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GUIDELINES FOR THE MANAGEMENT OF CULTURAL HERITAGE USING 3D MODELS FOR THE INSERTION OF HETEROGENEOUS DATA

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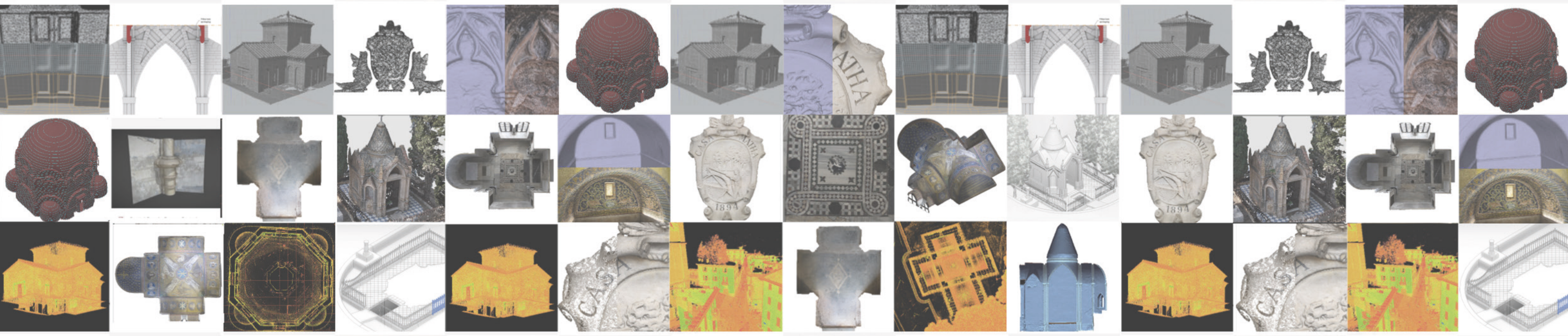

Guidelines for the Management of Cultural Heritage using 3D models for the insertion of heterogeneous data

Linee guida per la Gestione del Patrimonio Culturale tramite l'utilizzo di modelli tridimensionali per la raccolta di dati eterogenei

Directrices para la Gestión del Patrimonio Cultural a través de modelos tridimensionales como repositorios de datos heterogéneos

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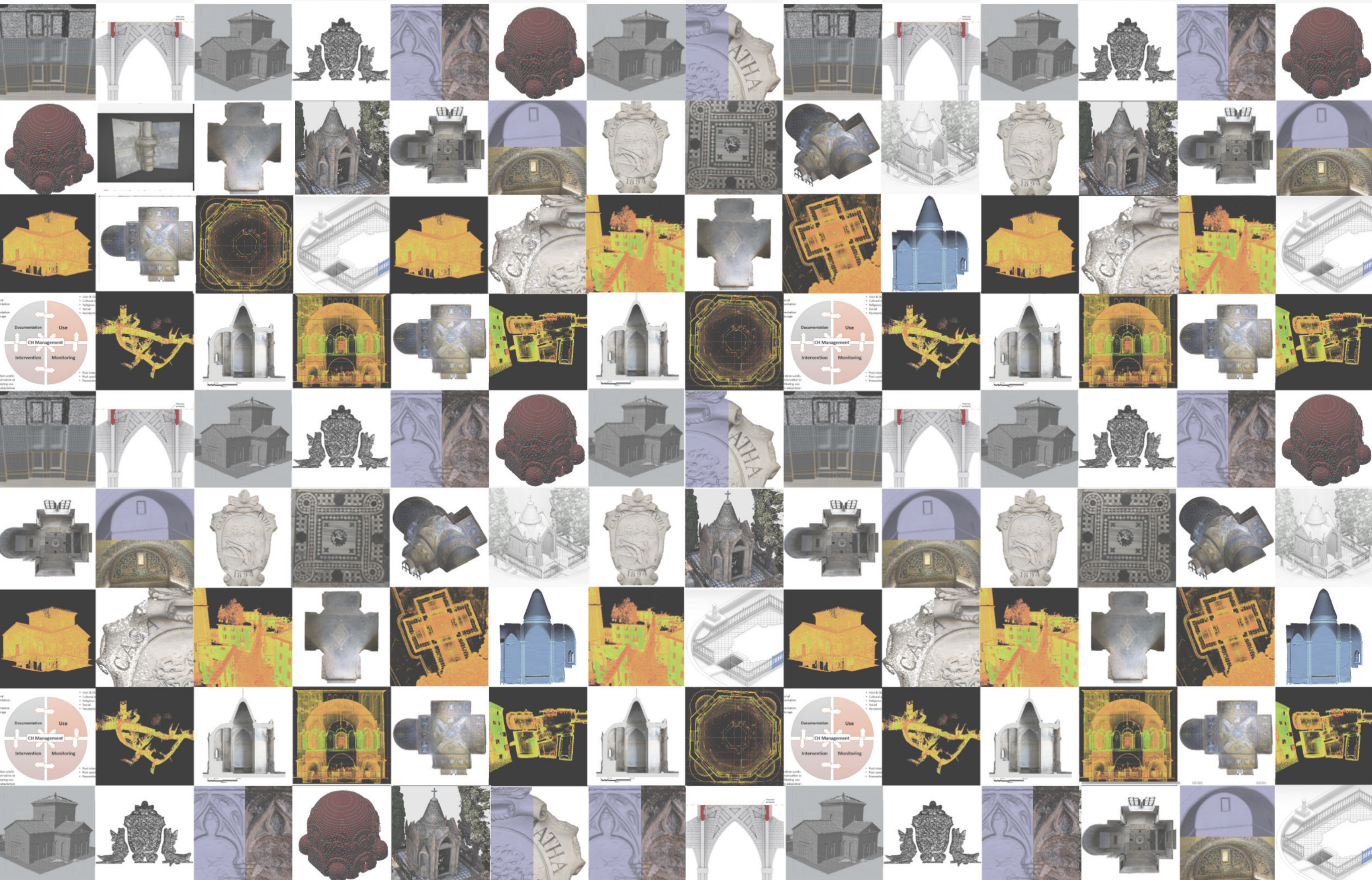

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CONTENTS

Abstract........ **13**

Chapter 1 - Introduction and premises........ **21**

1.1 The management of Cultural Heritage using 3D models........ 23
1.2 Current situation and prospects in digitisation and dissemination........ 25
1.3 Approach to research........ 26
- Reference list

Chapter 2 - State of the art........ **29**

2.1 The life cycle of a cultural asset........ 31
2.2 Main workflows used for documentation and management........ 32
2.2.1 Terrestrial laser scanning, digital photogrammetry and rapid acquisition techniques........ 34
- Reference list
2.2.2 Procedural Modelling, model optimization and use in game engines........ 37
- Reference list
2.2.3 Information System with reality-based 3D models and Historical BIM........ 39
- Reference list: Information Systems
- Reference list: HBIM
2.3 Using 3D models for dissemination........ 50
- Reference list
Conclusions

Chapter 3 - Hypotheses and objectives........ **59**

3.1 Current situation: digitisation, data storage and acquisition standards........ 61
3.2 Research objectives........ 65
Conclusions
- Reference list

Chapter 4 – Methodology and development.. **69**

4.1 Highlighted problems in the analysed workflows.. 71

4.1.1 Digital documentation phase.. 71

4.1.2 Digital data acquisition.. 72

4.1.3 Raw data processing.. 73

4.1.4 Digital data management.. 74

4.2 Presentation of case studies.. 75

4.2.1 Early Christian monuments of Ravenna.. 79

The Mausoleum of Galla Placidia.. 79

The Archiepiscopal Chapel.. 88

The Neonian Baptistery.. 89

4.2.2 The family chapel of Ramón Peres y Rovira - Castellón de la Plana (Spain)......... 94

4.2.3 Other monuments of Ravenna: the emblem of Casa Matha................................ 100

4.2.4 Hadrian's Villa: the dome of the Small Baths.. 104

4.2.5 Chiuro: urban survey and digital reconstruction for game engines...................... 107

4.3 Diffusion, dissemination and digitisation.. 112

Conclusions

- Reference list

Chapter 5 – Discussion of the results: guidelines.. **119**

5.1 Guidelines for the documentation and management of Cultural Heritage using 3D models.. 121

5.1.1 Digital documentation.. 123

5.1.2 Storage of collected data.. 126

5.1.3 Methods for acquiring and processing point clouds from Terrestrial Laser Scanners.. 129

5.1.4 Photographic acquisition and processing methods.. 134

5.1.5 Monitoring planning through digital documentation 140

5.1.6 Standards and digitisation.. 143

5.2 Management planning using 3D models.. 143

5.3 Dissemination strategies through 3D models.. 147

Conclusions

- Reference list

Chapter 6 - Conclusions and future lines of research.. **151**

Appendix.. **161**

INDICE DEI CONTENUTI

Abstract 13

Capitolo 1 - Introduzione e presupposti alla ricerca 21

1.1 La gestione dei Beni Culturali attraverso l'utilizzo di modelli tridimensionali

1.2 Situazione attuale e prospettive future nell'ambito della digitalizzazione e della divulgazione

1.3 Impostazione della ricerca

- Riferimenti bibliografici

Capitolo 2 - Stato dell'arte 29

2.1 Il ciclo di vita di un Bene Culturale

2.2 Principali workflow attualmente adottati per la documentazione e la gestione

2.2.1 Terrestrial Laser Scanner, fotogrammetria digitale e tecniche di acquisizione rapida

- Riferimenti bibliografici

2.2.2 Procedural Modelling, ottimizzazione dei modelli e uso nei game engines

- Riferimenti bibliografici

2.2.3 Sistemi Informativi 3D e Historic BIM

- Riferimenti bibliografici SI

- Riferimenti bibliografici HBIM

2.3 Utilizzo dei modelli 3D per la divulgazione

Conclusioni

- Riferimenti bibliografici

Capitolo 3 - Ipotesi e obiettivi della ricerca 59

3.1 Situazione attuale: digitalizzazione, conservazione dei dati e standard di acquisizione

3.2 Obiettivi della ricerca

Conclusioni

- Riferimenti bibliografici

Capitolo 4 – Metodologia e sviluppo della tesi 69

4.1 Principali problematiche evidenziate nell'analisi dei workflow

4.1.1 Fase di documentazione digitale

4.1.2 Acquisizione dei dati digitali

4.1.3 Processamento dei dati grezzi

4.1.4 Gestione dei dati digitali

4.2 Presentazione dei casi studio

4.2.1 L'architettura paleocristiana di Ravenna

Il Mausoleo di Galla Placidia

La Cappella Arcivescovile o di Sant'Andrea

Il Battistero Neoniano

4.2.2 La cappella funeraria di Ramón Peres y Rovira - Castellón de la Plana (Spagna)

4.2.3 Altri Beni Culturali della città di Ravenna: lo Stemma della Casa Matha

4.2.4 Villa Adriana: la cupola delle Piccole Terme

4.2.5 Chiuro: documentazione urbana e ricostruzione digitale per l'utilizzo in game engines

4.3 Diffusione, divulgazione e digitalizzazione

Conclusioni

- Riferimenti bibliografici

Capitolo 5 – Discussione dei risultati: linee guida 119

5.1 Linee guida per la documentazione e gestione dei Beni Culturali attraverso l'uso di modelli 3D

5.1.1 Documentazione digitale

5.1.2 Conservazione dei dati raccolti

5.1.3 Metodi di acquisizione e processamento delle nuvole di punti da Terrestrial Laser Scanner

5.1.4 Metodi di acquisizione e processamento delle fotografie

5.1.5 Pianificazione del monitoraggio attraverso la documentazione digitale

5.1.6 Standard e digitalizzazione

5.2 Pianificazione della gestione attraverso i modelli 3D

5.3 Strategie di divulgazione attraverso i modelli 3D

Conclusioni

- Riferimenti bibliografici

Capitolo 6 - Conclusioni e future linee di ricerca 151

Appendice 161

ÍNDICE DE CONTENIDOS

Resumen **13**

Capítulo 1 – Introducción y motivación de la investigación **21**

1.1 La gestión de los Bienes Culturales a través de modelos tridimensionales
1.2 Situación actual y perspectivas futuras en el ámbito de la digitalización y la divulgación
1.3 Enfoque de investigación
- *Referencias bibliográficas*

Capítulo 2 – Estado del arte **29**

2.1 El ciclo de vida de un Bien Cultural
2.2 Principales flujos de trabajo actualmente adoptados para la documentación y la gestión
2.2.1 Láser escáner terrestre, fotogrametría digital y técnicas de captura rápida de datos
- *Referencias bibliográficas*
2.2.2 Modelación procedural, optimización de modelos y uso en motores de juego
- *Referencias bibliográficas*
2.2.3 Sistemas de información e Historic BIM
- *Referencias bibliográficas SI*
- *Referencias bibliográficas HBIM*
2.3 Uso de modelos 3D para la divulgación
- *Referencias bibliográficas*
Conclusiones

Capítulo 3 - Hipótesis y objetivos **59**

3.1 Situación actual: digitalización, conservación de los datos y estándares de adquisición de datos
3.2 Objetivos de la investigación
Conclusiones
- *Referencias bibliográficas*

Capítulo 4 - Metodología y desarrollo **69**

4.1 Problemas destacados en los flujos de trabajo examinados
4.1.1 Fase de documentación digital
4.1.2 Adquisición de datos digitales
4.1.3 Procesamiento de datos brutos
4.1.4 Gestión de datos digitales
4.2 Presentación de los casos de estudio
4.2.1 La arquitectura paleocristiana de Rávena
El Mausoleo de Galla Placidia
La Capilla Arzobispal
El Baptisterio Neoniano
4.2.2 El panteón de Ramón Peres y Rovira - Castellón de la Plana (España)
4.2.3 Otros Bienes Culturales de la ciudad de Rávena: el Emblema de la Casa Matha
4.2.4 Villa Adriana: la cúpula de las Termas Pequeñas
4.2.5 Chiuro: documentación urbana y reconstrucción digital para la inserción en motores de juego
4.3 Difusión, divulgación y digitalización
Conclusiones
- *Referencias bibliográficas*

Capítulo 5 – Discusión de los resultados: directrices **119**

5.1 Directrices para la documentación y la gestione de los Bienes Culturales utilizando los modelos 3D
5.1.1 Documentación digital
5.1.2 Conservación de los datos adquiridos
5.1.3 Métodos de adquisición y elaboración de nubes de puntos de láser escáner terrestre
5.1.4 Métodos de adquisición y elaboración de fotografías
5.1.5 Planificación de la conservación preventiva a través de la documentación digital
5.1.6 Estándares y digitalización
5.2 Planificación de la gestión a través de los modelos 3D
5.3 Estrategias de divulgación a través de los modelos 3D
Conclusiones
- *Referencias bibliográficas*

Capítulo 6 – Conclusiones y líneas futuras de investigación **151**

Apéndice **161**

ÍNDEX DE CONTINGUTS

Resum **13**

Capítol 1 - Introducció i motivació de la investigació **21**

1.1 La gestió dels Béns Culturals a través de models tridimensionals

1.2 Situació actual i perspectives futures en l'àmbit de la digitalització i la divulgació

1.3 Enfocament d'investigació

- Referències bibliogràfiques

Capítol 2 – Estat d'art **29**

2.1 El cicle de vida d'un Bé Cultural

2.2 Principals fluxos de treball actualment adoptats per a la documentació i la gestió

2.2.1 Làser escàner terrestre, fotogrametria digital i tècniques de captura ràpida de dades

- Referències bibliogràfiques

2.2.2 Modelació procedural, optimització de models i ús en els motors de joc

- Referències bibliogràfiques

2.2.3 Sistemes 3D d'informació i Historic BIM

- Referències bibliogràfiques SI

- Referències bibliogràfiques HBIM

2.3 Ús de models 3D per a la divulgació

- Referències bibliogràfiques

Conclusions

Capítol 3 - Hipòtesi i objectius de la investigació **59**

3.1 Situació actual: digitalització, conservació de les dades i estàndards d'adquisició de dades

3.2 Objectius de la investigació

Conclusions

- Referències bibliogràfiques

Capítol 4 - Metodologia i desenrotllament de la investigació **69**

4.1 Problemes destacats en els fluxos de treball examinats

4.1.1 Fase de documentació digital

4.1.2 Adquisició de dades digitals

4.1.3 Processament de dades brutes

4.1.4 Gestió de dades digitals

4.2 Presentació dels casos d'estudi

4.2.1 L'arquitectura paleocristiana de Ravenna

El Mausoleu de Galla Placidia

La Capella Arquebisbal

El Baptisteri Neoniano

4.2.2 El panteó de Ramón Peres i Rovira - Castelló de la Plana (Espanya)

4.2.3 Altres Béns Culturals de la ciutat de Ravenna: l'Emblema de la Casa Matha

4.2.4 Vila Adriana: la cúpula de les Termes Xicotetes

4.2.5 Chiuro: documentació urbana i reconstrucció digital per a la inserció en motors de joc

4.3 Difusió, divulgació i digitalització

Conclusions

- Referències bibliogràfiques

Capítol 5 – Discussió dels resultats: directrius **119**

5.1 Directrius per a la documentació i la gestione dels Béns Culturals utilitzant els models 3D

5.1.1 Documentació digital

5.1.2 Conservació de les dades adquirits

5.1.3 Mètodes d'adquisició i elaboració de núvols de punts de làser escàner terrestre

5.1.4 Mètodes d'adquisició i elaboració de fotografies

5.1.5 Planificació de la conservació preventiva a través de la documentació digital

5.1.6 Estàndards i digitalització

5.2 Planificació de la gestió a través dels models 3D

5.3 Estratègies de divulgació a través dels models 3D

Conclusions

- Referències bibliogràfiques

Capítol 6 – Conclusions i línies futures d'investigació **151**

Apèndix **161**

Abstract

The Management of Cultural Heritage (MCH) is a very complex operation aimed at protecting the physical integrity of Cultural Heritage assets, while promoting their historical value and development of tourism industry. Composed by distinct phases (documentation, intervention, monitoring and use), MCH implies a great effort for the project manager to coordinate the interactions among very different professional figures.

In recent years, the use of digital technologies has become an essential part of the MCH delicate process, from early documentation to late intervention phases. The most commonly used methodologies for digital data acquisition, such as terrestrial laser scanning and digital photogrammetry, have become common practice in a broad range of professional activities. On the contrary, the use of three-dimensional (3D) models for MCH is still limited to few academic research to date, often lacking continuity and wide application after the end of specific projects. Furthermore, while on the one hand the European Commission encourages the digitisation and use of 3D models in the MCH field, very few supra-national standard guidelines regulating their use are available to date. As a consequence, the operator who

La Gestione del Patrimonio Culturale (GPC) è un'operazione molto complessa mirata alla conservazione dell'integrità fisica dei Beni Culturali e alla contemporanea divulgazione dei valori storici e fruizione del Patrimonio. Date le molteplici fasi che compongono la GPC (documentazione, intervento, monitoraggio, uso), il gestore è sottoposto a un grande sforzo nel coordinare le interazioni create da figure professionali molto diverse tra di loro, sia per background formativo che per esigenze specifiche nell'ambito della gestione.

Nel corso degli ultimi anni l'applicazione delle tecnologie digitali ai Beni Culturali è diventata una parte imprescindibile nella GPC, dalle fasi di documentazione fino all'intervento. Le metodologie più comunemente usate per l'acquisizione dei dati, come la scansione con laser scanner terrestre e la fotogrammetria digitale, sono diventate una pratica comune anche nelle attività professionali. Tuttavia, l'uso dei modelli tridimensionali (3D) per la gestione è finora limitato ad alcune ricerche e applicazioni accademiche, che spesso non hanno una continuità dopo la fine del progetto. Inoltre, mentre da una parte la Commissione Europea incentiva la digitalizzazione e l'utilizzo dei modelli 3D nel campo dei Beni Culturali, ad oggi sono pochi gli standard con carattere

decides to use a 3D model as a basis for management is faced with the scarcity and fragmentation of standards and guidelines in the field. Moreover, the lack of standard on quality of acquired data and digital products negatively influences the interaction between the academic research sector, the managers and the professional world.

The focus is on the use of 3D models as a valid support tool in the MCH process, highlighting their advantages in all the distinct phases of the management. As an example, 3D data can constitute themselves the basis for the digital database, gathering all available information concerning a Cultural Heritage site, exploitable for restoration works or for scientific dissemination. In particular, the aim of my PhD research is to develop guidelines to produce 3D models for MCH, with the purpose to efficiently entry, store and manage digital data. The here provided guidelines investigate every aspect of the process leading from data acquisition to cataloguing and archiving, processing and creation of a simplified information system for the management. Each recommendation guides the user through the management of digital data, by adapting to his/her level of knowledge with respect to digital technologies and methodologies. In this way, even with minimal previous knowledge of digital technologies, the manager can efficiently use 3D models in MCH projects.

In order to elaborate guidelines that could be suitable for as many typologies of Cultural Heritage as possible an international approach was chosen, developing the thesis in joint supervision under the University of Bologna and the Universitat Politècnica de València. We decided to apply state-of-the-art technologies of acquisition, elaboration and use of 3D models to a variety of case studies, each belonging to a specific type of Cultural Heritage. The main ones are the early Christian

sovranazionale che guidano gli Enti nel procedimento di creazione e uso dei modelli tridimensionali per la GPC. Questo comporta che il gestore che decide di utilizzare un modello 3D come base per la gestione si scontri con la scarsezza e la frammentarietà di standard e indicazioni in tale ambito. La mancanza di strumenti per controllare la qualità dei dati acquisiti e dei prodotti digitali incide quindi in maniera negativa sull'interazione tra il settore accademico della ricerca, il settore della gestione e il mondo professionale.

Nella ricerca si propone l'utilizzo dei modelli 3D come un valido strumento di supporto in tutte le fasi della gestione, sia usando il dato tridimensionale come base per l'archivio digitale che raccoglie tutti i dati inerenti al Bene, sia sfruttando tutti i prodotti ottenuti dal dato di base per le molteplici azioni di ogni fase, come l'utilizzo di dati digitali per gli interventi di restauro o dei modelli 3D ottimizzati per la divulgazione. Pertanto, l'obiettivo della tesi di Dottorato è quello di elaborare linee guida per la produzione di modelli 3D del Patrimonio Culturale per un'efficace gestione, inserimento e conservazione dei dati. Tali linee guida indagano ogni aspetto del processo che porta dall'acquisizione del dato, alla sua catalogazione e archiviazione, al suo processamento e alla creazione di un sistema informativo semplificato per la gestione. Ogni particolare indicazione guida l'utente in una specifica fase dell'elaborazione e dell'utilizzo del dato digitale e fornisce indicazioni che si adattano al livello di conoscenza rispetto alle tecnologie e metodologie digitali. In questo modo, anche con una conoscenza minima delle tecnologie digitali, il gestore può avvalersi dei modelli 3D per la gestione e controllarne la qualità e gli standard minimi.

Per arrivare all'elaborazione di linee guida che si adattino a più tipologie possibili di Beni Culturali è stato scelto un approccio interdisciplinare e internazionale, sviluppando

monuments of Ravenna (Italy) belonging to the UNESCO World Heritage List, and a small neogothic chapel located in Castellón de la Plana (Spain). The fruitful collaboration between two different countries allowed an invaluable exchange of MCH expertise and, more broadly, contributed to the elaboration of standardized and universally applicable MCH guidelines that will allow a better interaction between managers, the academic research world and the professional one.

The investigation, by highlighting the problems inherent to the MCH, made it possible to identify the main open issues that need to be explored in future lines of research, such as the application of standards to a large number of cultural assets in an iterative, continuous and automatic way, in order to perfecting the standards; the search for systems, for the automatic classification of raw data; the processing of collected data for the creation of relations, strategies and methods for the classification, integration and optimisation of heterogeneous data.

la tesi in regime di cotutela tra l'Università di Bologna e l'Universitat Politècnica de València. Per ottenere delle linee guida di carattere universale, le metodologie analizzate nello studio dello stato dell'arte sono state applicate a una molteplicità di casi studio, ciascuno appartenente a una specifica tipologia di Bene Culturale. I principali sono i monumenti paleocristiani di Ravenna (Italia) appartenenti alla World Heritage List della UNESCO e una piccola cappella neogotica situata a Castellón de la Plana (Spagna). Le esperienze realizzate sulla GPC nei due Paesi hanno contribuito all'elaborazione di linee guida e standard universali per il miglioramento delle interazioni tra il mondo accademico, i gestori e il settore professionale.

Il percorso di ricerca, evidenziando le problematiche inerenti la GPC, ha permesso di individuare le principali questioni aperte che devono essere approfondite in future linee di ricerca, come l'applicazione di standard a un alto numero di Beni Culturali in maniera iterativa, continua e automatica per condurre alla messa a punto degli stessi standard; la ricerca di sistemi per la classificazione automatica dei dati grezzi; l'elaborazione dei dati raccolti per la creazione di relazioni, strategie e metodi per la classificazione, l'integrazione e l'ottimizzazione di dati eterogenei.

Resumen

La Gestión del Patrimonio Cultural (GPC) es una operación muy compleja cuyo objetivo es preservar la integridad física de los Bienes Culturales y, al mismo tiempo, difundir los valores históricos y permitir el disfrute del Patrimonio. Debido a las múltiples fases que componen la GPC (documentación, intervención, conservación preventiva, uso), el gestor se ve sometido a un gran esfuerzo de coordinación de las interacciones creadas por figuras profesionales muy diferentes, tanto por formación como por necesidades específicas en el ámbito de la gestión.

En los últimos años, la aplicación de las tecnologías digitales al Patrimonio Cultural se ha convertido en una parte indispensable de la GPC, desde las fases de documentación hasta las de intervención. Las metodologías más utilizadas para la adquisición de datos, como el escaneo láser terrestre y la fotogrametría digital, también se han convertido en una práctica habitual en las actividades profesionales. Sin embargo, el uso de modelos tridimensionales (3D) para la gestión se limita hasta ahora a algunas investigaciones y aplicaciones académicas, que a menudo no tienen continuidad tras la finalización del proyecto. Además, aunque por un lado la Comisión Europea fomenta la

Resum

La Gestió del Patrimoni Cultural (GPC) és una operació molt complexa l'objectiu de la qual és preservar la integritat física del els Béns Culturals i, al mateix temps, difondre els valors històrics i permetre el gaudi del Patrimoni. A causa de les múltiples fases que componen la GPC (documentació, intervenció, conservació preventiva, ús) , el gestor es veu sotmés a un gran esforç de coordinació de les interaccions creades per figures professionals molt diferents, tant per formació com per necessitats específiques en l'àmbit de la gestió.

En els últims anys, l'aplicació de les tecnologies digitals al Patrimoni Cultural s'ha convertit en una part indispensable de la GPC, des de les fases de documentació fins a les d'intervenció. Les metodologies més utilitzades per a l'adquisició de dades, com l'escaneig làser terrestre i la fotogrametria digital, també s'han convertit en una pràctica habitual en les activitats professionals. No obstant això, l'ús de models tridimensionals (3D) per a la gestió es limita fins ara a algunes investigacions i aplicacions acadèmiques, que sovint no tenen continuïtat després de la finalització del projecte. A més, encara que per un costat la Comissió Europea fomenta la digitalització i l'ús de models 3D en l'àmbit

digitalización y el uso de modelos 3D en el ámbito del Patrimonio Cultural, hasta la fecha existen pocas normas supranacionales que guíen a las instituciones en el proceso de creación y uso de modelos 3D para la GPC. Esto implica que el operador que decide utilizar un modelo 3D como base para la gestión se enfrenta a la escasez y fragmentación de normas e indicaciones en este campo. Por tanto, la falta de herramientas para controlar la calidad de los datos y productos digitales adquiridos afecta negativamente a la interacción entre el sector de la investigación académica, el sector de la gestión y el mundo profesional.

La investigación propone el uso de los modelos 3D como una herramienta válida de apoyo en todas las fases de la gestión, ya sea utilizando los datos tridimensionales como base del archivo digital que recoge todos los datos relacionados con el bien, o explotando todos los productos obtenidos a partir de los datos básicos para las múltiples acciones de cada fase, como el uso de los datos digitales para las intervenciones de restauración o los modelos 3D optimizados para la divulgación. Por lo tanto, el objetivo de la tesis doctoral es desarrollar directrices para la producción de modelos 3D del Patrimonio Cultural con el fin de gestionar, introducir y preservar eficazmente los datos. Estas directrices investigan todos los aspectos del proceso que va desde la adquisición de datos, pasando por su catalogación y archivo, hasta su tratamiento y la creación de un sistema de información simplificado para su gestión. Cada directriz particular guía al usuario a través de una fase específica del tratamiento y el uso de los datos digitales, y proporciona indicaciones adaptadas al nivel de conocimientos respecto a las tecnologías y metodologías digitales. De este modo, incluso con un conocimiento mínimo de las tecnologías digitales, el gestor puede utilizar

del Patrimoni Cultural, fins a la data hi ha poques normes supranacionals que guien a les institucions en el procés de creació i ús de models 3D per a la GPC. Açò implica que l'operador que decidix utilitzar un model 3D com a base per a la gestió s'enfronta a l'escassetat i fragmentació de normes i indicacions en este camp. Per tant, la falta de ferramentes per a controlar la qualitat de les dades i productes digitals adquirits afecta negativament la interacció entre el sector de la investigació acadèmica, el sector de la gestió i el món professional.

La investigació proposa l'ús dels models 3D com una ferramenta vàlida de suport en totes les fases de la gestió, ja siga utilitzant les dades tridimensionals com a base de l'arxiu digital que arreplega totes les dades relacionats amb el bé, o explotant tots els productes obtinguts a partir de les dades bàsiques per a les múltiples accions de cada fase, com l'ús de les dades digitals per a les intervencions de restauració o els models 3D optimitzats per a la divulgació. Per tant, l'objectiu de la tesi doctoral és desenrotllar directrius per a la producció de models 3D del Patrimoni Cultural a fi de gestionar, introduir i preservar eficaçment les dades. Estes directrius investiguen tots els aspectes del procés que va des de l'adquisició de dades, passant per la seua catalogació i arxiu, fins al seu tractament i la creació d'un sistema d'informació simplificat per a la seua gestió. Cada directriu particular guia l'usuari a través d'una fase específica del tractament i l'ús de les dades digitals, i proporciona indicacions adaptades al nivell de coneixements respecte a les tecnologies i metodologies digitals. D'esta manera, inclús amb un coneixement mínim de les tecnologies digitals, el gestor pot utilitzar els models 3D per a la seua gestió i controlar la seua qualitat i els seus estàndards mínims.

S'ha optat per un enfocament interdisciplinari

los modelos 3D para su gestión y controlar su calidad y sus estándares mínimos.

Se ha optado por un enfoque interdisciplinar e internacional con el fin de elaborar directrices que se adapten al mayor número posible de tipos de Bienes Culturales, desarrollando la tesis en el marco de un acuerdo de cotutela entre la Universidad de Bolonia y la Universitat Politècnica de València. Con el fin de obtener unas pautas universales, las metodologías analizadas en el estudio del estado del arte se aplicaron a una serie de casos de estudio, cada uno de ellos perteneciente a un tipo específico de bien. Los principales son los monumentos paleocristianos de Rávena (Italia), pertenecientes a la Lista del Patrimonio Mundial de la UNESCO, y una pequeña capilla neogótica situada en Castellón de la Plana (España). Las experiencias realizadas sobre la GPC en los dos países han contribuido a la elaboración de directrices y normas universales que mejoren las interacciones entre el mundo académico, los gestores y el sector profesional.

La investigación, al poner de manifiesto los problemas inherentes a la GPC, ha permitido identificar las principales cuestiones abiertas que se deben explorar en futuras líneas de investigación, como la aplicación de estándares a un gran número de Bienes Culturales de forma iterativa, continua y automática para conducir a la puesta a punto de los mismos estándares; la búsqueda de sistemas para la clasificación automática de los datos brutos; el tratamiento de los datos recogidos para la creación de relaciones, estrategias y métodos de clasificación, integración y optimización de datos heterogéneos.

i internacional a fi d'elaborar directrius que s'adapten al nombre més gran possible de tipus de Béns Culturals Cultural, desenrotllat la tesi en el marc d'un acord de cotutela entre la Universitat de Bolonya i la Universitat Politècnica de València. A fi d'obtindre unes pautes universals, les metodologies analitzades en l'estudi de l'estat de l'art es van aplicar a una sèrie de casos d'estudi, cada un d'ells pertanyent a un tipus específic de bé. Els principals són els monuments paleocristians de Ravenna (Itàlia), pertanyents a la Llista del Patrimoni Mundial de la UNESCO, i una xicoteta capella neogòtica situada a Castelló de la Plana (Espanya). Les experiències realitzades sobre la GPC en els dos països han contribuït a l'elaboració de directrius i normes universals que milloren les interaccions entre el món acadèmic, els gestors i el sector professional.

La investigació, al posar de manifest els problemes inherents a la GPC, permet identificar les principals qüestions obertes que s'han d'explorar en futures línies d'investigació, com l'aplicació d'estàndards a un gran nombre de Béns Culturals de forma iterativa, contínua i automàtica per a conduir a la posada al punt dels mateixos estàndards; la busca de sistemes per a la classificació automàtica de les dades brutes; el tractament de les dades arreplegats per a la creació de relacions, estratègies i mètodes de classificació, integració i optimització de dades heterogènies.

