because I think is necessary to know what is the process to understand the final object. So it's important documenting the process and create repositories to keep this files in order and visible to everyone.

I believe that documentation is important as a resource that provides information about 3D models. If the documentation is properly managed, it allows to reconstruct / recreate the objects and scenarios, taking into account a series of scales, parameters in information on geometric, spatial, location, textures, historical and archaeological sources, metadata and paradata, and even the use they have had in their social context can be inferred. It is of great importance in terms of its dissemination, because it allows other professionals to explore and collaborate with knowledge.

To save the most information about the object. The data might get lost in the fututre

Because it allows us to develop models further and not wasting time on repeating just done part of research and modeling.

it's important both for well understand the result and to allow other people to work on the existing model

because it traks the work done

Documentation is important because it is the basis of the reconstruction process. Cataloging the sources in a clear and understandable way also allows other people to get to know the virtual reconstruction project in a comprehensive way. It also shows how reliable the reconstruction is in relation to the sources.

Documentation is necessary to allow public to understand which are the souces and improve transparency of the work

Because it is important to keep trace of the design process and the decisions chich have been taken and why.

It allows you to organize your work and in the end have an overall better work

It is a crucial part of the reconstruction, providing the crucial steps where to base the reconstruction.

Its always important because the hypotheses that are the reconstructions must always be based on rigorous documentation, otherwise they would fall into mere reconstructive fantasies without scientific foundation.

What are the characteristics of good documentation in your opinion?

18 responses

To allow full replication of the reconstruction process from data to final rendered model

It has to provide access to the sources of the reconstrutions and has to state the reasoning behind every decission that has been made.

It should be detailed, so that others can check it later and understand well

The characteristics of good documentation include a good compilation of sources, their analysis and the achievement of a retroactive study that indicates the changes that have affected the object of study. With all these well-studied elements, a reconstructive theory must be developed and validated. Good documentation involves recording each of these steps and making them reviewable.

Logic and simplicity of documentation.

well structured (categorised and ordered) data, logical and intuitive layout, including links to outside sources/ authors/articles etc

I think it must permit to add all the informations needed to understand the process and the final result of the model creation and the website must be simple and clear to use for everyone.

Good documentation should enable computer visualization methods and results to be understood and evaluated in relation to the contexts and purposes for which they are used (London chapter), be designed to allow rigorous use, be copyrighted, be clear to users, have information on the research sources used. Disseminated with data, metadata and paradata suitable for understanding. They should be disseminated using the most effective means and standards available.

Documenting every step and keeping track of every change/new source

It is legible, detailed, truthful and structured.

good documentation has to clarify especially sources and the process of reconstruction

good documentation must have been easy to understand

good documentation must be understandable, clear, and representative of as many details and specific features as possible.

I think good documentation should be easily accessible and understandable. Of course good docuumentation must be as accurate as possible.

A good documentation has to be clear, understandable to everyone, detailed.

Extensive documentation of reliable sources

Transparency, reliability of the documentation

Sources. The sources from which the documentation is obtained, since it is not the same thing for the documentation to have been reviewed over and over again by various personalities as it is for a hypothesis to have been launched in a conversion.

Do you know any online platform for creation documentation of reconstruction process? (excluding IDOVIR)

18 responses

No

no

No.

Platform from CARARE project.

no, i don't

wiki data

Do you know any online platform for creation documentation of reconstruction process? (excluding IDOVIR)

18 responses

No

no

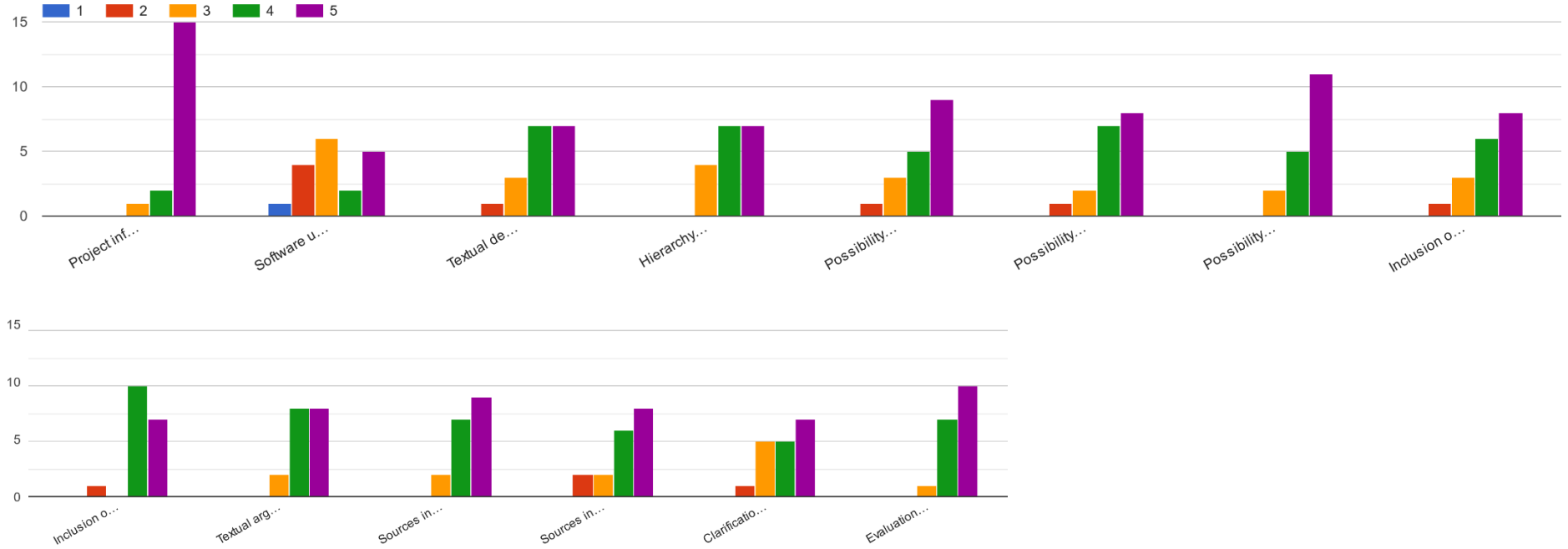
No.

Platform from CARARE project.

no, i don't

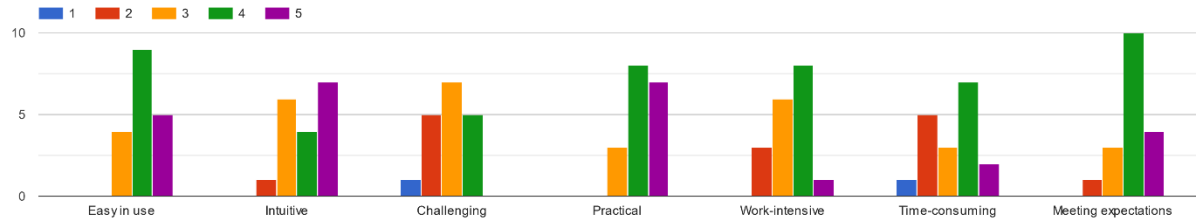
wiki data

Below you see the list of the various components of the documentation based on the IDOVIR system. Determine their importance by taking 1 as unimportant and 5 as very important.



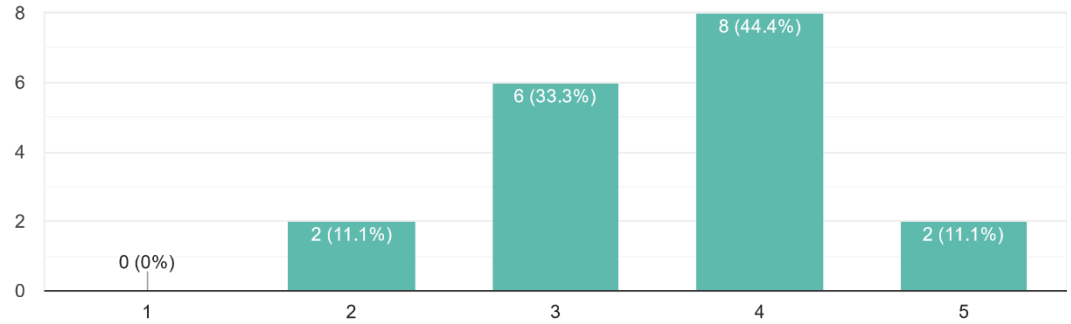
IDOVIR

Below is a list of adjectives. Rate how well the particular terms suit the IDOVIR system by taking 1 - as completely unsuitable and 5 - as very suitable.



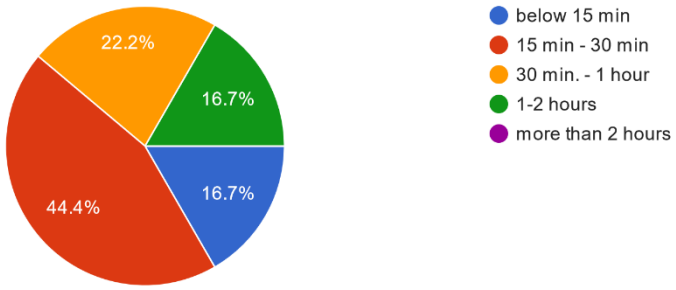
Rate the difficulty of using the tool to create a "Project structure". Take 1 as very difficult and 5 as very easy.

18 responses



Approximately how much time did you need to enter the "Project structure" into the system?

18 responses



Was there anything particularly difficult for you when creating 'Project Structure'?

13 responses

no

No

No.

Working in structure of team model is quite challenging, so preparation process of correct structure for the IDOVIR is complicated.

It was my first time using IDOVIR so I found some difficulties thinking about how to organize the objects of the reconstruction into layers.

Not really

No

Adding the same elements but with different value of certainty

as it was the first time we were using it, I struggled a bit with how to divide the model into different levels, which hierarchy to follow.

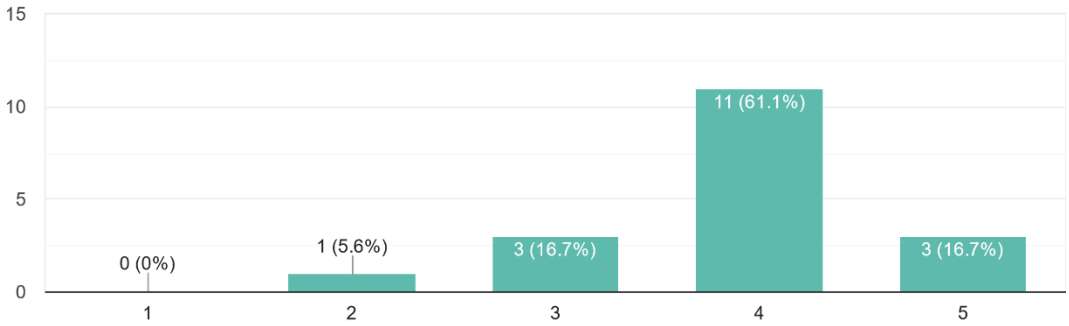
I found some difficulty to use the "variation" label. I think it isn't so intuitive.

Finding out how to hierarchy it. Not much time, but it can get confusing without indication.

No, the organization to do that was very clear and visual.

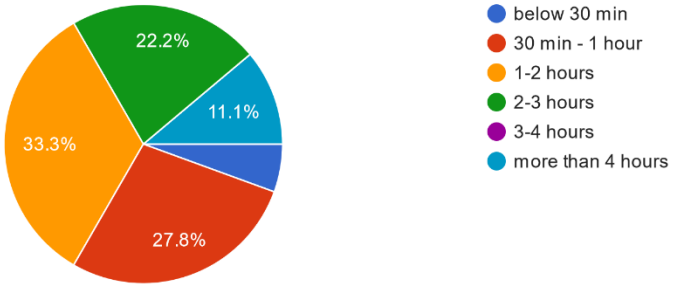
Rate the difficulty of uploading and describing sources with metadata to the system. Take 1 as very difficult and 5 as very easy.

18 responses



Approximately how much time did you need to upload and describe all the sources into the system?

18 responses



Did anything cause you particular difficulty when uploading and describing sources in the system?

14 responses

No

no

No.

It is not possible to put information in group of sources at once.

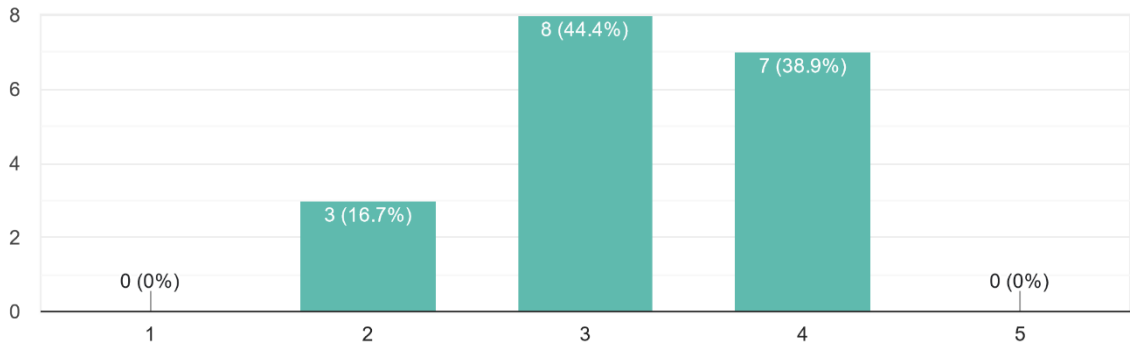
The fact that the sources are numerated only in one way and in a hypotetical case that a source needs to be cancelled, the other sources will not change the number associated.

I got a bit confused with the "publication" part of it, but generally no difficulty

To describing the real source of the documentation if there is not clear enough. Maybe to add new categories to the list.

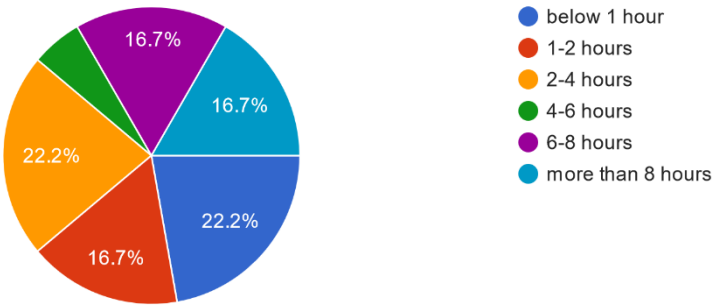
Rate the difficulty of documentation of the reconstruction (reasoning of the decision, upload and description of the reconstruction material, descripti...object). Take 1 as very difficult and 5 as very easy.

18 responses



Approximately how much time did you need for preparation of the whole documentation (excluding uploading and describing sources) into the system?

18 responses



Whether the methods of evaluation of the reconstruction met your expectations (division into section of geometry, surface structure and coloring with the possibility of changing the evaluation criteria). If not, what would you change?

18 responses

I think coloring the final uncertainty model id still far from ideal. We need more levels and better differentated

They did meet myexpectations, I have no change to suggest.

It was ok

they matched my expectations

The platform organization met my expectations.

The met my expectations

I think coloring can be considered as part of surface structure so maybe it's not necessary .

coloring with the possibility of changing the evaluation criteria

I would add the possibility to modify the Level of Uncertainty scale

It should allow to put our own categories and values

the methods met my expectations

yes, I think they are good

surface and color are two characteristics that describe the same part, I think for greater understanding they could be combined using a single term

I think division in geometry, surface and colour isnt't the best way to represent the value of reconstruction. It may be "general geometry", "detailed form", "material"

Yes

not really, it's too limiting, we should be able to add or remove categories of evaluation

They did

Yes, I wouldn't change a thing

Do you think you will continue to use IDOVIR in the future? Why?

17 responses

Tes. It is better t'han Otger platforms

Of course. I look forward to create scientifically accurate reconstructions of historial builindings and environments. The platform fulfills all of my requirements.

Maybe, it is still a small platform and most of the works are in german, which can be challenging for a non german speaker

I will continue because it's a very unique oportunity to have all the digital reconstructions together in the same repository and it's a very nice tool for study and conduct a research

Yes. I think it is good tool for project exchange and review.

If I were to make another reconstruction, I think I might use IDOVIR

If I will work in the field of virtual reconstruction I will continue to use it because I think it's really easy and fast to use and the documentation order is really clear and reusable from everyone.

For sure.

yes, its a fast way to document the sources and decisions made during modelling

If I will work with digital reconstruction - yes

Yes I think I might find application if I'll continue staying in the academic sphere

i think yes because it allow to write short texts to describe complex parts of the model and it is possible to compared other project uploaded

yes, because it is a practical and easy-to-use platform

I think if I will deal with somting related to Historical digital reconstruction yes.

I might think yes, it's a very good site and way to share projects and documentation about them

yes, it's a good tool to organize work

Yes, I think its the platform we must use for the documentation of 3D reconstructions.

Do you have any additional thoughts on the IDOVIR system?

13 responses

No

no

Not at all.

I think it could have more filters, like searching geographically or by historical periods

I think the layout of exported pdf file could be improved - now it leaves quite a lot of blank space, the font sizes are not consistent, and in general it looks a little messy

I think Idovir is a useful and well-structured tool, as a recommendation, I suggest adding the possibility to evaluate the observation made by the algorithmic models used in capturing the geometry of the object through different devices.

It has really great user experience and interface

I think that for the images it will be useful define standards of representation, such as the use of a correct perspective in order to understamd better the space of the building modelled

I think a 3D visualiser of the models would be very effective.

What does publishing a 3D model mean to you?

18 responses

To major transparent to others the lògic underlying t'he reconstruction process

An opportunity to foster my career and to recieve feedback about my work.

It is a nice finishing of a project that you can be proud of. Also, people can see it and understand the geometry better, which is very useful

sharing my work and my hypothesis to the scholar community

It means creating documentation of my model in website, exporting data from software into more easy going format.

Allowing other people to use and learn from my work

It important for the dissemination of the knowledge about 3d modeling into people and also to share informations between experts.

Publishing a 3D model implies sharing scientific information with the community through different media, standards and channels, so before being published, the model must have been processed using a scientific methodology, historical, archaeological and architectural sources. It implies using formats and standards that are accessible to all audiences and that there is recognition of the work of professionals and respect for regulations related to intellectual property.

It means sharing my work with a documentation of all sources and all decisions made during the modelling a

It is giving a public access to the model minimum, maybe with additional data

sharing my model means making it accessible for everyone and possible for users to receive information about it

I think that people will understand better the space of a building in three dimensions

publishing a 3d model means sharing the work done so that it is accessible and useful to anyone who may need it

It means publishing a model which can be used by other people

Show it to public, also to people who are not insiders of 3d reconstruction, in order to explain the project.

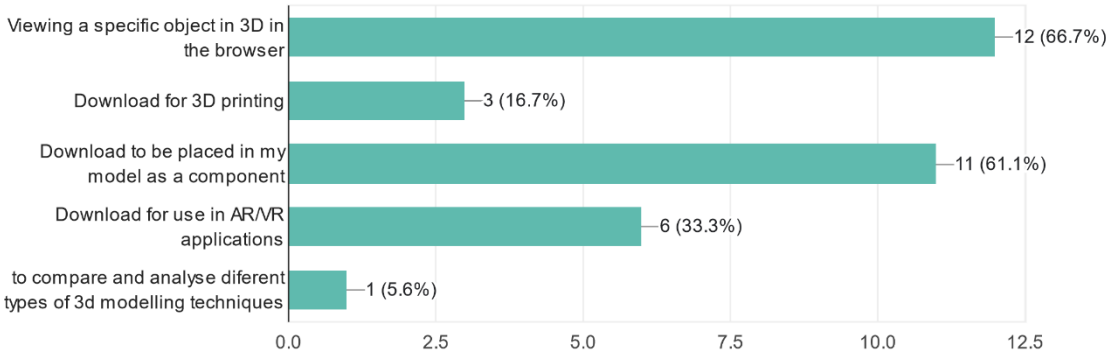
Sharing work with the scientific community

It means to open it to external viewers. To show your work to any interested subject

Expanding the knowledge gathered

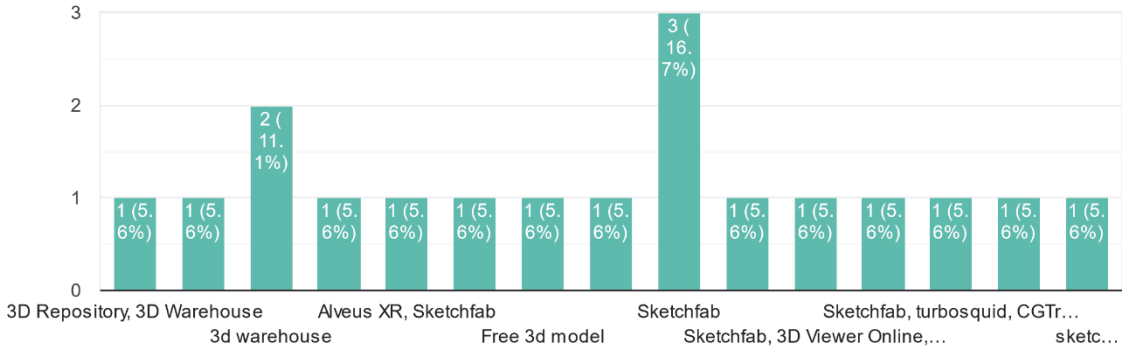
Have you ever search for 3D models online? For what purpose?

18 responses



Do you know of any platforms for publishing models online? Please list them below

18 responses



Have you ever publish model in online repository? Which one and for what purpose?