CHAPTER 1

INTRODUCTION AND PREMISES

Chapter 1 - *Introduction and premises*

1.1 - The Management of Cultural Heritage using 3D models

The management of Cultural Heritage (CH) is a very complex process, both on a large and small scale. Under the term “management”, in fact, are included all those actions and plans related to the specific asset that concern its whole life cycle, from documentation to conservation, from use to monitoring. Within these categories are activities as diverse as the investigation of a specific aspect, the provision of a compatible use for fruition, the decision of interventions to be implemented for its conservation and enhancement, the management of tourist flows, the preparation of monitoring plans, just to name a few. All this obviously determines a great variety of specialists and professionals belonging to different sectors who deal with the same asset, but specifically with only one or two aspects of its life cycle, while other users have to deal with coordinating the management of all these professionals, without being able to enter into the merits of every action to be undertaken. The application of information technology to CH management has provided a great help and impetus, starting with the first simple databases of archival material, moving on to GIS applications, and finally to the use of systems based on 3D models or their use in some phases of the management cycle. The users who deal with CH, and therefore use these digital tools, are professionals from very different disciplinary fields. Moreover, their cultural background includes some specific knowledge in their field of application, but few transversal skills. Therefore, the use of such sophisticated digital tools as three-dimensional models is not always realised at 100% of its real potential.

Furthermore, as the use of three-dimensional models for the management of CH is a relatively recent practice, especially in the professional world, workflows with standards for the acquisition, processing and storing of digitally collected data are still uncommon. The need for standards and regulations has increasingly emerged in recent years due to the growing application of digital technologies in the field of CH. This has led to an increased search for procedures that attempt to generalise the characteristics of CH to propose directions for digitisation. However, applications are still sporadic at national level (something at a European level) and this leads to major problems reported by the managers themselves, who do not know how to request, catalogue, archive and use digital data and models.

The use of 3D models for the management of CH has received a great boost in recent years, thanks above all to the technological advancement of data acquisition tools and the optimisation of data processing techniques. The reduction of data processing times, with the simultaneous increase of quality levels obtainable in less time and in a more automatic way, lead us towards the growing use of these technologies as tools of valid support to the operations of documentation, intervention and in general management of CH.

The digitisation process that transformed paper archives and cataloguing sheet into digital data was the basis for the creation of the first heterogeneous data repositories related to CH. In Italy, at the beginning of the 2000s, the ministerial system SiCAR[1] was created as an online repository of data on restoration sites. The platform is not only an online database of geo-referenced data on CH, but also a ministerial tool. In fact, its control the data entered and the interventions carried out, with some cataloguing standards, as the fields to be filled in are regulated by rules studied by the ICCD[2].

In spite of the importance of these types of databases that we can define as "bidimensional", it is only in the last few years that scholars are experimenting with information systems completely based on the use of 3D models, in the sense that the three-dimensional data are not just a type of deposited data but are the centre around which the entire information system is built. The 3D model reality-based of the cultural assets works for data retrieval (by simply selecting an element) or even for mapping of pathologies or data directly annotated on the mesh surface. In other cases, the 3D model, not reality-based but remodelled starting from the raw data, is however the centre of the information system and works well in the exchange of material or in the possibility of performing simultaneous operations on the file (like BIM - Building Information Modeling) (see chapter 2).

However, the increasing use of these technologies has not been accompanied by a parallel guidance of good practices and standards for the acquisition and use of digital data. Often academic experiments remain as such and are hardly linked to the professional world or regulated by legislation. CH managers increasingly complain about the lack of guidelines that coordinate and plan the management of CH through 3D models.

From these considerations it is necessary to analyse technical and managerial problems and possible solutions for the correct use of digital data in the management phases of a CH. An important issue is also the diffusion and dissemination of these digital methodologies and 3D products. In fact, while the advantages of a digital database over a paper archive are clear among all professionals and managers, there is not the same confidence about the use of digital

1 _ Sistema Informativo per i Cantieri di Restauro - Information System for Restoration Sites.
2 _ Istituto Centrale per il Catalogo e la Documentazione - Central Institute for Catalogue and Documentation.

technologies, and especially 3D models, for the management of CH. This is due to two main factors: (i) the inability to use digital tools correctly and (ii) the lack of knowledge about the possible uses of a 3D model as a tool for the study, conservation, restoration, monitoring of a cultural asset and the use as a database of heterogeneous data. This leads to a generic mistrust in everything related to the world of digital data, especially for professionals and users who have been trained in a traditional way and who encounter considerable difficulties in converting to digital with profit. The opposite excess is also a common problem, i.e. an excessive use of digital technologies or particular processes even when they are not absolutely necessary or not the best applicable methodology.

1.2 Current situation and prospects in digitisation and dissemination

In the previous section the general overview of the management of Cultural Heritage by means of three-dimensional models has been briefly described. The main problems were also mentioned, which basically concern two distinct but closely connected fields: on the one hand there are the technical problems encountered in the realisation of three-dimensional models of CH, on the other hand there are the problems in the use of these models for management, both by professionals and general users.

The current lack of shared standards for the acquisition, processing, cataloguing, and archiving of digital products leads to a general anarchy in the use and creation of data storages. Often digital data are collected with a considerable expenditure of economic resources in one-off actions that are not followed by a digital documentation plan for monitoring, nor by the provision of these data to the competent administration. Often the administration in charge initiates new documentation actions, generated by the lack of a structured data storage, homogenously standardised at national level, and by the frequent changes in the figures of cultural site managers.

In Italy, digitisation issues are therefore addressed from a point of view limited the process of transforming archival paper into digital database. In the recent national recovery and resilience plan (PNRR)[3] (Governo della Repubblica Italiana, 2021) the huge resources dedicated to the “digital strategy and platforms for Cultural Heritage”[4] (500 million Euros) refer, as explained in the same plan, in a generalised way to the «digitisation of what is preserved in museums, archives, libraries and places of culture, in order to allow citizens and operators in the sector to explore new ways of using cultural heritage and to have a simpler and more effective relationship with the public administration» (Governo della Repubblica Italiana, 2021, p. 108). The central institute for the digitisation of Cultural Heritage, or “Digital Library”, which is in charge of implementing what is defined by the PNRR, does not go into the issue of 3D models, except mentioning some products related to digital acquisitions (Virtual tours, Gaming) (MIBACT - ICDP, 2020, p. 21), but

3 _ Piano Nazionale di Ripresa e Resilienza
4 _ “Strategia e piattaforme digitali per i beni culturali”

without including them in digitisation actions.

The Italian regulatory gap is being addressed instead by European Commissions, which are focusing on the acquisition, treatment, preservation and use of digitised heritage and on the definition of workflows and standards (ERA Chair Mnemosyne Project, 2019), starting from the study of digitisation practices used by researchers on different case studies (see chapter 3). Given the wide variety of typologies of cultural assets, it is indeed appropriate to generalise starting from a broad base of case studies.

Given the complex relationships that underlie the digitisation of CH and the use of such digital products, it becomes increasingly important to establish standards, workflows and good practices to address current shortcomings and to properly plan the acquisition, conservation and use of digital data related to CH.

1.3 Approach to research

The PhD course developed around three main activities: (i) study of the state of the art; (ii) application of the methodologies to case studies; (iii) drafting of guidelines for the Management of Cultural Heritage and the inclusion of heterogeneous data through three-dimensional models.

The research was carried out under a cotutelle agreement with the Universitat Politècnica de València (Spain), with two stays of a total duration of 12 months at the Instituto de Restauración del Patrimonio of the same university.

During the first stay (01/02/2020 - 30/09/2020) it was possible to acquire the digital data (scans and photographs with reflex camera and drone) of the case study, a neogothic chapel located in the cemetery of Castellón de la Plana (València, Spain). The small building proved to be an emblematic case for the application of HBIM workflow, to provide restorers with a digital tool for carrying out restoration works (see section 4.2.2). In addition, three courses of the Máster Universitario en Conservación del Patrimonio Arquitectónico (Master's Degree in Preservation of Architectural Heritage: Study and analysis of interventions, Management of CH Workshop, World Heritage) were attended, providing specific knowledge on the local regulation and management of cultural assets, some of them belonging to the UNESCO World Heritage List. The case study of the Management of CH Workshop, the Lonja de los Mercaderes in València, is itself included in the UNESCO World Heritage List. Some of the activities related to the courses, such as the online seminars with the managers of some UNESCO sites and the study trip to Palma de Mallorca (Spain), made it possible to relate more closely to all types of figures involved in the management of CH, to understand their needs and to be able to compare the intervention and management strategies in different countries and contexts. The skills acquired were applied to the main case studies (in Italy the Early Christian Monuments of Ravenna and in Spain the already mentioned chapel) and to other minor ones (see chapter 4). The main purpose of the second stay (01/04/2021-10/08/2021) was to verify the correctness of the guidelines proposed within the thesis (see chapter 5) in order to optimise the processes of documentation and digital management of CH through 3D models, also in an international context.

The text of the thesis follows the division of the research work into the three main activities mentioned above. In particular, chapter 2 describes the study of the state of the art, focusing on the main methods of acquisition and processing of digital data related to CH, and creation of management systems through 3D models (Information Systems and BIM). The most used workflows are analysed by reporting the main and most significant case studies, as well as current and future lines of research in each field.

Chapter 3 describes the underlying hypotheses to the PhD research and the objectives to be achieved with the creation and use of guidelines, reporting an analysis of the current situation of standards for the digitisation and use of 3D models, relating the situation to the current regulatory framework.

Chapter 4 contains the methodological applications to the selected case studies and the justification for the choice of the various methodologies and workflows based on the issues highlighted through the state-of-the-art study. The multiplicity and variety of the selected case studies and the different applications of the methodologies were the basis for the creation of guidelines that could be applied to the great variety of CH.

Chapter 5 proposes guidelines for the management of CH through 3D models that touch every aspect of the management of an asset (Documentation, Conservation, Monitoring, Use). The guidelines therefore propose methods and standards for the correct acquisition, cataloguing, storing and use of digital data, relating the various types of users who deal with the asset during its management to the knowledge levels of each, to provide generic or specific indications and tools. The objective of the guidelines is the creation of a Management Plan based on a simplified Information System that through the use of 3D models allows the creation of a digital archive. This must be able to allow the insertion of heterogeneous data (thus functioning as a database), but at the same time allow the retrieval and use of data by users with different levels of experience, so as to be used as a tool for management actions.

Lastly, chapter 6 collects conclusions and future lines of research in the field of CH management through three-dimensional models.

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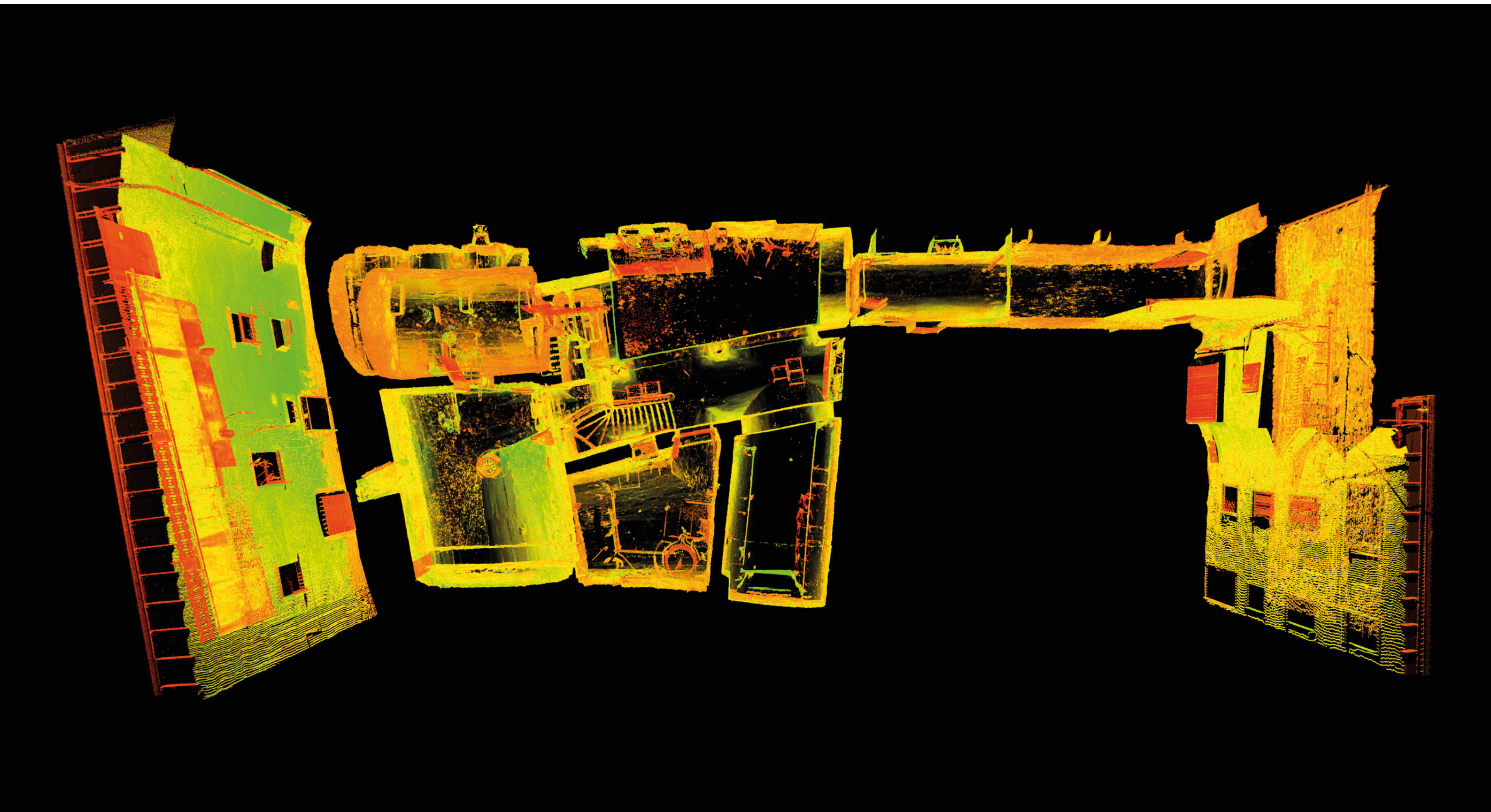
Point cloud of Palazzo Andres, Chiuro (Sondrio, Italy)

Chapter 2

State of the art

The chapter defines the concept of "life cycle" applied to the Management of Cultural Heritage. The chapter also contains an in-depth study of the state of the art that concern each aspect of the digitisation of Cultural Heritage: data acquisition through terrestrial laser scanning and digital photogrammetry; procedural modelling, model optimisation and use of game engines; Information Systems; HBIM; use of 3D models for dissemination.



Chapter 2 - State of the art

2.1 The life cycle of a cultural asset

The concept of "life cycle" has been used in the analysis of the Cultural Heritage (CH) management process. This is normally used in the assessment of the environmental impact of any new construction or product, from extraction of raw materials to disposal ("from cradle to grave" of the Life Cycle Assessment). In this thesis the concept of "life cycle" has been applied to the management of CH, where the life phases of an asset are exclusively conservation and enhancement. The previous phases of creation/construction and transformation over the centuries are in fact those that led to protection through the recognition of cultural value and are therefore concluded phases. On the other hand, the ongoing phases, i.e. those involving management actions, are precisely protection (the conservation of the physical integrity and identity of cultural values) and enhancement (actions to promote knowledge and fruition of Cultural Heritage). From these two phases, which may or may not be concurrent, derive four other phases or macro-areas of management, subdivided as follows: Documentation, Intervention, Monitoring, Use.

Each macro area can be interconnected with the others, depending on the type of action to be undertaken. For example, in the case of a conservative intervention, the first step is the study of the artefact through documentation (traditional and/or digital), to then plan right procedures and monitoring for the specific intervention. On the other hand, in the case of an action of dissemination, the documentation or the use of the database are intended to the creation of a specific product for the enhancement of the object (e.g., for a virtual visit, a web application, etc.).

Each action decided by the manager thus determines a network of interconnections between general professionals, specialised professionals and general users belonging to different macro-areas. In detail, the macro-areas will be defined in chapter 5, in the drafting of the guidelines, since the information system proposed for management through 3D models is based on the macro-areas and on the levels of knowledge that each user has with respect to digital methodologies.

2.2 Main workflows used for documentation and management

The digital documentation of CH deals with the collection of data that allow the two- and three-dimensional graphic restitution of an artefact. The choice of the specific type of digital technique depends on the dimensions and characteristics of the artefact, as well as on the purpose of the survey (Pintus et al., 2015). In the last decades, two methodologies have become widely used also in the professional world, namely Terrestrial Laser Scanner (TLS) and Digital Photogrammetry (DP) (Russo et al., 2011). As the workflows used for these technologies are widely tested and consolidated, the academic and professional landscape focuses on optimising these methodologies, improving tools performance and automating processes. As far as data processing is concerned, workflows need to speed up the currently onerous (in terms of time and computer performance) processing of the huge volumes of data that generally result from the acquisition phase. The management of CH through 3D models is still in a phase that we could define “experimental”, since most of the projects are limited to the academic world and hardly find application and continuity in the professional world.

In the study of the state of the art the digital products can be divided according to the various phases of the process that leads from the survey to the result: data acquisition (section 2.2.1), data processing (section 2.2.2) and management of CH through 3D models (section 2.2.3).

2.2.1 Terrestrial laser scanning, digital photogrammetry and rapid acquisition techniques

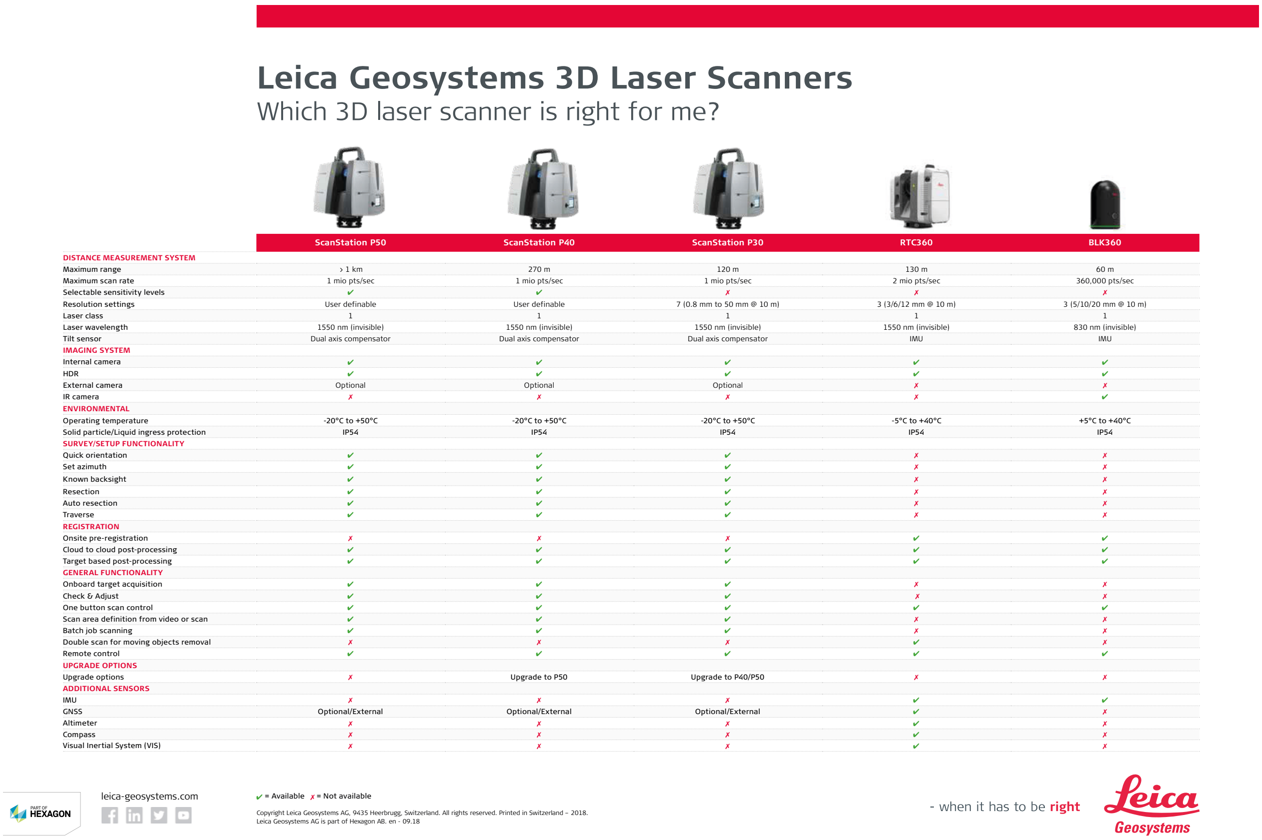
Since the first applications of Terrestrial Laser Scanners (TLS) to the documentation of CH, the potential of this instrument in acquiring millions of points in a very short time and describe the CH has been highlighted. With greater accuracy and precision compared to the direct survey, TLS is very powerful in describe the CH, characterised by a great variability and a difficult standardisation, minus a loss of details and information. Despite the latest improvement in performance, the weaknesses of this technology are still due to: (i) logistical limitations of the instruments (limited battery life, weight, complexity in small environments); (ii) characteristics of the materials and context that do not allow a correct point detection (reflective or completely black materials, atmospheric conditions that do not allow the instrument to work); (iii) cost of the instrumentation and file management software; (iv) time-consuming processing of the gathered files.

With regard to logistical issues (i), the major laser scanner manufacturers, such as Hexagon-Leica Geosystem®, CAM2® and Riegl®, have developed very small, lightweight and manoeuvrable, even mobile, instruments in recent years. For Hexagon Leica Geosystem®, the BLK360 is a compact and lightweight system; for CAM2®, the FARO Focus M 70; and for Riegl®, the VZ-400i (although the latter is already in a higher category than the other two). Mobile systems include the BLK2GO for Hexagon-Leica Geosystem® and the Freestyle 2 portable scanner for CAM2®. On the other hand, Riegl® focuses on car-mounted mobile systems, dedicated more to urban and infrastructure surveying (Chiang et al., 2021), being hardly applicable in the cultural field except on special occasions (Zlot et al., 2013; Rodríguez-Gonzálvez et al., 2017).

With regard to operational conditions (ii), these have also been improved by the manufacturers, however, being a specific technical issue, the guidelines will indicate ways to avoid such situations or take into account the results of acquisitions (see section 4.2.1).

The cost of instrumentation (iii) is still very high and involves a considerable initial investment: the average price of a professional TLS is between 20 and 50,000 euros. Some of them include the software to process the data in the purchased package, while for others it is necessary to consider the purchase of the software needed to transform the original scanner data into sharable files as PTX format. The latest versions of some free software such as CloudCompare allow the import of point clouds of various formats from major scanner manufacturers and subsequent export in PTX format. Of course, it should be noted that the tools offered in such software for aligning and managing large data sets are limited.

In terms of data processing and management (iv), many laser scanners offer the ability to automatically pre-align data in the field during the acquisition phase. With internal camera systems tracking the position of the scanner between locations, scans are automatically aligned and can be viewed on a tablet during the acquisition phase for immediate control. Mobile, super-lightweight or pre-alignment systems included, however, are designed to maximise throughput at the expense of accuracy and precision (fig.1 shows how resolution and range are significantly



	ScanStation P50	ScanStation P40	ScanStation P30	RTC360	BLK360
DISTANCE MEASUREMENT SYSTEM					
Maximum range	› 1 km	270 m	120 m	130 m	60 m
Maximum scan rate	1 mio pts/sec	1 mio pts/sec	1 mio pts/sec	2 mio pts/sec	360,000 pts/sec
Selectable sensitivity levels	✔	✔	✗	✗	✗
Resolution settings	User definable	User definable	7 (0.8 mm to 50 mm @ 10 m)	3 (3/6/12 mm @ 10 m)	3 (5/10/20 mm @ 10 m)
Laser class	1	1	1	1	1
Laser wavelength	1550 nm (invisible)	1550 nm (invisible)	1550 nm (invisible)	1550 nm (invisible)	830 nm (invisible)
Tilt sensor	Dual axis compensator	Dual axis compensator	Dual axis compensator	IMU	IMU
IMAGING SYSTEM					
Internal camera	✔	✔	✔	✔	✔
HDR	✔	✔	✔	✔	✔
External camera	Optional	Optional	Optional	✗	✗
IR camera	✗	✗	✗	✗	✔
ENVIRONMENTAL					
Operating temperature	-20°C to +50°C	-20°C to +50°C	-20°C to +50°C	-5°C to +40°C	+5°C to +40°C
Solid particle/Liquid ingress protection	IP54	IP54	IP54	IP54	IP54
SURVEY/SETUP FUNCTIONALITY					
Quick orientation	✔	✔	✔	✗	✗
Set azimuth	✔	✔	✔	✗	✗
Known backsight	✔	✔	✔	✗	✗
Resection	✔	✔	✔	✗	✗
Auto resection	✔	✔	✔	✗	✗
Traverse	✔	✔	✔	✗	✗
REGISTRATION					
Onsite pre-registration	✗	✗	✗	✔	✔
Cloud to cloud post-processing	✔	✔	✔	✔	✔
Target based post-processing	✔	✔	✔	✔	✔
GENERAL FUNCTIONALITY					
Onboard target acquisition	✔	✔	✔	✗	✗
Check & Adjust	✔	✔	✔	✗	✗
One button scan control	✔	✔	✔	✔	✔
Scan area definition from video or scan	✔	✔	✔	✗	✗
Batch job scanning	✔	✔	✔	✗	✗
Double scan for moving objects removal	✗	✗	✗	✔	✗
Remote control	✔	✔	✔	✔	✔
UPGRADE OPTIONS					
Upgrade options	✗	Upgrade to P50	Upgrade to P40/P50	✗	✗
ADDITIONAL SENSORS					
IMU	✗	✗	✗	✔	✔
GNSS	Optional/External	Optional/External	Optional/External	✔	✗
Altimeter	✗	✗	✗	✔	✗
Compass	✗	✗	✗	✔	✗
Visual Inertial System (VIS)	✗	✗	✗	✔	✗

✔ = Available ✗ = Not available

Fig. 1_ Laser Scanning comparison chart for Leica Geosystem lower for the BLK series, both mobile and fixed, and also for the series including RTC pre-alignment). For this reason, experiments in the CH sector are still limited to particular situations where a medium or low resolution is sufficient, but rapidity of execution is required (rapid urban surveys for urgent conditions such as earthquakes, narrow environments where it is impossible to use a large scanner requiring a tripod). As regards to the professional world, the lower price of these types of scanners makes them more accessible.

In addition to issues related to the instrument and the acquisition phase, many studies focus on the first phase of data processing. Indeed, acquired and aligned point clouds generally involve a large amount of unclassified data (no distinction between points belonging to a wall or a floor). The latest research in this field concerns the study of algorithms that correctly perform an automatic classification of points, which can lead to substantial improvements in the Scan-to-BIM process, i.e. the transformation from point clouds to BIM elements (see section 2.2.3). The latest experiments compare manual and automatic point segmentation (Grilli & Remondino, 2019, fig. 2; Murtiyoso & Grussenmeyer, 2019; Grilli, 2020). Point sets are analysed using software that allow point cloud management, such as the open software CloudCompare. The process works best so far if the buildings analysed have simple, repetitive elements, such as a series of columns. CloudCompare offers some built-in algorithms for segmentation and the most suitable perhaps for the segmentation of buildings is CANUPO. Before using this algorithm, it needs to be "trained" to recognise the classes into which the building is to be divided (e.g. plinth, column base, shaft, capital, entablature...). An element is taken and manually subdivided into classes.

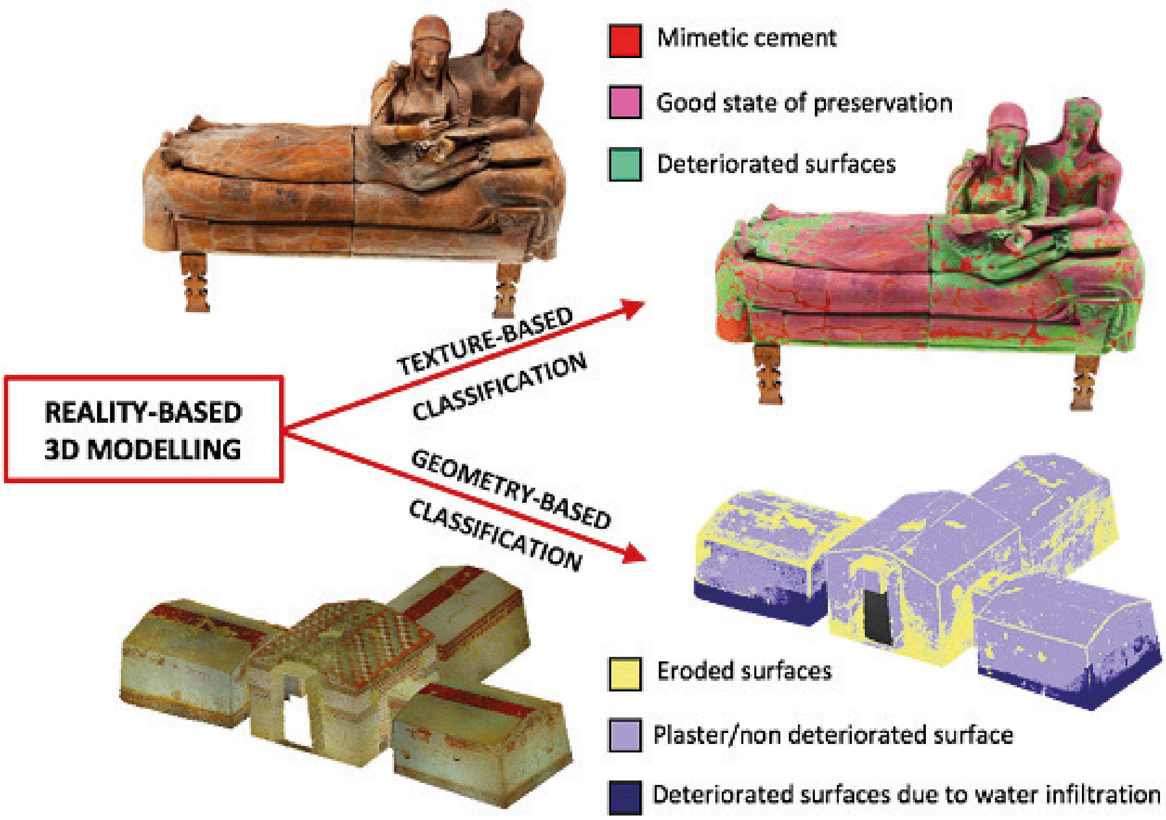


Fig. 2_ Classification methods. Grilli & Remondino, 2019

The algorithm is then used on the whole cloud. Theoretically, this is able to divide the cloud more or less correctly, depending on the experience gained and its effectiveness. Comparing the number of points per class of the manual subdivision and that of the automatic segmentation gives a percentage of the effectiveness of the algorithm. The same procedure can be applied to texture images. It is evident that the highest number of training data is needed to refine and correct the algorithm. It is therefore very important to share the data derived from the surveys (point clouds), in order to give the training machines the opportunity to process large amounts of data and thus improve the subdivision.

Digital Photogrammetry (DP) is another methodology that has been widely applied in recent decades to CH. With the development of Structure-from-Motion based software, the strong automation of the process and the achievable results have spread the methodology also outside the academic field. In addition, the low cost of instrumentation favours its wider use. A good SLR camera is sufficient and costs much less than buying a TLS. However, without the support of a TLS or topographic instrumentation, applications are limited to objects or small portions of a building. In recent years, the use of drones for surveying or integrating otherwise unreachable parts, such as roofs, elevated facades, inaccessible sites or large spaces such as archaeological sites, has also become widespread. Again, the price of the initial investment is lower than that of a TLS, although mandatory training is required and not all sites grant permissions to fly.

The latest version of the main used DP software, Agisoft Metashape v.1.7, includes the ability to automatically create low-poly models and Diffuse, Normal and Occlusion maps, for online publication and game design. Vertex Colors Baking is also possible, to obtain the texture map, and this can be modified directly in the software with delighting operations and removal of cast shadows or ambient occlusion, if necessary. It would therefore be useful to make comparisons between the results that can be obtained with the Agisoft Metashape 1.7 software and 3D modelling and rendering software such as Luxology Modo, McNeel Rhinoceros, Blender, which certainly offer many more tools, but are also more complex to use.

Scholars are experimenting with the use of mobile device systems for image acquisition via smartphones, proposing workflows for both image acquisition and processing (Muratov et al., 2016; Nocerino, Lago et al., 2017; Nocerino, Poiesi et al., 2017), and for colour check (Gaiani et al., 2019).

TLS and DP are two fundamental methodologies in data acquisition and processing workflows. In most fields of application, complete and better results are obtained by integrating the two methodologies (Cipriani & Fantini, 2018). In particular, the geometric accuracy of the laser scanner is complemented by the excellent texture obtained by DP (Remondino, 2011).

In the next section the procedures to optimise the products obtained by processing the raw data collected by these two techniques are analysed.

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2.2.2 Procedural Modelling, model optimization and use in game engines

Through the process of triangulation of the points that make up a cloud, a triangular mesh is obtained, generally composed of a high number of triangles. The greater the number of polygons created, the greater the geometric correspondence between the mesh and the real surface, while a lower quality of triangulation will result in a greater degree of approximation, which is particularly evident in plane changes. From this type of model, which some researchers define as a “Master Model”, 3D models with specific characteristics are derived for various purposes (Apollonio et al., 2018; Cipriani, Bertacchi S. & Bertacchi G., 2019). From the Master Model, geometric information can be extracted for procedural modelling (Cipriani, Fantini & Bertacchi S., 2017). In this, a set of rules or parameters are used that lead to the spatial generation of surfaces. By changing a rule or parameter, each part automatically changes accordingly. The advantages of using procedural modelling are therefore the possibility of interactive modification and the simplicity of the models (composed of subdivision surfaces) but starting from a geometric base derived from the Master Model and therefore derived from real data.

The optimisation of the models involves a progressive reduction of the polygons that make up the Master Model through automatic or manual retopology actions. The retopology transforms the initial triangular mesh into a more simplified quadrangular mesh. The degree of simplification is decided by the user in the automatic retopology by setting a percentage decrease in the number of polygons. This is done on the model almost uniformly, without distinguishing for example between flat or more articulate parts. In the manual retopology, a much more time-consuming procedure, the size of the polygons is decided by the user, who redraws the mesh manually (based on the triangular mesh of the Master Model, which serves as a basis). By using manual retopology, flat parts can be represented by fewer polygons. Many 3D modelling and reverse modelling software provide a lot of tools for modifying the topology of a mesh. An open software for quad-dominant remeshing is Instant Meshes (Jakob et al., 2015). However, the optimised meshes have a much higher level of approximation than the real geometry, which is better represented by the Master Model. In order to restore the detail in the visualisation phase, the mesh is parameterised according to a UV space, so that it corresponds to the UV space of the normal map and the diffuse colour

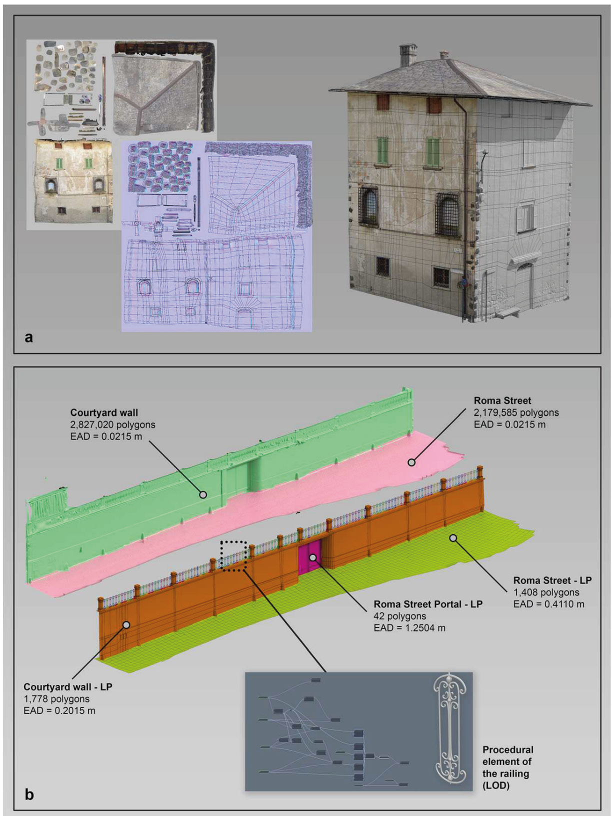

Fig. 3_ Modelling solution for details: a) optimised model of a building; b) original and optimised model with the detail of the railing created with a procedural workflow. From Bertacchi S. et al. (2021)

map, which are obtained a priori by baking operations (always performed with the main 3D modelling and reverse modelling software). Some experiments in this field can be found in: Merlo and Fantini, 2012; Cipriani and Fantini, 2018.

After this optimisation, models can then be inserted into game engines such as Unreal[tm] that allow real-time rendering and thus interactive exploration (Merlo, Dalcò & Fantini, 2012; Merlo, Sánchez Belenguer et al., 2013; Bertacchi S. et al., 2021, fig. 3). Interestingly, today the main solutions of this type derive from the application of the methodologies used in engineering for data acquisition and 3D modelling, but they are also strongly influenced by the methodologies used in videogames. In a videogame, in fact, the parameters of game fluidity accompanied by real-time rendering are essential. It is necessary (especially in recent decades with the development of videogames on online platforms) that the game environments load and display the polygons that make up the scene in a very short time, but without reducing the realistic detail to be achieved. Thus, when the number of polygons is reduced, detail is restored thanks to maps that simulate the roughness of surfaces during the rendering phase. Given the enormous worldwide turnover of videogames, the development of practical solutions to the problem of fast and detailed visualisation has received a strong impetus. At the same time, the game industry is exploiting geomatic techniques, such as digital photogrammetry, to create realistic settings with less creative effort (fig. 4) (Staham et al., 2020): sets, characters and textures are created from data captured from reality through photographs. Clearly, the purposes of creating a reality-based model for a videogame differ from those of academic research, for which certain parameters of accuracy and precision are the basis of data acquisition. In the world of scientific research, therefore, it is unthinkable to use an optimised model to extrapolate, for example, the section of an object, since the optimised mesh is an approximation of the real object. On the other hand, it would be unthinkable to insert a Master Model with a very high number of polygons forming the triangular mesh into a game engine and try to obtain a fluid visualisation, which is impossible even with a very powerful machine, certainly not with a home or portable or mobile system.

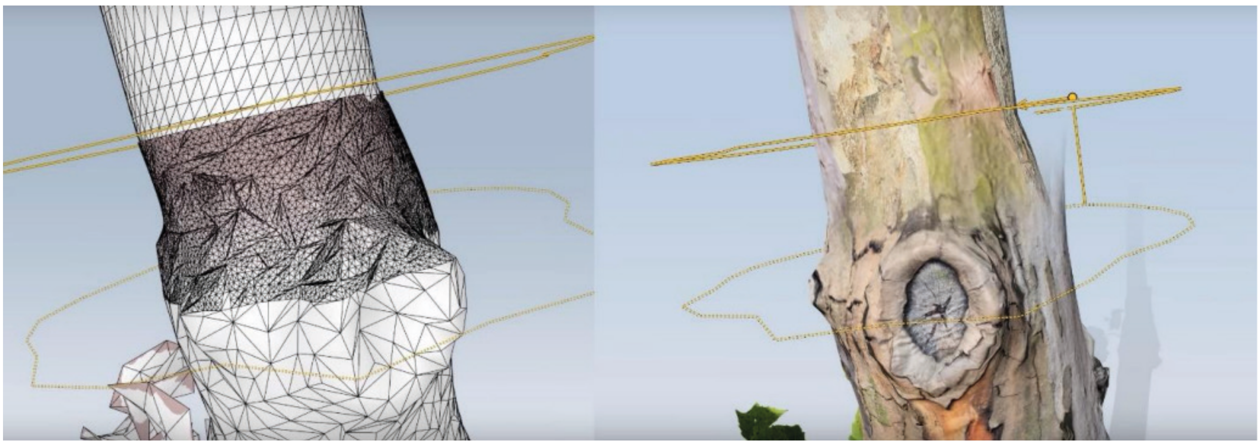

Fig. 4_ Digital photogrammetry used in the creation of videogame assets. From Staham et al. (2020)

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2.2.3 Information System with reality-based 3D models and Historical BIM

Three-dimensional Information Systems (IS) are defined as such because they focus on the use of a 3D model for the interactive input, retrieval and modification of data related to a particular cultural asset. Contrary, in fact, to the first two-dimensional IS, the 3D ones can not only contain various types of heterogeneous data, but the entire system revolves around the prior construction of a 3D reality-based model of the particular manufact being studied and managed. The multiple aspects that concern the management of CH, whether they are included in the field of cataloguing or documentation of the existing, maintenance, restoration, management, valorisation and enhancement of vast contexts (territorial/landscape, urban, archaeological, museum contexts, etc.), generate a very differentiated series of data, often not compatible with each other, or unusable if not by experts in the specific sector.

In the current landscape of integrated systems for the management of the huge amount of information concerning CH, there is still no manageable tool that allows the storage and use of large amounts of very different data, both by Public Administrations and private institutions. The currently available tools are often not usable by institutions (site managers, museums), technicians (architects, engineers, archaeologists, geologists), and the public (visitors, stakeholders, investors), and in general do not meet the different needs of all these actors. CH is in fact characterised by large amounts of data, not only geometric, but also analytical, bibliographical, etc.

The IS commonly used up to now for site and heritage management are a set of layers and sheets referring to specific maps and points on them. The user can consult the data present by accessing tabs related to points or data (such as in Geographic Information Systems, GIS). GIS and Web-based systems (Scopigno & Dellepiane, 2017) provided by many Italian regions (WebGIS) are widely used tools for collecting and visualising categories of CH data. Some applications use GIS systems, for example, to visualise historical maps superimposed on current cartography, to provide scholars with a user-friendly tool that allows them to make anntations quickly and accurately, given the accuracy of the superimposition process (Gatta & Bitelli, 2016). The website *vincoliinrete*, for the management of data related to CH, creates master data sheets on assets starting from the sharing of data present in the systems “Carta del Rischio”, “Beni Tutelati” and SIGECweb, offering also the possibility to visualize architectural and archaeological assets on a map.

A problem that emerges from the multitude of these IS and databases available online is the frequent possibility of misalignment of specific data related to an asset, such as geographical coordinates, which vary for the same cultural asset depending on the cartographic base used in the specific IS. While these tools generally contain only catalogue data, the ministerial software SICaR is used for documenting, planning and managing interventions in CH restoration sites (Baracchini, Fabiani et al., 2009), starting with the first prototype proposed in 2003 (Baracchini, Lanari et al., 2003). Presenting itself as an online IS, it allows consultation and addition of information directly during site operations (Siotto et al., 2016). However, it should be noted that the type of information contained in SICaR is mainly made up of 2D documents, such as sheets containing alphanumeric data of the asset, thematic maps related to the analysis and intervention (both vectorial and raster data), and materials related to documentation and site activities, but mainly two-dimensional (Fabiani et al., 2016). Although traditional documents and drawings have the advantage of greater diffusion and usability by users, because they have always been present as material for information exchange, they contain many limitations, for example for the analysis and intervention on very complex assets from the point of view of material or spatial conformation (which determines the presence of many different professionals in the context of an intervention, who must be able to access the same basic information).

The spread of 3D IS and online repositories in recent years has clearly gone hand in hand with the development and increased application of digital sensing technologies (Koller et al., 2009; Gaiani, 2015, 2017; Benedetti et al., 2010; Cipriani & Fantini, 2015; Adembri et al., 2016). A particularly significant example can be found in the research conducted for the restoration of the Neptune fountain in Bologna (Visual Computing Lab, 2017), where the online information system is based on a reality-based 3D model of the fountain (fig. 5), on which the different users involved in the project (especially restorers) can record and catalogue the operations of analysis of the state of conservation and mapping of degradation phenomena, directly on the mesh surface of the 3D model, aided by the presence of the high-detail texture (Apollonio, Ballabeni et al, 2017; Apollonio, Basilissi et al.,

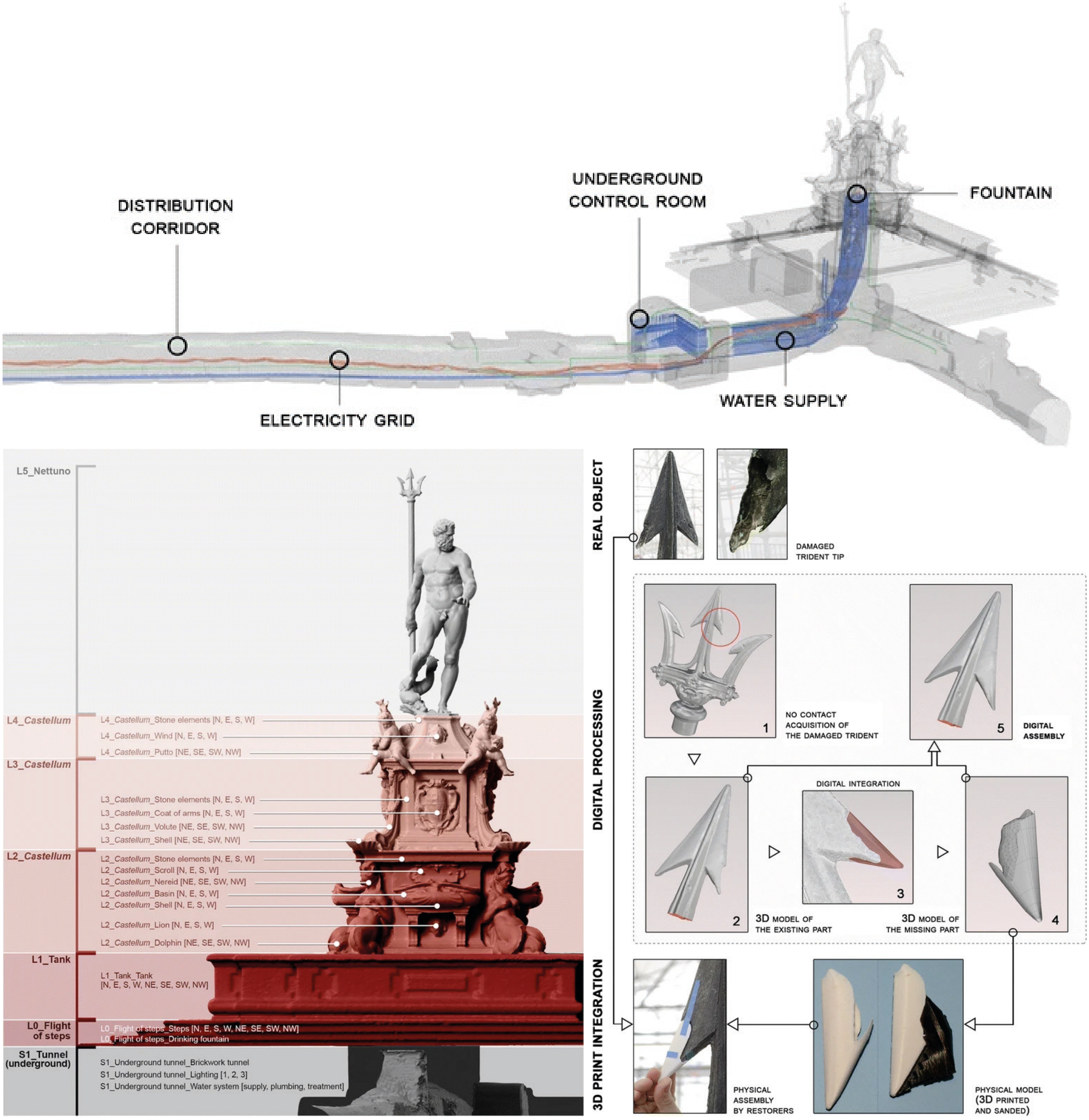

Fig. 5_ IS for the restoration work carried out on the Neptune's Fountain of Bologna. Cataloguing system; management plant model; 3D printing for restoration. From Apollonio, Ballabeni et al. (2018)

2018). Moreover, the open-source software used for the online visualization of the model, 3DHOP (3D Heritage Online Presenter, see section 2.3), developed by the Visual Computing Lab of ISTI-CNR (Potenziani, Callieri, Dellepiane et al., 2015), allows a fluid visualization, without the need of a powerful internet connection, maintaining the detail needed for operations on the model, and allowing access through portable devices such as tablets, to operate directly on site. An information system of this type therefore presents itself as a very versatile tool, if one thinks both of the uses it can have in the construction site phases by all those involved, and of the fact that the model preserves in itself the history of the interventions carried out, and therefore allows better administration of the interventions and constant monitoring. Moreover, the model thus created, and the entire IS can be used subsequently for the management. Another prototype of IS for the management of CH is the project SACHER (Smart Architecture for Cultural Heritage in Emilia-Romagna) (Apollonio, Rizzo et al., 2017; Bertacchi S. et al., 2018), an online platform for the management of CH on the territory, which integrates the multiple data related to CH, allowing the upload of 3D models of the assets, to which are linked analysis data and data produced by the site operations. The platform proposes, through differentiated services (in particular with the 3DCH - 3D Cultural Heritage service), to provide a tool for the management of the assets, accessible online in multi-user mode and usable by the multitude of subjects that deals with the asset, be they Public Administrations, private companies operating in the field of restoration or tourism, or general users, who use the asset or the services connected to it (citizens, tourists, official guides).

Both 3D information systems (analysed and compared in Apollonio, Gaiani & Bertacchi, 2019) were realised in collaboration with ICT experts, involved in the realisation of the IT structure (ISTI-CNR of Pisa in the case of Nettuno, CIRI ICT of the University of Bologna for developing the services and the SACHER platform). This therefore highlights a fundamental problem of 3D information systems, namely the necessary creation of an IT structure by experts, and above all its constant maintenance. The current tendency is to experiment with various solutions at an academic level, applied in the individual case study, but difficult to replicate in the future, partly because of the high costs of such a structure, which limit its application to experimental academic projects, and partly because of the lack of coordinated action at a national or supranational level that provides the necessary indications for developing solutions in a coherent manner. However, the choice to respect, for example, the lexicon of the Italian central institute for catalogue and documentation (ICCD) allows a possible future reapplication and reuse of the project.

Building Information Modeling (BIM) is also an IS based on a 3D model. However, the methodology is mainly applied in the AEC (Architecture, Engineering and Construction) industry for new buildings. This on the one hand allows a greater diffusion of the methodology at a professional level, on the other hand implies a limited number of tools suitable for its use in the “HBIM” (Historic BIM, according to Dore and Murphy, 2012), i.e. the application of BIM to CH. In fact, what characterises BIM is the use of libraries of families of parametric elements containing information on dimensions, type of material, material resistance, etc. These are easily entered during the design phase and the great advantage from the design point of view is that the modification of an element in a family immediately updates all the instances in the project. CH is highly variable in its characteristics, generally made up of unique elements, difficult to repeat, with a complex geometrical shape and sometimes non-standardisable. Therefore, not all of them are suitable for BIM modelling, which in some cases is applied excessively (see section 4.1.1). In spite of the technical problems arising from the very characteristics of CH (analysed below), the many advantages and versatility offered by the use of the BIM environment have meant that in recent years there has been a proliferation of experiences in this field, described in the numerous reviews available (Dore & Murphy, 2017; López et al., 2018; Pocobelli et al., 2018; Salvador-García et al., 2018; Yang et al., 2020). From these reviews and the recent experiences described in Banfi

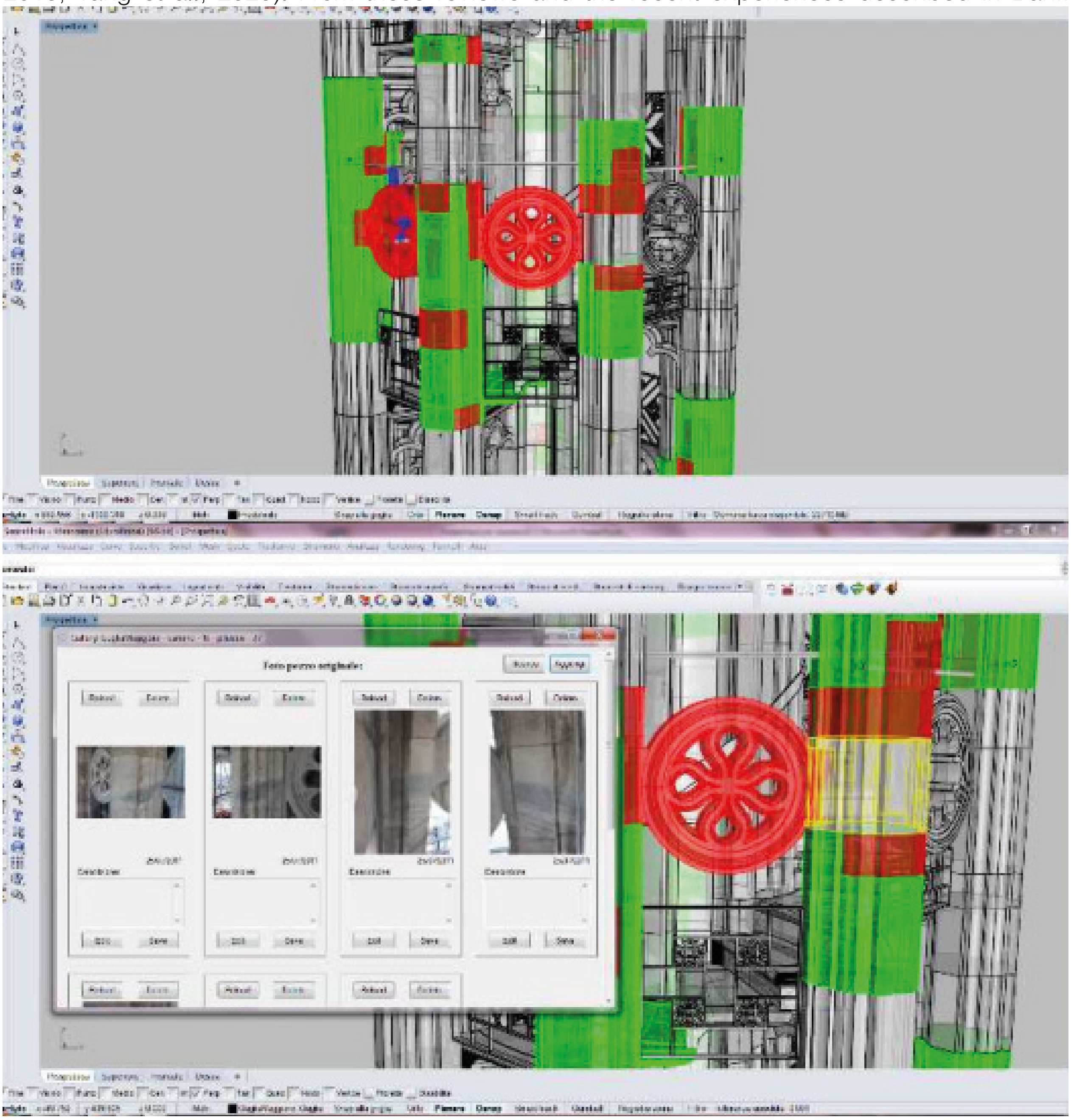

Fig. 6_ HBIM model implemented inside Rhinoceros Nurbs Modeller for restoration works. From Fassi et al. (2015)

(2021), it can be seen that HBIM is mainly used in: (a) creation of IS used for the management of a particular aspect (e.g. combination with GIS, tourist flows, facilities) (Dore & Murphy, 2012; Fassi et al., 2015; Wang at al., 2019); (b) restoration or rehabilitation interventions where the BIM model becomes a tool for the design, work, monitoring phase and a data repository (Agustín & Quintilla, 2019); (c) other management-related uses.

As anticipated, it is precisely from the difficult standardisation of CH that the main problems in the field of HBIM arise: (i) modelling criticalities; (ii) standardisation criticalities; (iii) criticalities related to the texture and final appearance of the model. The different workflows developed to cope with these criticalities do not always manage to propose solutions completely contained in the BIM environment. As is often the case in these fields, the integration of different methodologies and software leads to problem-solving strategies.

Critical modelling problems (i) refer to difficulties encountered in the process of transforming raw data, generally consisting of a point cloud or CAD data. This process, defined Scan-to-BIM, consists in the transformation of point clouds into elements of BIM families. In the current state of research, it still presents many problems, mainly due to the large amount of manual intervention required. Indeed, although BIM software offers some useful tools to facilitate modelling, these are not sufficient in the case of existing buildings and sites with complex architectural features that are difficult to model (vaults, irregular elements, decorations...). Moreover, the programme is not able to automatically detect the points of a cloud belonging, for example, to the exterior and interior part of the same wall, automatically reconstructing the geometry, which is often complicated by the irregularities present in the historical masonry. So, the modelling phase based on point clouds is still complex and time consuming. An advantage of using the Scan-to-BIM process is to insert the point cloud directly in the BIM software. The accuracy is improved, because in the other way (using 2D drawings to reconstruct the geometry) errors are more frequent. In fact, a more traditional workflow consists in extracting 2D plans and sections from the point cloud and then re-inserting the 2D drawings into BIM for almost complete remodelling. By skipping this step, it avoids the possible errors and approximations that can occur, and the point cloud is an objective reference for modelling, even if the software handles heavy files very badly and the whole process is slowed down. Since BIM software is designed for new constructions, in most cases made up of standard element families provided by the manufacturers themselves, the modelling tools offered by BIM software are still very limited and often do not allow to correctly represent the geometrical shape of an element that forms a historic building. The impossibility to have available families with elements reflecting the real characteristics of the interior of, for example, a wall according to traditional masonry techniques, which is difficult to standardise, takes away one of the most convenient features of BIM used for new constructions. In most cases it is necessary to resort to the creation of *ad hoc* elements, nullifying the advantages offered by the software itself for the treatment of instances and the information linked to them.

Modelling problems are solved by various approaches: (a) importing modelled elements with software external to BIM, such as McNeel Rhinoceros or Sketchup (fig. 6), which being specific for 3D modelling are easier to use and offer a wide range of modelling tools (Massafra et al., 2020); (b) developing specific plug-ins for creating mesh (fig. 7) (Garagnani, 2013) or importing mesh models in the BIM environment (Rodríguez-Moreno et al., 2018; Bolognesi & Caffi, 2019); (c) development of automatic point cloud segmentation and classification algorithms that speed up the Scan-to-BIM process (Croce et al, 2021); (d) parametric modelling using visual developers such as Dynamo from Autodesk Revit (Giovannini, 2017; Jiang et al. , 2020; Massafra et al., 2020); (e) exclusive use of the tools provided by the software even if with longer procedures and more simplified elements (Aubin, 2013). Some of the problems highlighted could be solved by software houses, which however generally have no interest given the limited application to HBIM compared to the AEC industry. The import and management of meshes within software is still very poor, and each import step from external software involves less control over the mesh data, such as the decimation done automatically by the software, and can therefore lead to errors, as well as requiring special skills in more than one software. Some scholars seek alternative solutions through open software and interchange format (Diara & Rinaudo, 2018).

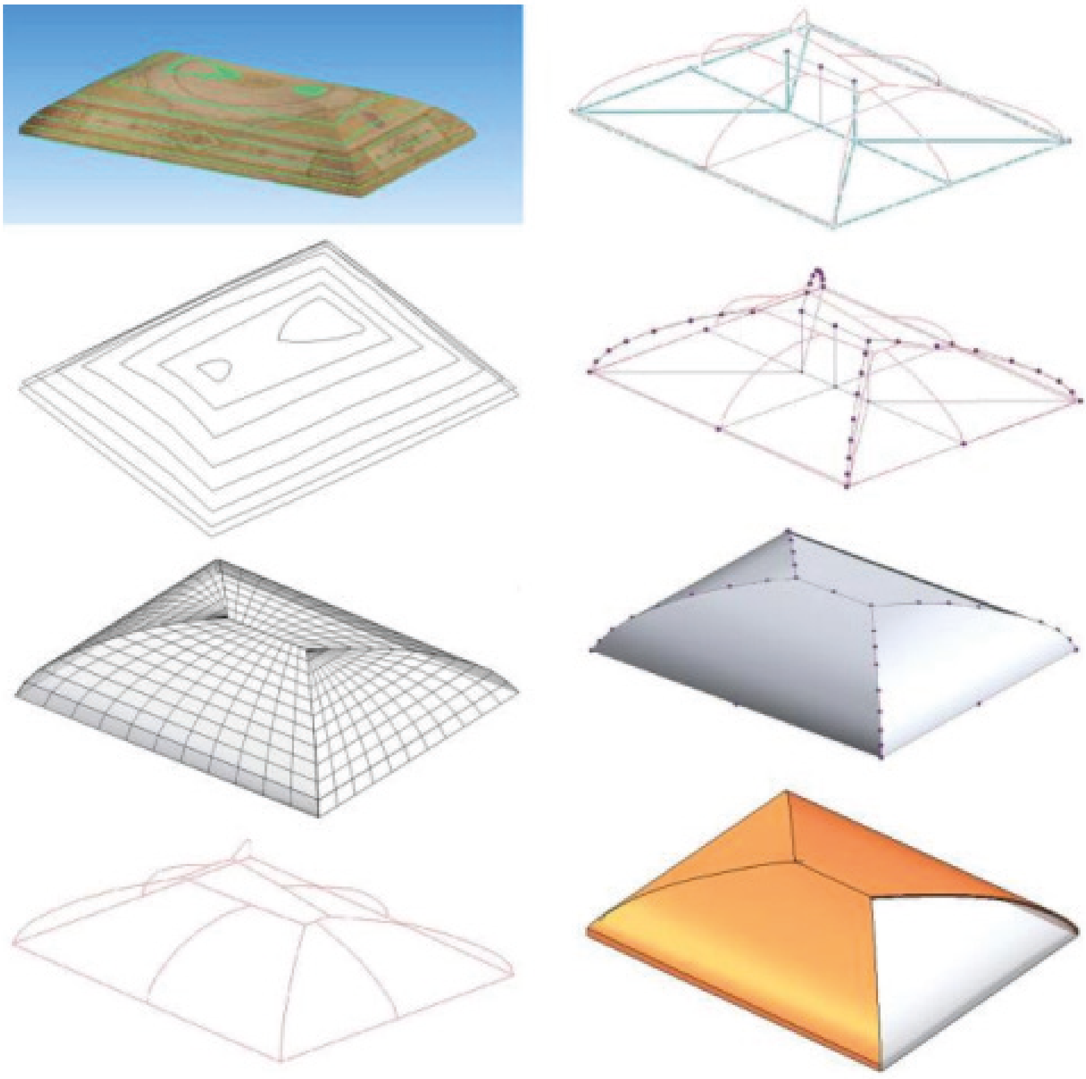

Fig. 7_ From the point cloud (upper left) to the re-topology and generator lines extraction. From Chiabrando et al., 2017

The issue of standardisation of elements (ii) will be explored further in Chapter 3, section 3.1.

Problems related to the application of textures on elements with complex geometry (iii) are related to the use of the model. During restoration operations it is important for a restorer to be able to visualise and map the degradation directly on the element. It would also allow the possibility to simplify the modelled elements in exchange for a high-quality appearance. However, BIM software does not provide automatic tools to reproduce the texture on the model in a simple and automatic way, as it is done in specific modelling or digital photogrammetry software. For flat elements such as facades, generally the solution encountered is the inclusion of high quality orthoimages as attachments (Tsilimantou et al., 2020). In other cases, Autodesk Revit adaptive components are used for pathology mapping (thus creating an element on top of the element or as an internal partition of an element) (Chiabrando et al., 2017). Adaptive components and partitions are also used to create detailed modelling, where each element can be assigned particular characteristics regarding, for example, its state of conservation (such as "brick-by-brick" modelling in Sun et al., 2019; or assigning conservation parameters to tiles modelling the floor in Bertacchi G. et al., 2021). The use of the command "parts" in Revit can be useful in cases where a coloured point cloud has been included in the design, which can serve as a basis for mapping. However, as already mentioned, the handling of point clouds in the Revit environment is not very fluid and therefore the modelling time remains high.

Despite the above-mentioned problems, the application of BIM to Cultural Heritage remains a rapidly expanding field, especially to try to exploit the strengths of BIM software, such as life cycle management (Mol et al., 2020) and the level of information that can be included in the model from a collaborative approach to the project (Heesom et al., 2020).

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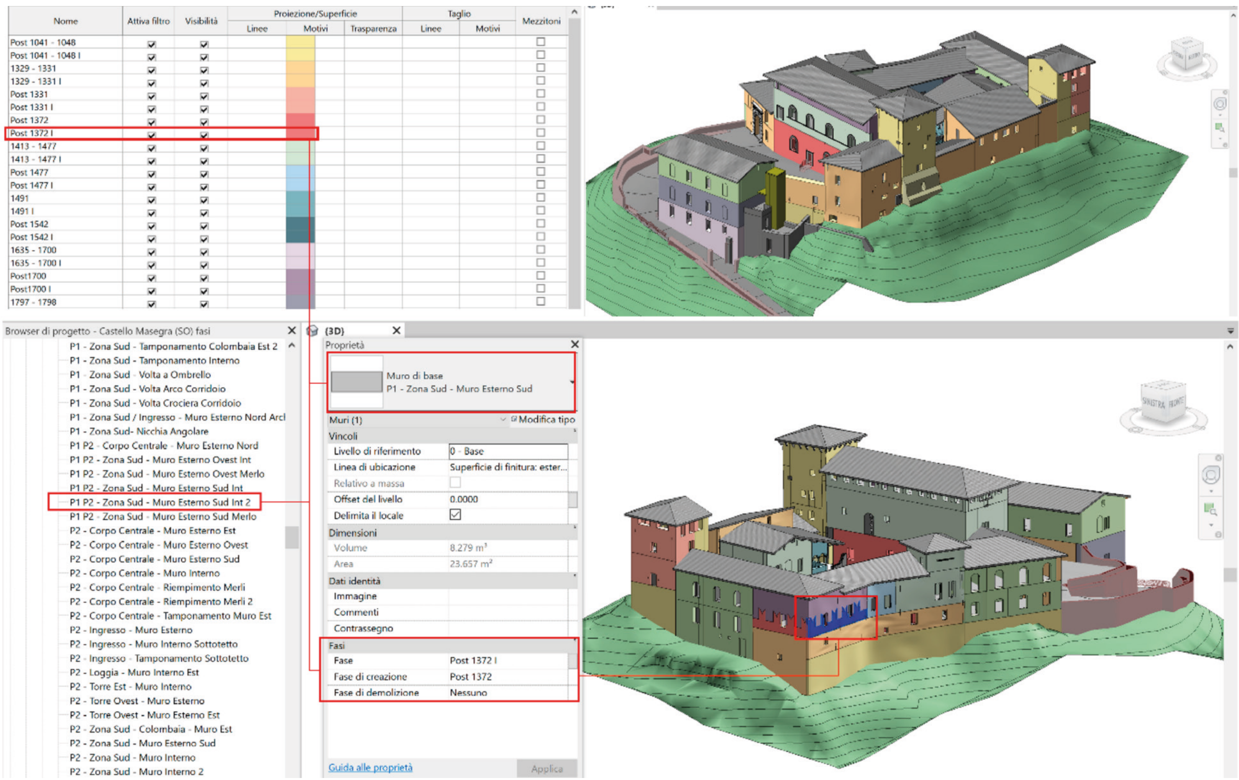

Fig. 8_ Management of historical phases in HBIM. From Banfi (2021)

2.3 Using 3D models for dissemination

Many of the techniques for optimising 3D models derive from the increasing demand for dissemination quality products. Since the early 1990s, digital models for dissemination have been created by modelling from 2D drawings, classical treatises and archival data. Digital reconstructions, simulations or anastylosis were used for dissemination purposes in video clips shown during exhibitions or television documentaries. The first reality-based CH models used technologies and methodologies derived from engineering (Levoy et al., 2000). The spread of TLSs for the documentation of CH and the integration of these methodologies with digital photogrammetry has led to an increasing quality of 3D models that goes hand in hand with better visualisation and online accessibility. Currently, the panorama of the use of 3D models for dissemination is very wide. Different products are increasingly requested by museums and cultural sites for dissemination purposes. As described in section 2.2.2, the main solutions for the optimisation and visualisation of 3D models come from the world of video games.