18 responses

- no
- No
- I've publish a few digitalised archaeological remians for dissemination and educational purposes.
- Architectural model for 3d walk around
- Sketchfab, I published just to try the platform
- For teamwork purposes of fast and effective working process.
- I haven't
- yes, into 3d repository for the workshop
- Yes, in Sketchfab.

Yes, it was a part of task of first course studies.

no, I don't

I only published my model in 3D repository for CovHer workshop

No until this Workshop

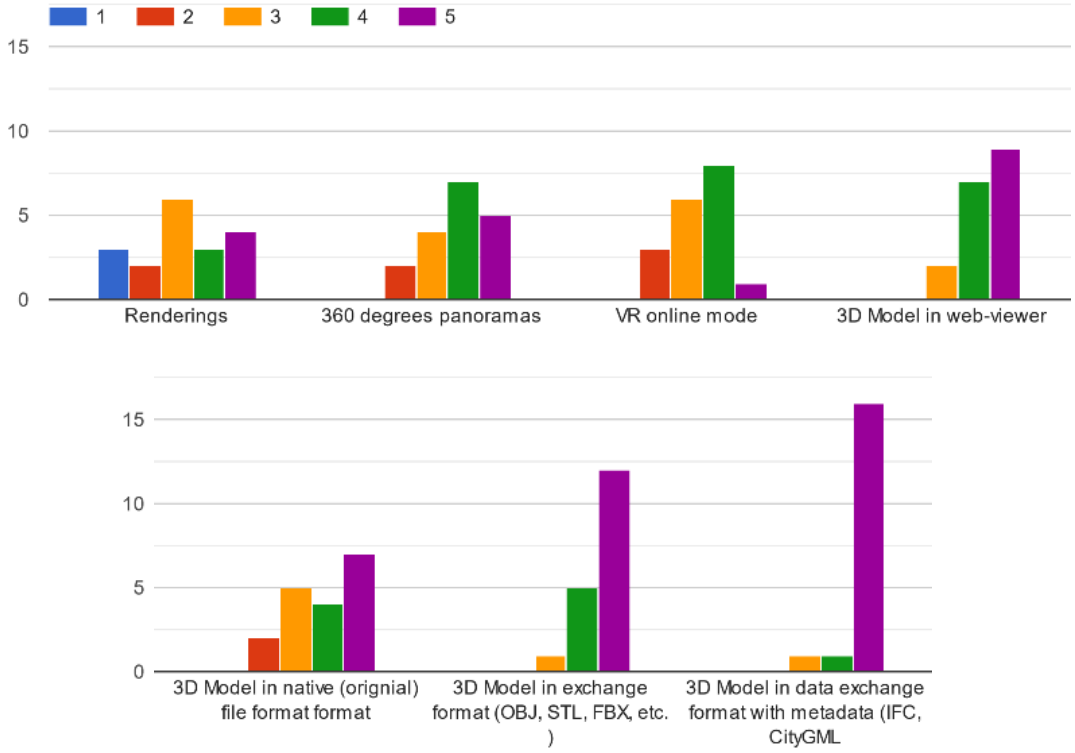
Yes, in sketchfab. For trying to upload my model and modify it to get it ready.

Yes, in Sketchfab. For academic exercises

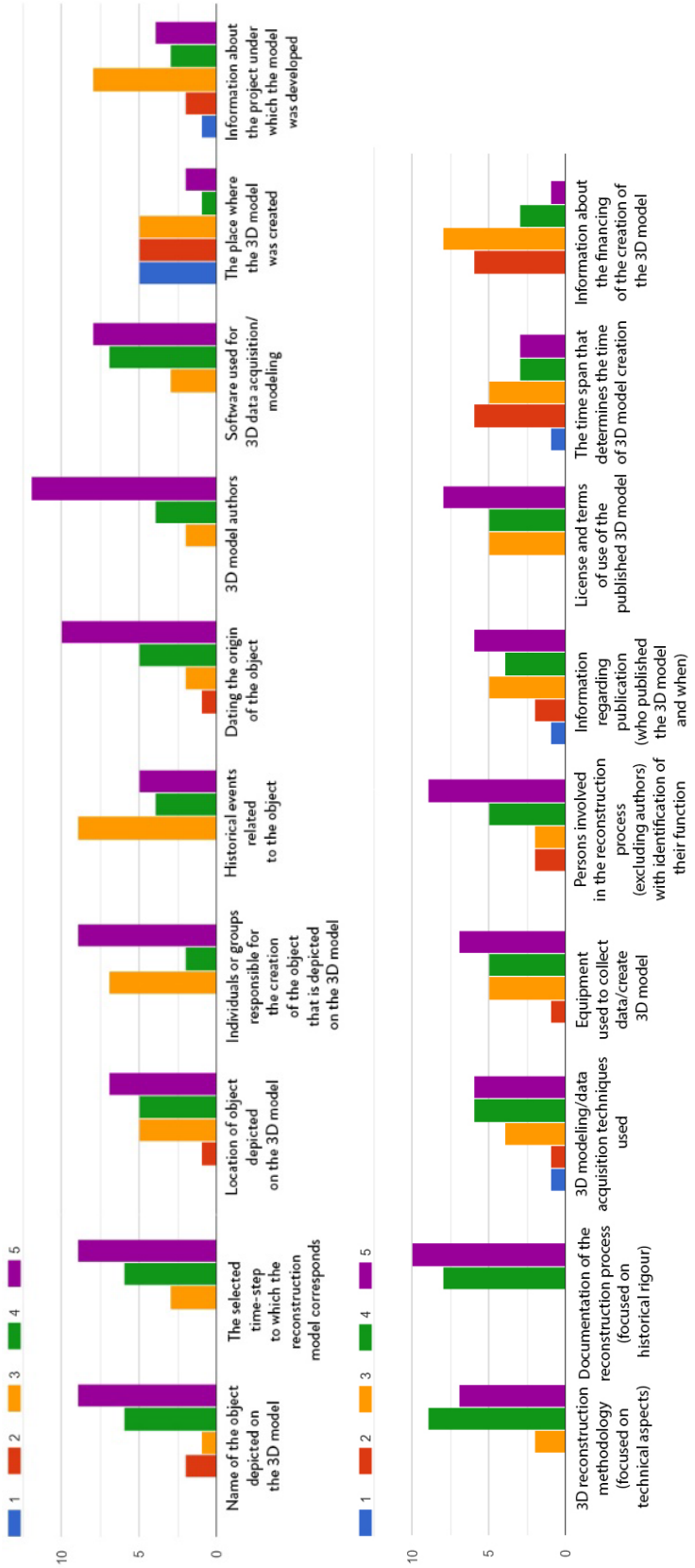
If you have never published a model online, what stopped you from doing so?

10 responses

Below there are listed various ways to publish the 3D model online. Evaluate to what extent, in your opinion, publication in specific form is needed. Take 1 - as completely unnecessary and 5 - as very necessary.



Below there are listed various ways to publish the 3D model online. Evaluate to what extent, in your opinion, publication in specific form is needed. Take 1 - as completely unnecessary and 5 - as very necessary.



Do you think the metadata for 3D model should include any information that are not listed above? If so, specify them.

7 responses

No

I cannot think about any suggestion.

I think is fine.

I don't think so.

no

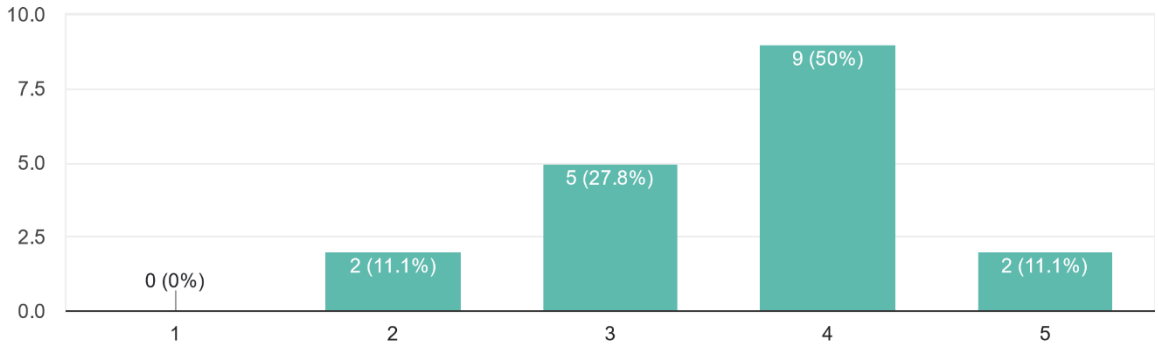
I think author of tre real building data should be included (not only authors of the reconstrution)

For the moment, I think it is a very concrete classification.

3D REPOSITORY

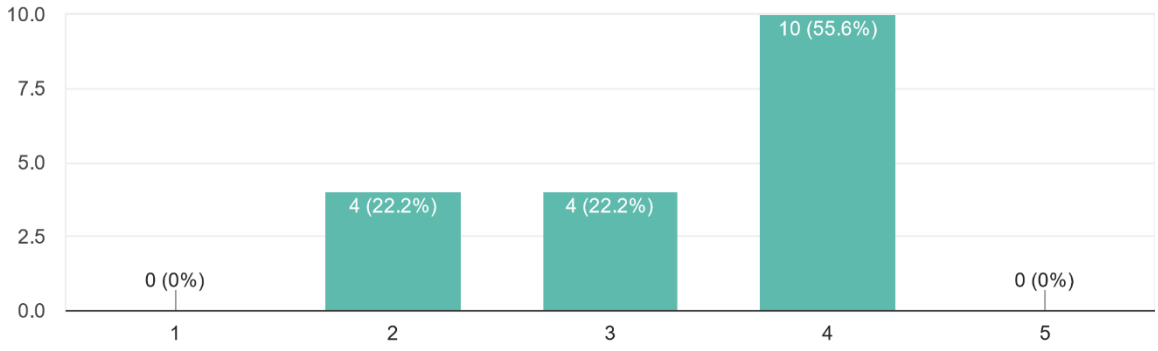
How do you assess the intuitiveness of the 3D Repository?

18 responses



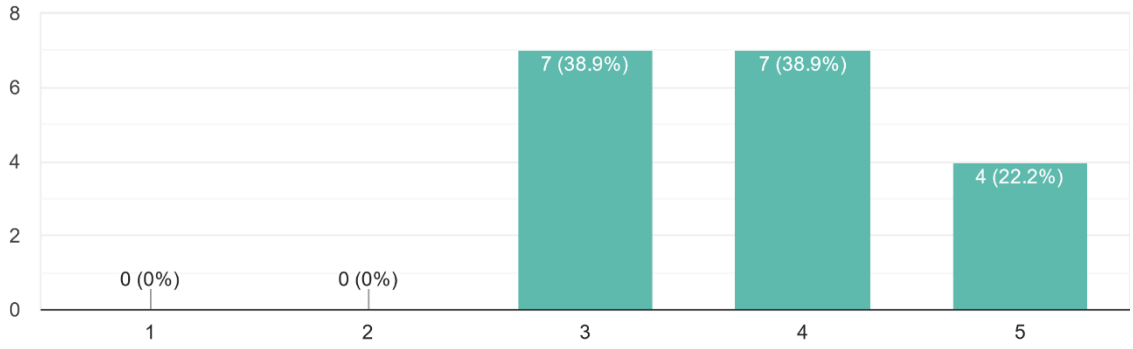
Rate the level of difficulty of filling ields in the metadata form.

18 responses



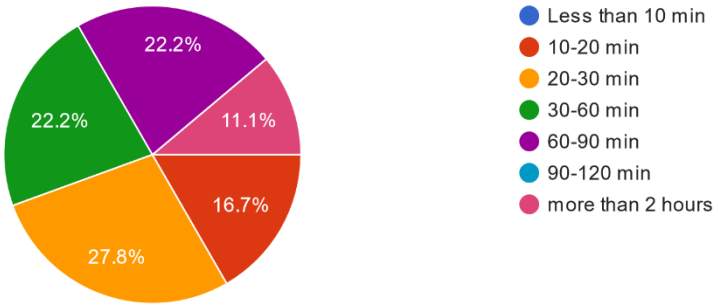
Were the field names and their descriptions clear and understandable?

18 responses



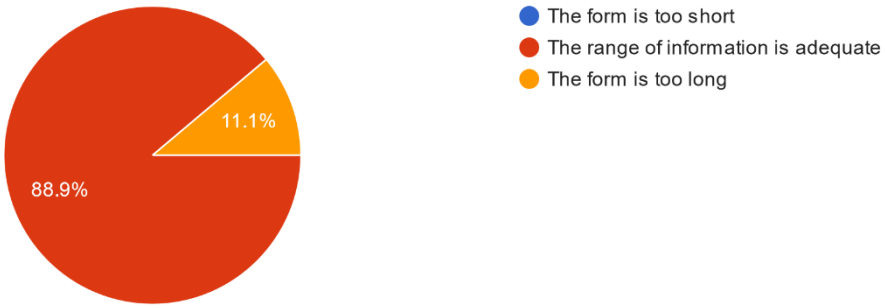
How much time did you need to complete the entire metadata form?

18 responses



Assess the scope of the information in the metadata form

18 responses



Did any sections of the form cause you particular difficulty? Which ones and why?

11 responses

No

No they were okay

To specify what type of drawings are some resources

The ones in which I had to find URL or codes into other websites. In some of them the research of the terms I needed was not immediate, because even if the term written into the research band was already registered into the site, it couldn't find it.

No.

The section about authors was troublesome because when adding another author we cant see the previous one, which tricked me into thinking that the site hasnt saved it. Also, I think all the information added should be visible after confirming it with a button. Its good to see what data is there at the final check. It is a good method to confirm the data with the green check button though. Confirming it and limited possibility to edit it right away, gives a bit of a satisfaction that a specific part is done. Also, I am not fond of the graphical solutions used in the forms. Its not very intuitive. It took me awhile to get to know the system and realise how it works. I appreciated the definitions of some terms that were listed. Made it easy to choose from options with non or least hesitation. It would be nice if the orcid number of the author would fill itself automatically after typing the name of the author. Or the other way around- the name by orcid number. Would make it much easier than to copy data all the time. There should be a list of uploaded models on my profile, couldnt find it, had to browse it like someone elses. I dont understand why is there a name of an author in the title. It is not the most impostant to learn at the first, scrolling through variety of models. If we write there was one author or more than one, it just should be listed with other information and credits.

no

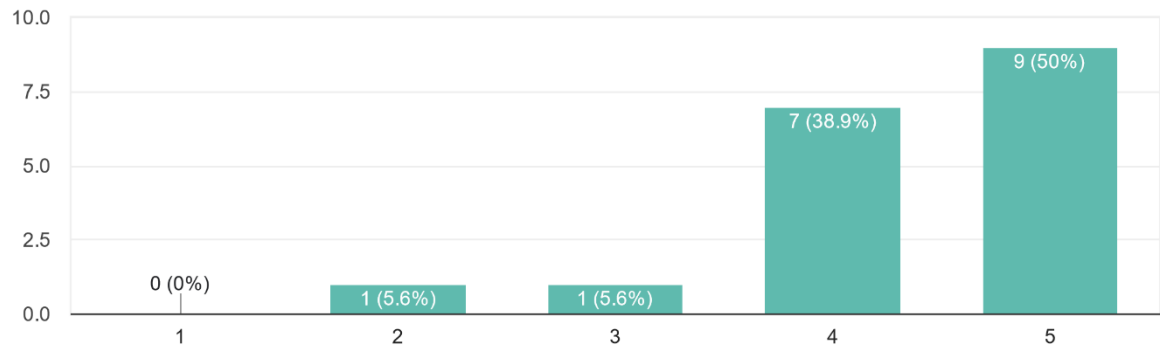
Copyright (as a school project it is not usually clearly defined, or at least in our case it wasn't). Also I the automatic views didn't generate themselves after model upload and creation of the automatic render

the publication of the project because my project wasn't published yet and I don't understand what I had to do

It is generally not user friendly interface

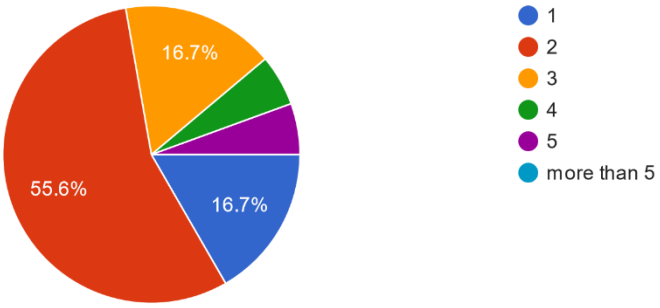
Were the instructions for preparing the file for upload clear to you?

18 responses



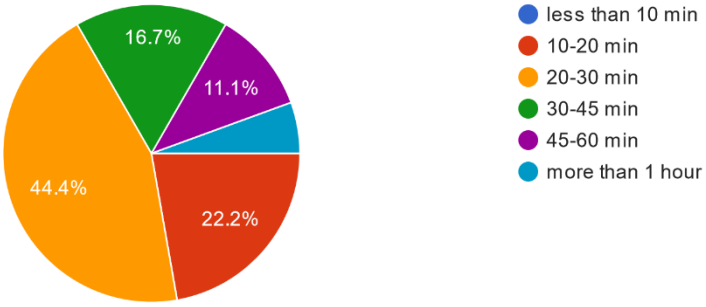
How many approaches did you need to make your model display correctly in the 3D viewer?

18 responses



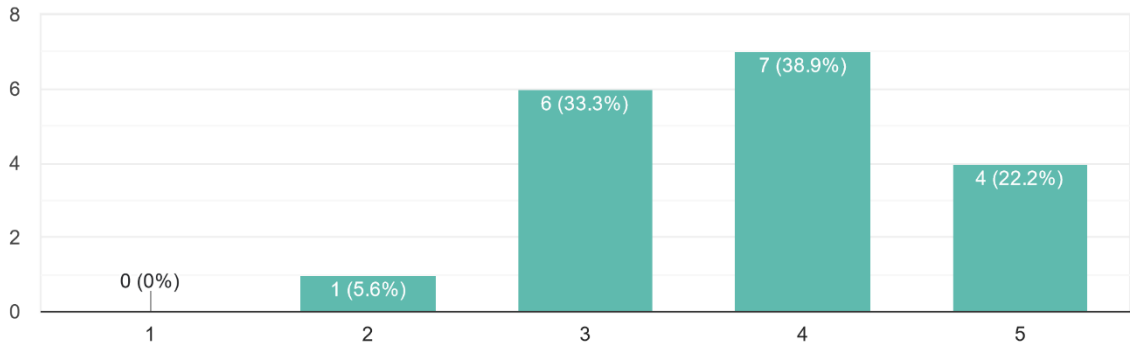
How much time did you have to spend preparing the model under the 3D Repository (Counting from the start of the first file export until the file was correctly loaded in the viewer)?

18 responses



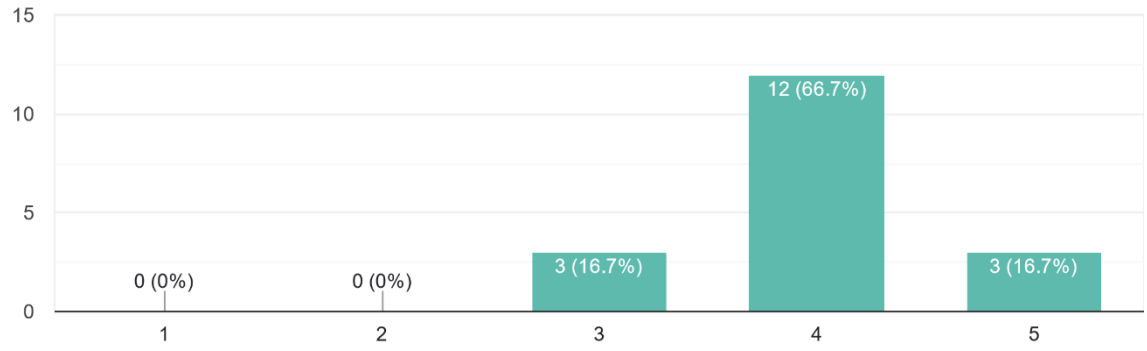
How would you rate the quality of the model visualization in the viewer?

18 responses



Evaluate the functionality of the repository and viewer (automatic renders, 3D section, scene and model editor in the viewer, number of errors encountered).

18 responses



Do you think you will continue to use 3D Repository in the future? Why?

18 responses

I think it is one of good and easy platforms to work with model and quite comfortable to navigate.

Yes, for educational and disseminational reasons I will continue to use the model.

Yes, because it is a great, well-documented platform for the unification of projects and 3D models.

Possibily yes

Yes, it's useful to upload models in a repository like 3d repository but I think it could be more intuitive and fast to use

Because it's a great tool to share and compare, in the case of the archaeologist, diferent information about diferent digital reconstruction

Yes, because is a useful tool, and open access, and have a good functionalities.

Maybe, I don't know yet

Yes, it is a trustful source of information

Yes because, it s a simple platform to use

Yes, I like that you can see really exhaustive model data before having to download it. Also the idea of sharing such complex models is in my opinion very important in order to save time and learn from each other - otherwise models could be only used once which is a massive waste of work!

Yes. It is a good way to share and visualize the model you recreated, which is a crucial complement to the reconstruction information.

yes because it's a really good way to share models with everyone

Yes, I think it is a good platform to share model

I think yes because i can compared my model with others

Yes

Not until it's user friendly and has better UX

yes, to share the models with other people

Do you have any additional thoughts on the 3D Repository?

10 responses

No

Not at all

Maybe to improve the visualisation of the 3D model textures, they appear a bit saturated.