Table 2.1 summarises the main uses of 3D models in dissemination:

Uses of 3D models	Possible uses for dissemination
(1) Physical reproduction	3D printing with a defined scale factor; Replicas of current or previous states, anastylosis (i); Replicas of museum collections for the creation of tactile models (ii); Replicas of artworks to lend to other museums (iii); Creation of museum gadgets and home 3D printing (iv).
(2) Digital reproduction for online visualisation	Publication on online platforms for visualising 3D models; Creation and publication on the official website.
(3) Digital reproduction for virtual exploration	Creation of applications and serious games for exploring and understanding CH with videogame mode.
(4) Digital reproduction as an educational tool	Possible original state and transformations; Anastylosis; Production of audiovisual content for education and dissemination (guides, in-depth content); Creation of applications to support guided tours.
(5) Virtual and Augmented Reality	First-person remote exploration of the current situation or digital reconstructions; Virtual tours with in-person guidance; Educational video.

Table 2.1_ Uses of 3D models in dissemination.

Physical reproduction from a 3D model (1) is a widespread technique (Bigliardi, 2016), derived from engineering and industrial applications of component prototyping. The difference in the quality and appearance of the final products depends on the printing resolution of the printer and the type of material and printing process used. The most widely used methods in additive printing are; FDM (Fused Deposition Modeling), a technique in which a plastic filament (ABS, PLA, also mixed with marble or wood powders to increase the realistic effect) is melted and deposited to form the object; stereolithography (SLA), which uses liquid resin polymerised by a laser to form each layer. The products derived from the FDM technique have a lower resolution and a worse surface finish than those obtainable with SLA printers. However, the printing process is faster and for this reason they are often used in prototyping. In the field of CH, different techniques and materials are used, depending on the purpose of the product (for restoration and integration, the resistance characteristics of the materials must also be assessed; for small objects in museum collections, the detail must be very high). Another technique used is powder bed printing, which is similar to SLA technology (the powder layer is fixed at the desired points by means of a moving head jet of the binder, which can also be coloured). In spite of the growing popularity of 3D printing, the cost of printers and materials are still very high to obtain high quality prints, necessary for example in 1:1 replicas. The advantages of the application of this technique to CH are: realization times (considering both digital modelling and printing time), much lower than the complete manual realization; geometric accuracy for complex shapes; replicability, at different scales and in different times; no damage to the original artefact thanks to the obtaining of data through indirect survey instruments.

According to Neumüller et al. (2014), 3D printing applications can be divided into two groups, the first one related to reconstruction and conservation, the second one to accessibility and dissemination. The first group includes all those applications that have a research and conservation purpose. Some examples are: physical reproduction of disappeared buildings; hypothesis of conformation of buildings in antiquity; creation of replicas to replace original ones when their conservation prevents their exposure to atmospheric agents (Bonora et al., 2021); digital reconstruction and 3D printing of missing parts used in restoration phases (Scopigno et al., 2011; Arbace et al., 2012; Apollonio et al., 2017). The second group includes all those uses related to dissemination and accessibility, sometimes closely linked to conservation needs. The various 3D printing products for dissemination are mainly used in museums and exhibitions.

A first use (i) is the printing of maquettes reproducing the current situation or previous states (such as phases of the building's historical development or situations prior to particular events such as earthquakes). These models help the understanding of a building or an archaeological site as a whole. Furthermore, they are usually placed at the beginning of exhibitions, so that the guided tour starts with an overview of the site. The scale of the print varies depending on the size of the initial object. In the case of a small or medium-sized building, if represented in its entirety, the reproduction scales are generally between 1:50 and 1:200, while for the representation of archaeological sites or urban complexes, scales of 1:500 to territorial scales are used. 3D printed maquettes replace hand-made ones, which are certainly more detailed and realistic, especially when using model materials. However, even in 3D printing, some finishing operations are carried out on the printed models, like cleaning and removing the supports or sandblasting and powdering with colours to improve their realistic appearance.

A second use (ii) is reproduction to enhance the understanding of a work or object. For many years, museums have tried to increase the inclusiveness of the visit for blind and vision-impaired people. The impossibility of touching the exhibits and works of art was justified by the conservation of the work itself, but resulted in a discriminatory visit (Candlin, 2004). On the other hand, accurate replicas involved an enormous economic investment and were sometimes not possible because of the impossibility of making casts, again due to conservation. With the use of digital data acquisition and 3D printing techniques, studies on accessibility conditions (Levent et al., 2013; Mesquita & Carneiro, 2016) and tactile museum experiences (Andersen, 2019) have multiplied, as digital data acquisition does not involve damage to the artefact. In addition to replicas of statues and labels in Braille language, some museums have equipped themselves with paintings, digitally transformed into bas reliefs or printed with an increased thickness of the contours, in order to understand the arrangement of the figures and architecture represented (Volpe et al., 2014; Belvedere, 2016). Moreover, virtual and augmented reality experiences with tactile sensors are very common (Vaz et al., 2018). These experiences are common in large museum centres (Andersen, 2019; Ginley, 2013), but also in small museums, which can count on a reduced number of visitors and therefore less funds at their disposal (3D-ArcheoLab, 2016; Puma, 2017). The use of 3D printing therefore seems to have an increasing application in the field of accessibility and inclusion, but it has been noted that the tactile exploration of the replicas is appreciated by all types of visitors (especially children), who can touch without damaging the original. This is beneficial for the conservation of statues, artefacts, paintings, but also decorative parts of architecture (such as the plaster decorations of the Alhambra in Granada, whose deterioration due to people touching the walls unintentionally or voluntarily is seriously endangering their conservation). 3D reproductions in some cases are not limited to objects: whole locations, normally inaccessible, are 3D printed to allow the visit, as the presence of people leads to an accelerated degradation of the wall paintings. Some caves (Diao et al., 2019) or tombs have been entirely reconstructed. In Lowe, 2017 the tomb of Siti, Egypt is printed with a subtractive 3D printing technique and then colour is applied. Direct colour replication is experimented in the field of Cultural Heritage, but it is not yet a commonly used technique due to high costs (Cipriani, Fantini and Bertacchi S., 2014; Jackson, 2019).

A third use (iii) of replicas produced with 3D printing is related to exhibitions: many statues and masterpieces cannot be moved to go on loan, due to impossible logistics or conservation conditions. They therefore resort to the creation of a 1:1 replica (Italyexpo2020, 2021), which can eventually be transported in pieces and assembled on site.

Finally, 3D models are increasingly used for printing museum gadgets (iv), often involving visitors themselves in the process, i.e. providing online access to digital models and instructions for printing at home (Undeen, 2013).

The second use of 3D models for dissemination purposes (2) concerns digital reproduction for online visualisation, applied mainly to museum collections, but also to entire sites and buildings. One of the most widely used platforms for uploading, downloading, purchasing and visualising 3D models is certainly Sketchfab[1], which with various forms of paid subscription offers additional services compared to the free basic subscription. Another platform for online visualisation, completely dedicated to CH, is 3DHOP (3D Heritage Online Presenter[2]), developed by the Visual Computing Lab of ISTI CNR in Pisa (Potenziani, Callieri, Dellepiane et al., 2015). The platform is free, open-source and is continuously being developed and updated (Potenziani, Callieri & Scopigno, 2018). Online platforms use a WebGL interface to display models, so the graphical content does not need external software to be displayed. To allow mesh models to be quickly loaded and displayed, a multiresolution approach is used. Usually the geometry is split:

> «into smaller chunks. For each chunk, multiple levels of detail are available. Transmission is on demand, requiring only to load and render the portions of the model strictly needed for the generation of the current view» (Potenziani, Dellepiane et al., 2015, p. 133).

The approach therefore allows very heavy models (in terms of polygons and textures) to be quickly loaded and displayed, even with a slow internet connection. In fact, the model is loaded and displayed at an increasing resolution as the data packets for each chunk are downloaded (fig. 9). The single-resolution model, before being loaded, is first broken down into parts and automatically decimated by an executable[3].

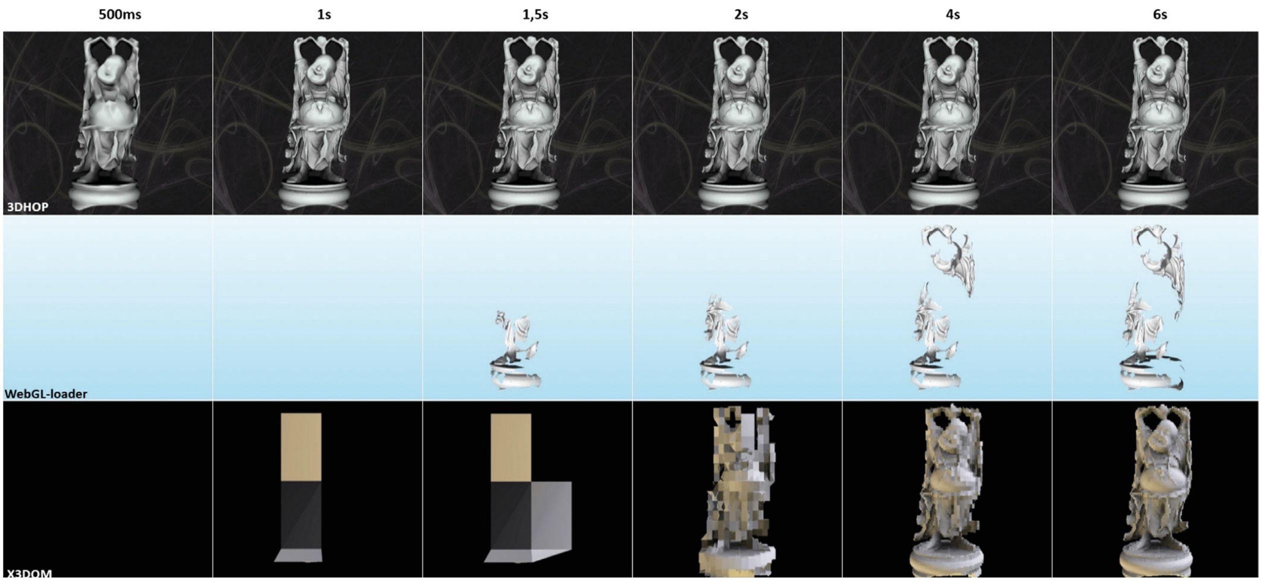

Fig. 9_ Comparative screenshots illustrating the webrendering of a 1M triangle mesh on a 5M bit/sInternetaccess,using the 3DHOP framework (first row), Web GL-loader (central row) and X3DOM binary POP Buffer Geometry (last row). From Potenziani, Dellepiane et al. (2015)

1 _ https://sketchfab.com/feed
2 _ https://www.3dhop.net/index.php
3 _ In the case of 3DHOP it is Nexus, developed by the Visual Computing Lab of ISTI-CNR in Pisa and described as "a multiresolution rendering and compression library that supports the conversion of single-resolution models into a multiresolution format suitable and optimised for the interactive streaming and visualisation of highly complex 3D models" on the official site https://www.isti.cnr.it/it/ricerca/software-ita.

Many museums have used these platforms to upload some 3D models of their collections online, improving accessibility. In some cases, non-institutional networks have also been formed to collect 3D models online, such as the 3DVirtualMuseum website[4]. The model may have been officially uploaded by museums and institutions or even by a generic user, which makes it more difficult to check their quality and accuracy.

In recent years, especially for the mobile world, a use of 3D models that has been widely spreading is the creation of apps and videogames that insert 3D models of objects and sites into game engines (3) (see section 2.2.2) to create game settings (Anderson et al., 2009; Mortara et al., 2014; Pescarin, 2020). So-called “serious games” are developed by museums that want to bring young audiences closer to the exploration of collections and sites. They are defined as “serious” because they use the game mode for mainly educational purposes and for the dissemination of CH (Mariotti, 2021), not only for entertainment. However, both the game mode and the typical structure (reaching goals, levels with higher difficulty, solving puzzles to advance) make them more appealing to younger people. In spite of this approach, there are also many applications aimed at the general public, which propose the discovery of CH, archaeological sites or particular historical events recreated in first-person videogame mode. Some applications recreate in 2D or 3D settings (such as “Father and Son”, produced by the Archaeological Museum of Naples), while others use 3D models as a basis. The use of 3D models obtained by laser scanning and/or close-range photogrammetry is not limited to the world of serious games, but is also applied in commercial videogames with fictional stories set in real places[5]. A parallel phenomenon, linked to the use of CH in commercial videogames, is videogame tourism (Dresseno, 2020), i.e. a type of tourism that arises in players who want to visit some real settings in which they have played, and this both for big cities (such as Florence, Venice, Athens, contained in the Assassin’s Creed series), and small less known villages (such as Monteriggioni, present in the same series). Commercial videogames thus become an instrument of indirect dissemination, even though the scientific aspect of the reconstructions clearly has less weight in the creation of such a videogame. On the other hand, in the case of serious games created ad hoc for places of culture such as museums, archaeological sites or urban complexes, the scientific aspect is the basis of the game and the fidelity of the reconstructions must derive from interdisciplinary scientific research (Cipriani et al., 2018; Smith et al., 2019).

The digital reconstructions used as educational support (4) have been separated in this review from the applications in serious games, since, although both products have an educational purpose, they differ in the degree of participation of the user, who generally has a more passive role. While in serious games the user must actively participate in order to acquire information and hints, in this case he/she receives the information almost passively. Despite the absence of the more involving “play” part,

4 _ http://www.3d-virtualmuseum.it/mission.

5 _ The cultural association IVIPRO (Italian Videogame Program) has created an accessible online database of existing videogames set in Italy and related to cultural places, as well as places, sites, stories related to the Italian CH that can be used for the creation of videogames, serious games, documentaries. For some of the proposed places, digital data are available and can be used in the development process.

digital reproductions facilitate and increase the understanding of the object. Some of the main ones reproduce the current state of an archaeological site, helping the visit, both guided and independent (thus replacing the maquettes). Very often they are accompanied by reconstructions of the original appearance, historical phases, transformations or virtual anastylosis. They are not only present in museums, but also include all those products that are used in other dissemination actions (internet, television, documentaries), such as educational videos, guides, contents for in-depth analysis of particular themes.

The last group of products (5) includes those of the Virtual or Augmented Reality type. They can be considered as halfway between serious games and digital educational reproductions. In Virtual Reality with visors applied, the modalities are certainly more interactive, even if the experiences are limited to a few minutes because prolonged use can cause sickness. There are applications for immersion in reconstructed architecture (such as an archaeological site) or unrealized buildings. Also, the application of particular effects to existing objects (such as the project "L'Ara com'era", in which it was possible to see the ancient colours of the Ara Pacis in Rome using a VR visor). Augmented Reality lends itself very well to the development of applications for mobile devices which, by simply using the camera to scan codes (such as QR codes), reproduce various contents on the screen in real time. This may involve 3D reconstructions that can be viewed by moving the device around an image or projecting colours or reconstructions onto real elements.

Given the versatility of digital data, there is a multiplicity of products and solutions for the dissemination and fruition of CH, even with mixed techniques and solutions (Ioannides et al., 2017).

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Fig. 10_ Carving of the Seti I's tomb to create a physical replica. Lowe, 2017

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Conclusions

The study of the state of the art has highlighted the main technical issues that are currently the subject of scientific research. The main issues concern the optimisation of workflows, the reduction of processing times and the automation of processes. In the currently expanding field of HBIM, the issues concern the modelling of elements and the reprojection of textures in a BIM environment. 3D products for dissemination are another growing field and often use integrated workflows and methodologies borrowed from other research fields. It is precisely in the integration of various different methodologies that a more effective result can be seen.

Upper view of the texturized model of the Archiepiscopal Chapel, Ravenna (Italy)

CHAPTER 3

HYPOTHESES AND OBJECTIVES

The chapter analyses the current situation of Cultural Heritage management using three-dimensional models. Critical issues that managers and professionals face in the management phases are highlighted. The analysis of the current panorama also covers the national and international level of digitisation actions and the standards and good practices currently used, focusing mainly on the European overview.

CHAPTER 3 - *HYPOTHESES AND OBJECTIVES*

3.1 Current situation: digitisation, data storage and acquisition standards

The multiplicity and variability of data generated during the management of a cultural asset are related to the different phases of the life cycle, as defined in chapter 2 (see paragraph 2.1).

Documentation, Intervention, Monitoring, Use: four main macro-areas that determine an interaction of professionals often belonging to completely different fields. Therefore, the figure of the manager becomes very important, as he/she must coordinate not only the different users and their actions, but also the data related to each procedure. In the specific case of digital geometric data such as point clouds, raster images, CAD drawings, etc., there are currently no specific guidelines on their storage and preservation. Despite the fact that digital data have been collected for decades, also with huge public investment, there is a great lack of good practice regarding their preservation. The main problems that cultural sites and public or private institutions have to face during the management are:

(i) Digitisation actions;
(ii) Correct cataloguing and storing of various types of data;
(iii) Storage of data over time;
(iv) Interchange and data transmit;
(v) Data security;
(vi) License, copyright and transfer.

Each cultural site or institution compares with at least one digitisation actions during the management cycle, which it has to undertake, depending on funding, to make CH more accessible. Digitisation campaigns promoted at European level since the 2011 Recommendations (European Commission, 2011) for the H2020 programme, and still in force, spoke about:

> «The digitisation and preservation of Europe's cultural memory which includes print (books, journals and newspapers), photographs, museum objects, archival documents, sound and audiovisual material, monuments and archaeological

> sites (hereinafter 'cultural material') is one of the key areas tackled by the Digital Agenda» (European Commission, 2011, art. 1, p. 1),

meaning a wide range of elements that make up "cultural materials". Although the European Commission's definition is very general, "digitisation" of CH is still meant as just scanning paper documents. In 2008, the online platform Europeana was launched, defined as "Europe's digital library, archive and museum" by the Recommendations themselves (European Commission, 2011, p. 1) The Commission encouraged Member States to share and upload digitisations carried out with public funds on the platform, in order to move "towards digitisation, online accessibility and (long-term) digital preservation of cultural heritage" (European Commission, 2016, p. 2), and achieve digitisation of the entire CH in 2025. In the latest report of the European Commission on the activity of the Member States between 2015 and 2017 (European Commission, 2019), an increase in the use of 3D technologies for the digitisation of Cultural Heritage is noted. However, of 52.5 million objects uploaded to Europeana (by Member States), only 27,861 are 3D content (European Commission, 2019, p. 41). In the same report, p. 17, it is mentioned that competent institutions in many countries (including Italy) have published guidelines and standards for digitisation in general.

The most recent regulation on digitisation of 2021 (in its widest meaning applied to all sectors), reiterates that Member States in the field of education, culture and media must:

> «Provide creators, creative industry and cultural sectors in Europe with access to the latest digital technologies from AI to advanced computing. Exploit the European cultural heritage, including Europeana, to support education and research and to promote cultural diversity, social cohesion and European society. Support the uptake of digital technologies in education, as well as private and publicly funded cultural institutions» (European Commission, 2021, Specific Objective 5, part I, art. 5, p. 31)

The Digital Europe Programme (DIGITAL) is therefore strongly focused on the theme of online accessibility of culture, and has considerably increased investments in this area, also included in national development programmes. Digitisation actions in Italy implement European directives and in 2019 establish a three-Year plan for the digitisation and innovation of museums[1]. However, in the text 3D is only mentioned in relation to fruition (3D models of museum artworks to offer augmented and virtual reality solutions or serious games, Direzione Generale Musei, 2019, pp. 43-45).

As regards the cataloguing system (ii), in Italy it is proposed and standardised by the ICCD (Istituto Centrale per il Catalogo e la Documentazione), the competent Italian institution for the documentation and cataloguing of CH[2] (see section 5.1.1), or from the Beweb cataloguing system of the Italian Episcopal Conference (CEI), which deals with the cataloguing of Church-owned

1 _ Piano Triennale per la Digitalizzazione e l'Innovazione dei Musei.
2 _ http://www.iccd.beniculturali.it/it/standard-catalografici. The ICCU, Istituto Centrale per il Catalogo Unico, deals with libraries and bibliographic information.

cultural assets. On the ministerial website of the ICCD, all the information needed to compile a spreadsheet containing exhaustive information on the characteristics, interventions and documentation of a given asset is available. However, in the “Sources and Reference Documents” section, where the existing documentation is indicated, the following categories are available:

- Photographic documents
- Graphic documents
- Video and film documents
- Historic record and archives
- Other multimedia documents
- Bibliography

Nothing specific, therefore, for example regarding point clouds, which should be included in “Other multimedia documents”, but no specific instructions are given for the compiler user. When creating cataloguing sheets, it is important to comply with the methods defined by the ICCD (e.g. with regard to lexicon), so that additions can be easily integrated and standardised. This is one of the provisions laid down, for example, in the agreement concluded in 2002 between the Ministry of Culture, represented by the ICCD, and the CEI “for the inventory and catalogue of movable cultural assets belonging to ecclesiastical institutions” (ICCD-CEI, 2002).

It must be taken into account that generally 3D digital data occupy a much larger amount than other types of files, both because of their own characteristics and because raw, semi-finished and final data are generally kept. This also generates problems in their physical storage (iii) in space and time. Spatially, they require physical data storage sites, such as local network storage systems, which are preferred to online cloud storage, as data storage (hundreds of GB on average per project) is expensive. However, there are specialised platforms offering cloud services for the storage of CH data (Hibberd & Dugenie, n.d.). Regarding digital data such as point clouds and 3D models, there are only sporadic projects (Comes et al., 2014).

Preservation over time (besides the state of preservation of the physical container) has to do with the type of data and its format, which may run the risk of becoming obsolete in a few years or of becoming corrupted and no longer usable. For this reason, shared and consolidated file formats are to be preferred, which will allow files to be used also in the future, for data interchange and transmit (iv).

In any case, a defined level of data security (v) must be established for each digital object and information contained therein, by including access levels according to the role (e.g. general user, general professional, professional in charge, manager, etc.). The same applies to the conditions of licenses, copyright and transfer (vi) of the digitised material and any uploaded material. If, on the one hand, accessibility to culture is to be promoted, on the other hand it is necessary to operate in compliance with copyright, according to the Recommendations (European Commission, 2021, p. 10). Moreover, it would be appropriate to establish in the calls for tender and in the public agreements who will produce a digital data, the characteristics that this data must have (for minimum quality control, for example) and in which terms and conditions the data must be delivered to the manager.

Regarding the presence of international standards for digitisation (meaning the acquisition and processing of 3D digital data), the European Commission launched the “Study on quality in 3D digitisation of tangible cultural heritage” in April 2020 (European Commission, 2020). In the same year, the Expert Group on Digital Cultural Heritage and Europeana published a series of good practices for 3D data acquisition, such as the principles of digitisation of CH, minimum quality, interchange formats, but all of them are very general (Expert Group, 2020), as well as some projects born with the intent to guide users in the creation of 3D models to be uploaded on Europeana. An example is the Share3D Project, (2020), based on the guidelines published by Corns (2013), which offer an important starting point in digitisation for a generic user with a minimum experience in the field of surveying and digital modelling, but do not offer many specific standards and indications on management using 3D models. Other ventures and publications offer technical and workflow indications, such as the guide by Bryan et al. (2009) that deals in a more general way with digital metric survey applied to CH. However, the proposed indications are very technical, for expert users. Although its “age” (more than ten years old), it offers some interesting hints on acquisition standards, grafic errors, etc.

One field in which there is a greater presence of standards is BIM, since its application in new projects has led to the establishment of international standards for the increasing detail of models. The system proposes various LODs (Levels of Development), from level 100 to level 500, with a crescendo of information included that goes hand in hand with the project phase (preliminary, definitive, executive, up to the state of construction, “as built”, LOD 500). These levels are also used to advantage in invitations to tender. As far as HBIM is concerned, the issue is more complex, given the difficulty in standardising the elements and the difference in the modelling phases of a specific cultural asset. In fact, the specifications to be included in a 400 LOD on the internal conformation of the elements (the layers that compose a wall, for example) do not always find a corresponding application in the built heritage, where the survey results often do not provide reliable and accurate information, unless more in-depth analyses are carried out. Academic research in this area focuses on apply the LODs to Heritage (Biagini & Donato, 2016; Castellano-Román & Pinto-Puerto, 2019; Banfi, 2017, 2020). The level established in the creation of an HBIM model derives from the use of this model in the restoration project, comparing the level of detail to the one used in 2D drawings with different scales of representation (Brumana et al., 2019).

However, the modelling time is still slowed down by the lack of libraries of elements that can be used in multiple projects (given the variety of the Heritage) and the difficulty of finding sharable standards (see section 2.2.3).

3.2 Research objectives

From the overview presented in the previous chapters it emerges that the world of digitisation and the use of 3D models for the management of CH is composed of many different disciplines. It therefore struggles to find a unified line for the multiple actions of data acquisition, processing and conservation.

The study of the state of the art (see chapter 2) provided a summary of the multiple areas of investigation, highlighting problems, potentialities and future developments. In addition to this, the analysis carried out in this chapter brings out the following considerations, concerning the digitisation of CH:

- difficulty in establishing shared standards at national and international level due to the difficult standardisation of CH;
- lack of good practices and regulations for the correct use of public resources in the phases of data acquisition and conservation (incorrect or non-existent archiving; methodologies, data ownership and quality not defined a priori in the calls for tender);
- differences between the levels of competence and knowledge of the users involved in the use of digital data;
- multiplication of digitisation projects and platforms for the collection of digitised CH following European recommendations, but without a general coordination;
- absence of specialised users with a mixed educational background able to follow the management process with digital technologies.

For these reasons, the thesis research proposes the compilation of guidelines that give solid answers during all phases of management and to all types of users involved. The indications provided derive from the level of knowledge the user has of digital technologies and 3D models. The research approach must therefore be interdisciplinary, to incorporate the needs and aims of the types of professionals and users involved in the management cycle. In this way, the guidelines become a tool that can be used by more than one type of user and the 3D model is not just a final product but a central tool of the digital database.

To compile the guidelines, I proceeded with the application of the methodologies analysed during the phase of study of the state of the art to a multiplicity of cases. Thus, Ch is divided into different typologies, for each of which methodologies and standards are proposed. The application of methodologies is more related to the technical aspects arisen in the state of the art. By the way, it is analysed the basic procedures for the creation of a simplified information systems that can be used also by non-expert users for the management of CH.

In the process of research and creation of the guidelines a fundamental role is played by the dissemination of methodologies, intended both as scientific publications on methods used, and as dissemination to a non-expert public (which includes both generic users, managers and professionals with expertise in other fields). Both should concern data processing methodologies, digital documentation products and the potential of using 3D models in every phase of CH management. Dissemination should go hand in hand with the training of specialised figures in the field of Cultural Heritage management who have sufficient technical and humanistic skills (Benedetti et al., 2021).

Conclusions

The analysis carried out in the chapter on the current management of Cultural Heritage by means of three-dimensional models has highlighted the criticalities affecting the four macro-areas of management (Documentation, Intervention, Monitoring, Use). The Documentation phase is closely linked to digitisation actions, which currently lack shared standards and best practices. In the next chapter, the workflows and methodologies analysed in the state-of-the-art study will be applied to the selected case studies, in order to find solutions to the current shortcomings of the management process, which will be defined in chapter 5.

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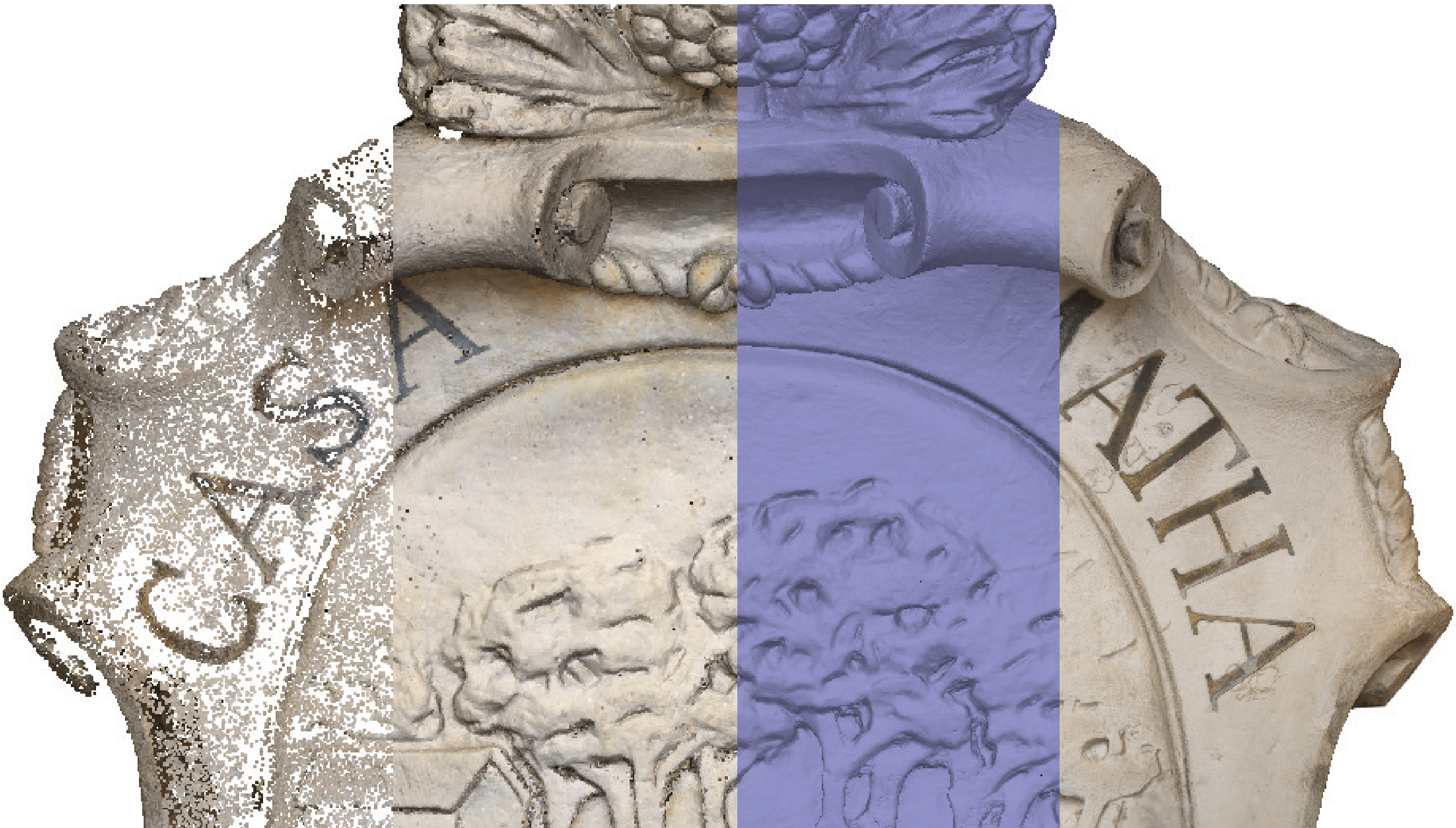
Digital photogrammetric processing of the Casa Matha emblem, Ravenna (Italy)

CHAPTER 4

METHODOLOGY AND DEVELOPMENT

The chapter applies to selected case studies the main methodologies and workflows for digital documentation analysed in Chapter 2. In section 1 the main problems highlighted in the phases of acquisition, cataloguing, archiving and processing of digital data are recalled. In section 2 the methodologies are applied to the case studies, depending on their characteristics and the objective of digital documentation. In section 3 the characteristics of dissemination, diffusion and digitisation of Cultural Heritage are analysed.



Chapter 4 - *Methodology and development*

4.1 Highlighted problems in the analysed workflows

From the analysis of the state of the art (see chapter 2), a broad picture emerged of the problems encountered when using three-dimensional models for the management of Cultural Heritage.

The criticalities observed can be divided into technical issues, related to the workflows used for data acquisition and processing, and management issues, i.e. related to the actions taken by the various professionals involved in the life cycle of the asset. We intend to describe these problems found in the analysis phase starting from the concept already defined above of "life cycle applied to Cultural Heritage".

4.1.1 Digital documentation phase

We have defined this phase as the one in which the digital data related to a given object of study are acquired and processed. It is evident that the motivations and purposes at the basis of the choice to digitally document a Cultural asset are fundamental for the determination of the modalities of acquisition and processing of the raw data, or at least they should be. Often, in fact, the decision to document with a specific methodology a cultural asset doesn't provide a real benefit to the project. It is therefore fundamental that the administration that decides to choose this method for the documentation of a given object should have a thorough knowledge of the characteristics of the object to study, the applicable methodologies, the purposes of the documentation. From the combination of these three factors, we can understand the better way to document the monument (that will be part of the proposed guidelines). Limiting to highlighting the main problems of the digital documentation phase, we analyse those defined as managerial. As anticipated in the state of the art, the lack of knowledge of the basic technical aspects of digital documentation and of the possible outputs that can derive from it, leads the administrations to two behaviours: (i) refusal, because it is considered unnecessary or not indispensable, not "orthodox" compared to traditional documentation, and also less verifiable and reliable, or (ii) misunderstanding and therefore incorrect use of digital documentation in relation to the case study and the aims of the project. This reaction hides precisely the difficulty of communication between scholars, professionals and managers, i.e.:

- inability of researchers to adequately disseminate the results of their work, explaining the pros and cons of the methodologies used and the results that can be obtained;
- willingness of professionals to carry out work in a more familiar field, with standards and software they know best and with which they can achieve better results, such as the BIM environment;
- lack of knowledge by managers on how to digitally document and use 3D models, willingness to use traditional methods, which are considered more reliable and verifiable, or to follow regulations with little application to Cultural Heritage

The result of these misunderstandings and gaps leads, for example, to apply BIM modelling to all types of Cultural assets indiscriminately. This process, which we can define as excessive "BIMification", has serious consequences when the administrations responsible for drawing up an invitation to tender include the presence of a BIM model as a fundamental requirement, thinking in this way that they are more protected from the point of view of results, but completely ignoring whether there is a real need to use BIM. Management issues can be referred to the "design" phase of digital documentation, i.e. precisely when a public or private administration, in charge of a Cultural asset, decides to collect digital data. However, since the practical phase of documentation is very articulated, it is useful to further subdivide digital documentation into sub-phases that concern the acquisition, processing, management (storage and sharing) of raw data.

4.1.2 Digital data acquisition

As it appears from the state-of-the-art analysis, the most widespread practices currently used for Cultural Heritage data collection are Terrestrial Laser Scanning (TLS) and Digital Photogrammetry (DP) (mostly used for small and medium buildings), in specific cases combined with other tools and methodologies. Only these two methodologies have been analysed in depth. Through them it is possible to create a rather exhaustive basic documentation for most of the types of objects that constitute the Cultural Heritage. Furthermore, these two practices have now become part of the professional world (especially the TLS). The need to create standards and indications to be able to control quality and results arises spontaneously from the diffusion and the use by a larger number of users, not all of them specialised in these methodologies. After all, in the last ten years the Italian university courses in Architectural Surveying have developed specific modules dedicated to the digital documentation, mainly through lessons and workshops in terrestrial laser scanning and digital photogrammetry. It obviously reflects the development and diffusion of digital technologies and a simultaneous demand by the professional world. We have seen that the two basic methodologies are also the most common. However, the initial investment, especially for laser scanners, is still very high compared to other surveying methods, and the data processing phase is still quite time-consuming. As we have seen from the analysis of the state of the art, the latest experiments in this field focus precisely on reducing the costs of the tools and the acquisition and processing times. However, this part of the research lies outside the principal aim of this thesis, as it is experimental and too specialised to be applied to the professional world.

It is now analysed the relationship between the most widespread methodologies, the professional world and the user, i.e., it is highlighted how the basic workflows (now with more than a decade of experimentation behind them) have been recognized by the professional world and whether it is possible to manage them correctly.

First of all, there is a lack of national standards for data acquisition (see chapter 3), i.e. precise indications on how data should be collected and processed in numerical terms (e.g. for clouds from laser scanners, the resolution and storage format, and for photogrammetry, the pixel/inch definition of the texture and the number of polygons in the model). There is also a lack of recommendations on how the administrations are to manage these data: are they properly stored? Is the ownership of these data stipulated in the invitation to tender and how can the contracting authority dispose of them? As things stand at present, unless specified in some invitation to tender, these decisions are left to each administration, since there is no national or supranational directive. The result is anarchy in decision-making and a waste of resources. There is also no obligation to plan digital documentation operations (every how many years, after particular events such as restoration works, monitoring...), with specific indications on the parts to be surveyed and on how to integrate new data with the previous ones.

We have already seen how the technical problems, which are also related to the various sub-phases, have substantially improved in the last decades. In logistical terms, for example, the most common difficulties relating to the impossibility of accessing certain spaces have been resolved by limiting the size and weight of the tools used (a fundamental aspect in case of documenting archaeological sites or those at risk of collapse). Furthermore, the increasing use of drones has made it possible to obtain good results for otherwise inaccessible sites (see section 2.2.1).

4.1.3 Raw data processing

With regard to data processing, many technical and specific problems arise here, for which many effective solutions are being investigated by academics. The problems of the most tested workflows, described in chapter 2, are recalled here.

The first concerns the automatic or semi-automatic processing of point clouds or texture images. As Cultural Heritage is generally made up of objects of complex shape, it is very difficult to find algorithms that can correctly subdivide the points of a cloud in a completely automatic way according to the classes set by the operator (see section 2.2.1).

In the BIM field, the data processing presents some problems related to the inadequate modelling tools offered by the software and others related to the methods of transformation of the elements of a cultural asset into BIM elements. The *Scan-to-BIM* process still presents many problems, it is time consuming and still far from the complete automatization (see section 2.2.3). Other issues of the BIm software are linked to the texture and to the exchange format of the files.

Another much-discussed concept is whether or not to use free or commercial software. In the context of this thesis, a radical choice was not made, but on a case-by-case basis it was decided to use free and open-source software when these are easy to use and offer valid tools without the presence of excessive bugs, which require some specific computer skills to be resolved. In the case of commercial software, some of the most widely used in the professional field have been chosen, such as those belonging to the Autodesk suite.

4.1.4 Digital data management

As things stand at present, there are no national regulations or specific guidelines for either the collection or the storage of raw data (see chapter 3). As already pointed out in the management problems detected, the lack of knowledge on the part of managing institution regarding surveying methodologies is also reflected in the output derived from the surveys, such as point clouds and 3D models. The main problems are:

- raw data request and property definition;
- lack of specific indication for data definition and format;
- incorrect storage over time;
- impossibility of integrating future data with existing data;

When an administration, public or private, decides to document a Cultural Heritage, it generally does not care about the raw data collected by the operators performing the survey or the mesh models produced, but at most it concentrates on the final data (e.g. CAD data extracted from point clouds), with which it is more familiar. In this way, the administration loses the possibility of having the raw data available to perform a constant monitoring and comparison with the previous and future situations of an asset or part of it. Moreover, as the ownership of the data is never defined (which should belong to whoever finances the survey), it is never possible to dispose of these data for the administration in charge, to provide them, for example, to another professional for further analysis.

The possibility of being able to share data is clearly possible if universal exchange formats are used (such as PTX for point clouds and OBJ for mesh models), which many software, including open source, can easily read (see chapter 5, section 3). And very important is also the storage of such data over time, since they generally take up a lot of space and not all of them can be translated into a paper format.

Poor data management on the part of administrators and professionals often means having to repeat the survey or not having sufficient data to make a history of the condition of the property surveyed, to make comparisons and to set future actions, thus causing a waste of resources.

4.2 Presentation of case studies

The case studies were chosen for a combination of intrinsic factors and management perspectives, in order to apply in the various phases one or more of the analysed methodologies that best fit these characteristics and to determine the corresponding guidelines.

The main case studies are the early Christian monuments of the city of Ravenna included in the UNESCO World Heritage List and a neogothic funerary chapel located in the cemetery of Castellón de la Plana (Spain). The Spanish case study was documented and processed during the two stays at the Universitat Politècnica de València that took place within the cotutelle framework of the thesis.

Other case studies were included in the thesis work, although the application of the methodologies only referred to a part or a particular phase. The table 4.1 summarises the main cases and areas of application that led to a greater range of experiments in order to correctly draft the guidelines.

Fig. 1_ Arian Baptistery. Ph.: author

Fig. 2_ Interior of San Vitale. Ph.: author

NAME	TYPOLOGY	DIGITAL DATA ACQUISITION	OUTPUT
Mausoleo di Galla Placidia	Architectural Isolated building **World Heritage List**	SCANS (11 - 2018) Photogrammetry (11 - 2018)	Simplified Information System for the CH management
Cappella di Sant'Andrea	Architectural Interior **World Heritage List**	SCANS (2019) Photogrammetry (2019)	Simplified Information System for the CH management
Battistero Neoniano	Architectural Isolated building **World Heritage List**	SCANS (2019) Photogrammetry (2019)	Simplified Information System for the CH management
Battistero degli Ariani	Architectural Isolated building **World Heritage List**	SCANS (2013) Photogrammetry (2013)	Simplified Information System for the CH management
Basilica di San Vitale	Architectural Isolated building **World Heritage List**	SCANS (2015) Photogrammetry (2015)	Simplified Information System for the CH management
Sant'Apollinare Nuovo	Architectural Isolated building **World Heritage List**		Simplified Information System for the CH management
Sant'Apollinare in Classe	Architectural Isolated building **World Heritage List**		Simplified Information System for the CH management
Panteón de Ramón Peres y Rovira	Architectural Isolated building	SCANS (2020) Photogrammetry (2020)	Restoration work (HBIM) Monitoring (HBIM) Dissemination
Lonja de los Mercaderes (Valencia, Spain)	Architectural Isolated building **World Heritage List**		Dissemination Guided & virtual tours
Mercado Central (Valencia, Spain)	Architectural Isolated building **BIC**		Dissemination Guided & virtual tours
Iglesia de los Santos Juanes (Valencia, Spain)	Architectural Isolated building **BIC**		Dissemination Guided & virtual tours
Chiesa di San Francesco (Ravenna, Italia)	Architectural Isolated building BC	SCANS (2019) Photogrammetry (2019)	
Chiesa di San Carlino (Ravenna, Italia)	Architectural Isolated building BC	SCANS (2019) Photogrammetry (2019)	Workshop
Stemma Casa Matha (Ravenna, Italia)	Objects - statue BC	SCANS (2019) Photogrammetry (2019)	3D print Dissemination
Chiuro	Urban Historic centre	SCANS (2016-2021) Photogrammetry (2016-2021)	Virtual exploration Dissemination Workshop
Cupola Piccole Terme, Villa Adriana (Roma)	Architectural Isolated building **World Heritage List**	SCANS (2018-19) Photogrammetry (2018-19)	Restoration work Monitoring
Tiburio del Duomo di Milano di Leonardo	Drawing - Architecture	2018	Virtual reconstruction

Table 4.1_ Case studies

The main case studies in Ravenna include the monuments on the UNESCO World Heritage List, i.e. the main examples of early Christian and Byzantine architecture declared World Heritage Sites in 1996 for being “unique testimonies of the artistic contacts and developments in a highly significant period of the cultural development in Europe. They constitute an epitome of religious and funerary art and architecture during the 5th and 6th centuries AD. The mosaics are among the best surviving examples of this form of art in Europe and have added significance due to the blending of western and eastern motifs and techniques” (UNESCO World Heritage Centre, n.d.). Beyond the architectural and artistic value of these monuments, the case study is very interesting from the point of view of management. Administratively, in fact, the management is divided between the State and the Church. The Arian Baptistery (fig. 1), the Mausoleum of Theodoric and the Basilica of Sant’Apollinare in Classe are managed by the *Soprintendenza Archeologia, Belle Arti e Paesaggio* for the provinces of Ravenna, Forlì-Cesena and Rimini, while the Neonian Baptistery, the Archiepiscopal Chapel, the church of San Vitale (fig. 2), the Mausoleum of Galla Placidia and the Basilica of Sant’Apollinare Nuovo are managed by the *Opera di Religione* of the Diocese of Ravenna. Since the 1996 declaration, two reports have been presented (and available on UNESCO’s official website[1]), the latest in 2014, which show a shortage of available professionals in the Research and Monitoring disciplines, despite the fact that the opportunity for specific training is rated as “average”. It is therefore possible to improve the management of the complex of monuments starting for example from a shared documentation for each one of the eight monuments on the list.

Fig. 3_ Family chapel of Ramón Peres y Rovira, Castellón de la Plana, Spain. Ph.: author

The case study of the Spanish oratory chapel (fig. 3) was chosen because it combines interesting features for the application of 3D models to particularly complex Cultural Heritage as a tool for restoration works. In fact, given the presence of many different materials, a rich decorative apparatus, and the need to perform restoration works, it was chosen to apply the workflow for the creation of an HBIM model, supported by other outputs, such as 3D model optimisation and online publication.

The other case studies reported in table 4.1 concern, for example, the dissemination of historical heritage using 3D printing from

1 _ https://whc.unesco.org/en/list/788/documents/

3D models (as was done for the emblem of the Casa Matha, which was digitally surveyed, and processed for dissemination and 3D printing; fig. 4).

The studies carried out at Hadrian's Villa concerned the data collection in archaeological contexts. The survey campaigns organised made it possible to collect and process data for research and restoration purposes, as in the case of the Small Baths, for which there was a collaboration with the architectural and engineering firm commissioned to design a roof over the octagonal hall of the Small Baths with previous consolidation of the existing structure. Multiple survey campaigns were carried out during the various phases of work, pre and post restoration. The models were used in the design phase of the roof.

In the case of the survey campaigns carried out in Chiuro, the focus was always on the dissemination of the research results. Various workshops were organised for the fieldwork of university students and professionals. The workshops included an approach to digital surveying using terrestrial laser scanning and digital photogrammetry. In addition, conferences for a general public of local citizens or to specialists and professionals were organised, both during the workshops and in study days included in the Radici Project involving the localities of the Sondrio district[2]. The final objective of the work on Chiuro is the creation of an application for smartphones in which, thanks to the operations of surveying, processing and optimisation of the 3D data, the salient buildings of the small village are inserted in a game engine. The app will allow the virtual exploration with an educational aim that, in addition to visualisation, provides some historical notations.

Another interesting case study is Leonardo's never realised project for the *tiburio* of the Milan Cathedral. In this case, starting from two drawings by Leonardo, three-dimensional modelling was used to virtually reconstruct two different hypotheses of the project (fig. 5). Each hypothesis is based on historical, geometrical and stylistic considerations. This case study is described in detail in Frommel et al. (2020).

From the general overview of the main case studies, in each case the workflow that best suited the case study was experimented with. The main ones will now be analysed in detail.

Fig. 4_ Emblem of the Casa Matha. Ph.: author

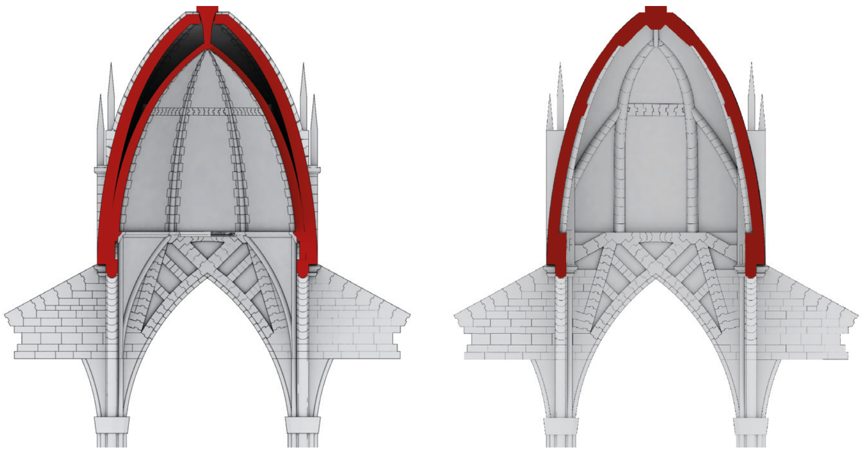


Fig. 5_ Leonardo's solutions for the tiburio of the Duomo of Milano. 3D model: Gianna Bertacchi. Image from Frommel et al., 2020.

2 _ https://www.radicidentita.it/

4.2.1 Early Christian Monuments of Ravenna

The eight monuments on the World Heritage List date from different historical periods between the 5th and 6th centuries AD. The oldest ones, the Mausoleum of Galla Placidia dated 425 AD and the Neonian Baptistery built in the first half of the 5th century, date back to when Ravenna was the capital of the Western Roman Empire. The Arian Baptistery, the Archiepiscopal Chapel, the Basilica of Sant'Apollinare Nuovo and the Mausoleum of Theodoric, built by Theodoric in his building plan during his reign (493-526 AD), were built later. It was the Eastern Emperor Justinian who realised the other representative buildings of Ravenna, reconquering the city in 527 AD. He was responsible for the rebuilding and extension of the church of San Vitale and Sant'Apollinare in Classe. Despite the fact that they were built in different periods and under different sovereign, we can see many common elements, not only in the presence of mosaics (Fiorentino, 2020), which are the reason for the inscription in the World Heritage List, but also in the construction characteristics, for example the use of brick, although the architectural conformation differs from one monument to another.

The Mausoleum of Galla Placidia

The building was commissioned by Empress Galla Placidia, regent in place of her son, in 426 AD as a mausoleum for her future remains. The small building is in the shape of a Latin cross with the sides not perfectly perpendicular. The external architecture is composed of an apposition of simple volumes (fig. 6). The brick exterior contrasts with the interior where every surface is covered with alabaster, marble on the side walls and mosaic on the vaults. According to scholarly reconstructions, the mausoleum was part of the complex of the nearby church of Santa Croce and was connected to it by a narthex. It is assumed that on the opposite side of the narthex there was a building identical to the mausoleum, of which no traces remain. The mausoleum, like all the other ancient buildings in Ravenna, has been subjected to the phenomenon of subsidence. However, while in other cases the ancient level of the floor has been restored, here the current level (dating back, in any case, to an ancient period) is almost the same of the outside, while the original level must have been about 1.5 metres deep, a fact which therefore alters the current perception. The historical hints reported are only intended to insert the monument in its context, to report the main features and to illustrate the strategy chosen for the digital documentation. For further information see the specific bibliography (Rizzardi, 2011, pp. 39-55; Malafarina, 2008).


Fig. 6_ Mausoleum of Galla Placidia. Ph.: author

The survey campaign was carried out in November 2018 using a Leica C5 terrestrial laser scanner, the 3DEYE System (a camera on an extendable pole, fig. 7) and a NIKON D5100 reflex camera.

A total of 28 interior and exterior scans were taken. For the digital photogrammetry, 367 photos of the interior and 705 photos of the exterior were taken in maximum quality (4928x3264 pixels) and RAW format, of which 123 were of the roof and exterior paving, made using the extensible pole system (5472x3648 pixels).

The first step in the data processing was the cataloguing of the laser scanner and photogrammetry data. A Level 0 folder was created containing the raw data (scanner projects, clouds in PTX format and photographs in RAW format). In this way it is always possible to restart from the original data in case of error or doubt about processing (see chapter 5 for more indications about data storing).

A manual registration of the point clouds has been carried out using the software Leica Cyclone 9.0. The 28 interior and exterior clouds were imported into the software and progressively aligned using homologous points corresponding to the targets affixed for the photogrammetric part (figs. 8-9). The origin of the axes was positioned in the left corner of the main façade and the x-axis was aligned with the

Fig. 7_ Mausoleum of Galla Placidia. Extendable pole for camera shots. Ph.: author

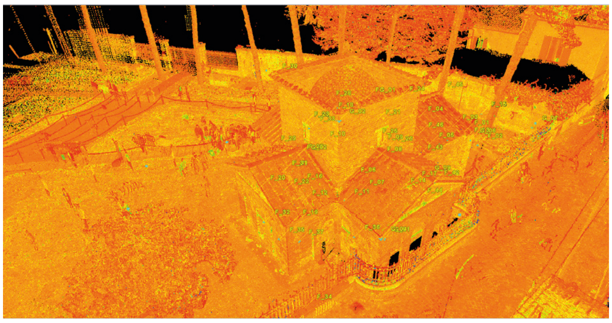


Fig. 8_ Mausoleum of Galla Placidia. Targets in Leica Cyclone

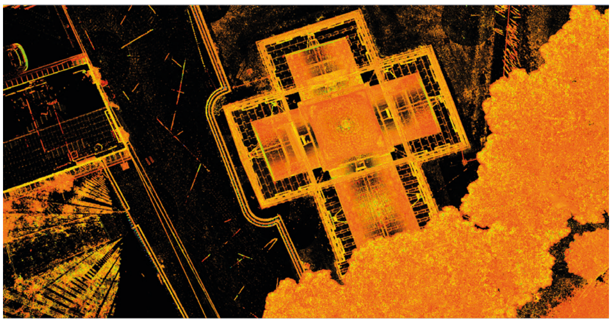


Fig. 9_ Mausoleum of Galla Placidia. Aligned point clouds in Leica Cyclone

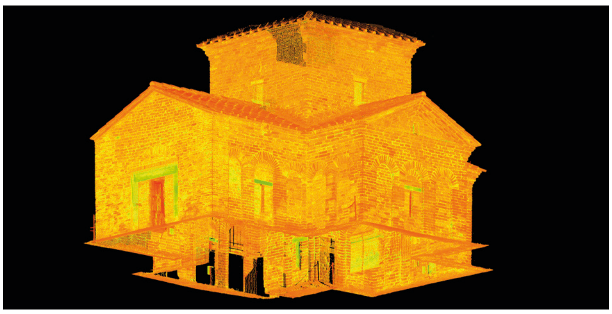


Fig. 10_ Mausoleum of Galla Placidia. Point cloud of the exterior

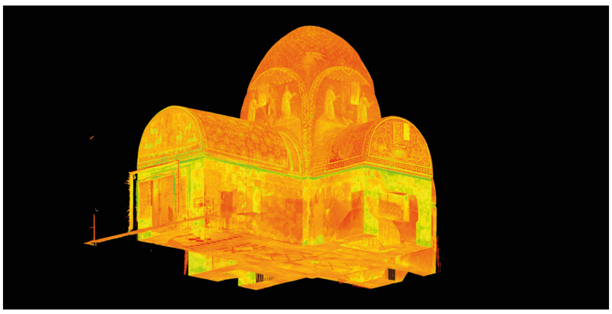


Fig. 11_ Mausoleum of Galla Placidia. Point cloud of the interior

direction of the façade. The origin chosen must be convenient for the extrapolation of plans, sections and orthoimages in general and to be able to refer all subsequent models to the same tern of axes to allow future integration. Since the origin is a point on the architecture, it is possible to use topographical references from previous surveys, or sometimes it is possible to insert new ones to become the reference for subsequent data collections. In most point cloud or model management software it is also possible to insert another axis origin that follows the direction of the cardinal points and easily switch between the two views.

The result of this processing step is a global point cloud, saved in the format of the software used (in this case IMP, from Leica Cyclone). At this level of data processing corresponds the Level 1 folder that contains the PTX file exported from the total point cloud, which only covers the building and a few metres around it. In this way the file will be lighter and more manageable than the total file (figs. 10-11).

The PTX file was used to produce different outputs, i.e., mainly, the 2D drawings and the high detail mesh model. The cloud was cleaned by removing unnecessary or erroneous points. In fact, it is necessary to check the correctness of the point cloud in case of slightly translucent surfaces: in the interior of the Mausoleum, marble or reflective surfaces such as mosaic tiles completely cover the interior. In the case of marble and alabaster, the phenomenon of subsurface scattering may occur (Levoy et al., 2000, p. 3), resulting in a shift in the actual position of the point and, in the case of tesserae, in a duplication of points as the laser light reacts as it does when it hit a reflective surface.

The 2D drawings were made from orthoimages extracted from the point cloud (fig. 12) and then inserted into the CAD environment. Although there is the possibility of automatically extracting sections from the mesh model and importing them into the CAD environment using the DXF

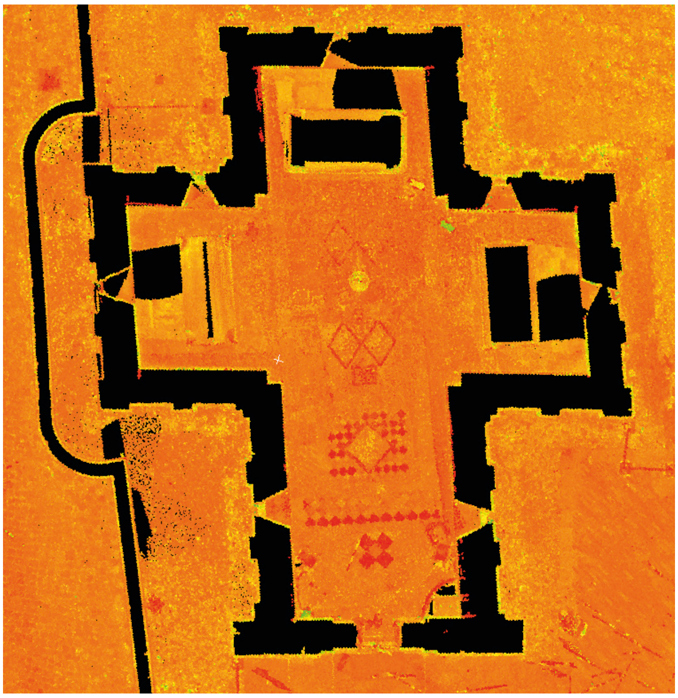


Fig. 12_ Mausoleum of Galla Placidia. Plan in Leica Cyclone

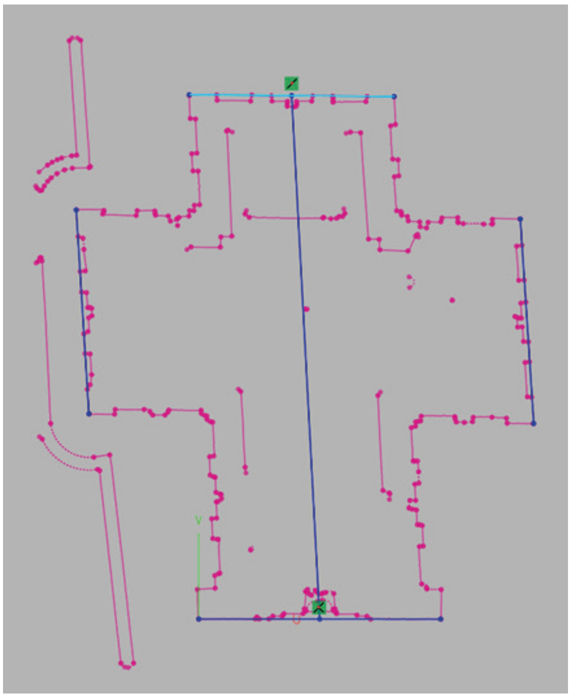


Fig. 13_ Mausoleum of Galla Placidia. Section lines extracted from the mesh with Geomagic DesignX

format (fig. 13), these must then be checked at critical points where the model may be incorrect or have holes, and often need to be simplified, so this operation can be done later to compare the results of the manual and automatic methods.

Despite limiting the working file to the building only, it is likely that the PTX is still too heavy to handle smoothly on a PC with average performance (the PTX of the building occupies 6.27 GB on hard disk and the IMP file 2.2 GB). It may therefore be convenient to decimate it when importing it into the meshing software. In the case of the Mausoleum, the cloud of the building consists of approximately 150 million points. The PTX file was imported into Geomagic Design X 2016 without decimating the clouds. In this case, in fact, it was decided not to import a single global cloud of the building, but rather to import the clouds already aligned, but still separated, in order to proceed to a manual check of the clouds to verify the correct triangulation of some problematic points of the structure (for example, the roof where there were few points available or some parts of the interior where the points relating to stone surfaces did not correspond to the real position of the surface).

After importing into Geomagic Design X reverse modelling software, some parts of the cloud were manually cleaned, and others were checked. Subsequently, different types of commands for the creation of the mesh model were experimented. First, the clouds were triangulated individually with the "Points > Triangulate" command, seeing that the best results were obtained with the 2D triangulate, spherical option (the vertices of the polygons are projected onto a sphere that has the laser scanner head as its centre (fig. 14). Subsequently, three methods (1) (2) (3) for obtaining a mesh from two single meshes were compared. Considering that the processing times of an average sized point cloud (about 3.5 million points) into mesh were equal among the various methods, the results were observed. Using the tool (1) "Polygons > Mesh Buildup Wizard > New Mesh Construction" the "Global Shape Fitting Resolution" has been set between HD (high density) and UHD (ultrahigh density), and the "Noise reduction sampling" to medium. The empty

Point cloud 18 Galla Placidia
Points: 1.036.141

Point Cloud 19 Galla Placidia
Points: 2.415.759

Points > Triangulate > 2D triangulate:
- Spherical
- Face removal criteria: maximum edge lenght is larger than 30 mm; Area is larger than 450 mm²

Mesh point cloud 18
points: 948.458
polygons: 1.706.611

Mesh point cloud 19
points: 1.477.568
polygons: 2.497.218

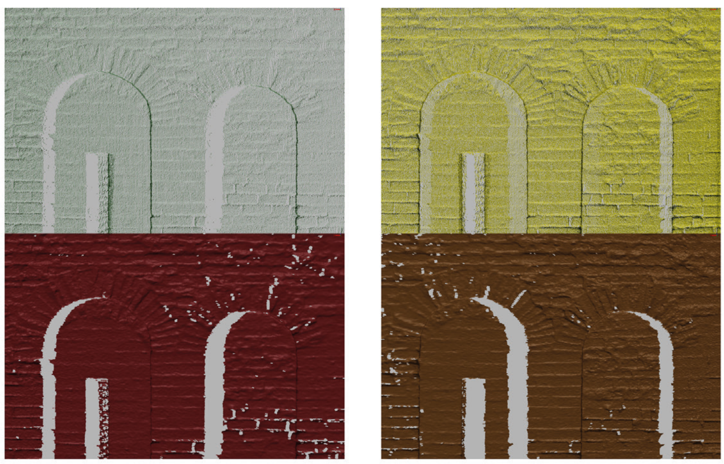
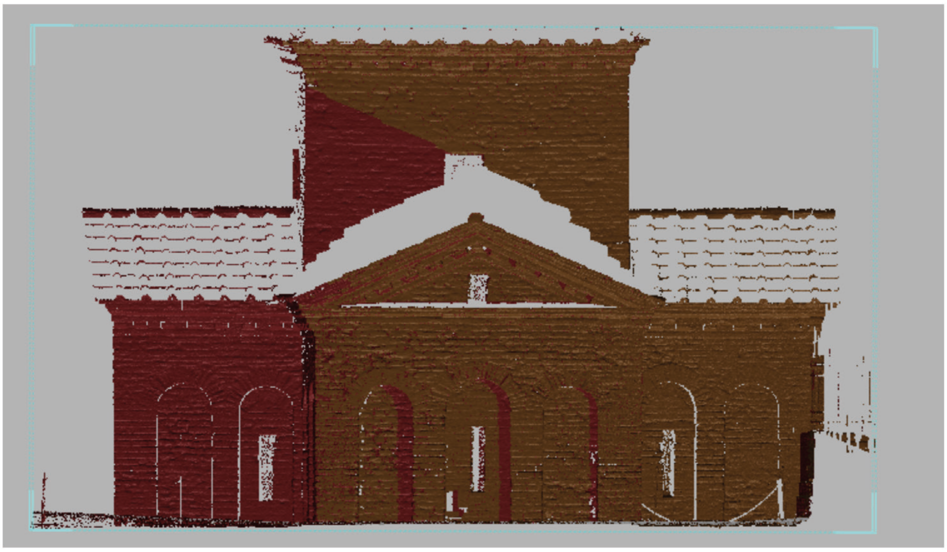


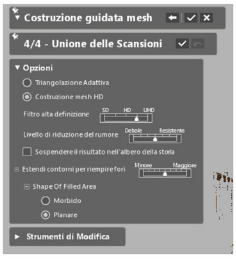
Fig. 14_ Comparing different methodology of point triangulation with Geomagic DesignX v2016

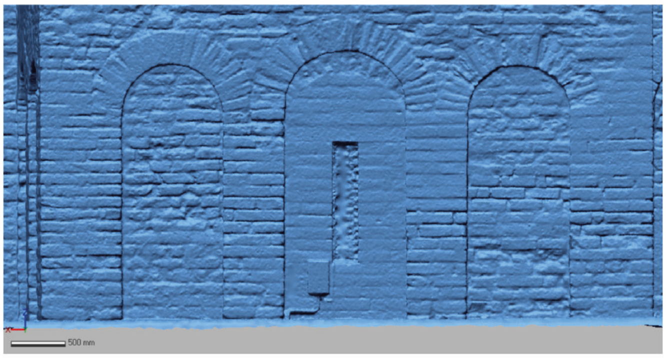
Point cloud 18 Galla Placidia
Points: 1.036.141

Point Cloud 19 Galla Placidia
Points: 2.415.759



Polygons > **Mesh Buildup Wizard**
Results:
points: 3.350.373
polygons: 6.677.201





Polygons > **Combine**
Results:
points: 2.426.026
polygons: 4.203.829

Polygons > **Merge**
Results:
points: 2.849.767
polygons: 5.617.007

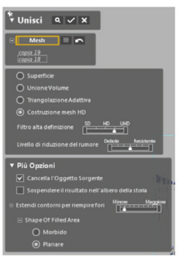
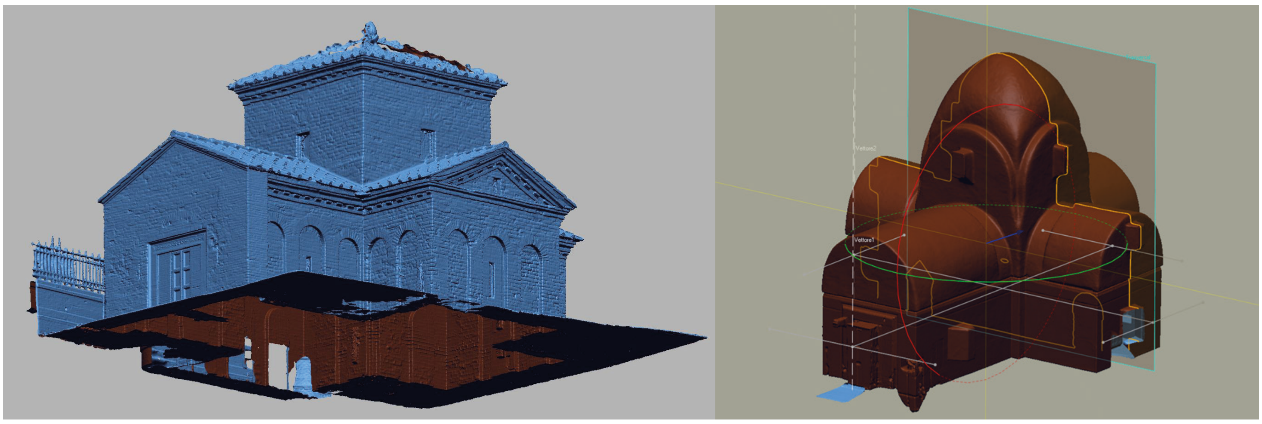


Fig. 15_ Comparing different methodology of mesh construction with Geomagic DesignX v2016

areas were automatically filled with “Planar” condition. When using the “Polygons > Combine” command (2), the process is fully automatic, and the mesh options cannot be controlled. In the “Polygons > Merge” command (3), on the other hand, the settings have been kept similar to the Mesh Buildup Wizard (fig. 15). The option (3), despite the high number of polygons, does not give good results, while the options (1) and (2) produce a better mesh. In the case of the Wizard (1), the time taken is slightly longer, but the result looks better from the point of view of pre-optimisation of the mesh, which is not the case with Combine (2), as the surface has much more noise. Once it had been proven that the Mesh Buildup Wizard was the best method, it was decided to use it for the remaining clouds, in order to obtain a global model of the interior and exterior. This whole process still has a considerable manual component, which increases the data processing time. It is certainly avoidable in the case of simpler architectures in which no errors are found. Furthermore, if the errors mentioned above are resolved on a case-by-case basis and a powerful machine is available, it is possible to mesh all the clouds at once.