The possibility to add some rights for the publication of the model with the native file

No, everything is fine, congratulations.

I hope pla and pln extensions will work better. Also, I am not sure if it is the issue of my internet connection or a computer, but the site gets stuck, is cracking sometimes. Especially when the model on the viewer is loading, but also after that. It is hard to scroll the site and copy text from it. Not sure if the model is that heavy

no

The miniature generation was the only part that wasn't intuitive to me. And failing to generate the miniature meant that the model couldn't be displayed in the 3D repository library

It has great potential in improving the interface and UX. Wisski not working properly.

Appendix 13: CoVHer Survey 2 (CoVHer Repository)

Survey with students specialising in cultural heritage fields (architecture, archaeology, digital humanities) from five European countries: Italy (University of Bologna), Germany (Hochschule Mainz - University of Applied Sciences), Poland (WUT), Spain (Universitat Autònoma de Barcelona), and Portugal (University of Porto) during 2nd CoVHer Workshop about digital 3D heritage in Porto[158] – 16 responses. The survey focuses on documenting and publishing 3D models and two specific tools for this purpose: IDOVIR and 3D Repository. The survey is divided into five sections which deal with:

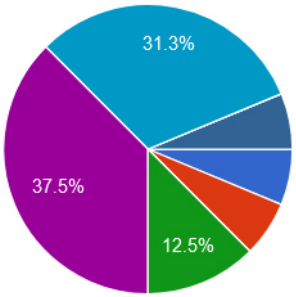
1) general questions related to individual documentation methods,
2) practical experiences with IDOVIR,
3) general questions related to experience with the publication of 3D models,
4) experience with our 3D repository as a data publisher,
5) experience with our 3D repository as a data explorer.

IDOVIR: https://idovir.com/
3D Repository: https://repository.covher.eu/

PERSONAL DATA

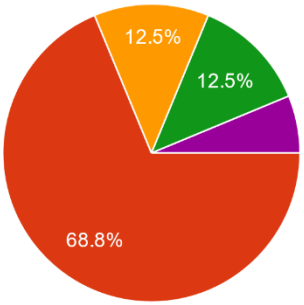
Who are you?

16 responses



What is your area of study?

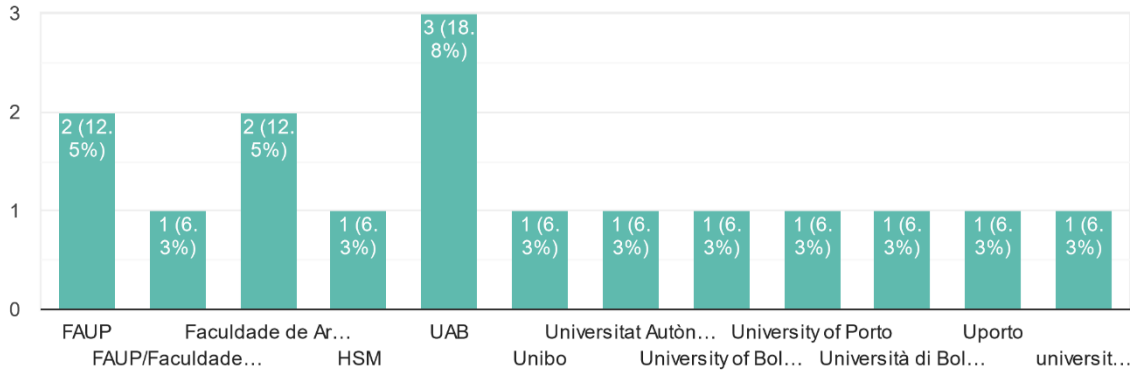
16 responses



[158] The workshop took place at the Faculty of Architecture of the University of Porto (FAUP) from 4-11 September 2024.

What is the name of your organization/university?

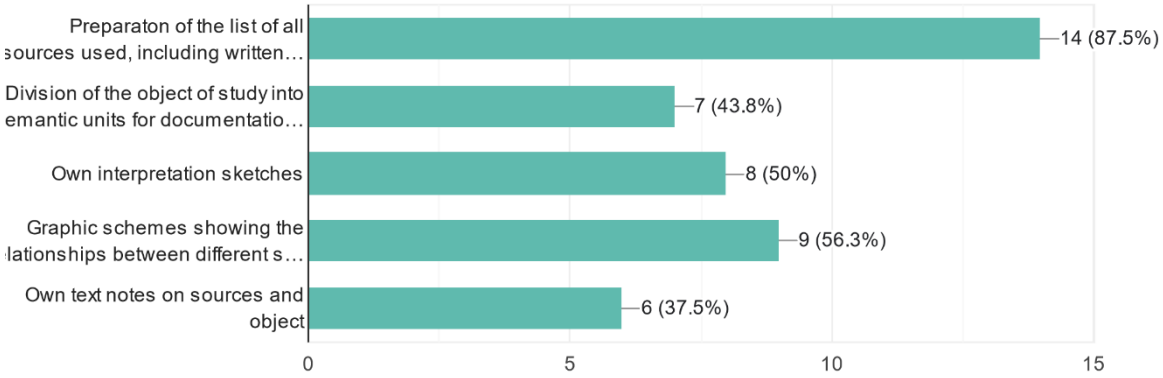
16 responses



DOCUMENTATION

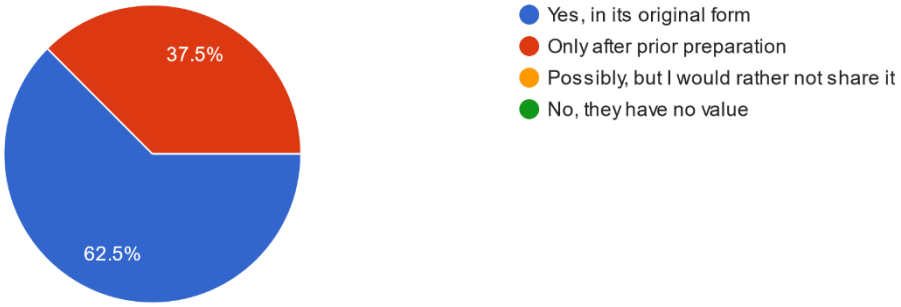
Did you use the following forms of documentation and interpretation prior to your work at the workshop? Select all the methods you used

16 responses



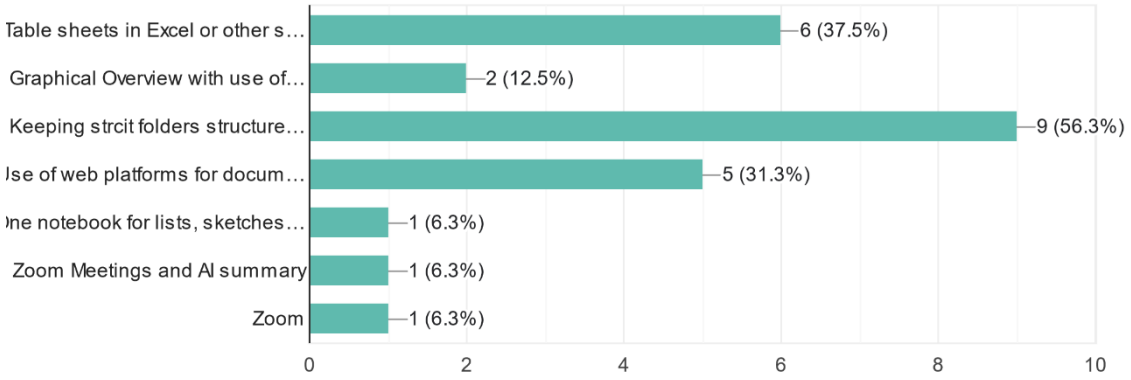
Do you think these materials that helped you understand of the sources and object of study are worth including in the project documentation?

16 responses



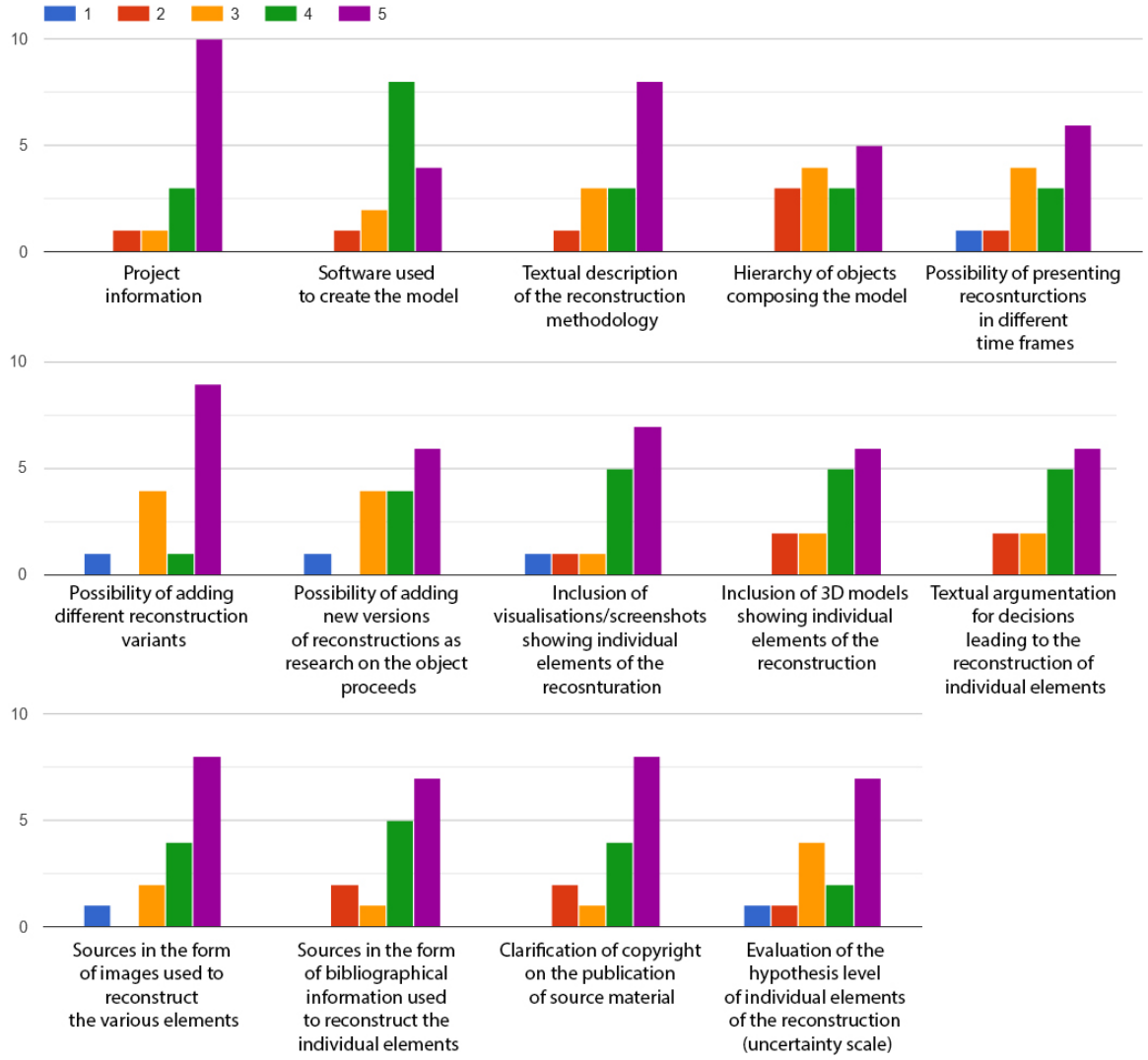
Have you used any of the methods listed to organize your work? Select all the methods you used

16 responses



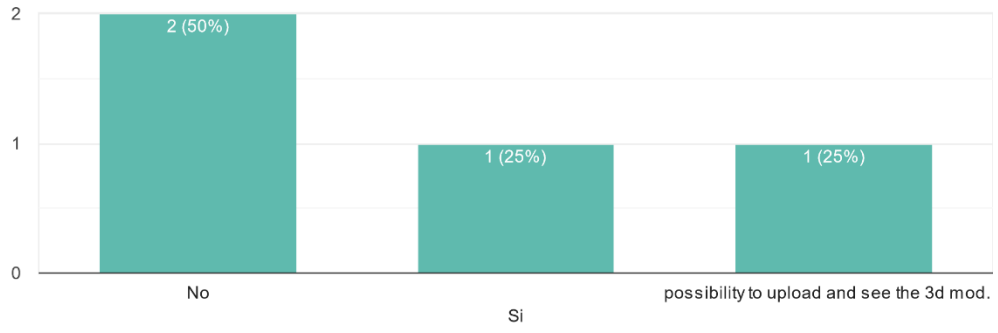
IDOVIR

Below you see the list of the various components of the documentation from IF. Determine their importance by taking 1 as unimportant and 5 as very important.

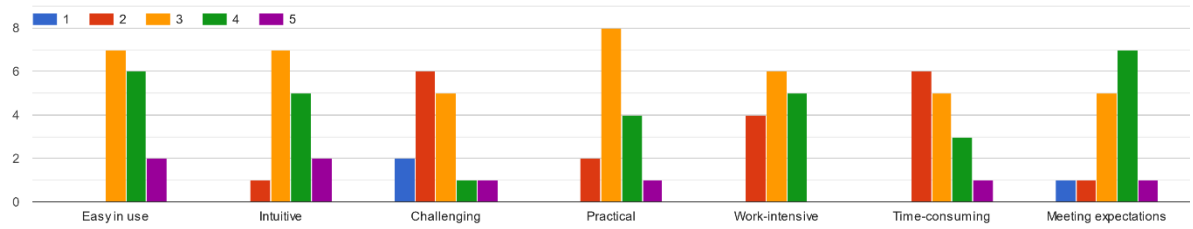


Do you think the documentation should include any components that are not listed above? If so, specify them.

4 responses

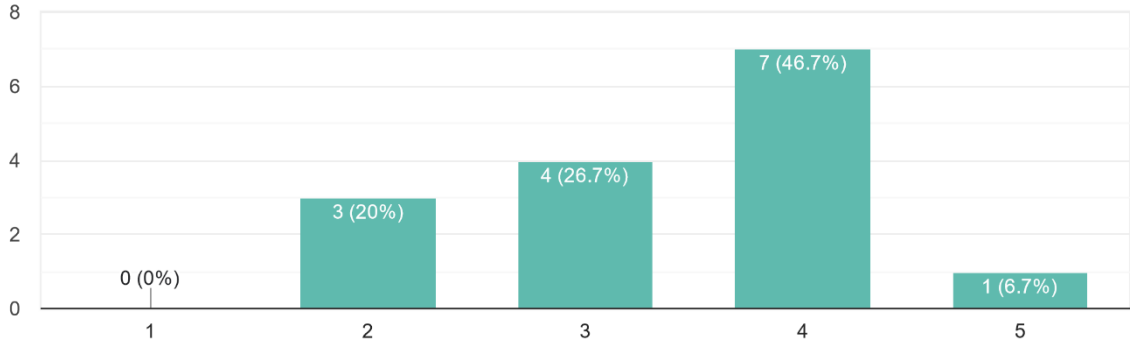


Below is a list of adjectives. Rate how well the particular terms suit the IDOVIR system by taking 1 - as completely unsuitable and 5 - as very suitable.



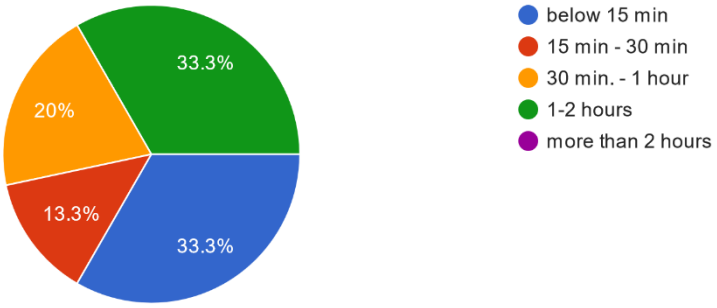
Rate the difficulty of using the tool to create a "Project structure". Take 1 as very difficult and 5 as very easy.

15 responses



Approximately how much time did you need to enter the "Project structure" into the system?

15 responses



Was there anything particularly difficult for you when creating 'Project Structure'?

10 responses

Our project not have the structure that all the project have (because we don't have a architecture)

The project structure had already been created by my professor, so i didnt have to do it

The UX of the web could be more intuitive, less clicks to upload the diferents parts of the project.
Initially, when you don't know the platform, it is difficult to understand where are your projects and how they are organized.

No

It didn't let me use both languages for the project, only English.

I had some problems editing names. I had to cancel the sub layer and redo it everytime.

Understanding what kind of information should the project structure have. If it should have the process of the project or just analyses of the object and its elements.

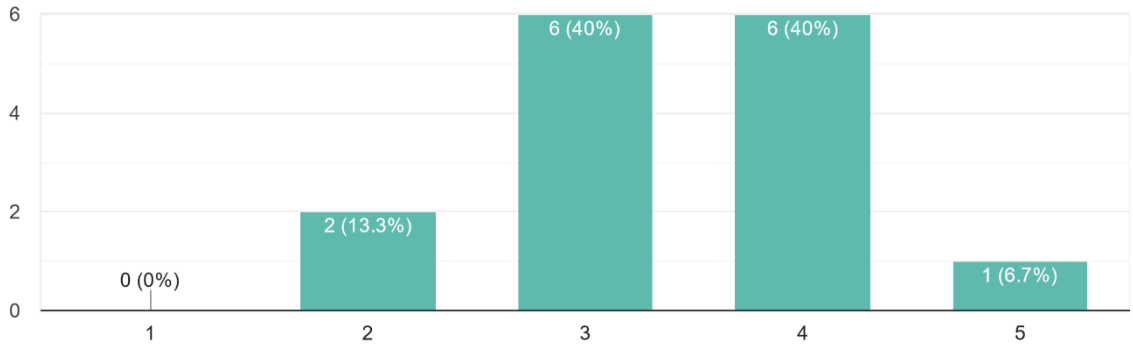
To choose which structure would fit best for the analysis of my specific object.

I struggled to create it, because we had a lot of drawings at the same document, and we had only 3 documents (direct sources) so we realised that would be easy to understand if we have no structure.

Not being able (or just not knowing how to) to create more layers of sub-folders

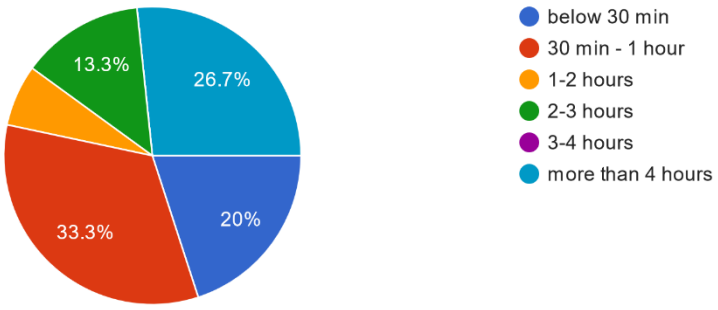
Rate the difficulty of uploading and describing sources with metadata to the system. Take 1 as very difficult and 5 as very easy.

15 responses



Approximately how much time did you need to upload and describe all the sources into the system?

15 responses



Did anything cause you particular difficulty when uploading and describing sources in the system?

7 responses

no

No

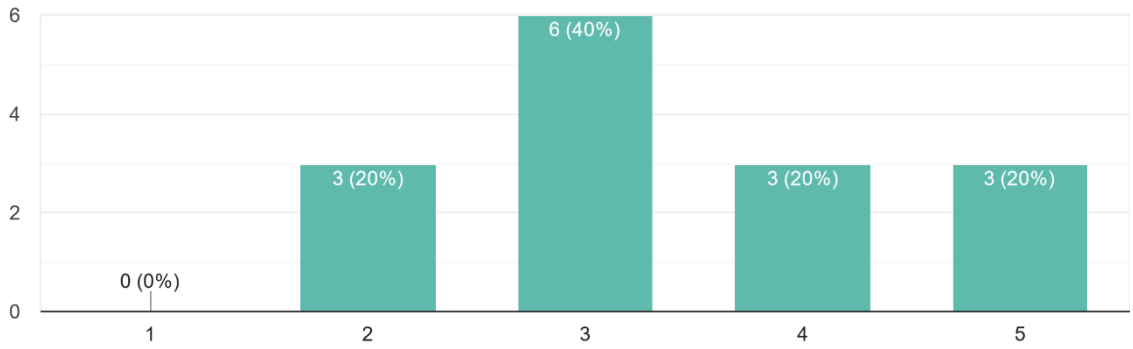
Need to be constantly challenged according to the reconstruction process.

Reuploading of Images (e.g. in the overview) not possible sometimes

The dificulty of having to delete each individual source instead of being able to select multiple source for deleting. Also not being able to delete a source that it in the project structure was quite annoying. (I then figure that each source is identified of where in the project structure it is) The Data Storage as the area images "folder" that is confusing, since we cannot add anything to it from the "+ Add New Data" button, manking it a bit dificult at first of why it is there.

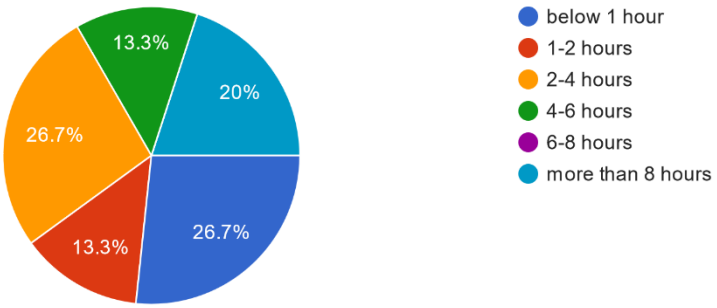
Rate the difficulty of documentation of the reconstruction (reasoning of the decision, upload and description of the reconstruction material, descripti...object). Take 1 as very difficult and 5 as very easy.