After the triangulation and mesh fusion procedure, the model obtained had a high number of triangles (in the mausoleum the exterior consists of about 22.6 million polygons, fig. 16, and the interior of about 4 million polygons, fig. 17). We can consider this result as the Master Model, used for the subsequent optimisation operations. In this case the model, derived from the triangulation of the point cloud, obviously has the same holes as the clouds. In the case of the Mausoleum, these were some internally, behind the sarcophagi, where it was not possible to position the scanner, given the limited space available. Externally, however, they mostly concerned parts of the roof.

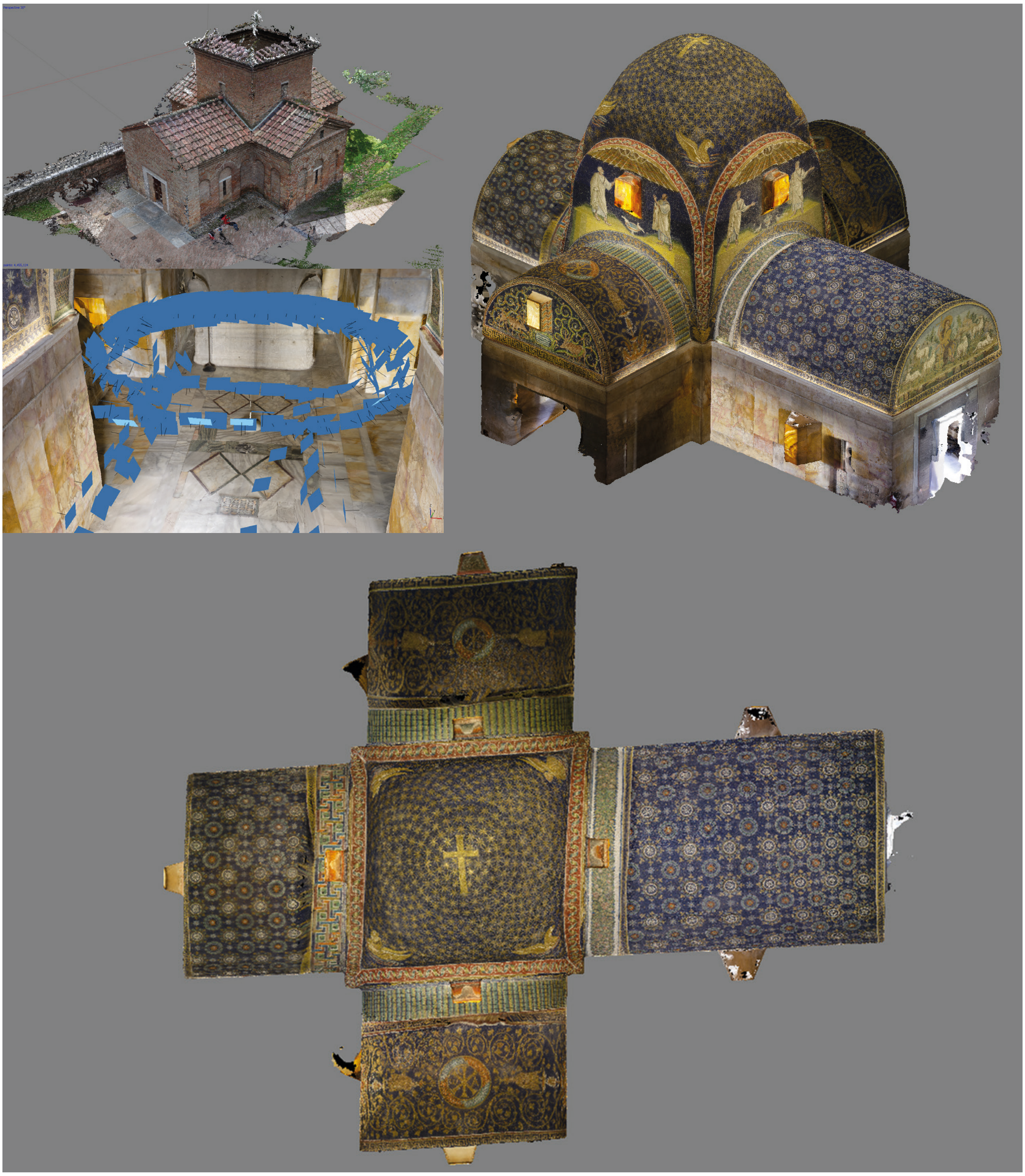
It was therefore decided to integrate the missing parts either with automatic tools of the Geomagic software, such as “Fill Holes” or “Edit Boundaries”, or by joining the mesh model derived from the photographs taken with the extensible pole system. The integration of missing parts by joining two mesh models made with different acquisition technologies can lead to a suboptimal result, both because of the increased probability of making errors, given the presence of many manual actions, and because the two models must have the same scale and position in space, but also the same density and size of polygons. Geomagic offers the possibility of calculating the average side length of the triangles forming the mesh and proceeding with a resampling (“Polygons > Global Remesh”), in order to standardise the



Figs. 16-17_ Mausoleum of Galla Placidia. Exterior an interior mesh

Tab 4.2_ Chunks of the photogrammetric model of the Mausoleum of Galla Placidia

	Photos	Tie Points	Dense Cloud Points	Quality	3D Model Faces
Interior	332	128.496	27.388.847	MQ	5.477.769
Roof (3DEYE)	123	113.515	65.329.015	HQ	6.303.332
North façade	157	49.499	12.168.822	MQ	4.500.000
West façade	83	38.964	4.636.579	MQ	1.269.622
South façade	87	56.940	8.627.567	MQ	723.593
East façade	113	1.337.435	30.939.011	MQ	-
TOT exterior	563	396.353	117.662.848		13.594.655



Figs. 18-21_ Mausoleum of Galla Placidia. Photogrammetry models of exterior and interior


Fig. 22_ Mausoleum of Galla Placidia. Digital phorogrammetry workflow from point cloud to textured mesh

surface of the triangles. In this way, we obtain data on the initial quality of the mesh, and we are also able to standardise the detail of the added parts.

Parallel to the processing of the point cloud data, photographs of the interior and exterior were processed with the Agisoft Metashape Pro 1.5.1 software.

The total model obtained from the processing of the photos was created by aligning various different chunks, oriented and scaled thanks to the reference coordinates extracted from the point cloud, already oriented according to the chosen axis origin. The data relative to the various chunks are indicated in the table 4.2 (figs. 18-22).

With regard to the orthophotos that can be extracted from the photogrammetric model, the maximum achievable quality is very high, with excellent results up to a scale of 1:10, given the high quality of the photographs taken. Some problems were encountered on the east side of the mausoleum, being very close to the railing, which hindered the correct position for taking the photographs.

Once the mesh model obtained from the triangulation of the cloud points has been integrated and the main holes have been closed, it is possible to proceed with the optimisation and integration of the parts for which no information is available (e.g. the covering of the central part).

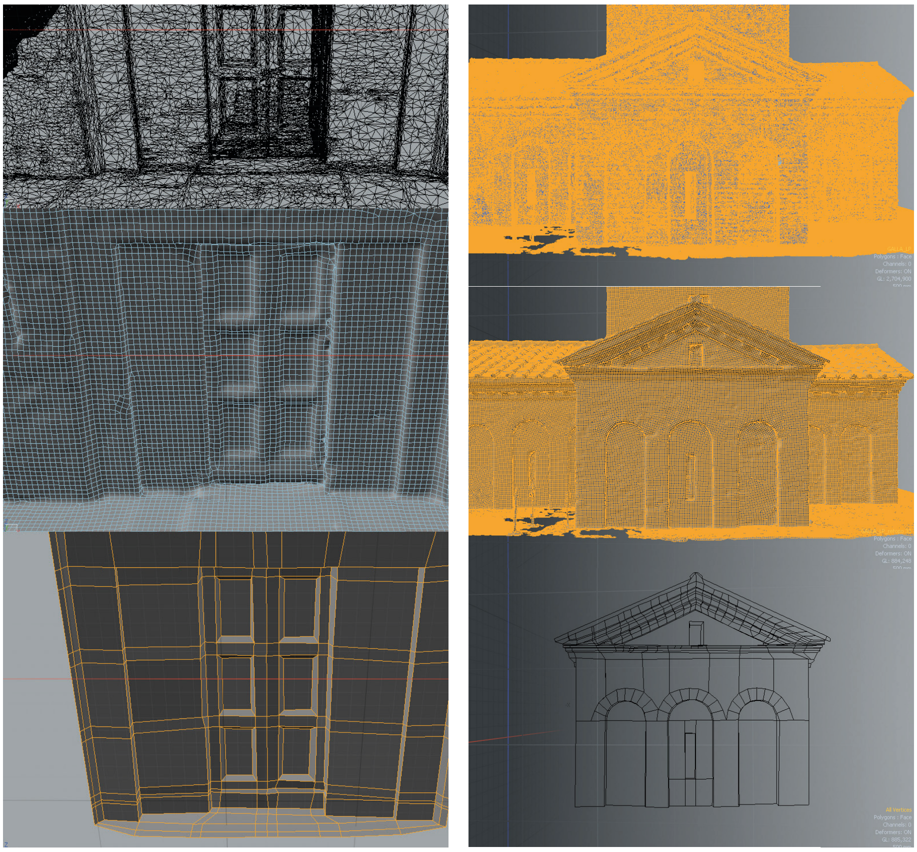
The methodology used follows these steps: (1) re-importing the optimised model into Agisoft Metashape (keeping the uv calculated); (2) recalculating the texture; (3) re-exporting the model for processing in 3D modelling and rendering software. In this case, Luxology Modo v12 was chosen, which also allows the optimisation of the model and the creation of bump and normal maps.

Using Modo, two separate retopology operations were performed on the mesh model: the first was automatic, reducing the number of polygons to 33% of the total, and the second was manual, in order to create a model with the lowest possible number of quadrilaterals and the greatest possible adherence to the original surface (figs. 23-24).

In both cases, the aim of the operation is to optimise the triangle model by reducing the number of faces and converting the triangles into quadrilaterals. Automatic retopology has the advantage of being relatively fast but does not allow ideal optimisation of points with less or more detail. External walls such as those of the mausoleum can, for example, be reduced to a few polygons where they are flat and then increase the number in the presence of a curvature or a change of plan direction. The surface detail of the brickwork, for example, is subsequently restored by calculating the bump map, applied together with the texture in the rendering phase on a model that is therefore very light in polygons.

It is clear that the model optimised in this way cannot be used, for example, to extract detailed sections, since the mesh surface is at a very simplified level with respect to the initial geometry, and would therefore lead to excessive simplification errors. For this reason, the various phases of the mesh model must be stored in order to have a model that we can call Master (belonging to level 2 - processed data) which is used as the basis for the subsequent processing phases to produce different outputs. In this workflow we consider the mesh model obtained from the triangulation of the point clouds as the Master model.

The optimised model with applied maps is one of the possible outputs that can be produced from the master model. The same procedure can be applied for small portions, in order to have detailed elements. The main use of such optimised models is to allow them to be quickly visualised, e.g. by being published online or inserted into game engines for the production of heritage content.



Figs. 23-24_ Retopology. Exterior of the Mausoleum of Galla Placidia.
Master Model, Automatic retopology 33%, Manual retopology

The Archiepiscopal Chapel

The small chapel of St Andrew is located on the first floor of the Archbishop's Palace of Ravenna, adjacent to the Cathedral. The small space develops in the form of a Greek cross with a dome in the central part. The entrance is preceded by a small rectangular vestibule covered by a barrel vault. The two rooms are lit by two openings, one of which is a mullioned window. The chapel is a private oratory of the bishops, originally called *Monasterium Sancti Andreae Apostoli*. According to historians (Deichmann, 1969, pp. 201-206), the founder was Peter II (bishop between 494 and 519 AD, at the time of Theodoric), during the works to enlarge the ancient diocese. The dedication to St Andrew already appears in ancient times in the *Liber Pontificalis Ecclesiae Ravennatis*, and perhaps dates back to Archbishop Maximian (546-556 AD) who had the saint relics transported from Constantinople. However, the chapel was originally dedicated to Christ, to whom the decoration of the interior refers and to whom the Palatine chapels were usually dedicated. During the 16th century, Cardinal Giulio della Rovere had the mullioned window altered, the walls redecorated (with mirroring marble and a stucco frame separating the marble panels from the mosaic vault) and the mosaics in the northern and southern lunettes replaced with frescoes. Another important change took place in 1643, when Cardinal Luigi Capponi had the apse demolished and moved the new arched entrance into it, thus reversing the original orientation. In 1911, restoration work was undertaken by Giuseppe Gerola, who also painted the cross in the starry sky of the semi-dome covering the altar, simulating a mosaic.

Again, it was decided to use two well-proven

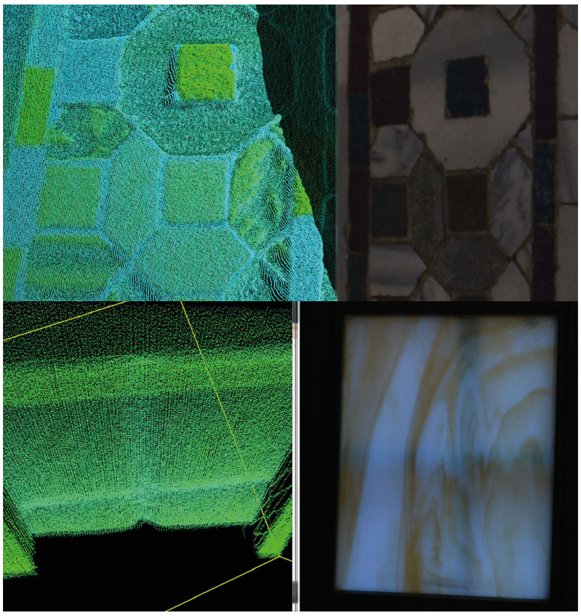


Fig. 25_ Subsurface scattering problems on translucent materials with Faro Focus 3D X130

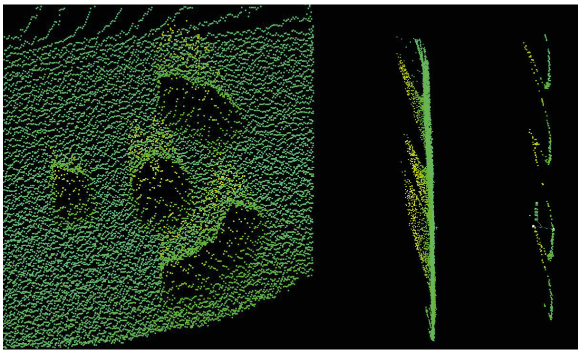


Fig. 26_ Problems encountered on printed targets

Fig. 27_ Leica ScanStation C5 in the vestibule of the chapel

methodologies (terrestrial laser scanning and digital photogrammetry) for documentation. However, some problems were encountered in the restitution of the data. The presence of translucent materials such as marble and alabaster (in the walls, windows and floor) or black materials such as granite (in the floor) caused some subsurface scattering problems in the laser scanner survey (figs. 25-26), especially in the one carried out with the Faro Focus 3D X130, a very compact and fast phase difference laser scanner. The best results, however, were obtained with the Leica Scan Station C5 time-of-flight laser (fig. 27), although the survey itself is more complex and time-consuming due to the size and weight of the instrument. Many of the problems of point displacement experienced with laser scanning technology are not encountered in digital photogrammetry. In this one, the main problems were due to the poor natural lighting of the environment, which, when artificially lit, caused a strong alteration of the texture image. Furthermore, given the small space of the chapel, there were problems in the parts of the marble facing, because it was difficult to control the right focus, given the small portion of marble framed whose surface pattern appeared to the camera as out of focus.

As in the other cases, the data processing involved the point clouds from the laser scanner for the production of the high-poly model and the subsequent optimisation of the mesh and reprojection of the texture. An example of the procedure with reference to the central dome can be found described in detail in the Appendix 1.

The Neonian Baptistery

The Neonian Baptistery is an octagonal building located a few metres from the north side of the present 18th-century cathedral of Ravenna, rebuilt on the ancient Basilica Ursiana. Scholars define two main building phases, both belonging to the early Christian era. The second, attested by an epigraph, is due to Bishop Neon, who intervened in the interior decoration around 458 AD. The highest part of the outer curtain wall is probably a medieval reconstruction, the exact period of which is not known, but it has certainly been identified as not belonging to Neon's time. The lower part of the curtain wall, on the other hand, is the result of 19th-century restorations. In the 1950s, in fact, the baptistery was subject to archaeological excavations conducted by the engineer Filippo Lanciani, during which the ancient level of the building was found to be

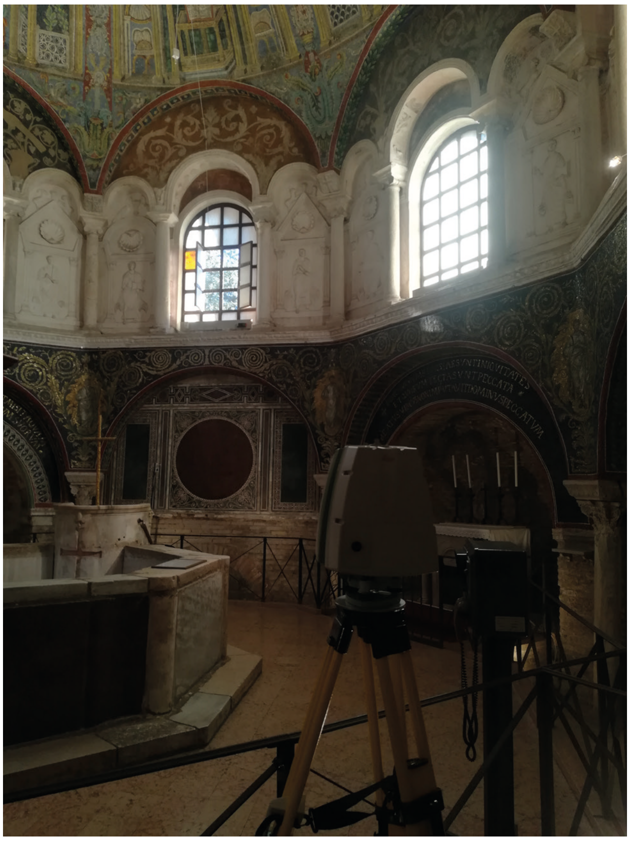


Fig. 28_ TLS survey. Ph.: author

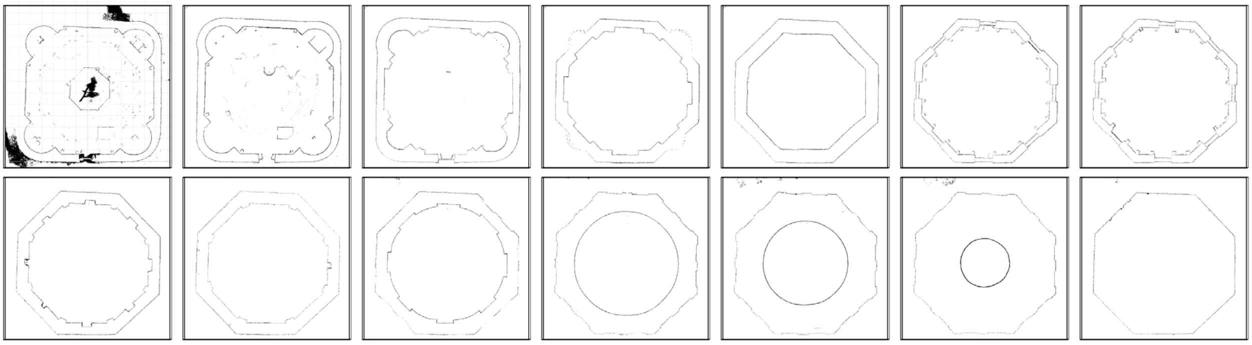
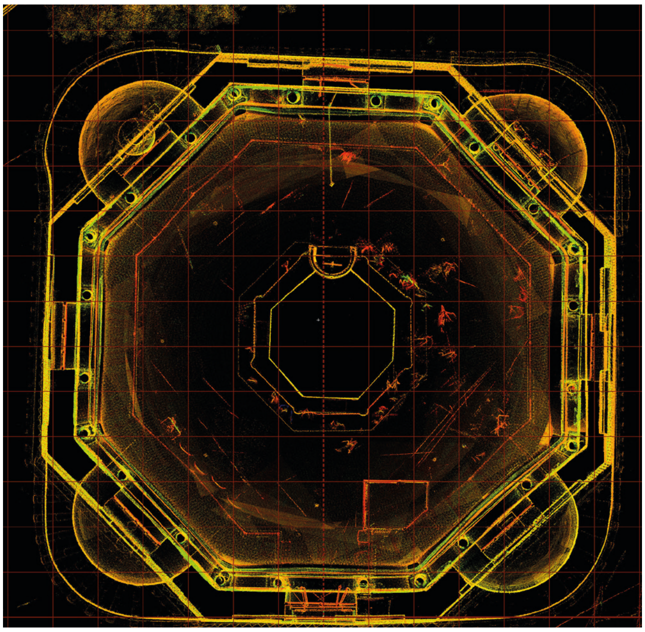
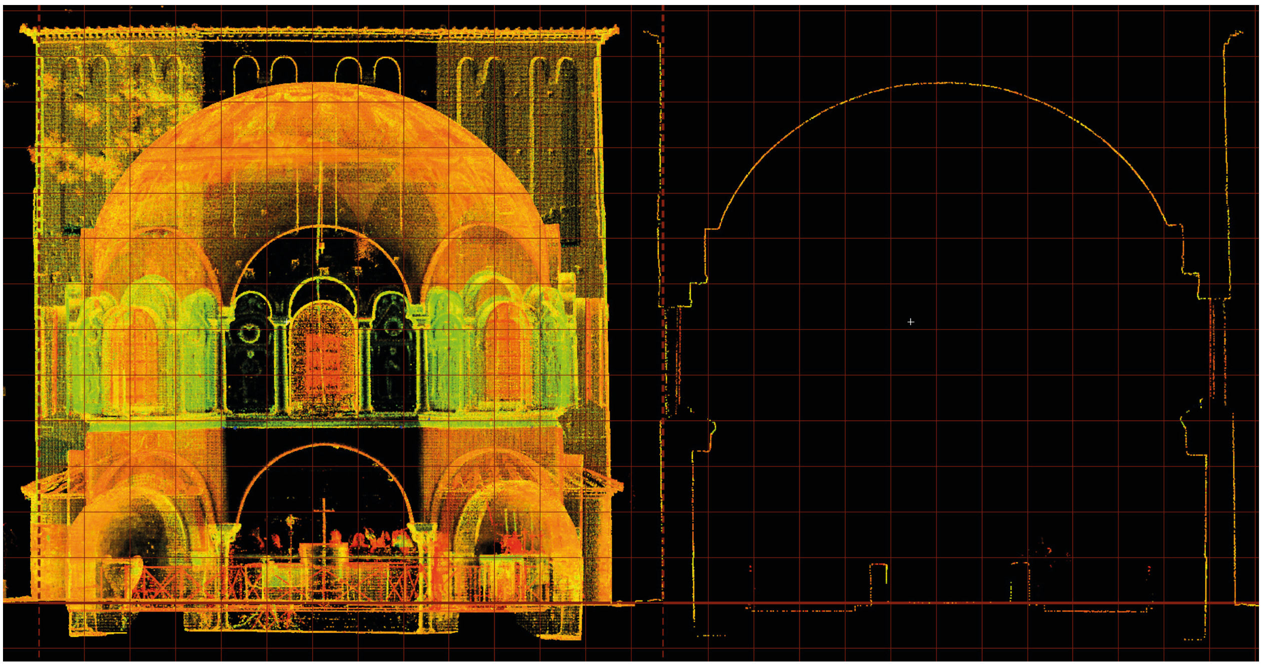


Fig. 29_ Neonian Baptistery. Plans every 50 cm



about 3 metres below the present one (partly due to the phenomenon of subsidence from which the whole city of Ravenna suffers). During subsequent restoration work, two of the four apses that originally stood on alternate sides of the octagon were completely rebuilt. However, the reconstruction took place by extending the sides of the octagon until they met the curve of the apses, so that the mixtilinear shape that characterises other baptisteries of the same period disappeared in the plan. Subsequent research conducted by Giuseppe Gerola focused instead on the upper part of the Baptistery: in addition to the



Figs. 30-32_ Neonian Baptistery. Plan and sections

aforementioned difference in the external curtain wall, Gerola identified an internal stucco cornice present at a height of about 8 metres from the current level of the internal floor, immersed in the masonry of the dome. This would testify to an early phase in which the baptistery was crowned by a roof with wooden beams, later replaced by a masonry dome[3]. The construction technique of the dome is the same as that used in many early Christian buildings from the 5th and 6th centuries AD in Ravenna[4]: the lower part is made of rings of ceramic clay tubes arranged horizontally and embedded one inside the other, while the upper part is made of pumice blocks, as it was impossible to use clay tubes, as the small circumferences of the final rings did not physically allow the joint. Since the materials and construction technique used in the dome are intended to give it lightness, it would not have been able to support the weight of the roof, and it is for this reason that the roof rises above the dome and unloads its weight onto the outer walls (a fact that contributes greatly to the external height of the building). Inside, the dome, unlike San Vitale, rests on eight corbels and is pierced at the base by eight arched windows (Brandt, 2012, pp. 191-241).

The main purpose of the digital documentation carried out was to investigate the dimensions of the architecture, to relate them to similar buildings and obtain information on the structural situation of the dome. In addition, the photogrammetry carried out on the exterior was aimed at reconstructing the external curtain walls in order to identify the stratigraphic units present and to monitor their condition.

A total of 28 interior and exterior scans were made with the Leica ScanStation C5 terrestrial laser scanner with medium resolution (approximately 14 million points, size 2356x6282, horizontal and vertical resolution 1 cm at 10 metres) with a scanning time of approximately 6 minutes. After aligning the scans, the horizontal and vertical sections were extracted for processing in 2D format (figs. 28-32). The point cloud limited to the building was exported to proceed with the automatic triangulation in Geomagic Design X 2016 (figs. 33-34). The high-detail mesh was subjected to the automatic creation of horizontal sections with a 30 cm pitch. This highlights the course of the dome (fig. 35). Each section can thus be used to establish, with the “Mesh sketch” and “Circle”

Figs. 33-34_Neonian Baptistery. Mesh model

3 _ Gerola attributes to Neon the construction of the dome and the elevation of the outer walls to support the new wooden roof above the dome (Ranaldi, 2011, p. 13).

4 _ Cfr. the domes, vaults and apses of San Vitale (Rizzardi, 1968), Basilica Ursiana, Sant’Apollinare Nuovo, Archbishop’s Chapel (Deichmann, 1969).

commands, the size of the circumference that best fits the section (fig. 36): by selecting the points of the mesh section, the software automatically reconstructs the regular circumference that best fits the layout of the section and it is then possible to display graphically how much the section deviates from the regular circumference (fig. 37) or to export the two sketches in DXF format to analyse the deviation in detail. In this way, it is possible to identify bending points in the vault and check for structural failure, for example.

The geometric analysis concerned both the plan and the elevation, to try to establish the relationship between the interior and exterior in the light of the restorations and the changes in height of the original floor level. Still using the mesh model, the best-fitting circumferences of the main sections were obtained (fig. 38), which have the diameters of: A. diameter: 11.04 m. B. diameter: 10.84 m. The dashed red line indicates the hypothetical ancient floor level. Analyses of the plan at a level of 1.20 m above the current floor level (fig. 39) revealed a deviation between a regular square (in yellow) and an irregular polygon that follows the course of the outer sides (in red) of approximately 3 degrees. Furthermore, at the same elevation but internally, the regular octagon circumscribed by a circle with a diameter of 10.98 metres is highlighted. If we draw an offset of this octagon equal to the thickness of the masonry and extend the curves of the outer apses, we obtain what must have been the original plan before the 20th-century restoration works. Each measure extracted from the mesh model could be compared with ancient units of measure to establish relations between the elements that compose the building.

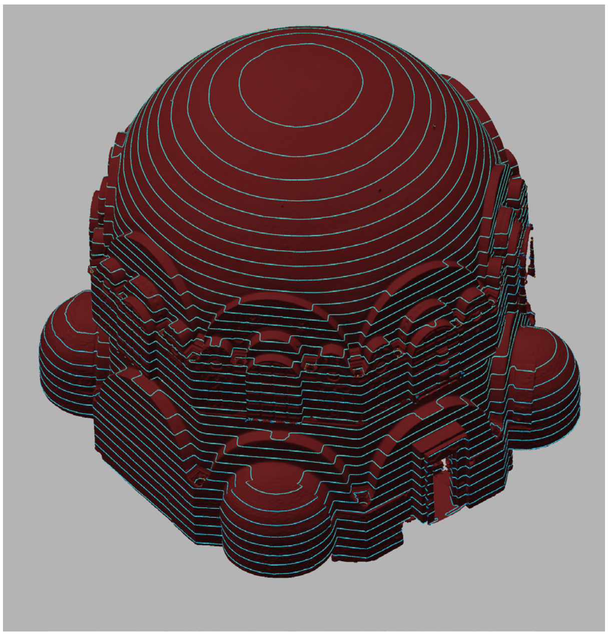


Fig. 35_ Neonian Baptistery. Sections made on the mesh model of the interior with Geomagic DesignX

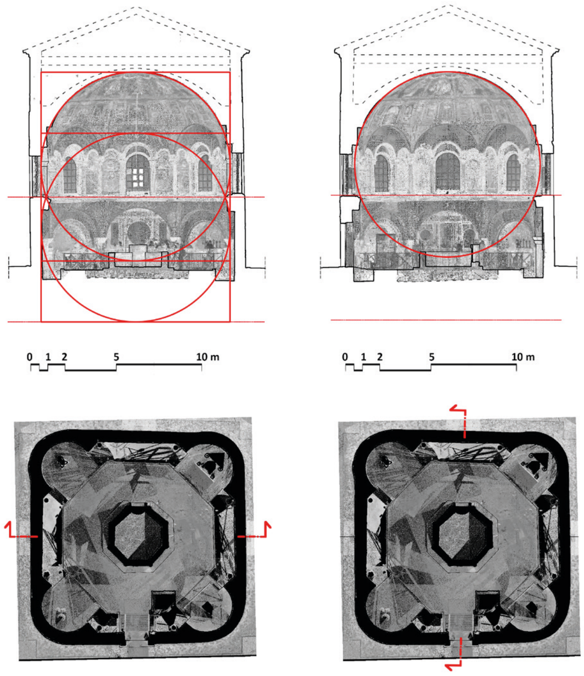


Fig. 38_ Diameter and ancient floor level

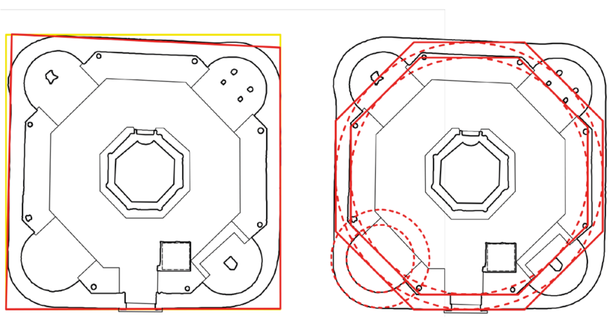
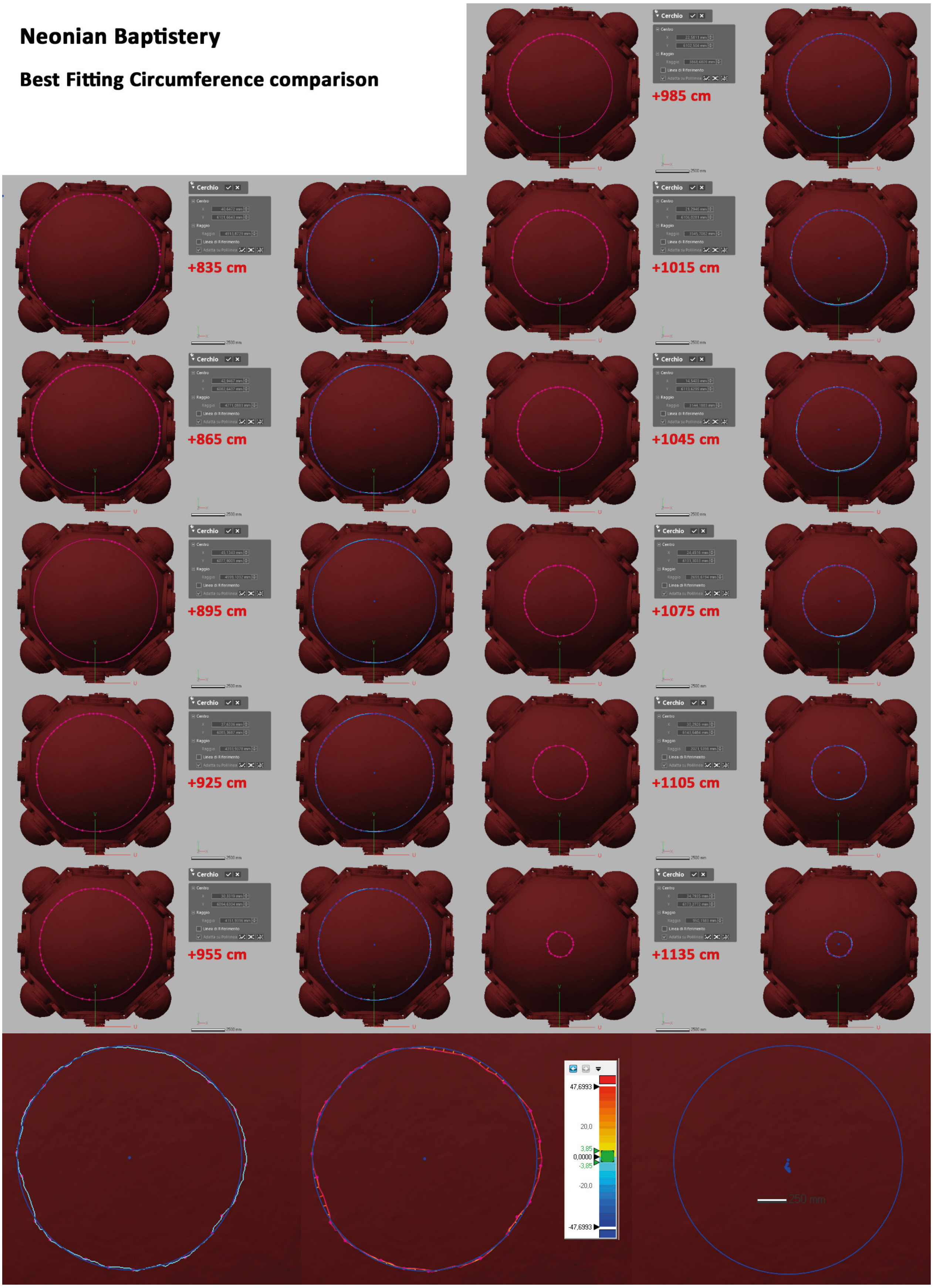


Fig. 39_ Deviation from a regular square



Figs. 36-37_ Neonian Baptistery. Best fitting circumferences comaprison, Best fitting deviation and differences between the position of the centres

4.2.2 The family chapel of Ramón Peres y Rovira - Castellón de la Plana (Spain)

The little family chapel or *panteón* of Don Ramón Peres y Rovira is located in the historical part of the cemetery of Castellón de la Plana (Valencia, Spain) (fig. 40). There is few historical information on the neogothic building, but, according to archive documents, it was built in the 1860s, since Ramón Peres' wife was granted permission to build on the site in 1866. Compared with other chapels in the area, it stands out for its rich decoration in ceramic elements, unusual in chapels of the same historical period, which favoured stone elements. This was probably influenced by the large and prestigious ceramics industry in the Castellón area, which developed and became one of the main national producers, especially in the last few centuries (Ortells Chabrera, 2005).

Fig. 40_ Exterior view of the chapel. Ph.: author

The chapel is set in an enclosure bordered by a wrought iron fence and paved with alternating white and blue glazed ceramic tiles. It is laid

Fig. 41_ Panteón. Ceramic decoration. Ph.: author

out in the shape of a Latin cross with slightly protruding side arms. Inside, barrel vaults and a pointed profile cover the four arms, while the central part is covered by a false conical dome and the altar by a pointed rib semi-dome. The presence of the altar, two side benches and the holy water stoup define it as an oratory chapel. Moreover, the remains of the buried are in the crypt below, accessible from the outside through an opening in the floor in front of the entrance. The sobriety of the materials used internally (smooth walls, simple plaster cornices marking the corners and a white marble and granite floor with a white cross in the centre on a black background) contrasts with the decorative richness of the exterior (fig. 41). Here, ceramic decorations often have a double function, not only decorative, but also structural (such as the capitals inserted into the masonry) or to keep rainwater away, such as the leaf-shaped roof tiles whose ceramic paste is alternately light and dark, as their arrangement forms a geometric pattern.

Details such as the geometric design of the roofs are scarcely visible today, as the chapel suffers significant structural damage and pathologies of degradation, due both to the lack of maintenance in recent decades and to the conditions of the context, such as the presence of three large cypresses very close to the building, which increase the vegetal deposit on the roof and the consequent infiltration. Some sporadic events have also contributed to further damage to the *panteón*, such as the strong disruption of the gate in the north-east corner and the probable fall of the statue of an angel that originally crowned the dome (that we can see in a historical photo from 1905), which damaged the decoration of the south-east corner and of which there is evidence in a piece of wing located on the roof.

Given its current condition, the Municipality of Castellón decided to carry on a conservative restoration, commissioning the *Instituto de Restauración del Patrimonio* of the Universitat Politècnica de València to document the chapel in order to proceed with the proposal of a preliminary restoration project. Given the complexity of the building, but also the presence of many standardised elements (the ceramic decorations were probably part of catalogues of the time or at least were made with the help of moulds and not sculpted one by one as with stone) it was decided to proceed with digital documentation for the creation of a BIM model. This would provide the restorers with support during the design, restoration and monitoring operations, both with 2D technical drawings and with 3D cataloguing and intervention tools or 3D printing. Furthermore, given the presence of standard elements, it was decided to create a digital archive of BIM families that could be reused in similar projects, thus using this chapel as a pilot project for similar buildings in the area. As the building has not yet been declared of cultural significance according to the local law, the survey data was also used for the dissemination of this historical heritage, for example with the publication of some detailed models of the decorations on the online platform Sketchfab.

As already mentioned in the description, the complex has a number of characteristics that determined the specific data acquisition and processing methodology:

Geometrical complexity of the shape and characteristics of the context: unlike most neogothic chapels of the same period and geographical area, which have a rectangular floor plan, the *panteón* presents a Latin cross plan and the vaults are quite complex, although the juxtaposed volumes are generally simple. In addition, the presence of many decorative ceramic elements immersed in the masonry means that they cannot be removed for restoration. The cypress trees around the building not only create problems in terms of pathology, but also during the surveying operations, creating gaps and preventing the photographs from being taken correctly;

the presence of many materials (ceramics, glazed ceramics, iron, stone elements, plaster, masonry): the great variety of materials that make up the architecture and the decorative apparatus entails the presence of different professional figures of restorers specialised in each field and who have different needs from each other;

the presence of a rich ceramic decoration: made up of standard elements which, thanks to in-depth archive research, prevented at this time by restrictions due to the COVID-19 pandemic, could be found in catalogues from the same period or in similar projects, or provide information on elements that are completely missing in the current state of conservation (such as the decorations crowning the gables, which can be seen in the old photo from 1905). Apart from the material, the geometric shape of some elements, such as the pinnacles, is typical of the neogothic style and can therefore be found in many chapels, even if made of stone.

In two main survey campaigns (February and March 2020) digital data collection was carried out with laser scanner and reflex camera. During subsequent surveys, detailed photographs of some elements were acquired, and general photos were taken for monitoring purposes (June and August 2020, July 2021).

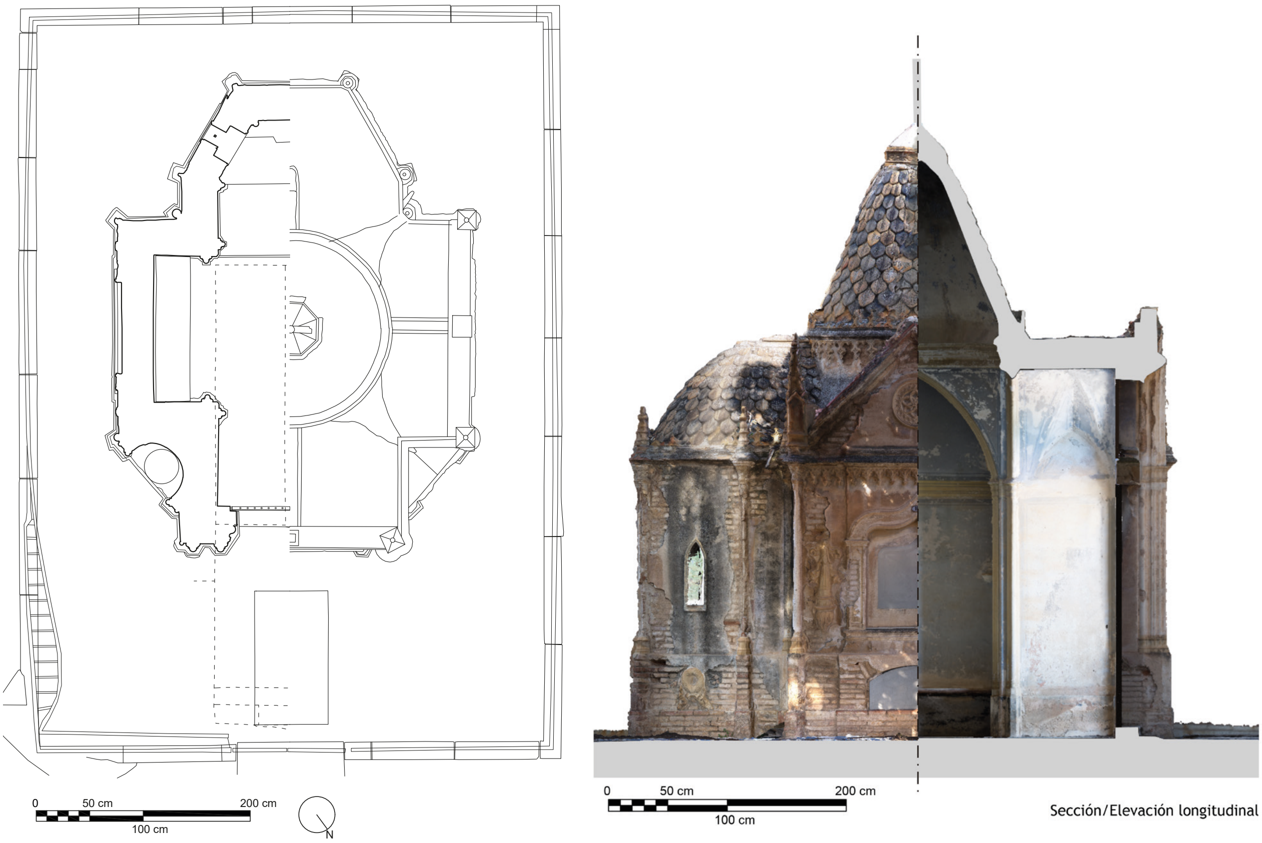


Fig. 42_ Panteón. Plan, section and 3D textured model.

The photographs were taken with a Sony ILCE-a5100 mirror-less camera (24,3 megapixels, photo resolution 6000x4000 pixels). There are 210 photos of the outside, 70 of which are of the roof, taken with an extendable pole. Inside, 158 photos were taken. The detailed elements, such as decorations and frames, were photographed with a mirror-less Sony ILCE-a6000 (model similar to the previous one in the technical characteristics, 24,3 megapixels, photo resolution 6000x4000 pixels). The 14 scans of the exterior, interior and crypt were acquired with a time-of-flight Trimble TX6 Terrestrial Laser Scanner.

Data processing followed the mixed workflow previously illustrated in the other case studies for both photogrammetry and laser scanning. The photos in RAW format were converted with the Adobe Photoshop plugin (Camera Raw 2015, v9.3.0.506) to TIFF format and LZW non-destructive compression to be subsequently masked of unnecessary parts of the background and trees in order to facilitate the reconstruction phase in the software used for the digital photogrammetry, Agisoft Metashape, 1.5.q build 7618 (64 bit). Three different chunks were created (interior, exterior and roofs) which were processed with a laptop computer HP Pavilion 15, CPU Intel® Core™ i7-5500U 2.40GHz 2.40GHz, RAM 16.0 GB. However, given the large number and quality of the photos and the average characteristics of the processor used, some geometric reconstruction problems were encountered in the photogrammetric model in correspondence with the cypress trees, which hindered the correct realisation of the photographs. The problem can be clearly seen

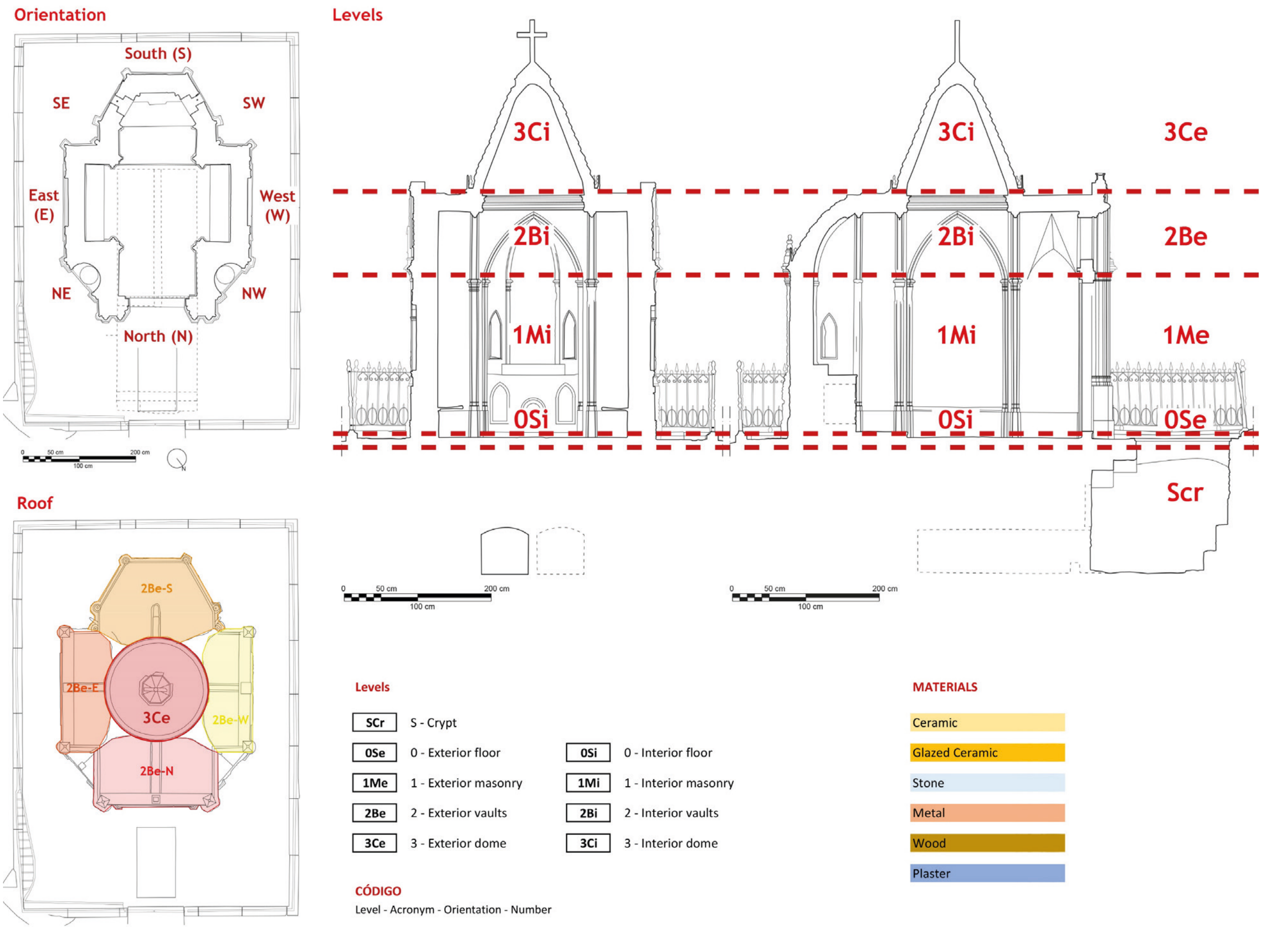


Fig. 43_ Panteón. Cataloguing of the element composing the building according to levels, position and materials

by comparing the two meshes (37 million from laser scanning and 28 million from photogrammetry) using Geomagic Design X. The problem was solved by making the model in Agisoft Metashape at a higher quality with a more powerful processor (which made it possible to obtain a total sparse cloud of 254,741 points and a dense cloud of 59,520,729 points), since the integration with the mesh obtained from the laser scanner data presented many more gaps than that obtained from photogrammetry. The survey has been described in Bertacchi et al. (2020) (fig. 42).

From the processed data it was possible to start setting up the HBIM model. However, it was considered necessary to create a catalogue of the decorative and non-decorative elements, in order to allow the correct setting of the BIM model, to understand the needs of the restorers and to develop them in the BIM environment. To create the catalogue, the *panteón* was divided into external and internal levels (crypt, floor, walls, vaults, dome). Each element was then assigned a code consisting of the level, the indication of the side according to geographical orientation, an abbreviation and a progressive number referring to the corresponding side. Each element is thus coded and easily identifiable in the building (fig. 43). With this preliminary cataloguing it was possible to understand the best strategy to transform the survey data into a BIM model and create the corresponding families.

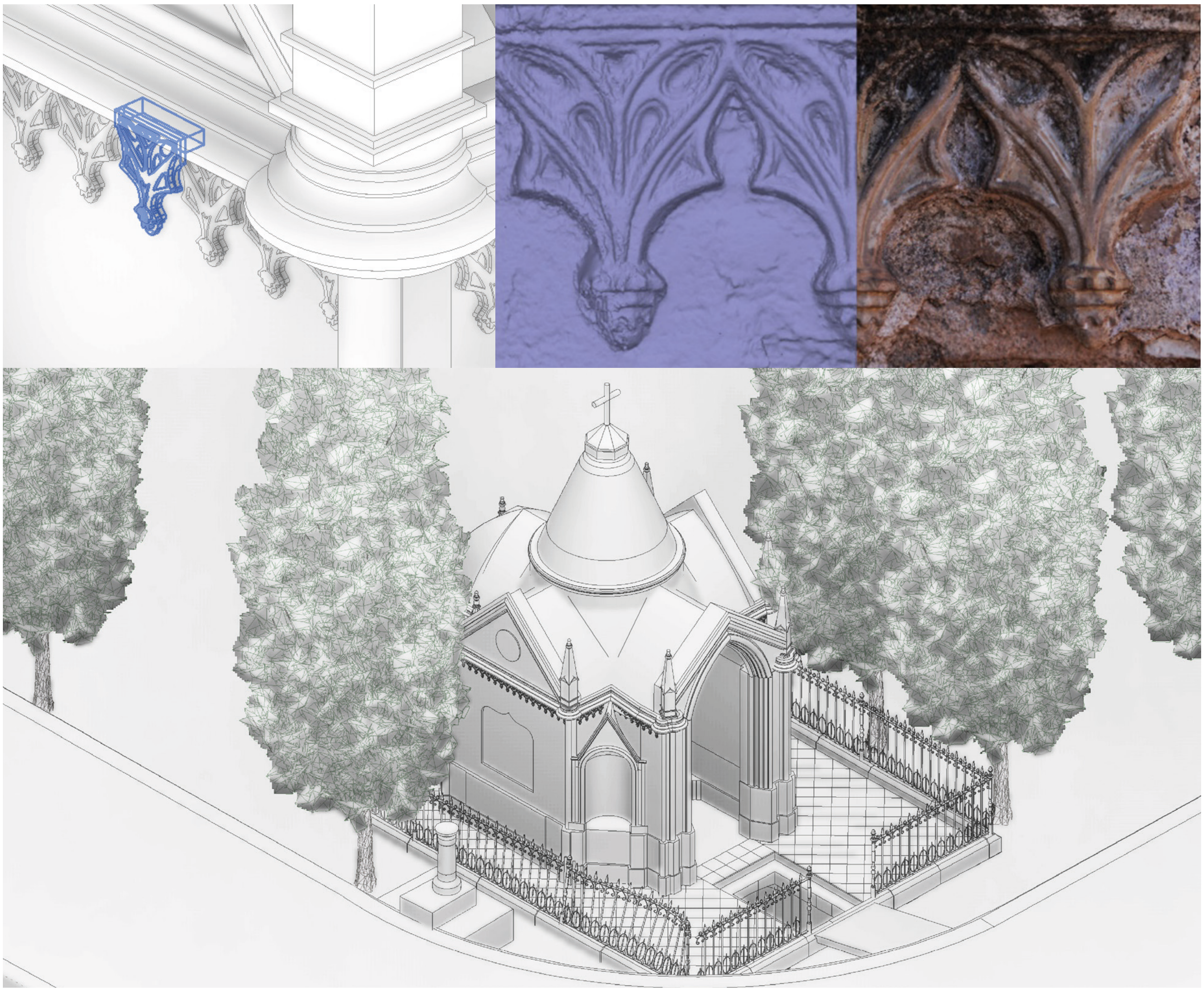


Fig. 44_ The HBIM model and the integration between the BIM element and a high detailed mesh model obtained with digital photogramemtry of a decorative element

Initially the BIM file in Autodesk Revit v2019 was set up by inserting the CAD drawings and the point cloud, to proceed to the setting of the fundamental levels (which reflect those established in the catalogue) and the realisation of the masonry of the building (fig. 44). Some problems were encountered in the modelling of the vaults, especially in the part above the entrance. With the modelling tools provided by Revit it is in fact impossible to create the same real profile, as it is not possible to create a mass by extruding a profile that is not perpendicular to the curve used as a path. The problem can be solved by importing the mesh model modelled with other software such as McNeel Rhinoceros. In this project, however, it was decided to limit the import of models from other software as much as possible. After the creation of the structural part, some specific elements were created. The Appendix 2 analyses in detail some workflows applied to the metal railing, the stone curb on which the railing rests, the external floor and a type of ceramic decoration. The elements analysed have been chosen because they belong to different types and materials, so as to be used as examples for the complete realisation of the project. A detailed description is available in the paper Bertacchi, Juan-Vidal and Cipriani (2021) and in the Appendix 2.

As described, the BIM model is proposed as a tool to support restoration and monitoring operations (fig. 45). However, it is useful to process and optimise the data, following the other workflows. While the BIM model is dedicated to professionals, the optimised reality-based models are aimed at a more general audience of users for dissemination and scholars for study purposes. Some detailed models have been included in the online visualisation platform Sketchfab.

In conclusion, the experience was proposed as an experiment for the drafting of the preliminary restoration project, in which the different methodologies applied to the raw data produce specific outputs for each phase and use. In particular, the BIM model is proposed as a tool for the restoration and monitoring phases, which have not yet started. For this reason, it is necessary that the approach to the creation of the model is interdisciplinary and flexible in adapting to the requests. The modelling operations should not a simple juxtaposition of elements starting from the point cloud but need to follow the construction logic of the building.

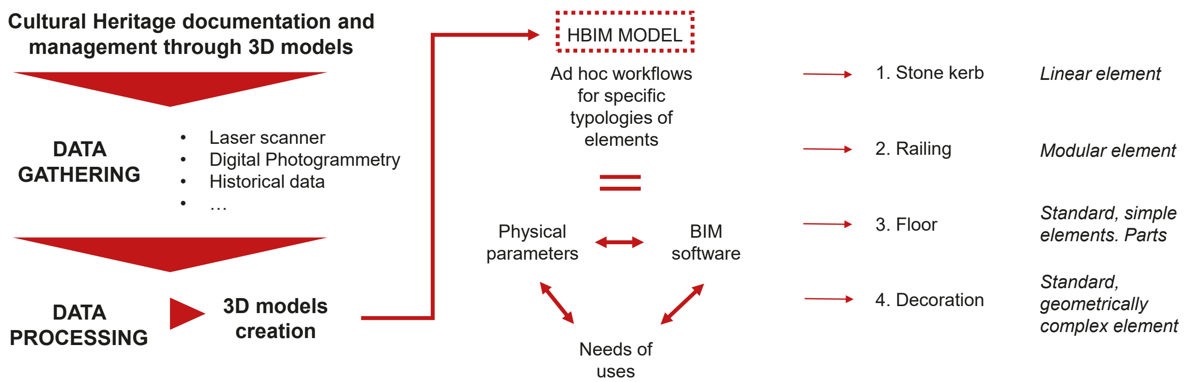


Fig. 45_ Generation scheme for the BIM model

4.2.3 Other monuments of Ravenna: the Casa Matha emblem

During the renovation of the Ravenna Covered Market (2017-2019) the sculptural complex above the main entrance was restored. It consists of two pairs of fish on either side of a central emblem of the Casa Matha, the fishermen's guild that acquired in 1254 the area where the market is now located. The emblem depicts a fishing scene in bas-relief and was made in 1894 to be placed at the top of the central entrance of the *Nuova Peschiera* in Ravenna.

A laser scanner and photogrammetric survey of the sculptural complex was carried out, with the technical support of engineer Simone Rostellato (Studio Tecnico ARCHIgraphic) (figs. 46-47).

A Faro CAM2 Focus3D X 130 HDR terrestrial laser scanner was used for the survey. Twelve point clouds were acquired, with an error of 3 mm at a distance of 10 metres. The sculpture complex is made of marble, and this caused some problems with the displacement of the points, especially when the inclination of the laser light was very accentuated with respect to the surface being scanned. Given the relatively small size of the sculptural complex, it would have been possible to use a triangulation laser scanner, which would have provided better results, although it would have required more pick-up points and mobile scaffolding to reach the top of the emblem. At the time of the survey, the three sculptures were not in their original position, but in a building dedicated to restoration, thus in a more accessible situation than their original location. The restoration workers were also able to move the two lateral fish statues so that they could also reach the side parts of the complex with the scanner and reflex camera. Unfortunately, this situation was not optimal for photogrammetry, as the light hit the main face, while the back remained much darker and with artificial lighting too sharp shadows were produced, given the geometric conformation of the sculptures. In addition, during the photo's shots by standing in front of the statue interposed between the external light source and the statues, caused a slight shadow that have affected the texture.

The most foreshortened parts of each cloud were eliminated, keeping those relating to the surfaces almost perpendicular to the point of capture. In this way, errors in the subsequent construction of the mesh were avoided. However, a comparison between the laser scanner mesh and the photogrammetry

Fig. 46_ Casa Matha. Survey phases. Ph.: author

mesh shows a deviation in some points and a lesser correspondence with reality in the bas-relief part, where the large number of photos has better reconstructed the holes and recesses, while the limited number of scans does not allow an accurate reconstruction.

As far as photogrammetry is concerned, as already mentioned there were some logistical problems related to lighting. It was therefore decided to make two separate sets for each sculpture, one for the front part, which is more illuminated, and the other for the back part, which is darker, in order to balance the exposure in the photos and not have a strong inhomogeneity in the texture. The photos were taken with a Nikon D5200 reflex camera in Raw format and Fine quality (6000x4000 pixels). In addition, thanks to the presence of a colour checker at the beginning of each set, it was possible to balance the white and eliminate components of light colour. The photos were then balanced with Adobe Photoshop Camera Raw v9.3.0.506 and saved in TIFF format with a non-destructive LZW compression. Another procedure carried out on the TIFF files was the creation of masks to isolate the statues from the background, which is very similar in colour and therefore problematic for the reconstruction carried out by the software.

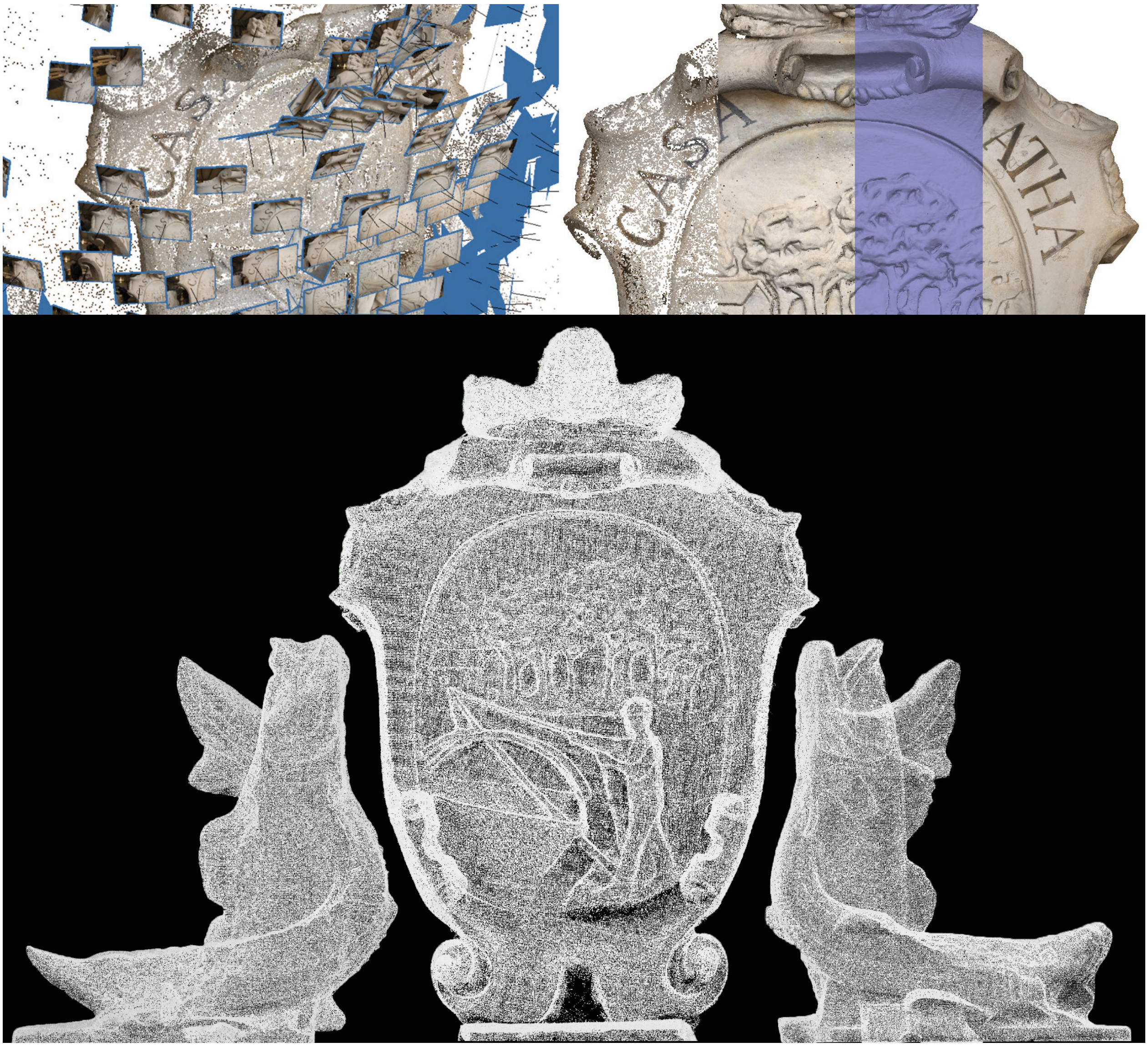


Fig. 47_ Casa Matha. Digital photogrammetry survey and TLS point cloud

Fig. 48_ Casa Matha. Optimised mesh textured model

The photos were then inserted into Agisoft Metashape 1.5.1 build 7618 (64 bit). The procedure for the realisation of the mesh model with texture follows the workflow of the software (fig. 48).

The mesh models obtained were further modified mainly in two software (Geomagic Design X and Luxology Modo) to optimise the mesh and correct some local errors. For example, for the fish on the left, the eye was modified and the fin, currently detached from the statue, was repositioned. In the first case, the strong concavity created in the sculpture around the eye, which is very dark, had not allowed the recognition of homologous points in the photos (because they were underexposed in that point) and therefore the photogrammetric reconstruction did not respect the real depth of the hole. The mesh (optimised with global remesh and hole closure procedures) was exported in OBJ format to be imported into Luxology Modo, which offers many more tools than Geomagic for mesh editing and three-dimensional modelling. Thanks to all the specific commands such as “Sculpt” and “Carve”, it was possible to correct the error locally. Clearly, the high percentage of manual work in the process makes it suitable only for the optimised model and for the formal correctness of the mesh, that have the final appearance given by the maps (for example, the displacement map in the rendering phase applies a displacement that would not be correct in the presence of an underlying mesh with geometric errors). The fin has been moved to its original position and the missing parts have been restored by modifying the mesh in the section in order to have a closed and continuous model (fig. 48).