15 responses



Approximately how much time did you need for preparation of the whole documentation (excluding uploading and describing sources) into the system?

15 responses



Whether the methods of evaluation of the reconstruction met your expectations (division into section of geometry, surface structure and coloring with the possibility of changing the evaluation criteria). If not, what would you change?

15 responses

Yes

nothing

yes

I think I not change anything

it was good

Couldn't say since our project wasn't architectural.

the methods of evaluation of the reconstruction met my expectations

Si

personally didn't use it yet

Do you have any additional thoughts on the IDOVIR system?

5 responses

no

A bit too architecture-based in case it ever wants to expand onto other mediums.

The overview can be included in the project structure (redundant information)

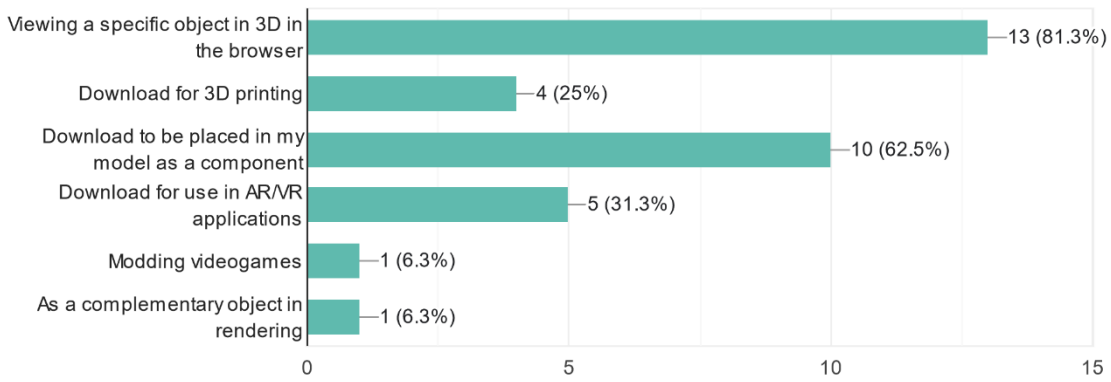
No

I could not change the main photo, that appearence in miniature, the button does not permit to change it, so i deleted the first version of our IDOVIR and create it again. I don´t know if it is a problem to everyone or just me. But, for the rest, it is a great tool.

PUBLICATION

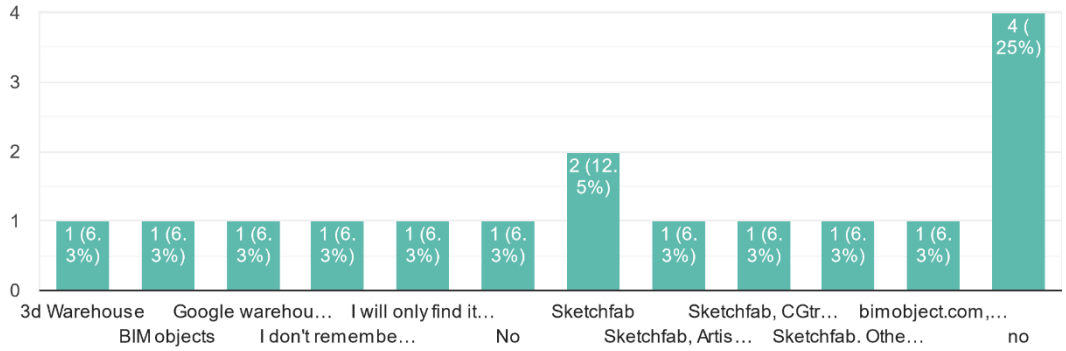
Have you ever search for 3D models online? For what purpose?

16 responses



Do you know of any platforms for publishing models online? Please list them below

16 responses



Have you ever publish model in online repository? Which repository was it and for what purpose did you publish?

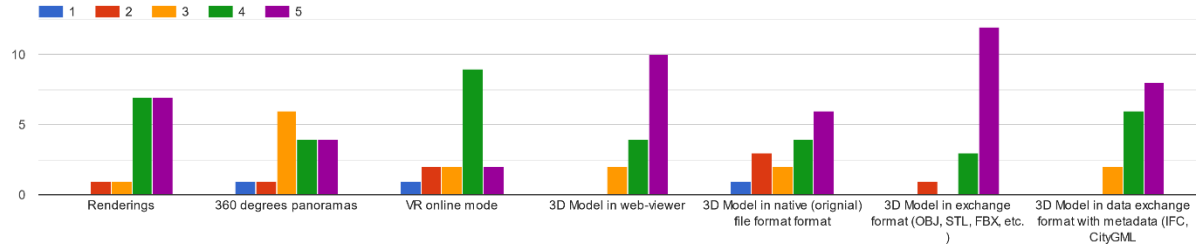
16 responses

- No
- no
- In Sketchfab with a academic reason
- HSM repository for a class
- -
- Sketchfab, for work.
- Si
- Only the one for this workshop
- haven´t published any yet
- Yes, on Google warehouse for other students to use
- No, only the one from the workshop

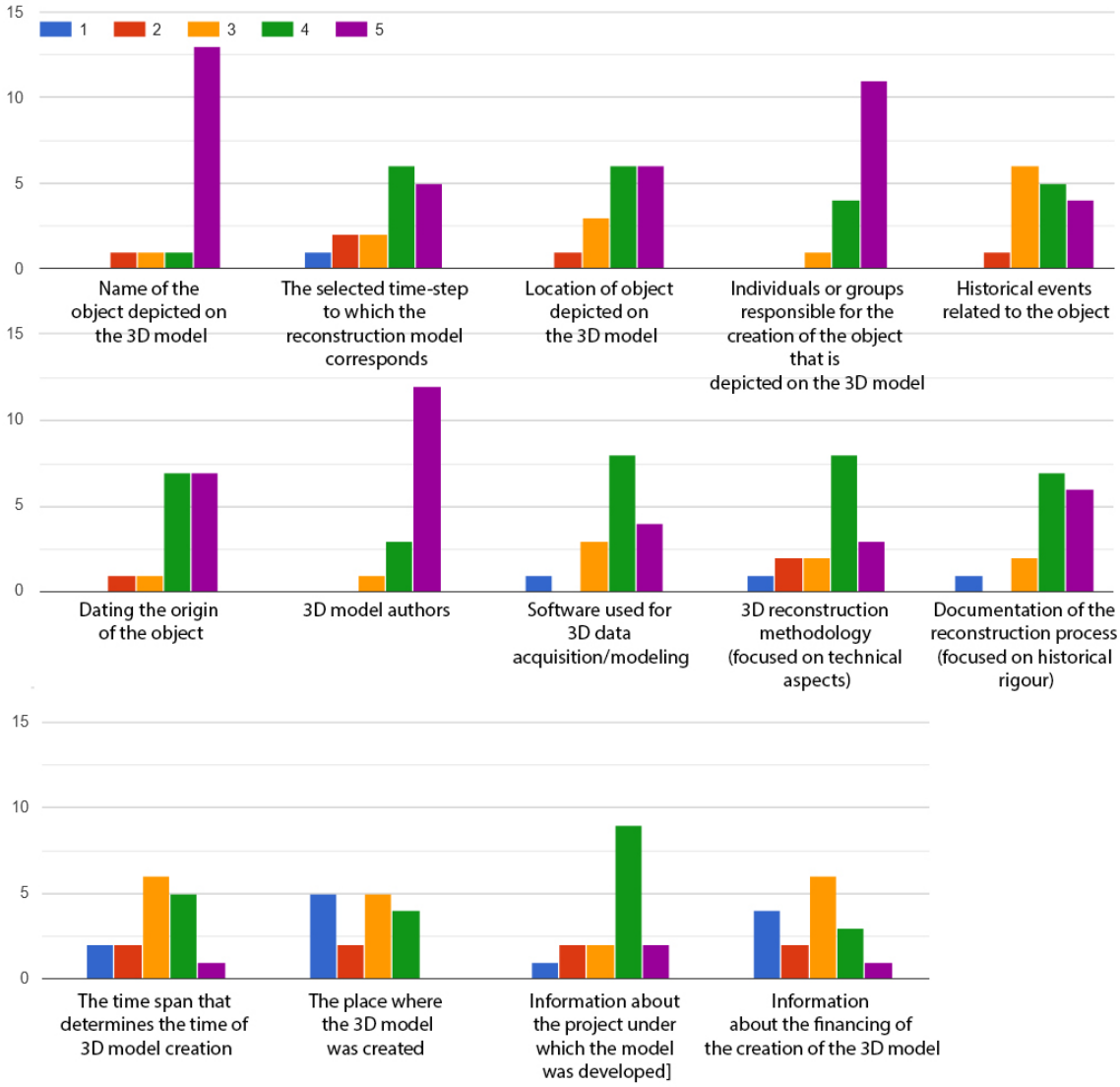
If you have never published a model online, what stopped you from doing so?

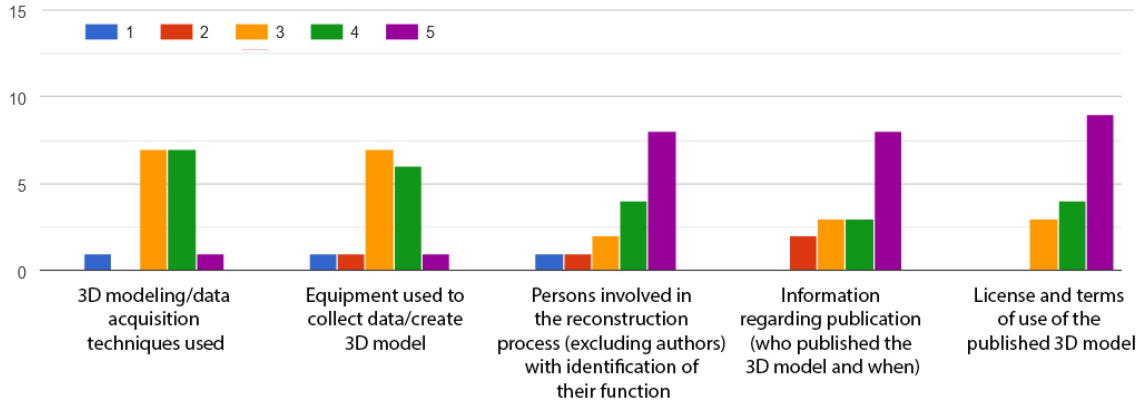
11 responses

Below there are listed various ways to publish the 3D model online. Evaluate to what extent, in your opinion, publication in specific form is needed. Take 1 - as completely unnecessary and 5 - as very necessary.



Publishing a model on the web also requires describing it with metadata. Which of the following information do you think is most important when publishing online? Take 1 - as unimportant and 5 - as very important.

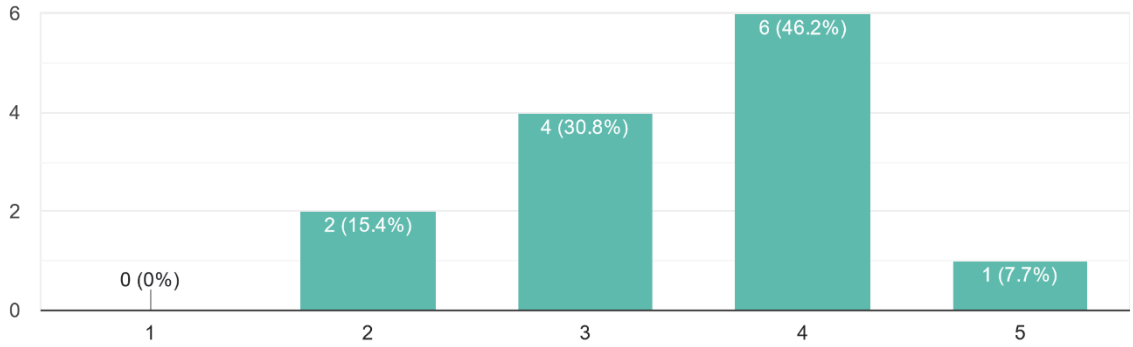




3D REPOSITORY – DATA PROVIDER

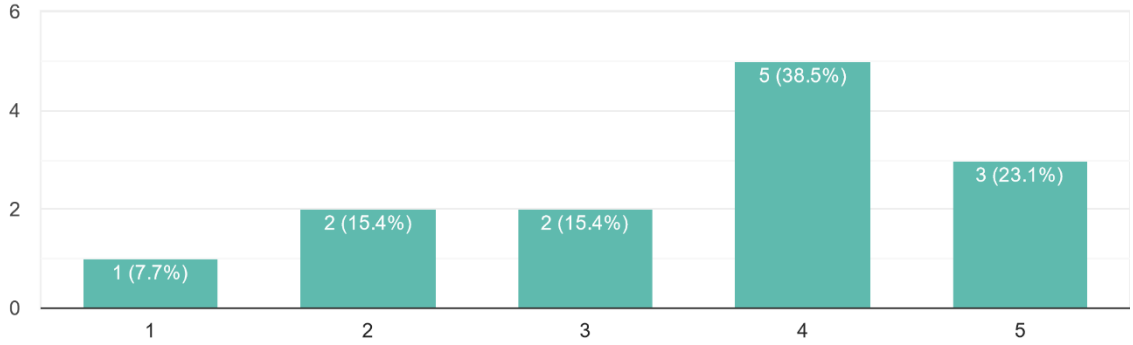
How do you assess the intuitiveness of the 3D Repository?

13 responses



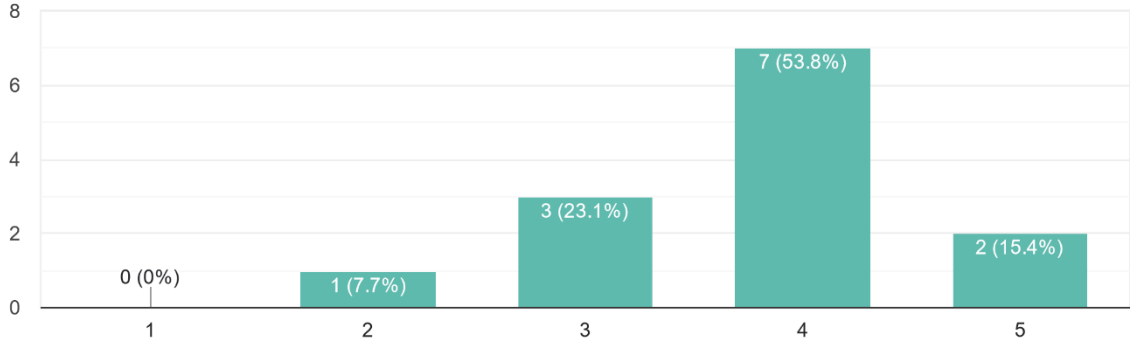
Rate the level of difficulty of filling fields in the metadata forms.

13 responses



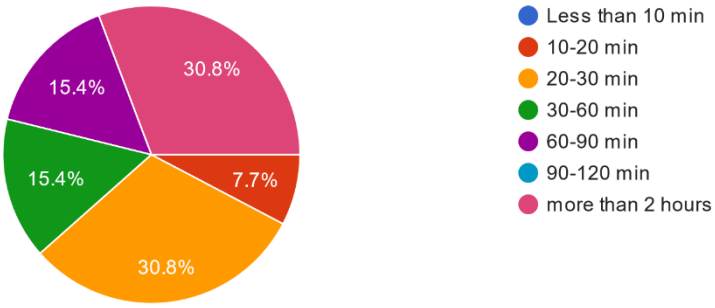
Were the field names and their descriptions clear and understandable?

13 responses



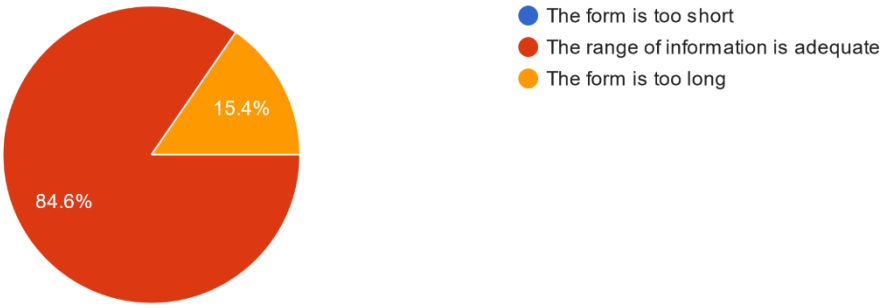
How much time did you need to complete the all metadata forms?

13 responses



Assess the scope of the information in the metadata forms

13 responses



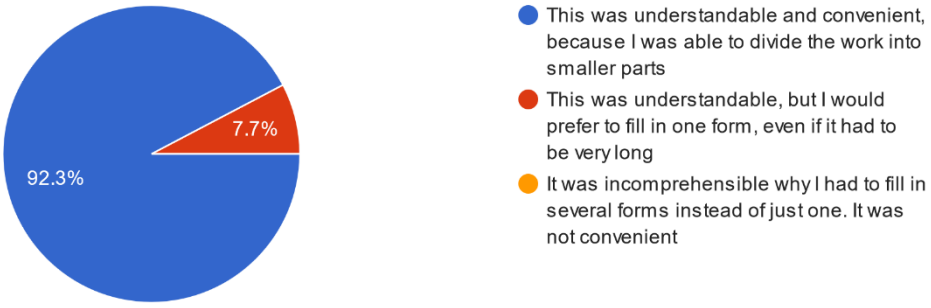
Did any sections of the form cause you particular difficulty? Which ones and why?

6 responses

no
The paradata about the sources. It did not have added at the system the place where the sources was.
No
when i uploaded my project in the repositery the servers were too slow
credits
"Add entry" part sometimes comes error.

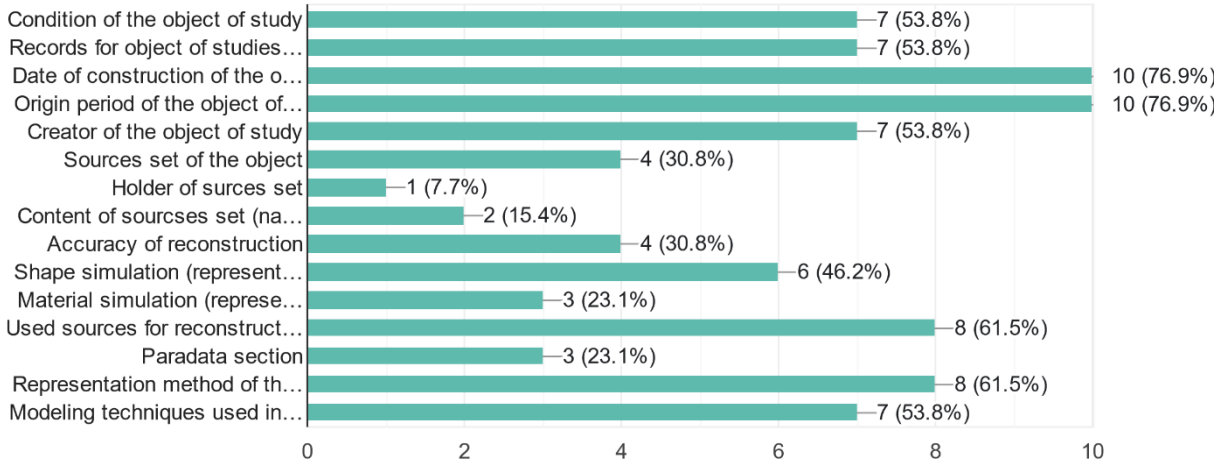
This year we have changed the metadata form by splitting one long form into several smaller forms (separate for persons, organizations, projects, cul...nd reconstruction). How do you evaluate this form?

13 responses



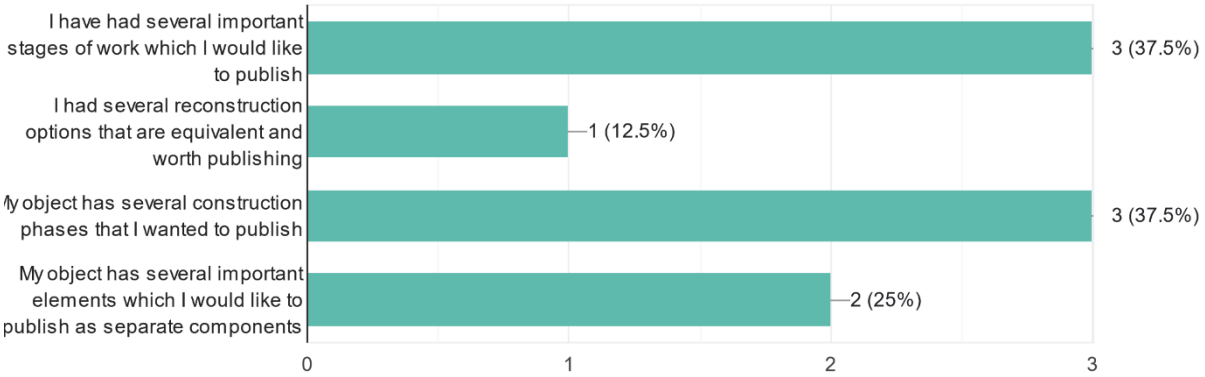
We have also introduced some additional features to the repository documentation that were not mandatory. You will find a list of these below. Please tick the ones you have filled in on your form.

13 responses



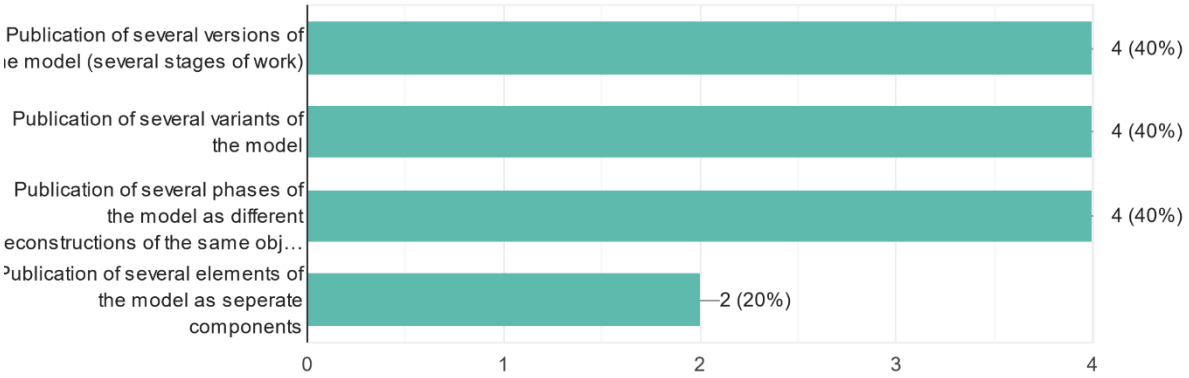
We have also introduced file history and the possibility of publishing versions, parts and variants of models. Choose all the sentences that describes your project

8 responses



Now please choose which of the following functions you actually used in your publication

10 responses

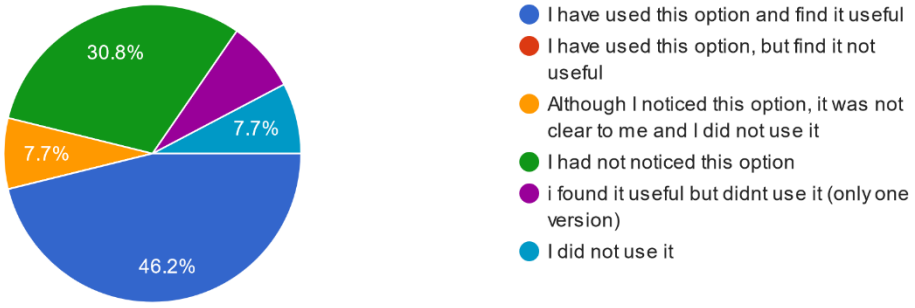


Due to the creation of a history of 3D models used in reconstruction, a system of using 'Prefix' to create, shorter and more practical names for indivi...(e.g. SyVo1929). What do you think of this system?

13 responses

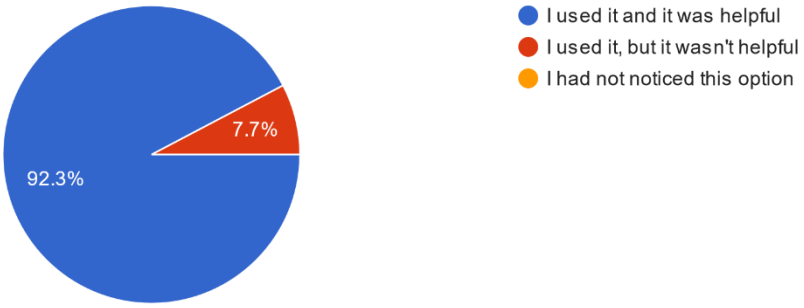
For the publication of variants, versions and parts as well as derivatives of 3D models, a referencing system is used, which indicates the order in whic...ed model evolved. How do you assess this system?

13 responses



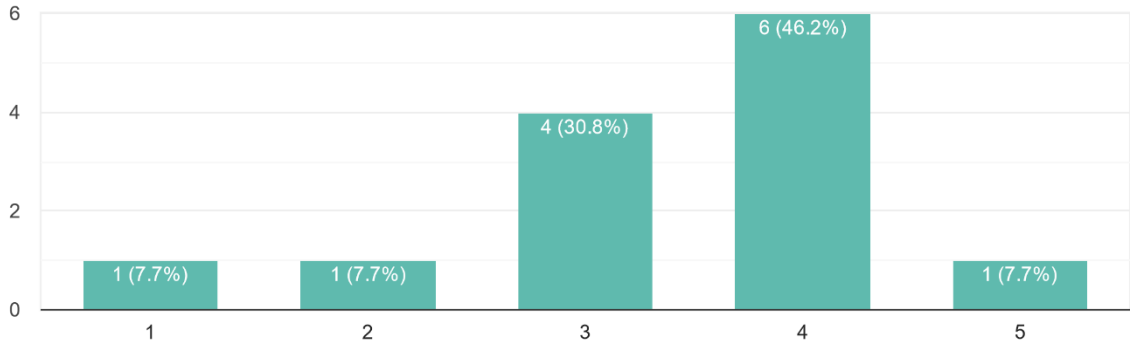
Each of the metadata forms contained instructions hidden under a question mark icon in a grey circle. When you click it, you should see additional instructions. How would you rate this feature?

13 responses



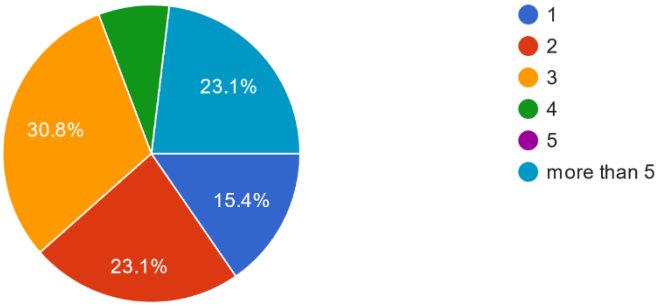
Were the instructions for preparing the file for upload clear to you?

13 responses



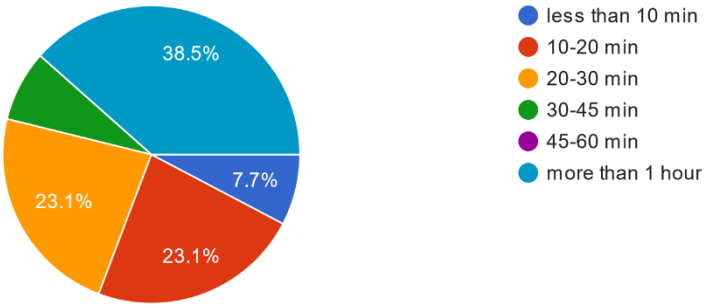
How many approaches did you need to make your model display correctly in the 3D viewer?

13 responses



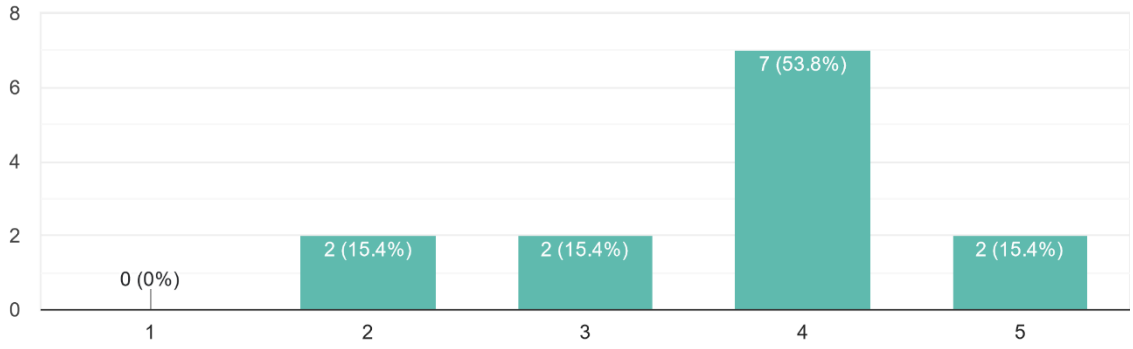
How much time did you have to spend preparing the model under the 3D Repository (Counting from the start of the first file export until the file was correctly loaded in the viewer)?

13 responses



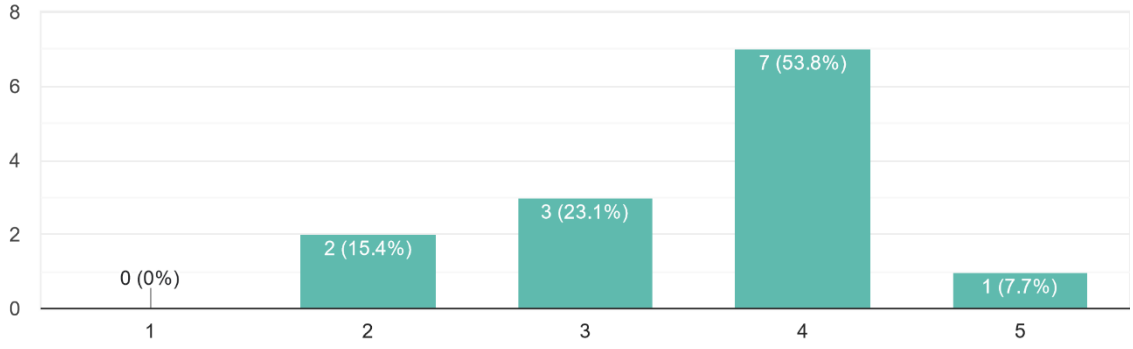
How would you rate the quality of the model visualization in the viewer?

13 responses



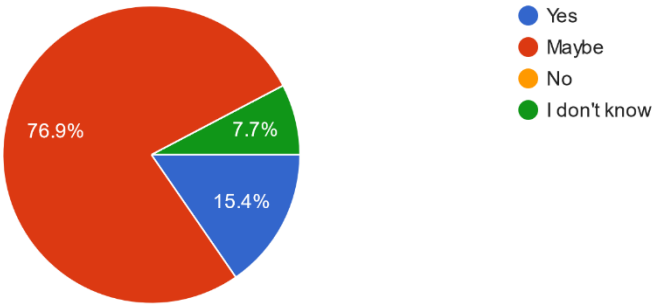
Evaluate the functionality of the repository and viewer (3D section, scene and model editor in the viewer, number of errors encountered).

13 responses



Do you think you will continue to use 3D Repository in the future for data publication?

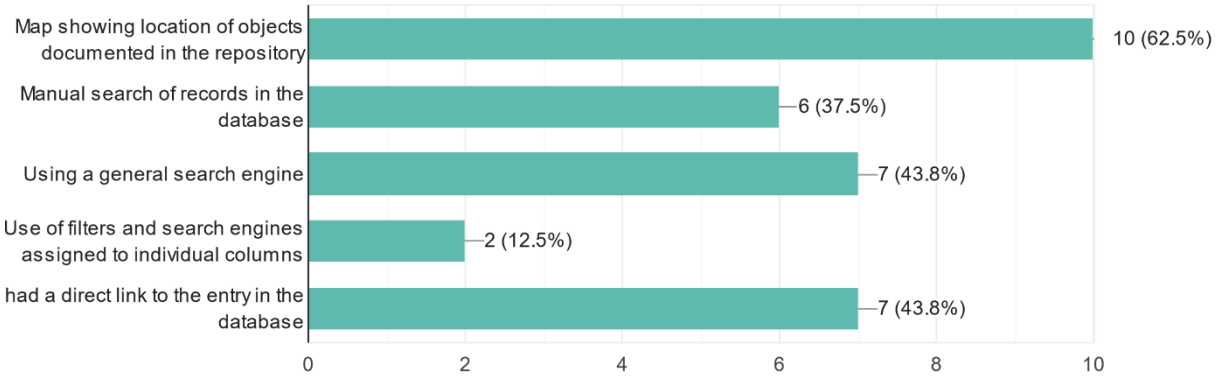
13 responses



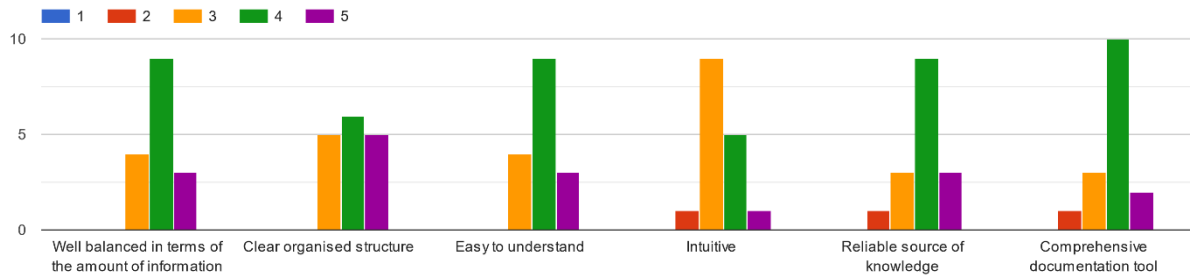
3D REPOSITORY – DATA EXPLORER

What of exploration options did you use? Select all that apply

16 responses

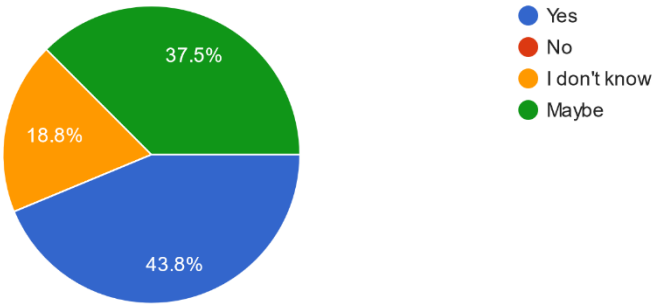


Each reconstruction in the database is saved as a record, where we can read all the metadata. Please rate the record in the database on a scale of 1-5, taking 1 as the most negative answer and 5 as the most positive in the categories listed below.



Do you think you will continue to use 3D Repository in the future for data exploration?

16 responses



Do you have any additional thoughts on the 3D Repository?

2 responses

No

IDOVIR provides a clearer and more accurate presentation of the project. Therefore, completing the 3D repository (intended for the EU) is entirely unnecessary.

Appendix 14: PURE3D – Reconstruction Process Articles

Reconstruction Process: Discovered Remains

The reconstruction process began in 2018 with the collection of source materials. Written sources from that period only mention the existence of the church, but not its form. Therefore, information was gathered from archaeological work conducted at the church since 2013 under the guidance of Dr. Guido Faccani, who became the main consultant for this reconstruction. Layers from the 7th-8th centuries were located nearly 2.8 meters below the current floor level (Faccani, 2019). It is likely that the building from that period was demolished to the floor level to provide a foundation for the next phase of reconstruction in the 10th century.

Excavations uncovered fragments of exterior walls on the north, west, and south sides, but not on the east side. The location of the western wall was offset by nearly 15 meters from the current location of the church's western exterior wall. The positions of the east and west walls are roughly in the middle of the side aisles of the current building. An important finding in the reconstruction was the discovery of three rectangular pillar foundations that delineated the division of the building into the nave and side aisles (Faccani, 2020).

Fundaments of one of the columns corresponding to the 800 AD phase. The background of the photo has been greyed out to better identify the element. Full-size picture is available here.© Igor Bajena

On the north side, fragments of two walls perpendicular to the church building were found, suggesting that another building might have been directly attached to the church. Additionally, fragments of other walls were discovered in areas to the south and west of the church's outline, though they were not in direct contact with the church.

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1. Faccani, G. (2020). St. Johannis von Mainz: archäologische Präliminarien zur Baugeschichte einer evangelischen Gemeindekirche. In: S. Lomartire, *Archeologia del territorio*, 63-92.

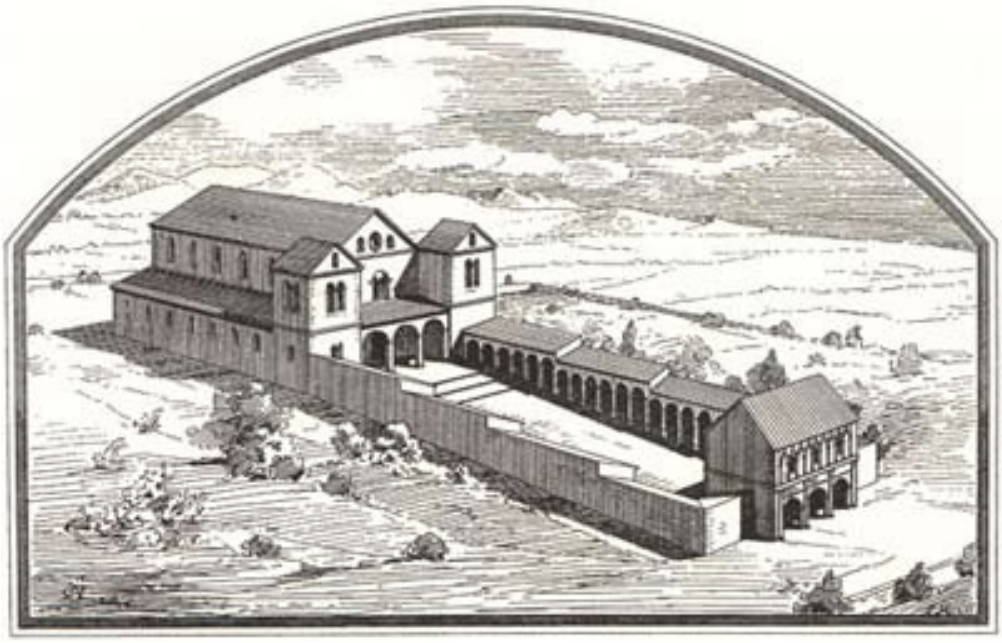
Reconstruction Process: Reconstructed Plan

The first stage of reconstruction was outlined on the archaeological documentation plan (Faccani & Ziorkewicz, 2019). This plan formed the basis for estimating the building structure in 3D. The original elements on the model were marked in a light colour, while their hypothetical vertical extrusion was marked in orange. The dashed lines on the plan indicate all the elements that were not discovered but deduced based on the found structures (dark brown elements on the model). This approach allowed for a partial reconstruction of the church's plan from the north, west, and east sides.

The excavated pillar foundations made it possible to determine the width of the main nave (about 9.5 meters) and the width of the side aisles (about 4.5 meters), with the distance between columns being approximately 7 meters. However, the eastern wall was not found, as its location extends beyond the excavation area. The assumed length of the church and the number of columns are hypothetical. The fragments of walls perpendicular to the building on the north side were reconstructed as the beginning of an attached structure, which could have been another building or the remains of walls from a Roman period building.

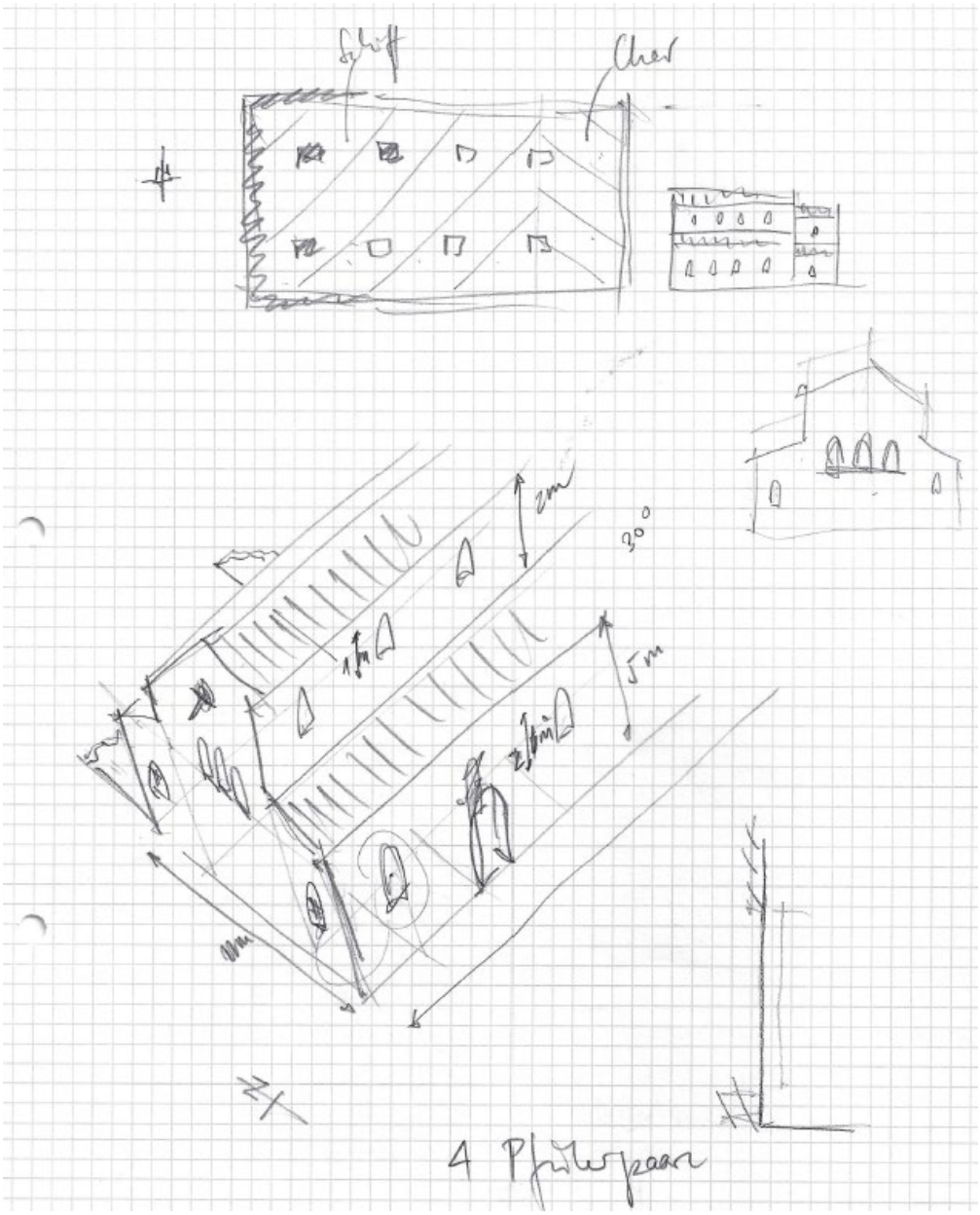
Reconstruction Process: First Variant

The reconstruction involved many unknowns from the very beginning. The length and height of the entire building were uncertain, as were the shape and placement of windows and entrances. Even the form of the building itself could vary. The reconstructed plan could correspond to either a hall church or a basilica. However, examples of sacred architecture from the Carolingian period, such as the Church of St. Michael in Fulda and Lorsch Abbey, suggest a basilica.



Drawing of the Reconstruction of Lorsch Abbey with basilica church by Rudolf Adamy (1891). Source: Order of Prémontré.

The height of the outer wall of the side aisle was assumed to be about 5 meters. Each bay of the side aisle was equipped with a window approximately 2 meters high, centered on the bay. The reconstructed windows have a semicircular arch, characteristic of the period. The walls of the nave were elevated 2 meters above the roof of the aisles, and a strip of windows 1 meter high, also ending in arches, was added. The east and west elevations were reconstructed symmetrically. Each side aisle ended with a single window with a semicircular arch, aligned with the nave. The main nave concluded with a triforium at a height slightly higher than the windows of the side aisles. The entrance to the church was placed on the longer southern elevation in the form of a portal with a semicircular arch. The roof was inclined at a 30-degree angle.

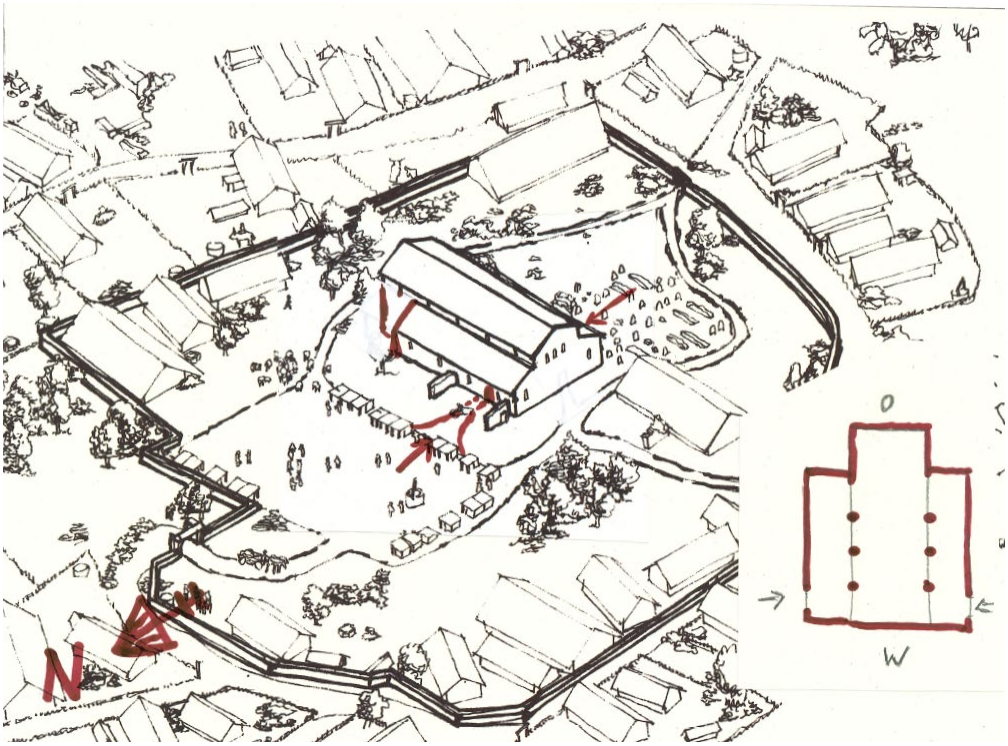


The first findings of the reconstruction in sketch form during consultation with Dr. Guido Faccani, ©AI MAINZ, 2018 .

Wall fragments on the north side of the church were initially considered to be from the Roman period. At that point, no broader interpretation of their significance was attempted. They were reconstructed as a ruined wall attached perpendicularly to the church wall.

Reconstruction Process: Other Variants

Other possible reconstruction alternatives emerged during the project. These changes focused on the eastern part of the church, which was located outside the archaeological site. Several alternatives emerged regarding the building's height and the level of the windows. The second variant considered raising the last bay on the west side to the height of the other spans. The third variant was influenced by the church's form in 1200, a reconstruction previously developed by Architectura Virtualis. This variant assumed shortening the side aisles by one bay compared to the main aisle while maintaining a constant roof ridge height over the main nave throughout the length of the church. However, based on current research, we now understand that the structures of the church in 800 and 1200 are not connected. Between these periods, the building was completely demolished to ground level and reconstructed from scratch.



Draft of changes to Variant 3 based on the future form of the building from the 13th century, ©AI MAINZ, 2020.

The fourth variant involved shortening the length of the church by removing the last eastern bay. Due to contemporary urban development, no excavations have been carried out at the site where this bay would have been located, so the exact length of the building and its eastern ending cannot be clearly determined. The exact changes between all the reconstruction variants in chronological order can be seen in the video below.

Variants of reconstruction with animated changes. Produced in 2024:
https://youtu.be/Cmyv2zvDAuk?si=kt9o29Gp5u3HV8Ua

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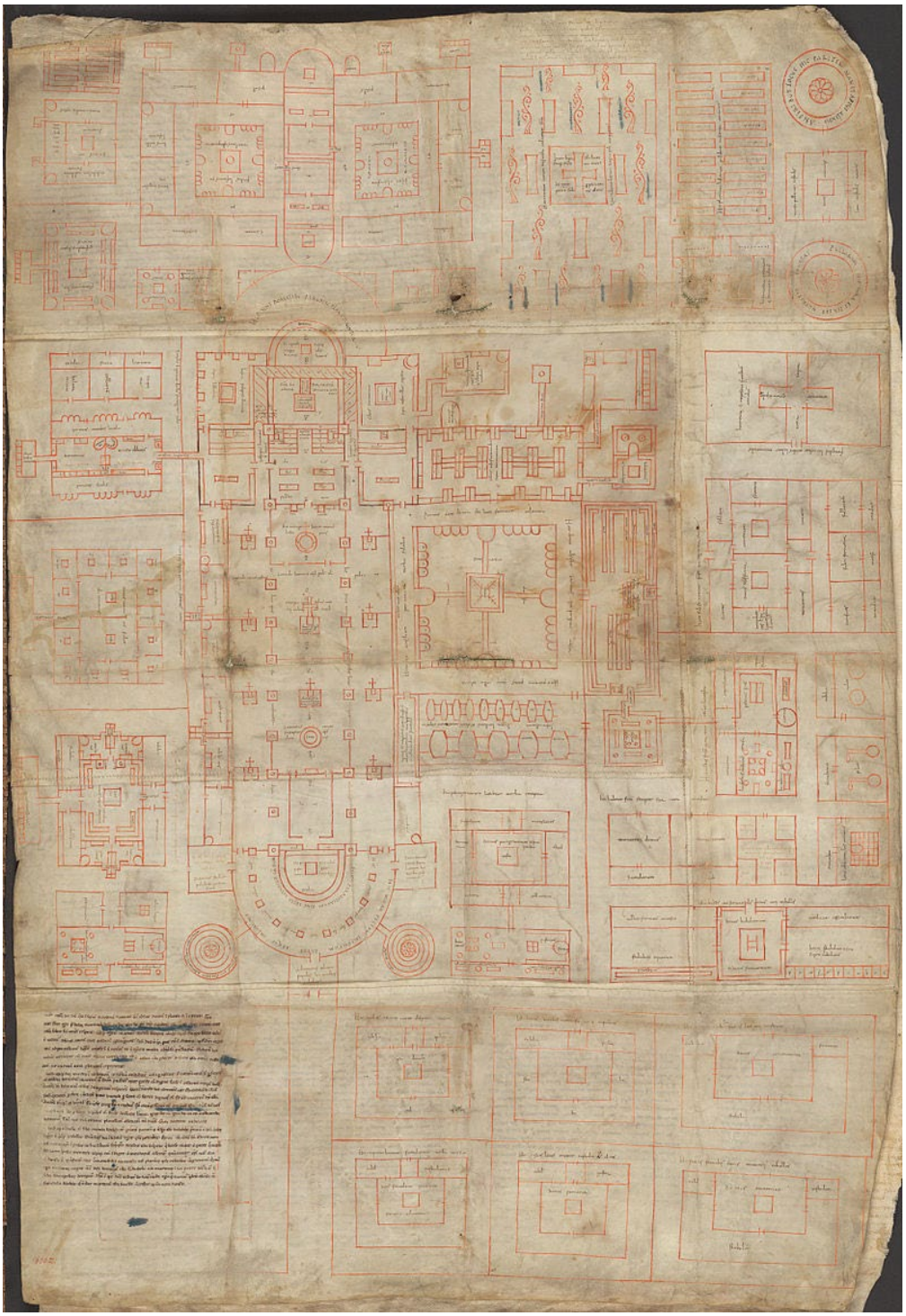
Reconstruction Process: Final Variant

The final variant emerged in May 2020, after a major change in the interpretation of the wall remains on the north side. These remains served as the basis for hypothesizing the reconstruction of a three-sided cloister. A two-story cloister in an 'L' shape was added, along with a single-story extension on the north side. On the north façade of the church, the windows in the first and last bays at ground level were removed to allow the cloister to be attached to the church. However, this solution should be regarded as highly hypothetical, even though similar arrangements exist in Carolingian-period cloistered monasteries, such as the monastery of St. Gallen in Switzerland.



Plan of Saint Gall. Reichenau, early 9th century (ca.820–830). Source: Wikipedia, No copyright.

The assumptions regarding the location of the eastern wall of the building were also changed. The length of the church was reduced by one bay, with the side walls' length based only on certain wall fragments discovered during the excavations. Although this solution lowers the level of hypothesis regarding the building as a whole, it does not confirm the exact location of the eastern wall.

The south wall was also slightly altered. The entrance portal was moved to the center of the bay, and the window above it was removed to improve the visual perception of the façade. The levels of the window band and the top of the portal were too close to each other.

Reconstruction Process: Uncertainty Evaluation

Any digital restoration runs the risk of literalising the message. Therefore, following the completion of the project, an attempt was made in the preparation of this edition to assess the level of uncertainty of the final reconstruction option. To this end, the object was divided into symantic elements and the level of uncertainty was assessed in two categories: the location of the element in space and its form.

		Location				
		1	2	3	4	5
Form	1	20%	30%	40%	50%	60%
	2	30%	40%	50%	60%	70%
	3	40%	50%	60%	70%	80%
	4	50%	60%	70%	80%	90%
	5	60%	70%	80%	90%	100%

Matrix of possible uncertainty level percentages, based on a summary of the uncertainty levels of the location and form of the reconstructed element, along with the colour code. © Igor Bajena

A five-point rating scale was adopted for both categories. Level 1 (uncertainty in the range of 0-45%) indicates that archaeological excavations are the basis for the assumptions. Level 2 (uncertainty in the range of 46-65%) means the assumptions are based on deductions complementing the findings of the excavations. Level 3 (uncertainty within 66-75%) involves assumptions based on logical deduction derived from the excavated form. Level 4 (uncertainty within 76-90%) relies on analogies from the same region and period. Level 5 (uncertainty between 91-100%) is based mainly on personal knowledge. The percentage level for each element was calculated as an average. The final result, however, was illustrated on a six-point scale to better visualize the nuances in the differences of high levels of uncertainty.

	Location	Form	**Uncertainty**
Portal to church	4	4	**80,00%**
Wall East	5	3	**80,00%**
Wall West	1	4	**50,00%**
Wall North	1	4	**50,00%**
Wall South	1	4	**50,00%**
Pillar 1-3	1	4	**50,00%**
Pillar 4-6	3	4	**70,00%**
Windows	3	4	**70,00%**
Triforium	3	4	**70,00%**
Cloister	3	4	**70,00%**
Convent	5	4	**90,00%**
Convent Entrance	5	5	**100,00%**
Inner arches	3	4	**70,00%**
Roof	4	4	**80,00%**
Floor	1	1	**20,00%**
Upper walls	3	4	**70,00%**

Calculation of uncertainty level percentages for individual semantic elements of the church © Igor Bajena

The preparation of the methodological and colour study was inspired by existing solutions for the assessment of uncertainty (Cazzaro, 2023; Apolonio et al. 2024).

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Credits

This 3D scholarly edition was made by Igor Bajena in the framework of Pure3D. The materials presented were created as part of the Digital Urban History Lab (DUHL) project and a partnership between the Institute of Architecture of the Hochschule Mainz (AI MAINZ) and the Rhineland-Palatinate General Directorate for Cultural Heritage (GDKE), funded by GDKE, German Federal Government Commissioner for Culture and the Media, Sparkasse Rhein-Nahe and J. Molitor Immobilien GmbH. You can read more about the project in the following article. Team involved in the project include:

- Piotr Kuroczynski (AI MAINZ)
- Julia Merz (AI MAINZ)
- Ellen Riemer (GDKE)
- Guido Faccani
- Gernot Frankhäuser (GDKE)
- Peggy Grosse (AI MAINZ)
- Igor Bajena (AI MAINZ)
- Kinga Wnęk (AI MAINZ)
- Aliyah Mahmood (AI MAINZ)
- Marta Zielińska (AI MAINZ)
- Patrycja Stelmach (AI MAINZ)
- Michael Sherman (AI MAINZ)

This edition is also a part of Igor Bajena's doctoral thesis on methods of documentation and publication of digital reconstruction, which is being prepared as part of a scholarship from the University of Bologna. The work is supervised by Prof. Fabrizio Apollonio (University of Bologna) and prof. Piotr Kuroczyński (AI MAINZ).
A great deal of support in the creation of the edition was provided by Dr Gudio Faccani, who is directing the excavations at the St. Johannis Church site, and by Dr Ellen Riemer and Gernot Frankhäuser of the GDKE for delivery of part of the bibliographic materials. Credit is also given to Carla Flohr for help in collecting materials at the excavation site.

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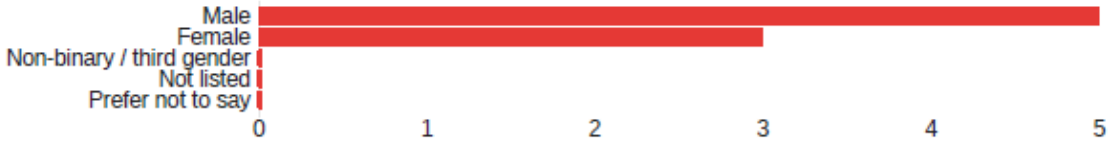
Section 1: Demographics

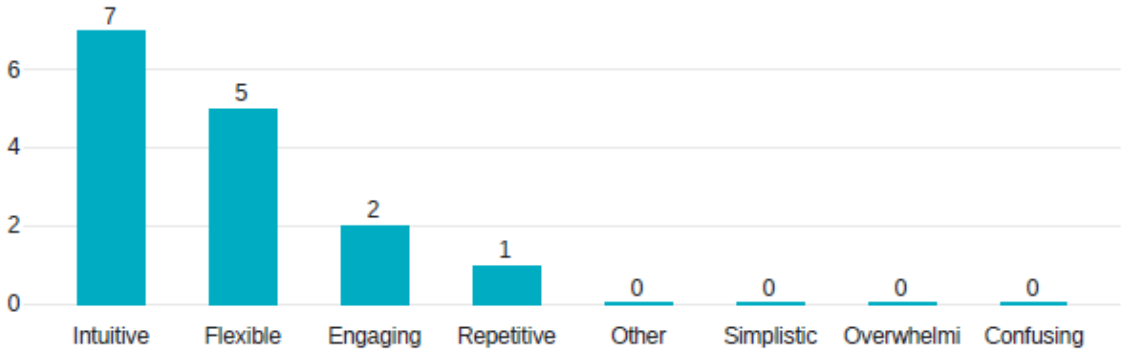
Q4 - What is your age?

Q5 - What is your gender? - Selected Choice

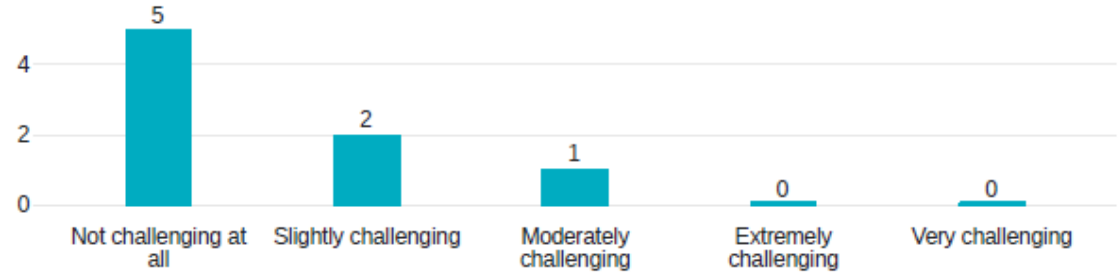


Section 2: Navigation

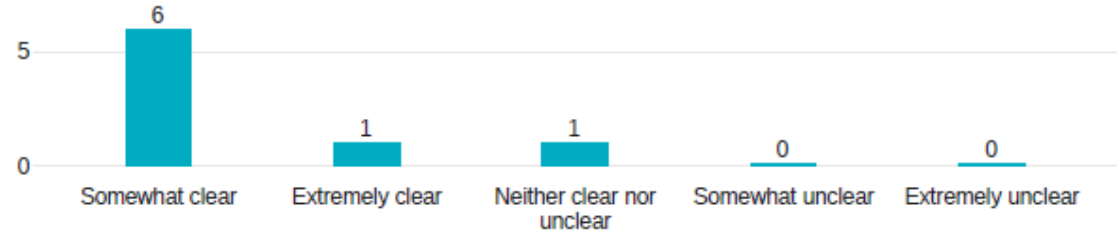
Q7 - I would describe my experience with the interface as...(choose as many as you like) - Selected Choice



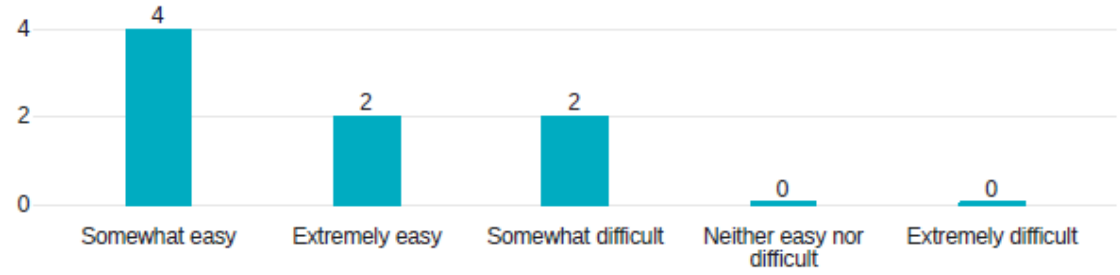
Q8 - I found receiving information via the interface...



Q9 - I found the icons used for navigation...

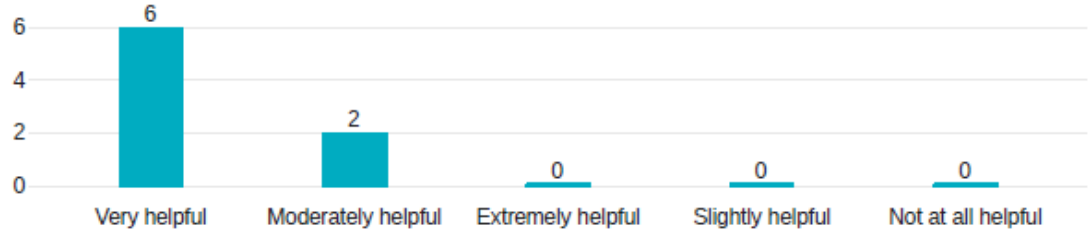


Q10 - I found going back to find information I previously read...

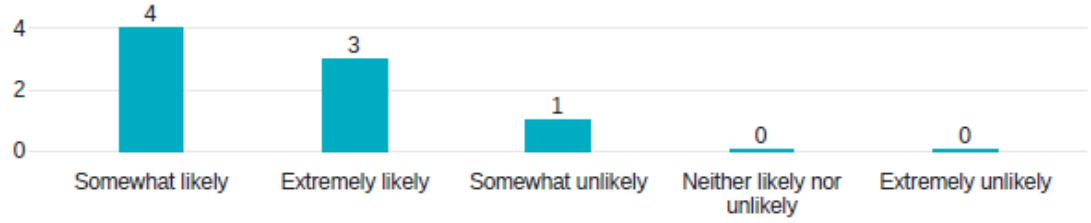


Q13 - Did you follow one or more of the guided ‘tours’? - Selected Choice

Q14 - Were the 'tours' helpful in structuring the content?



Q16 - What is the likelihood of you using this interface again with a new topic?



Please briefly explain why you chose this answer in the space provided below.

Because it provides a lot of information about a historical building and this information is well presented.

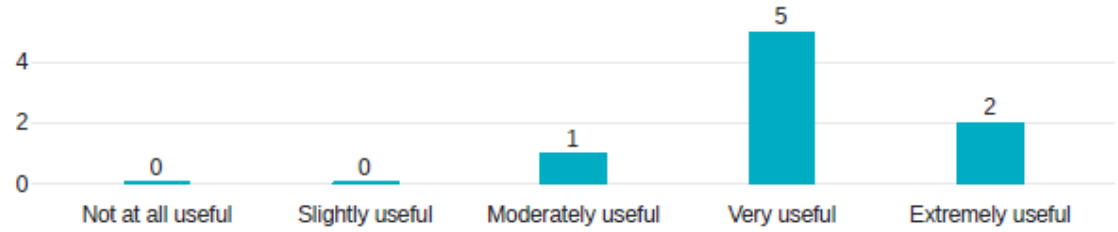
Because it offers the possibility to present content in an immersive and engaging way, it allows to create different narratives/stories at the same time and, also, it allows the use -and, even, the superimpose- of different layers of information presented through different media (e.g. texts, 3D models, videos etc.).

I find the knowledge dissemination strategy very effective, both from a professional point of view and from a visitor's point of view (e.g. in a museum environment).

I'll be in contact with the subject (history of St. John's Mainz) further.

I would like to use this to present a project of mine or to explore another project of study

Q18 - Was the 3D Edition useful for your understanding of the subject matter presented on?



Please briefly explain why you chose this answer in the space provided below.

The user get an imoression of the build envionment and the context.

Clear overview of what the building looked like

The written description and the photos/videos provided a solid framework in order to understand the case study and to being imagining how it looks/looked like. However, the 3D edition made the visualisation of the monument under study very clear and in a very short time.

It makes easier to understand the different construction phases

The building history of the first centuries in St. John's (Mainz) is quite complicating and has been rarely published in printed studies.

If you have any other feedback regarding navigation of the interface, please provide it in the space provided below.

The icons could be more clear, e.g. guided tours represented by the globus is not clear (some times the icon for www), better > path with flags, dialog bubble for annotations is also not so clear (maybe "tag" icon), the comment bubble should be used for the own comments on the model (one annotations).

Some of the icons are somewhat confusing (the globe for tours, for example, I would consider a signpost or something similar to be more intuitive). With some of the icons, I could only figure out what they meant by mouse-over (but I don't think that's a bad thing)

The function of each one of the icons used for the navigation was clear for someone that had heard the recorded introductory message. If not, it was still easy to understand their function after trying to use them a couple of times. However, when I heard the introduction I understood how to use this toolbar much better.

a) It is strange to have the Y axis vertical instead of Z axis in the section tool.
b) the grid is not really useful to me, it would have been more useful to have an indication of the north instead, or the image of the surrounding
c) all the options to change the background are a bit too many, it would have been sufficient to have a button to turn on of the photografic environment and maybe the 3 environment options
d) the environment change do not affect either the light or the color of the model
e) maybe this is because it's a sample model without the aim to be photorealistic, but the textures on the model are often out of scale.

Section 3: Presentation

Q22 - Did the presence of the 3D model add value to your understanding?

Please briefly explain why you chose this answer in the space provided below.

The 2d excavation plan is very unclear to read, an the thrid dimension is very helpful to understand the building history and the context.

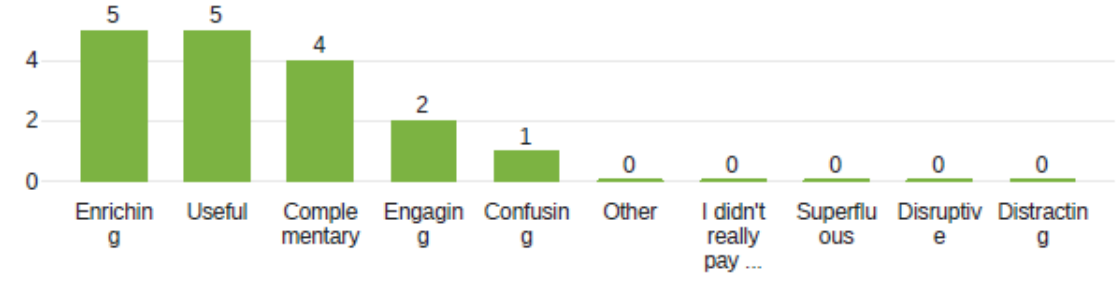
Because then you can get a vivid idea of the parts of the building described

It helped to visualise all the changes, phases, processes etc. that were described through the texts. Also, it created a direct connection between the photos/videos of the original remains and the reconstruction(s) proposed.

In particular, as the understanding of architectural spaces is concerned, 3D reconstruction is one of the most streamlined communication methods to report the historical development of cultural heritage assets

The 3D model is in the case of St. John's (Mainz) very helppful because the building history is very complex in the first centuries.

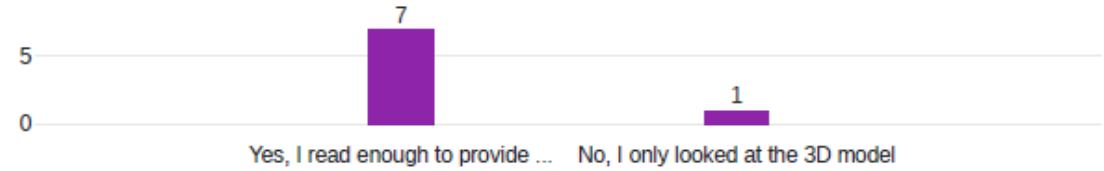
Q24 - Did you find the addition of the multimedia elements embedded within the text...(choose as many as you like) - Selected Choice



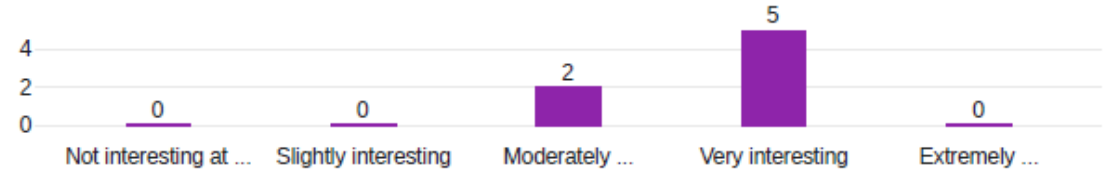
Q25 - Do you feel you were taken on a journey (storytelling) as opposed to receiving information (like a newspaper article)?

Section 4: Historical Content

Q28 - Did you read the text-based content provided in the interface?



Q29 - I would describe the texts as...



Q30 - I would describe the amount of text within the interface as...

Q54 - 1. During the first virtual tour of St. John's Church in Mainz (St. Johannis), you were introduced to basic information about the building. How do you evaluate the usefulness of this information in the overall context of the edition? Was it presented clearly? Do you think the introductory details were provided in the right amount?

1. During the first virtual tour of St. John's Church in Mainz (St. Johannis), you were introduced to basic information about the building. How do you evaluate the usefulness of this information in the overall context of the edition? Was it presented clearly? Do you think the introductory details were provided in the right amount?

Yes. The content was fine, but there were many mistakes (mostly orthographic).

I skiped the introduction, I have to admit (as I'm normally doing, because introductions are somewhat self explaining and repeating)

Yes

The information was interesting and helped to create the historical context of the church. However, there were some details, mainly related to specific periods (e.g. names), that could seem unknown or even not interesting to someone that doesn't have related knowledge or specific interest.

Very useful and clearly presented

I think it's okay in this form, but I have discussed this item since some years.

it was clearly presented and useful

Q57 - 2. The edition's key focus is on the significance and function of the church area in Mainz around the year 800. Did you find the information provided both interesting and clear? Were the visual aids appropriate? Which method of presenting information (annotations, articles, virtual tour) did you find most effective, and why? Was the amount of information about this topic appropriate?

2. The edition's key focus is on the significance and function of the church area in Mainz around the year 800. Did you find the information provided both interesting and clear? Were the visual aids appropriate? Which method of presenting information (annotations, articles, virtual tour) did you find most effective, and why? Was the amount of information about this topic appropriate?

I found the guided tour supported by external links very helpful to understand the topic and issue of the reconstruction process.

I found the text a little too long, as already stated. The media elements helped to break it up a bit, so they helped a lot! I think the annotations have been the most convincing to provide information

The mixture of different sources shows the complexity of the topic and the visualisation can be understood on the basis of the sources given.

The information was clearly presented and the combination of different media was, in my opinion, very successful. It helped in presenting the information and in maintaining the interest. however, in some cases I would have liked less written information.
Regarding the methods, I personally enjoyed more the virtual tour and the possibility of combining different annotations/layers, as it was a way of putting together all the pieces of information presented.

It is very clear from both an information and a presentation point of view. The interesting thing is the balance between these two aspects.

I'm not sure if the presentaion worked right just in this.

It was informative, well-explained, and useful, the amount of information could have been a bit shorter but still interesting.

Q53 - 3. The third virtual tour showcased various reconstruction variants. Were you able to understand the need for these different variants? Did you comprehend the reasoning behind the choice of the final version? What are your thoughts on this method of presenting variants of hypothetical digital reconstructions?

3. The third virtual tour showcased various reconstruction variants. Were you able to understand the need for these different variants? Did you comprehend the reasoning behind the choice of the final version? What are your thoughts on this method of presenting variants of hypothetical digital reconstructions?

It is very important to show varaints and explain, why we have them. Well done. Sometimes there very mistakes in the naming of the variants (after 1 v the 4v was displayed!)

Yes, of course I understand the benefits of different variants and I was able to understand them well. I think it's good to present the different variants and also their differences through the transitions from one variant to the next, so that you don't have to work it out for yourself

It is good that the different variants are shown. However, I would find it easier to compare them if I could see them side by side rather than one behind the other. However, I also only have one screen, so part of the problem with the display is probably due to that.

Yes, it was understandable. Maybe some key words or some annotations directly on the parts of the model that changed between the different variants would also help to make the reasoning between the variants even more evident.
As a method of presenting different variants I found it efficient, clear and very intriguing. I liked that I could navigate from one variant to the other.

Variants add a scientific value to the reconstruction and make us aware of the choices made while modelling, with the aim of presenting a plausible final version.

Were you able to understand the need for these different variants? YES
Did you comprehend the reasoning behind the choice of the final version? YES
What are your thoughts on this method of presenting variants of hypothetical digital reconstructions? THIS IS IMPORTANT

it was informative and useful, it shows that the selected version was not the only possible, preventing misconceptions and historical falsehoods

Q55 - 4. The second part of the third tour proposed visualising the levels of uncertainty in the reconstruction of individual building elements. Did you understand why this kind of representation is significant? Was it clear how criteria for different uncertainty levels on the scale work? What do you think about this approach to visualising the uncertainties in the hypothetical digital reconstruction? Do you find it effective?

4. The second part of the third tour proposed visualising the levels of uncertainty in the reconstruction of individual building elements. Did you understand why this kind of representation is significant? Was it clear how criteria for different uncertainty levels on the scale work? What do you think about this approach to visualising the uncertainties in the hypothetical digital reconstruction? Do you find it effective?

I found it effactive and useful. It would be great to have a standard in this case. Localisation and geometry is a nice concept, but there are maybe more evaluated and useful concepts.

Yes, I could understand it why it was significant and the criteria were very clear. I consider the development of such a matrix to be a senseful development in order to be able to quantify the uncertainty. However, I am unsure to what extent such a quantification will be accepted by the community.

I find this type of presentation understandable; it allows you to see at a glance the high degree of uncertainty in some areas of the reconstruction.

Yes, the criteria, scale, reasoning related to the uncertainty levels were clearly explained. I liked that the scale was also presented by the side of the ´coloured´ model and not only explained in the text, because it made the process of understanding it much faster and more efficient.

It is clear and I found it really interesting. Levels of uncertainty should be more used in scientific reconstructions and this is a very good methodological example.

Did you understand why this kind of representation is significant? YES
Was it clear how criteria for different uncertainty levels on the scale work? COULD BE CLEARER PERHAPS
What do you think about this approach to visualising the uncertainties in the hypothetical digital reconstruction? IT'S A FITTED APPOACH
Do you find it effective? YES

Very effective, about this I would have loved a more in-depth description of the scale and how the various levels were selected

Q75 - 5. How would you rate the edition overall? Were the lengths of the virtual tours and the articles well-balanced? Which part did you find most and least interesting, and why? Is there anything you would change to enhance your experience of the edition?

5. How would you rate the edition overall? Were the lengths of the virtual tours and the articles well-balanced? Which part did you find most and least interesting, and why? Is there anything you would change to enhance your experience of the edition?

The tour was interesting, not overloaded but sometimes less clicks o the 3d model would be helpful (in reocnstruction part there were ca. 50 clicks! to much! and not needed.

I think the length of the texts was too long. I would focus more on the visual design through the sequence of the different variants and also the non-security matrix. However, I would change the colour scheme of the matrix. With green, I would say that it intuitively has the least uncertainty and not blue (i.e. blue rather in the centre or through a gradation of green, yellow and red shades)

The problem of the still controversial Carolingian royal palace is presented here as more or less solved based on only one research opinion. The texts themselves could be somewhat shorter overall.

I would probably shorten some of the texts or, at least, present the information in a more general or simpler way. The use of the 3D models of the church made the experience very interesting allowing the user to freely discover the information that they mainly wanted. I would have probably enjoyed a voice over narration in some parts, but reading the texts and navigating through the model was also more than enough.

In my opinion this is very well done.

Were the lengths of the virtual tours and the articles well-balanced? YES
Which part did you find most and least interesting, and why? THE 3. TOUR WITH THE VARIATONS.
Is there anything you would change to enhance your experience of the edition? FOR THIS I HAVE TO SEE IT MORE OFTEN.

the most interesting parts were the variants, and the uncertainty false colour view

Appendix 16: Pathbuilder of CoVHer Repository

Show row weights

Title	Path	Enabled	Field Type	Cardinality	Operations
Authority Document	Group [http://www.cidoc-crm.org/cidoc-crm/E32_Authority_Document]	☑		Unlimited	Edit
Name	http://www.cidoc-crm.org/cidoc-crm/E32_Authority_Document → http://www.cidoc-crm.org/cidoc-crm/P102_has_title → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	1	Edit
Full Name	http://www.cidoc-crm.org/cidoc-crm/E32_Authority_Document → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	1	Edit
Website	http://www.cidoc-crm.org/cidoc-crm/E32_Authority_Document → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Link	1	Edit
Time Span	Group [http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span]	☑		Unlimited	Edit
Start	http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☑	Text (plain)	1	Edit
End	http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☑	Text (plain)	1	Edit
ID set	Group [http://www.cidoc-crm.org/cidoc-crm/E42_Identifier]	☑		Unlimited	Edit
ID Provider	http://www.cidoc-crm.org/cidoc-crm/E42_Identifier → http://www.cidoc-crm.org/cidoc-crm/P70i_is_documented_in → http://www.cidoc-crm.org/cidoc-crm/E32_Authority_Document	☑	Entity reference	1	Edit
ID	http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Text (plain)	1	Edit
URI	http://www.cidoc-crm.org/cidoc-crm/E42_Identifier → http://www.cidoc-crm.org/cidoc-crm/P139_has_alternative_form → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Link	1	Edit
Person	Group [http://www.cidoc-crm.org/cidoc-crm/E21_Person]	☑		Unlimited	Edit
Name	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Profession	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
E-mail	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P76_has_contact_point → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Email	Unlimited	Edit
ID Set	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
Affiliation	Group [http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment]	☑		Unlimited	Edit
Organization	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Role	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
Affiliation Time Span	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P4_has_time-span → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☑	Entity reference	1	Edit
Bio	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → http://www.cidoc-crm.org/cidoc-crm/E33_Linguistic_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (formatted, long)	1	Edit
Picture	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P138i_has_representation → http://www.cidoc-crm.org/cidoc-crm/E36_Visual_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Image	1	Edit
Author of reconstructions	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P14i_performed → oph:M25_Digital_Reconstruction	☑	Entity reference	Unlimited	Edit
Supported recontructions	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P140_assigned_attribute_to → oph:M25_Digital_Reconstruction	☑	Entity reference	Unlimited	Edit
Collaborated in projects	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P140_assigned_attribute_to → oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P9i_forms_part_of → oph:M14_Research_Project	☑	Entity reference	Unlimited	Edit
Modeller in projects	http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P14i_performed → oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P9i_forms_part_of → oph:M14_Research_Project	☑	Entity reference	Unlimited	Edit
Organization	Group [http://www.cidoc-crm.org/cidoc-crm/E74_Group]	☑		Unlimited	Edit
Name	http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit

Type	http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Website	http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → http://www.cidoc-crm.org/cidoc-crm/E89_Propositional_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Link	1	Edit
E-mail	http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P76_has_contact_point → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Email	Unlimited	Edit
ID Set	http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
Members	http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment	☑	Entity reference	Unlimited	Edit
Location	http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P74_has_current_or_former_residence → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53b_Location	☑	Entity reference	1	Edit
Logo	http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P138i_has_representation → http://www.cidoc-crm.org/cidoc-crm/E36_Visual_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Image	1	Edit
Participated in projects	http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → oph:M14_Research_Project	☑	Entity reference	Unlimited	Edit
Digital Resource	Group [http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object]	☑		Unlimited	Edit
Prefix	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	1	Edit
Type	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
Title	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → http://www.cidoc-crm.org/cidoc-crm/P102_has_title → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	1	Edit
Author(s)	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P14_carried_out_by → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	Unlimited	Edit
Creation date	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P4_has_time-span → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☑	Text (plain)	1	Edit
Link	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → oph:R1i_was_published_by → oph:M5_Digital_Publication_Event → http://www.cidoc-crm.org/cidoc-crm/P94_has_created → oph:M6_Digital_Record → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Link	1	Edit
Status (disabled)	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → http://www.cidoc-crm.org/cidoc-crm/P140i_was_attributed_by → http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	List (text)	1	Edit
Publication (disabled)	Group [http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → oph:R1i_was_published_by → oph:M5_Digital_Publication_Event]	☐		1	Edit
Publication Year (disabled)	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → oph:R1i_was_published_by → oph:M5_Digital_Publication_Event → http://www.cidoc-crm.org/cidoc-crm/P4_has_time-span → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☐	Text (plain)	1	Edit
Retrived from (disabled)	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → oph:R1i_was_published_by → oph:M5_Digital_Publication_Event → http://www.cidoc-crm.org/cidoc-crm/P16_used_specific_object → http://www.cidoc-crm.org/cidoc-crm/E89_Propositional_Object → http://www.cidoc-crm.org/cidoc-crm/P102_has_title → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☐	Text (plain)	1	Edit
ID set (disabled)	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☐	Entity reference	Unlimited	Edit
Copyright disclaimer	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → http://www.cidoc-crm.org/cidoc-crm/E30_Right → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit
File(s)	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	File	Unlimited	Edit
Used in digital reocnsturctions	http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → oph:M25_Digital_Reconstruction	☑	Entity reference	Unlimited	Edit
Software	Group [http://www.cidoc-crm.org/extensions/crmdig/D14_Software]	☑		Unlimited	Edit
Name	http://www.cidoc-crm.org/extensions/crmdig/D14_Software → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Website	http://www.cidoc-crm.org/extensions/crmdig/D14_Software → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → http://www.cidoc-crm.org/cidoc-crm/E73_Information_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Link	1	Edit
Cultural Heritage Object	Group [oph:M26_Cultural_Heritage_Thing]	☑		Unlimited	Edit
Name	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Type	Group [oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type]	☑		1	Edit

Name	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
ID set	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
Category	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_55b_Broader_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
Condition	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P140i_was_attributed_by → http://www.cidoc-crm.org/cidoc-crm/E14_Condition_Assessment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E3_Condition_State → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
ID set	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
Records	Group [oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → oph:M6_Digital_Record]	☑		Unlimited	Edit
Web Service	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → oph:M6_Digital_Record → http://www.cidoc-crm.org/cidoc-crm/P148i_is_component_of → http://www.cidoc-crm.org/cidoc-crm/E73_Information_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Link	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → oph:M6_Digital_Record → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Link	Unlimited	Edit
Style (disabled)	Group [oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P140i_was_attributed_by → http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_55d_Object_Type]	☐		1	Edit
Name (disabled)	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P140i_was_attributed_by → http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_55d_Object_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	Text (plain)	1	Edit
ID set (disabled)	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P140i_was_attributed_by → http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_55d_Object_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☐	Entity reference	1	Edit
Location	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P130_shows_features_of → http://www.cidoc-crm.org/cidoc-crm/E22_Human-Made_Object → http://www.cidoc-crm.org/cidoc-crm/P53_has_former_or_current_location → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53b_Location	☑	Entity reference	1	Edit
Location Map	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P130_shows_features_of → http://www.cidoc-crm.org/cidoc-crm/E22_Human-Made_Object → http://www.cidoc-crm.org/cidoc-crm/P53_has_former_or_current_location → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53b_Location → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Geofield	1	Edit
Creation	Group [oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P92i_was_brought_into_existence_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation]	☑		1	Edit
Creation Date (Numerical Year)	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P92i_was_brought_into_existence_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P4_has_time-span → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☑	Number (integer)	1	Edit
Creation Date (Textual Time Span)	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P92i_was_brought_into_existence_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P4_has_time-span → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Origin Period	Group [oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P92i_was_brought_into_existence_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P10_falls_within → http://www.cidoc-crm.org/cidoc-crm/E4_Period]	☑		1	Edit
Name	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P92i_was_brought_into_existence_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P10_falls_within → http://www.cidoc-crm.org/cidoc-crm/E4_Period → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
ID set	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P92i_was_brought_into_existence_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P10_falls_within → http://www.cidoc-crm.org/cidoc-crm/E4_Period → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
Concept/Design Creator	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P92i_was_brought_into_existence_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P14_carried_out_by → http://www.cidoc-crm.org/cidoc-crm/E39_Actor	☑	Entity reference	Unlimited	Edit
Creator ID	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P92i_was_brought_into_existence_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P14_carried_out_by → http://www.cidoc-crm.org/cidoc-crm/E39_Actor → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
Concept Carrier (disabled)	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P92i_was_brought_into_existence_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P94_has_created → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	List (text)	1	Edit
Sources Set	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P70i_is_documented_in → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source	☑	Entity reference	Unlimited	Edit
Execution (disabled)	Group [oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P130_shows_features_of → http://www.cidoc-crm.org/cidoc-crm/E22_Human-Made_Object]	☐		1	Edit
Construction time span (disabled)	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P130_shows_features_of → http://www.cidoc-crm.org/cidoc-crm/E22_Human-Made_Object → http://www.cidoc-crm.org/cidoc-crm/P108i_was_produced_by → http://www.cidoc-crm.org/cidoc-crm/E12_Production → http://www.cidoc-crm.org/	☐	Entity reference	1	Edit

Signature (disabled)	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P130_shows_features_of → http://www.cidoc-crm.org/cidoc-crm/E22_Human-Made_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	Text (plain)	Unlimited	Edit
Description	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31a_Annotation	☑	Text (formatted, long)	1	Edit
Preview	oph:M26_Cultural_Heritage_Thing → http://www.cidoc-crm.org/cidoc-crm/P138i_has_representation → http://www.cidoc-crm.org/cidoc-crm/E36_Visual_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Image	1	Edit
Reconstructions	oph:M26_Cultural_Heritage_Thing → oph:R14i_is_reconstructed_by → oph:M25_Digital_Reconstruction	☑	Entity reference	Unlimited	Edit
Historical Actor	Group [http://www.cidoc-crm.org/cidoc-crm/E39_Actor]	☑		Unlimited	Edit
Name	http://www.cidoc-crm.org/cidoc-crm/E39_Actor → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
ID set	http://www.cidoc-crm.org/cidoc-crm/E39_Actor → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
City	Group [http://www.cidoc-crm.org/cidoc-crm/E53_Place]	☑		Unlimited	Edit
Place Name (disabled)	http://www.cidoc-crm.org/cidoc-crm/E53_Place → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	Text (plain)	1	Edit
City ID	http://www.cidoc-crm.org/cidoc-crm/E53_Place → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
Location	Group [https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53b_Location]	☑		Unlimited	Edit
Map	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53b_Location → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Geofield	1	Edit
Coordinates	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53b_Location → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Geofield	1	Edit
Address	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53b_Location → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13c_Location_Assignment → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
City	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53b_Location → http://www.cidoc-crm.org/cidoc-crm/P89_falls_within → http://www.cidoc-crm.org/cidoc-crm/E53_Place	☑	Entity reference	Unlimited	Edit
Is location of the object	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53b_Location → http://www.cidoc-crm.org/cidoc-crm/P53i_is_former_or_current_location_of → http://www.cidoc-crm.org/cidoc-crm/E22_Human-Made_Object → http://www.cidoc-crm.org/cidoc-crm/P130i_features_are_also_found_on → oph:M26_Cultural_Heritage_Thing	☑	Entity reference	Unlimited	Edit
is location of organization	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_53b_Location → http://www.cidoc-crm.org/cidoc-crm/P74i_is_current_or_former_residence_of → http://www.cidoc-crm.org/cidoc-crm/E74_Group	☑	Entity reference	Unlimited	Edit
Device	Group [http://www.cidoc-crm.org/extensions/crmdig/D8_Digital_Device]	☑		Unlimited	Edit
Name	http://www.cidoc-crm.org/extensions/crmdig/D8_Digital_Device → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Type	http://www.cidoc-crm.org/extensions/crmdig/D8_Digital_Device → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Web Service	Group [http://www.cidoc-crm.org/cidoc-crm/E89_Propositional_Object]	☑		Unlimited	Edit
Name	http://www.cidoc-crm.org/cidoc-crm/E89_Propositional_Object → http://www.cidoc-crm.org/cidoc-crm/P102_has_title → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	Unlimited	Edit
Website	http://www.cidoc-crm.org/cidoc-crm/E89_Propositional_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	Unlimited	Edit
Project	Group [oph:M14_Research_Project]	☑		Unlimited	Edit
Full Name	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	1	Edit
Acronym	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_35e_Alternative_Title	☑	Text (plain)	1	Edit
Type	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
Time Span	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P4_has_time-span → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☑	Entity reference	1	Edit
Is sub-project of	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P9i_forms_part_of → oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	Unlimited	Edit
Involved Institutions	Group [oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment]	☑		Unlimited	Edit
Organization	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	Unlimited	Edit

Role	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit
Description	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31a_Annotation	☑	Text (formatted, long)	1	Edit
Reconstructions in project	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P9_consists_of → oph:M25_Digital_Reconstruction	☑	Entity reference	Unlimited	Edit
Participants (supporters)	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P9_consists_of → oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P140i_was_attributed_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person	☑	Entity reference	Unlimited	Edit
Modellers	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P9_consists_of → oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P14_carried_out_by → http://www.cidoc-crm.org/cidoc-crm/E21_Person	☑	Entity reference	Unlimited	Edit
REF Organization	oph:M14_Research_Project → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E74_Group	☑	Entity reference	Unlimited	Edit
Digital Reconstruction	Group [oph:M25_Digital_Reconstruction]	☑		Unlimited	Edit
Prefix	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	1	Edit
Reconstructed Object	oph:M25_Digital_Reconstruction → oph:R14_has_reconstructed → oph:M26_Cultural_Heritage_Thing	☑	Entity reference	1	Edit
Reconstructed Time Frame	oph:M25_Digital_Reconstruction → oph:R15_simulates_time → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Reconstruction Preview	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/extensions/crmdig/L11_had_output → oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P62i_is_depicted_by → http://iflastandards.info/ns/lrm/lrmoo/F5_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Embed Sketchfab	1	Edit
Type (disabled)	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	List (text)	1	Edit
Dataset License	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_30a_Copy_Right → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
Part of the project	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P9i_forms_part_of → oph:M14_Research_Project	☑	Entity reference	1	Edit
Authors	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P14_carried_out_by → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	Unlimited	Edit
Contributors	Group [oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P140i_was_attributed_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment]	☑		Unlimited	Edit
Name	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P140i_was_attributed_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	Unlimited	Edit
Role	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P140i_was_attributed_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit
REF_Supporters	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P140i_was_attributed_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person	☑	Entity reference	Unlimited	Edit
Used sources	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P16_used_specific_object → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source	☑	Entity reference	Unlimited	Edit
Accuracy	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P9_consists_of → oph:M19_Simulation → oph:R18_has_accuracy_value → oph:M27_Accuracy_Value → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Shape Simulation	Group [oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → oph:M22_Digital_Shape]	☑		Unlimited	Edit
Shape Representation	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → oph:M22_Digital_Shape → oph:R10i_is_simulated_by → oph:M19_Simulation → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
Shape Provenance	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → oph:M22_Digital_Shape → oph:R10i_is_simulated_by → oph:M19_Simulation → http://www.cidoc-crm.org/cidoc-crm/P16_used_specific_object → http://www.cidoc-crm.org/cidoc-crm/E70_Thing → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit
Material Simulation	Group [oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → oph:M16_Digital_Material]	☑		Unlimited	Edit
Material Representation	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → oph:M16_Digital_Material → oph:R10i_is_simulated_by → oph:M19_Simulation → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit

Material Provenance	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → oph:M16_Digital_Material → oph:R10i_is_simulated_by → oph:M19_Simulation → http://www.cidoc-crm.org/cidoc-crm/P16_used_specific_object → http://www.cidoc-crm.org/cidoc-crm/E70_Thing → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit
Produced paradata	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P94_has_created → http://www.cidoc-crm.org/extensions/crmdig/D1_Digital_Object	☑	Entity reference	Unlimited	Edit
Reconstruction Models	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/extensions/crmdig/L11_had_output → oph:M1_3D_Object	☑	Entity reference	Unlimited	Edit
Derivatives	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/extensions/crmdig/L11_had_output → oph:M15_3D_Feature	☑	Entity reference	Unlimited	Edit
3D Preview File	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/extensions/crmdig/L11_had_output → oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P138i_has_representation → http://www.cidoc-crm.org/cidoc-crm/E36_Visual_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	File	Unlimited	Edit
3D Preview File Name	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/extensions/crmdig/L11_had_output → oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P138i_has_representation → http://www.cidoc-crm.org/cidoc-crm/E36_Visual_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	1	Edit
3D Preview Renders	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P138i_has_representation → http://www.cidoc-crm.org/cidoc-crm/E36_Visual_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Image	Unlimited	Edit
REF_Modellers	oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P14_carried_out_by → http://www.cidoc-crm.org/cidoc-crm/E21_Person	☑	Entity reference	Unlimited	Edit
3D Model	Group [oph:M1_3D_Object]	☑		Unlimited	Edit
Prefix	oph:M1_3D_Object → http://www.cidoc-crm.org/extensions/crmdig/L11i_was_output_of → oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	1	Edit
Type	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
Version Number	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_35c_Subtitle	☑	Number (integer)	1	Edit
Variant Number	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_35e_Alternative_Title	☑	Number (integer)	1	Edit
Part Name	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Author	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P14_carried_out_by → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	Unlimited	Edit
Software	oph:M1_3D_Object → http://www.cidoc-crm.org/extensions/crmdig/L11i_was_output_of → http://www.cidoc-crm.org/extensions/crmdig/D10_Software_Execution → http://www.cidoc-crm.org/extensions/crmdig/L23_used_software_or_firmware → http://www.cidoc-crm.org/extensions/crmdig/D14_Software → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	Unlimited	Edit
Creation date	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P4_has_time-span → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☑	Text (plain)	1	Edit
File	oph:M1_3D_Object → oph:R12i_is_embedded_in → oph:M17_Digital_Environment	☑	Entity reference	Unlimited	Edit
File	oph:M1_3D_Object → oph:R12i_is_embedded_in → oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	File	Unlimited	Edit
File Type	oph:M1_3D_Object → oph:R12i_is_embedded_in → oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit
Version of	oph:M1_3D_Object → oph:R5_is_following_version_of → oph:M1_3D_Object	☑	Entity reference	Unlimited	Edit
Variant of	oph:M1_3D_Object → oph:R6_is_alternation_of → oph:M1_3D_Object	☑	Entity reference	Unlimited	Edit
Is part of	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P106i_forms_part_of → oph:M1_3D_Object	☑	Entity reference	Unlimited	Edit
Based on	oph:M1_3D_Object → oph:R4i_has_preceding_version → oph:M1_3D_Object	☑	Entity reference	1	Edit
Description	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31a_Annotation	☑	Text (plain, long)	1	Edit
Device (disabled)	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → http://www.cidoc-crm.org/extensions/crmdig/D10_Software_Execution → http://www.cidoc-crm.org/extensions/crmdig/L12_happened_on_device → http://www.cidoc-crm.org/extensions/crmdig/D8_Digital_Device → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	Text (plain)	Unlimited	Edit
Representation Method	Group [oph:M1_3D_Object → oph:R17_has_representation_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type]	☑		1	Edit
by specific method	oph:M1_3D_Object → oph:R17_has_representation_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
by spatial configuration/ morphology	oph:M1_3D_Object → oph:R17_has_representation_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_55b_Broader_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit

by geometric continuity	oph:M1_3D_Object → oph:R17_has_representation_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P2i_is_type_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_55b_Broader_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
Modeling Technique	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → http://www.cidoc-crm.org/extensions/crmdig/D10_Software_Execution → http://www.cidoc-crm.org/cidoc-crm/P32_used_general_technique → oph:M23_3D_Modelling_Technique → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit
Shape Simulation (disabled)	oph:M1_3D_Object → oph:R13_consist_of → oph:M22_Digital_Shape → http://www.cidoc-crm.org/cidoc-crm/P137i_is_exemplified_by → http://www.cidoc-crm.org/extensions/crmdig/D9_Data_Object → http://www.cidoc-crm.org/extensions/crmdig/L11i_was_output_of → oph:M19_Simulation → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	Text (plain)	Unlimited	Edit
Material Simulation (disabled)	oph:M1_3D_Object → oph:R13_consist_of → oph:M16_Digital_Material → http://www.cidoc-crm.org/cidoc-crm/P137i_is_exemplified_by → http://www.cidoc-crm.org/extensions/crmdig/D9_Data_Object → http://www.cidoc-crm.org/extensions/crmdig/L11i_was_output_of → oph:M19_Simulation → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	Text (plain)	Unlimited	Edit
Copyrights (disabled)	Group [oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_30a_Copy_Right]	☐		1	Edit
Author/Rights holder(person) (disabled)	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_30a_Copy_Right → http://www.cidoc-crm.org/cidoc-crm/P75i_is_possessed_by → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	Text (plain)	Unlimited	Edit
Author/Rights holder (organization) (disabled)	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_30a_Copy_Right → http://www.cidoc-crm.org/cidoc-crm/P75i_is_possessed_by → http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☐	Text (plain)	Unlimited	Edit
License (disabled)	oph:M1_3D_Object → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_30a_Copy_Right	☐	List (text)	1	Edit
Used in reconstruction	oph:M1_3D_Object → http://www.cidoc-crm.org/extensions/crmdig/L11i_was_output_of → oph:M25_Digital_Reconstruction	☑	Entity reference	1	Edit
Derivatives	Group [oph:M15_3D_Feature]	☑		Unlimited	Edit
Prefix	oph:M15_3D_Feature → http://www.cidoc-crm.org/extensions/crmdig/L11i_was_output_of → oph:M25_Digital_Reconstruction → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E35_Title	☑	Text (plain)	1	Edit
Type	oph:M15_3D_Feature → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
Derivative from	oph:M15_3D_Feature → http://www.cidoc-crm.org/extensions/crmdig/L22i_was_derivative_created_by → http://www.cidoc-crm.org/extensions/crmdig/D3_Formal_Derivation → http://www.cidoc-crm.org/extensions/crmdig/L21_used_as_derivation_source → oph:M1_3D_Object	☑	Entity reference	1	Edit
Technology	oph:M15_3D_Feature → http://www.cidoc-crm.org/extensions/crmdig/L22i_was_derivative_created_by → http://www.cidoc-crm.org/extensions/crmdig/D3_Formal_Derivation → http://www.cidoc-crm.org/extensions/crmdig/L23_used_software_or_firmware → http://www.cidoc-crm.org/extensions/crmdig/D14_Software → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Software	oph:M15_3D_Feature → http://www.cidoc-crm.org/extensions/crmdig/L11i_was_output_of → http://www.cidoc-crm.org/extensions/crmdig/D10_Software_Execution → http://www.cidoc-crm.org/extensions/crmdig/L23_used_software_or_firmware → http://www.cidoc-crm.org/extensions/crmdig/D14_Software → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Creation Date	oph:M15_3D_Feature → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P4_has_time-span → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☑	Text (plain)	1	Edit
Author	oph:M15_3D_Feature → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P14_carried_out_by → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	Unlimited	Edit
Description	oph:M15_3D_Feature → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31a_Annotation	☑	Text (plain, long)	1	Edit
Add file	oph:M15_3D_Feature → oph:R12i_is_embedded_in → oph:M17_Digital_Environment	☑	Entity reference	Unlimited	Edit
File	oph:M15_3D_Feature → oph:R12i_is_embedded_in → oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	File	Unlimited	Edit
File Type	oph:M15_3D_Feature → oph:R12i_is_embedded_in → oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit
Documentation	oph:M15_3D_Feature → http://www.cidoc-crm.org/cidoc-crm/P70i_is_documented_in → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31d_Note → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	File	Unlimited	Edit
Created in	oph:M15_3D_Feature → http://www.cidoc-crm.org/extensions/crmdig/L11i_was_output_of → oph:M25_Digital_Reconstruction	☑	Entity reference	1	Edit
Role Assignment	Group [https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment]	☑		Unlimited	Edit
Person	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Role	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit

RolAss_Person ID Set	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
RolAss_Person_Affiliation	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P141i_was_assigned_by → http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E74_Group	☑	Entity reference	Unlimited	Edit
RolAss_Person_Picture	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P138i_has_representation → http://www.cidoc-crm.org/cidoc-crm/E36_Visual_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Image	Unlimited	Edit
Participant_in_reconstruction	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P140_assigned_attribute_to → oph:M25_Digital_Reconstruction	☑	Entity reference	Unlimited	Edit
RolAss Person Email	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P76_has_contact_point → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Email	Unlimited	Edit
RolAss_Person	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person	☑	Entity reference	Unlimited	Edit
RolAss_Assigned_Projects	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → oph:M14_Research_Project	☑	Entity reference	Unlimited	Edit
RolAss_Organization	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E74_Group	☑	Entity reference	Unlimited	Edit
REF_Organization_Type	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
REF_Organization_ID_set	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
REF_Organization_Logo	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_13d_Role_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P138i_has_representation → http://www.cidoc-crm.org/cidoc-crm/E36_Visual_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Image	1	Edit
File	Group [oph:M17_Digital_Environment]	☑		Unlimited	Edit
Type	oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
Format	oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P165_incorporates → http://www.cidoc-crm.org/cidoc-crm/E73_Information_Object → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	1	Edit
Copyright disclaimer	oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P129i_is_subject_of → https://www.ontscidoc3d.hs-mainz.de/ontology/osd_30a_Copy_Right → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit
File	oph:M17_Digital_Environment → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	File	Unlimited	Edit
Attribute Assignment (Organization)	Group [http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment]	☑		Unlimited	Edit
Person	http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Text (plain)	Unlimited	Edit
Role (Organization)	http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	Unlimited	Edit
Time Span	http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P4_has_time-span → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☑	Entity reference	Unlimited	Edit
Person ID	http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier	☑	Entity reference	Unlimited	Edit
Person Picture	http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person → http://www.cidoc-crm.org/cidoc-crm/P138i_has_representation → http://www.cidoc-crm.org/cidoc-crm/E36_Visual_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Image	Unlimited	Edit
Ref_Organization	http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E74_Group	☑	Entity reference	Unlimited	Edit
Person_ref	http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E21_Person	☑	Entity reference	Unlimited	Edit
Ref_Organization_Logo	http://www.cidoc-crm.org/cidoc-crm/E13_Attribute_Assignment → http://www.cidoc-crm.org/cidoc-crm/P141_assigned → http://www.cidoc-crm.org/cidoc-crm/E74_Group → http://www.cidoc-crm.org/cidoc-crm/P138i_has_representation → http://www.cidoc-crm.org/cidoc-crm/E36_Visual_Item → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Image	1	Edit
Sources Set	Group [https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source]	☑		Unlimited	Edit
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Holder	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source → http://www.cidoc-crm.org/cidoc-crm/P105_right_held_by → http://www.cidoc-crm.org/cidoc-crm/E74_Group	☑	Entity reference	1	Edit

Creation Date	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P4_has_time-span → http://www.cidoc-crm.org/cidoc-crm/E52_Time-Span	☑	Text (plain)	1	Edit
Author	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source → http://www.cidoc-crm.org/cidoc-crm/P94i_was_created_by → http://www.cidoc-crm.org/cidoc-crm/E65_Creation → http://www.cidoc-crm.org/cidoc-crm/P14_carried_out_by → http://www.cidoc-crm.org/cidoc-crm/E39_Actor	☑	Entity reference	Unlimited	Edit
Content	Group [https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source → http://www.cidoc-crm.org/cidoc-crm/P106_is_composed_of → http://www.cidoc-crm.org/cidoc-crm/E31_Document]	☑		Unlimited	Edit
Type	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source → http://www.cidoc-crm.org/cidoc-crm/P106_is_composed_of → http://www.cidoc-crm.org/cidoc-crm/E31_Document → http://www.cidoc-crm.org/cidoc-crm/P2_has_type → http://www.cidoc-crm.org/cidoc-crm/E55_Type → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	List (text)	1	Edit
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URI	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source → http://www.cidoc-crm.org/cidoc-crm/P106_is_composed_of → http://www.cidoc-crm.org/cidoc-crm/E31_Document → http://www.cidoc-crm.org/cidoc-crm/P1_is_identified_by → http://www.cidoc-crm.org/cidoc-crm/E42_Identifier → http://www.cidoc-crm.org/cidoc-crm/P139_has_alternative_form → http://www.cidoc-crm.org/cidoc-crm/E41_Appellation	☑	Link	1	Edit
Ref Source	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source → http://www.cidoc-crm.org/cidoc-crm/P106_is_composed_of → http://www.cidoc-crm.org/cidoc-crm/E31_Document	☑	Entity reference	Unlimited	Edit
Ref Reconstruction	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source → http://www.cidoc-crm.org/cidoc-crm/P16i_was_used_for → oph:M25_Digital_Reconstruction	☑	Entity reference	Unlimited	Edit
REF Object	https://www.ontscidoc3d.hs-mainz.de/ontology/osd_31b_Source → http://www.cidoc-crm.org/cidoc-crm/P70_documents → oph:M26_Cultural_Heritage_Thing	☑	Entity reference	Unlimited	Edit
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