The surveying and data processing operations were analysed in an article requested by the Fondazione Casa Matha itself. The use of laser scanning and digital photogrammetry was described in a very simplified manner to make it possible to understand the functioning of the instruments and the processing of the data, showing images of the digital data and the final output. In addition, for the dissemination of the survey data, the emblem was chosen to be 3D printed on a reduced scale. The final model was therefore optimised and closed, without losing the detail that was to be achieved during the printing phase. In fact, this was to be done on a scale of 1:10, so the dimensions of the original parallelepiped (130x60x185 cm) were reduced to 13x6x18.5 cm. At the time the model was developed, the technical characteristics of the printer were not known. Therefore, it was decided to maintain a very high level of detail, which could then be reduced if necessary. The mesh model obtained from photogrammetry and integrated with the model obtained from the laser scanner point clouds was closed and optimised without losing surface detail. Data processing was also carried out with the reverse engineering software Geomagic Design X 2016. The model obtained has a number of polygons equal to 3.210.269. A global Remesh was implemented on this to standardise the average edge length to 2 mm, resulting in a model of 2.900.836 polygons. Being the main part of the bas-relief representation, it was very important to maintain a high number of polygons in this one, while the back of the emblem could be left at a lower definition, as it only consisted of the uncarved stone and the metal support. A further Global Remesh was then carried out, imposing the average edge length at 20 mm and obtaining a model of 33.052 polygons. The two models were then merged, maintaining a high detail front. As a result, the final model for 1:10 printing has a polygon count of 1.714.459 and an average triangle edge length at the front of 0.2 mm, which is a very good resolution for a 3D printer. In addition, the print-ready file exported in STL format takes up around 80 MB, compared to 140 MB for the model that is not decimated at the rear.

4.2.4 Hadrian's Villa: the dome of the Small Baths

At Hadrian's Villa, a UNESCO World Heritage Site since 1999, the complex of the Small Baths is located in a southern area, near the Canopus and the Great Baths. The complex has been the subject of repeated survey campaigns, carried out by means of terrestrial laser scanning and digital photogrammetry, coordinated by Professors Luca Cipriani and Filippo Fantini of the Department of Architecture of the Alma Mater Studiorum Università di Bologna. Starting in 2018, the Villa's administration, under the guidance of Dr. Benedetta Adembri and Dr. Andrea Bruciati, began a survey campaign specifically targeting the dome of the Octagonal Hall of the Small Baths in order to proceed with the restoration and reopening of the complex to public visits. The work, conducted by the Regional Secretariat of Lazio and directed by Enrico Calcara and Elsa Rizzi (Finestresullarte, 2021), made use of the surveys carried out over the years and of a number of campaigns involving the extrados of the dome during the restoration works.

The experience is very important from the point of view of the relationship between survey and restoration, which in specific and difficult cases such as this cannot but be closely related. The restoration works in fact included the removal of some parts of the masonry due to the works carried out in the 1950s, and the delicate removal of the layer of *cocciopesto* present in the dome for the subsequent consolidation of the masonry and the insertion of a roof. The Roman structure of the dome is made of *opus caementicium* and is missing the central part, which has fallen over the centuries. The various studies that have been conducted in the past on the geometrical shape of the Small Baths Hall have shown that the surface of the intrados has been modified in its geometrical form during previous restorations, which makes it difficult to interpret the original shape. Thanks to the possibility of analysing the surfaces that make up the intrados through the

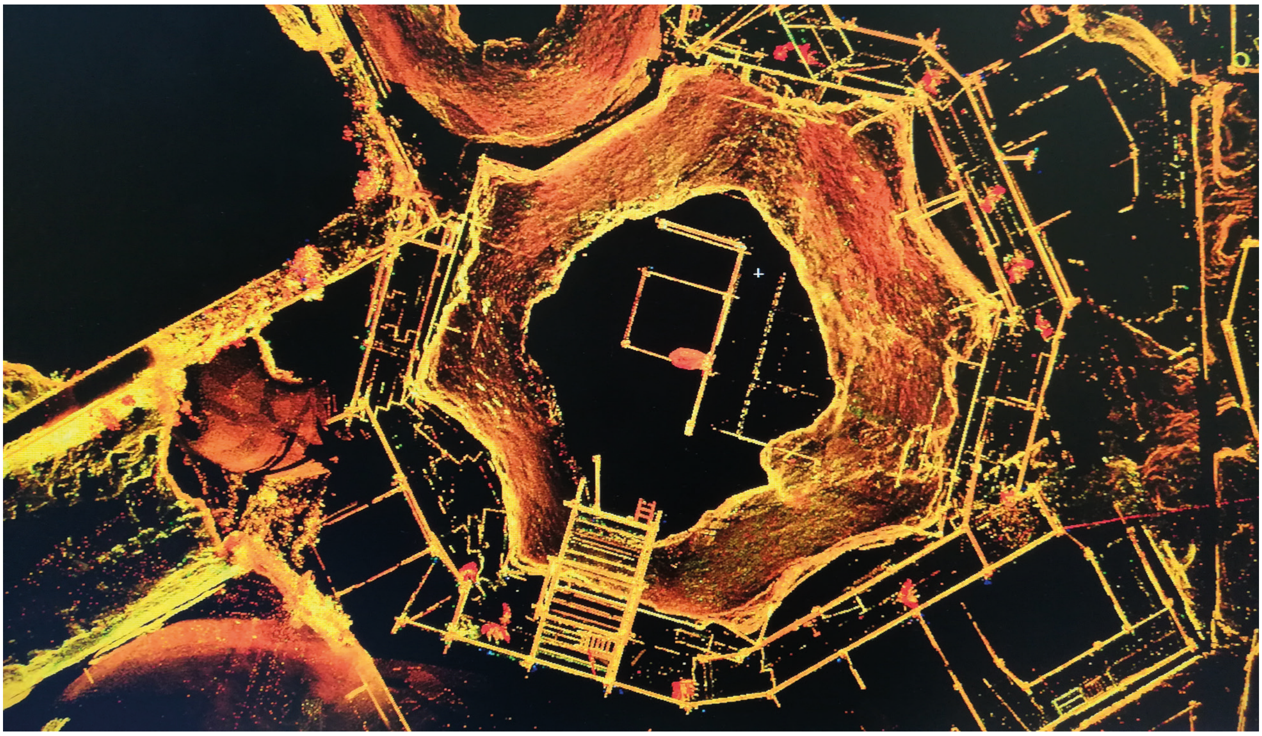


Fig. 49_ Small Baths. TLS point cloud of the survey of 2019. Zenital view

use of digital reconstructions, it has been possible to advance research and formulate hypotheses on the original design, but also to identify those points that have been modified over the centuries and are therefore inconsistent with the original structure (Cipriani, Fantini & Bertacchi, 2017). In the case of such a complex monumental structure, which is unique in its kind and therefore difficult to standardise, the use of digital documentation and three-dimensional models appears essential for making the right choices during the restoration phase. In particular, in the case of the dome of the Octagonal Hall, the models served both as a basis for structural design and for decisions about the removal or preservation of restorations that had more or less modified the original appearance.

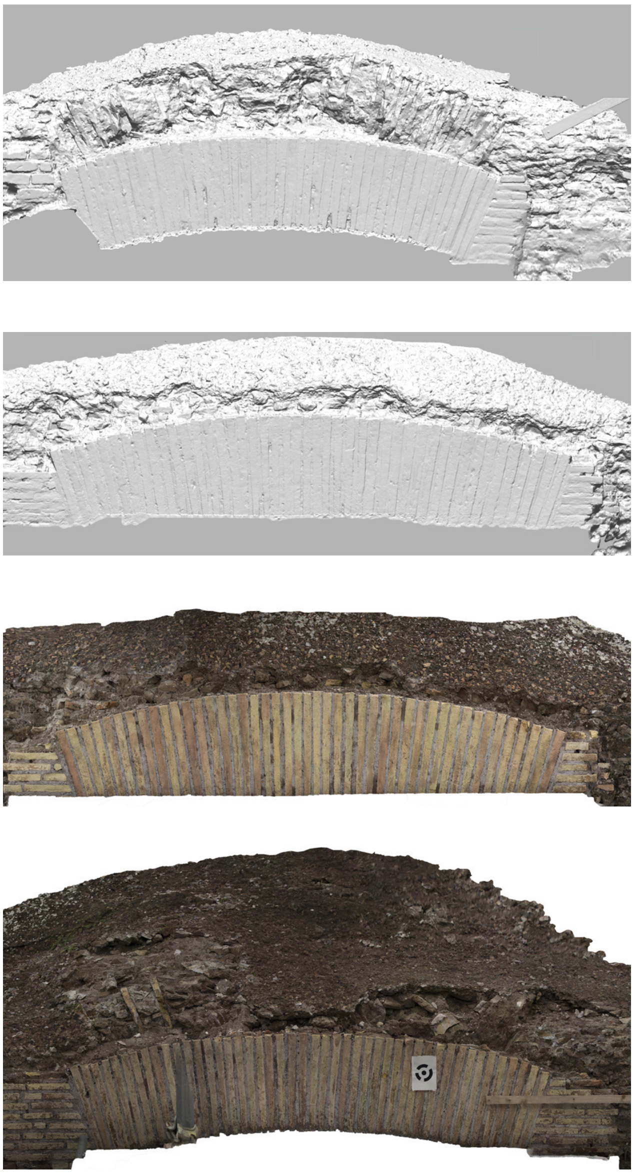
As regards to the structural design phase, the mesh model complete with intrados and extrados was used to calculate the strength of the dome, whose small section (about 30 cm including the *cocciopesto* in the remaining part closest to the centre) immediately excluded the possibility of bearing the weight of the new roof. It was therefore decided to place the main weight of the new structure on the side walls.

During the restoration work, the original arches of the openings, hidden in the masonry of a subsequent restoration that had recreated the openings by building new arches with a different curvature, were highlighted.

The importance of the survey was not only limited to the preliminary phase of the project but accompanied its development with survey campaigns of the extrados carried out during the work, also taking advantage logistically of the scaffolding present inside and outside up to the top of the dome. In fact, the restoration of such a complex object needs to be flexible, changing during the work phase, in order to find the best solution for the conservation of the asset. The interaction with the architectural and engineering firm that carried out the restoration work under the direction of Enrico Calcara and Elsa Rizzi made it possible to propose solutions for using 3D models to meet the needs of the restorers, such as extracting specific sections to verify the structure and curvature of the dome and providing a 3D model to serve as the basis for the creation of a BIM model.

The writer took part in two survey campaigns (January 2019 and August 2019), with processing of the data collected, and in a meeting with the technical firm in charge of the works. The first survey campaign in January 2019 (fig. 49) concerned the extrados of the dome, surveyed using a Leica C5 terrestrial laser scanner, and digital photogrammetry of the original arches lately discovered. Two subsequent survey campaigns in August 2019 and February 2020 made it possible to monitor the progress of the work.

The laser scanner survey of January 2019, which covered the extrados, consisted of 16 scans made with Leica C5 TLS at a medium and low resolution. The photogrammetric survey was carried out with a Nikon D5200 reflex camera and concerned the four original arches that were previously covered by the masonry realized during the restorations of the 1950s. A different set was made for each arch, using a colour checker for the subsequent balancing of the whites.



Figs. 50-53_ Small Baths. Rediscovered arches.

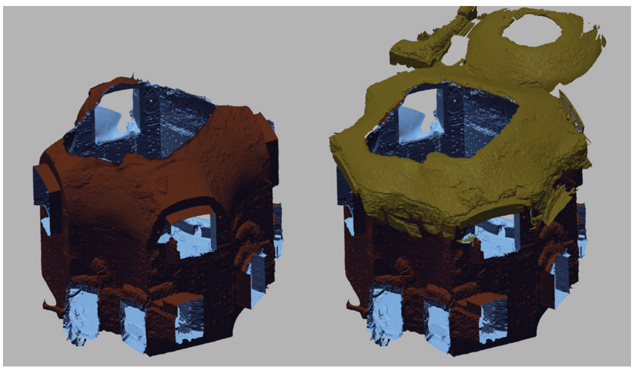


Fig. 54_ Small Baths. Left: 2016 survey. Right: 2019 roof survey

The photos were taken in Raw format and Fine quality (6000x4000 pixels). Each set consists of about 30 frames. Thanks to the integration of laser scanning and photogrammetry, it was possible to scale and compare the models of the arches, studying their geometric characteristics, including their dimensions[5] and their curvature, for which it is possible to see the difference with the later additions (figs. 50-53).

The second survey of the roof was carried out in August 2019 with a TLS. The aim was to document the progress of the work, in particular the restoration of the layer of *cocciopesto* in the extrados of the structure (fig. 54). In this way, the firm in charge of the project was able to use the final model for the design of the ETFE polymer and steel roof that rests on the side walls, protecting the dome from rainwater and allowing visits to the interior from the post-restoration inauguration in May 2021 (Finestresullarte, 2021).

In addition to monitoring and use before and during the works, the models obtained from the various survey campaigns are an important basis for reconstructing the history of the interventions and remain as a digital archive of the monument. The use of the models in the various phases of the life cycle of the cultural asset (most recent research is described in Adembri, Cipriani and Fantini, 2021) is therefore emphasised: documentation, intervention and monitoring, hoping as far as possible, given the poor accessibility of the site, for future surveys of the post-intervention extrados.

5_ Related to the ancient units of measurement used in the construction of the Villa, the Roman feet, equal to 29,64 cm.

4.2.5 Chiuro: urban survey and digital reconstruction for game engines

The experiment carried out in Chiuro (SO, Italy) is part of a long-term study. Initially, the work of the Alma Mater Studiorum (coordinated by Professor Luca Cipriani) concerned the digital documentation of the central streets of the historical centre of Chiuro, a small village in the province of Sondrio, with a medieval urban shape, in which some tower-houses dating back to the 14th century are preserved, together with other buildings of great architectural importance such as the 17th century portal for accessing to the sacred enclosure of the church. Given the geographical distance from Ravenna and Bologna, the survey campaigns were concentrated on a few days in October and April (also to avoid difficult weather conditions due to snow and cold temperatures). Some survey campaigns were accompanied by workshops for students[6] and meetings for professionals. These initiatives were then merged into the "Le radici di una identità" project[7], which aims to protect, research and enhance the Valtellina between prehistory and the Middle Ages and involves municipalities, associations, local authorities and universities[8], each engaged in specific projects in different fields, for the rediscovery and reacquisition of awareness of the territory. The project is based on the formula of active participation of citizens and students in the workshops and meetings. In the case of Chiuro, the final objective of the project is the rediscovery and enhancement of the small village by means of digital technologies, in particular, as anticipated, through the inclusion in game engines of the material collected for the creation

Fig. 55_ Chiuro. Digital data of the centre

6_ Between 2016 and 2019, several workshops were organised for students on the courses of Disegno Edile T-2 (Laurea in Ingegneria Edile), Modellazione BIM and Survey of Historic Buildings (Laurea Magistrale in Ingegneria dei processi e dei sistemi edilizi), of the Alma Mater Studiorum – University of Bologna.

7_ For more information on the project, refer to https://www.radicidentita.it/.

8_ The lead partner is the Comunità Montana Valtellina di Sondrio; there are 19 municipalities participating in the project; the four universities involved are Alma Mater Studiorum – Università di Bologna, Politecnico di Milano, Università degli Studi di Bergamo, Università degli Studi di Torino. The project is funded by Fondazione Cariplo and Regione Lombardia.

of an application for mobile media for the cultural discovery of the village. Moreover, it's very important the use of digital data in other fields of action related to the professional world, such as the restoration of an ancient wooden loggia or the provision of some survey data for professionals who need it. The work thus brings together a number of current digital documentation topics such as urban surveying, the management of large amounts of data and the insertion of 3D models in game engines for virtual exploration and cultural dissemination with serious games.

Over the years, the writer has participated in numerous survey campaigns that have allowed the collection of a large amount of data (both by terrestrial laser scanner and digital photogrammetry) and part of the data processing for the optimisation of the 3D models. Detailed info on the number of scan can be found in Bertacchi S. et al. (2021). The scans, carried out mainly with Leica ScanStation C5 medium-resolution laser scanner, involve both open spaces such as the town's squares and streets, and buildings of particular architectural importance (fig. 55), while digital photogrammetry was limited to those architectural and artistic features of particular value (figs. 56-58). During subsequent survey campaigns, in fact, a number of topics characterising the village were highlighted, both of an urbanistic, architectural and artistic nature, and therefore the methodologies used were adapted to the particular typology from which data was to be collected for digital reconstruction. The main topics addressed are:

- the urban relationship between exteriors and interiors (streets and palaces and their cellars) with the frequent presence of connections between the main communication routes, which follow the isohypses of the terrain, by means of steeply sloping streets or staircases using the porticoed spaces of the palaces and buildings in each block;
- the large stone portals providing direct access from the street to the internal courtyards;
- The porticoed courtyards of each palace, essential spaces for carrying out various tasks in open spaces, partly covered with porticoes;
- The artistic themes relating to the frescoed decorations (such as in the access portal to the sacred enclosure and in the portico of the Disciplini) and the stone coats of arms of the most important families;
- The most important palaces derived from the extension of medieval tower-houses;
- The theme of water and all the buildings that developed along the course of the water;
- The theme of the loggia as a covered-open space on several floors.

Figs. 56-58. Chiuro. Some of the topics investigated: porticoed courtyard of Palazzo Besta de' Gatti; wooden loggia; stone portal

For each theme, the data required for further processing were collected. In the case of the documentation of artistic elements, great importance was given to digital photogrammetry in order to obtain a high-quality texture. However, the photogrammetry was not limited to a few isolated elements, but a specific campaign was carried out to survey the most relevant street fronts and cobblestones for sampling and subsequent use for texturing in the digital reconstruction inserted in the game engine. In this case, in fact, in order to speed up the visualisation of the global model, the optimisation concerns not only the single meshes, but also all those textures that can be obtained from the repetition of a single sample, without therefore being a faithful representation of reality because they are less interesting from the point of view of the final result to be obtained. As mentioned, an example are the streets, which clearly do not need the same level of detail as the texture of a fresco, but which however through sampling contribute to achieving an optimal result of virtual reconstruction. The data of the photogrammetric surveys are summarised in Bertacchi S. et al. (2021)

The fundamental aspects for which this case study is reported are the approach chosen to survey specific urban topics with digital technologies, aimed at the realisation of an application for the virtual exploration. Moreover, there is the importance of the project as a didactic laboratory for direct experience by students.

Fig. 59. Optimising workflow for a 3D reality-based model. From Bertacchi S. et al. (2021)

The first aspect concerns the acquisition and management of large amounts of data and the optimisation of models for virtual exploration. The systematisation of the collected data and the subdivision into thematic areas were fundamental for the preservation of the data. The choice of certain known control points allows for the subsequent integration of the surveys carried out at different times and for the future integration of new data.

With regard to the creation of the models, it was decided to integrate methodologies according to the levels of detail required for the purpose of dissemination. Some architectural elements were modelled in detail and automatically optimised to create a square polygon mesh on which the maps were applied (fig. 59). These models were uploaded into the online platform Sketchfab as the first result of the project with the addition of historical notations for quick online viewing (CTLAB_RAVENNA, 2021).

For the exploratory video game, it was decided to recreate some of the village's architecturally prestigious spaces, such as the main square, which is overlooked by the Quadrio palace and the 17th-century portal, or the sacred enclosure that includes the portal, the church with its bell tower and the *Portico dei Disciplini*. In this case, the technique used to obtain the different models

	Sensor	Processing criticalities		Modelling solution	Maximum allowable deviation (cm)
Horizontal connective	TLS	Low	**Low frequency details**		
			low relief paving	Quad dominant remeshing	≤ 2 cm
Elevation fronts	TLS	High	**High frequency details**		
			carvings	Manual retopology	≤ 1 cm
			mouldings	Manual retopology	≤ 1 cm
			bossage	Quad dominant remeshing	≤ 2 cm
			Tiny elements	Procedural	≤ 5 cm
			window grilles	Procedural	≤ 5 cm
			traffic signs	Manual retopology	≤ 1 cm
			public lighting devices	Manual retopology	≤ 1 cm
			downspouts	Procedural	≤ 5 cm
			intrados beams	Quad dominant remeshing	≤ 2 cm
			Low frequency details		
			flat vertical masonry	Manual retopology	≤ 1 cm
			additional elements (benches, swings, etc.)	Manual retopology	≤ 1 cm
Roofing	UAV	Low	**Tiny elements**		
			chimneys	Manual retopology	≤ 1 cm
			antennas	Procedural	≤ 5 cm

Table 4.3 Modelling tasks overview: criticalities and strategies. The maximum allowable deviation depends both on the semantic subdivision and the modelling solution used. From Bertacchi S. et al., 2021

varies according to the elements that compose them, subdivided by type, geometric conformation and architectural importance. From the processing of the survey data to create the master reference models, some problems were found, such as gaps in parts that were not accessible or not surveyed, and some erroneous reconstructions of particular elements, the results of which, both from laser scanning and photogrammetry, were not satisfactory. For example, to model the balcony railings, the procedural method was used, modelling a single element and repeating it as an instance to lighten the global model. The facades and flat elements were modelled with the manual retopology tools ("schematising" the surface manually, based on the high detail mesh obtained from the triangulation of the point clouds). The modelling procedures used for each type of element are analysed and summarised in table 4.3.

In this way, the game engine loads the meshes faster, since they are composed of few polygons, while it returns the detail thanks to the maps in the real time rendering phase (fig. 60), even on machines with average technical characteristics. The process of creating the maps (normal, bump, displacement, texture...) follows the procedures illustrated in the previous examples and is summarised in the contribution Bertacchi S. et al. (2021).

Fig. 60_ Different uses of 3D models, for real-time rendering, online visualizaton and professional uses. From Bertacchi S. et al. (2021)

4.3 Diffusion, dissemination and digitisation

As seen from the case studies, the application of digital documentation and data processing to Cultural Heritage is a fundamental tool for Cultural Heritage management. However, for it to become a more and more used and effective tool, it is necessary to proportion and spread the right knowledge about strengths and weaknesses of the use of 3D models and digital technologies. As a matter of fact, it has been pointed out in the introduction that one of the problems of the application of digital technologies to the Cultural Heritage is precisely the lack of knowledge of the potentialities of the use of 3D models for the management of Cultural Heritage, the wrong way of realising such models with respect to the specific aims to be achieved, or the lack of awareness of how important digital documentation is for the protection and valorisation of Cultural Heritage. For these reasons it is necessary that both the final results and the methodologies used are described and disseminated to the public, distinguishing between academic experts in the sector, experts from other sectors, professionals, general public. In fact, for each category the contents and language must change and adapt to the receptor audience without distorting the content of the message to be conveyed.

There are several levels of transmission of procedures and results, each with different purposes and target audiences. For this reason, the language must be adapted to the end user, so that it is possible for them to achieve full communication and understanding of what the researcher wants to convey.

Between peers in the same scientific field, communication is extremely specific and many basic concepts that are obviously known to those interested in reading the publication must be omitted, while more focus must be placed on the technical details of the scientific advances proposed. The language used is very specific and technical and the structure of the publication must follow pre-established paragraphs (such as introduction, state of the art, development and methodology, results, conclusions...). Elements such as the bibliography and the data used are also essential to allow the scientific replication of the experiment or procedure, and thus the verification of the scientific validity of the research.

On the other hand, in the case of an audience of professionals, who have some knowledge of the subject but are unable to understand all the specific facets (and it is not even important that they understand them to obtain the desired result), the language and form of the publication change and adapt to the correspondent level. We speak in this case of “scientific diffusion” among peers, but belonging to different, though related, scientific fields. The type of language is still technical, but excessive use of overly specific concepts and technicalities is avoided. In the case of digital documentation of Cultural Heritage, it is important that the methodologies of data collection and processing are passed on, so as to create an active awareness among Heritage managers about the potential and the right techniques to use, even if they do not know the technical details. In this context, to establish a specific and shared vocabulary could be very useful: each term or concept contains different explications depending on the different level of knowledge of the final

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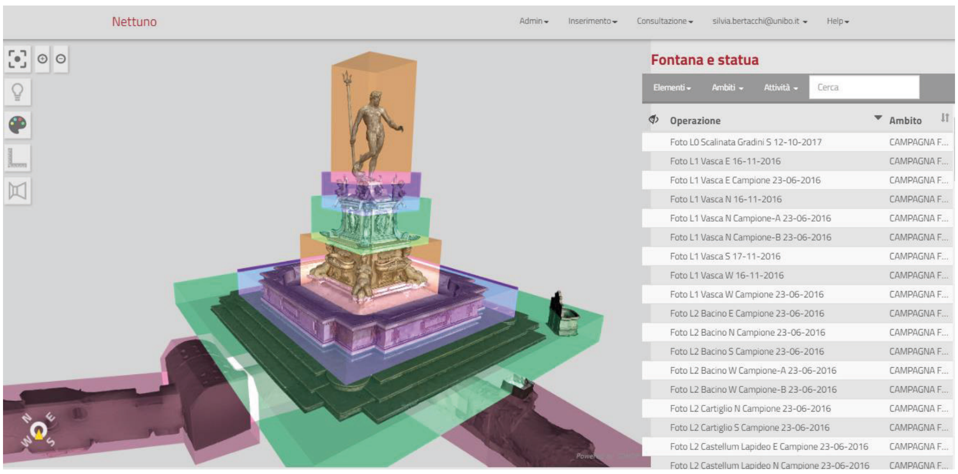
PATRIMONIO CULTURAL: INSTRUCCIONES PARA EL USO

Los modelos digitales tridimensionales se han convertido en una herramienta de gestión de los bienes culturales, pero ¿qué pautas se deben seguir para una gestión eficaz?

Gestionar un bien cultural no es fácil. Son muchos los profesionales que se relacionan con un monumento protegido por su interés cultural. Generalmente pertenecen a profesiones muy diferentes y necesitan ser coordinados para alcanzar satisfactoriamente los principales objetivos en la gestión del Patrimonio Cultural: conservación, uso y puesta en valor. Por lo tanto, el órgano de gestión debe interactuar con muchos actores diferentes y tratar de coordinar y autorizar acciones, en cumplimiento de las leyes de competencia, que siempre consideran la conservación como esencial y más importante del uso (a veces se prohíben las visitas o ciertos usos de un sitio cultural para salvaguardar su conservación).

En los últimos años la representación digital de bienes culturales se ha convertido en una valida herramienta para facilitar todos estos procesos relacionados con el ciclo de vida entero del bien. Los modelos 3D se utilizan cada vez más como núcleos de sistemas de información, para simulaciones de flujos turísticos o de procesos de intervención, se utilizan para imprimir réplicas en los museos o para crear reconstrucciones virtuales de las arquitecturas originales.



El sistema de información utilizado para la gestión de la Fuente del Nettuno en Bologna (IT). El sistema se basa en un modelo tridimensional de la fuente a través del cual los profesionales pueden insertar archivos y acceder a toda la información útil para la gestión y restauración.
Fuente: http://nettuno.comune.bologna.it/esplora/

Fig. 61_ First part of a blog post written for dissemination purposes during the course “Estrategias de divulgación científica para investigadores”. The aim of the course was to familiarise the researcher with the practice and uses of scientific dissemination in written and audiovisual media and to provide a series of guidelines for better dissemination of scientific activity. Prof. José María SEGUÍ SIMARRO, Escuela de Doctorado, Universitat Politècnica de València user (generic, peer, scholar…)

The dissemination of results, on the other hand, concerns the level that should be the most accessible of information, understandable even by those who have no knowledge of the subject (fig. 61). Disclosing the results obtained is important from several points of view, mainly, as defined in Seguí et al. (2015), ethical (to show how public funding for research is used and what positive effects it can have on society) and pragmatic (to improve the public image of the researcher). In the case of Cultural Heritage, the positive impact on society is in the conservation and enhancement of the heritage itself. For conservation, the various uses of digital data in scientific research, restoration, management and therefore in all those actions aimed at documenting and preserving the heritage have been illustrated in the case studies, for which both diffusion among professionals and dissemination to the general public are important. In fact, dissemination in this sense focuses more on the enhancement of the Heritage and the transmission of historical or artistic knowledge, but rarely effectively explains which techniques, tools and methodologies are used for digital documentation and why they are important.

At present, 3D models are used to enhance Cultural Heritage by conveying historical and artistic information in a more engaging way than a simple explanation in a guidebook or text. The emotional and physical involvement, especially of young people, is greater and allows for better learning and remembering of concepts and information received. According to the state of the art and the applications tested in the case studies, 3D models are mainly used as a support to the visit or as a partial replacement of it. In the first case we speak of applications designed for mobile devices such as smartphones and tablets for use in situ, during the visit. In the second case, for example, we are talking about virtual visits or reproductions from 3D printing (fig. 62-

Figs. 62-63_ 3D printed replicas of cultural assets of the CTLAB of Ravenna (profs. Cipriani, Fantini). Right: Mausoleum of Theodoric. 3D model by S. Bertacchi and F. Fantini

64), which are created to increase the inclusiveness of particular users (such as those who are physically unable to visit in person), but which become a tool for general enhancement (such as virtual visits during movement restrictions due to the Covid-19 pandemic or virtual access to certain parts excluded from the usual visit route).

The point on which more attention needs to be paid is the dissemination of information in order to make people understand the scientific work behind the collection and processing of data and the scientific advances that have been achieved through the use of digital detection and reconstruction technologies.

Conveying the importance of these methodologies, as mentioned, justifies public investment, and invites private investment in the same sector, since, by proposing digital methods as a basis for valorisation, there is a feedback on the increase of visits and on the general satisfaction of the final user.

The theme of dissemination and diffusion of digital documentation methods is linked to digitisation programmes at national and European level. However, these generally focus on digitisation in the sense of moving from paper to digital resources (the Italian recovery plan mentions archives, libraries, museums), given the recent need for access to digital resources during the pandemic period (see chapter 3). However, nothing in particular is specified about the digitisation of Cultural Heritage, in terms of collecting basic data for the creation of a digital archive of 3D data. This is certainly due to the problems already highlighted during the study of the current situation on the difficulty to standardise the products of digital documentation and on what the European

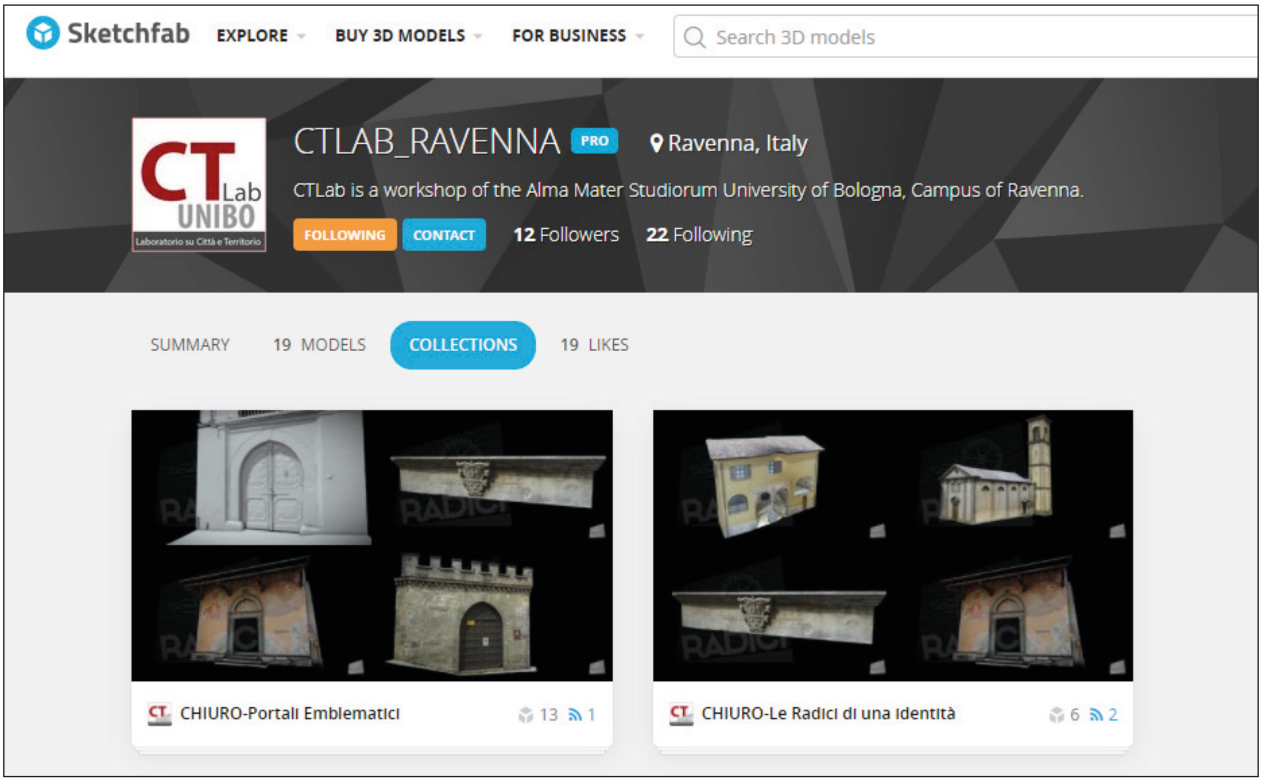


Fig. 64_ CTLAB official page on SketchFab platform

Commission is doing with the “Study on quality in 3D digitisation of tangible cultural heritage” (European Commission, 2020). At least at European level, a digital archive of data derived from digital documentation should be established, with standards for the collection and processing and exchange format of the collected data, so that every institute, museum, institution, whether public or private, can contribute to the documentation and especially to the monitoring.

Conclusions

In this chapter, the main problems in the process of digital documentation and use of 3D models of Cultural Heritage are highlighted. A specific workflow was applied to each case study, based on the characteristics of the Cultural Heritage and the final product to be obtained, with respect to documentation, diffusion, dissemination and/or digitisation for management. The experimentation highlighted specific criticalities and shortcomings in the current process of Cultural Heritage management through three-dimensional models. For each criticality a specific solution is proposed. Thanks to the multiplicity of case studies used, a generalization of these specific solutions is proposed in the next chapter. The compiled guidelines address all the phases of Cultural Heritage management, trying to solve the criticalities highlighted, proposing tools and good practices for management.

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Chapter **5**

Discussion of the results: guidelines

The chapter defines the guidelines in the form of indications and practical tools for the use of 3D models in the Management of Cultural Heritage. Each tool is adapted to the type of user and his level of knowledge of digital methodologies. Each step and action taken by managers and professionals is guided by standards and indications for practical application. The indications provided aim to guide the user in the correct drafting of a Management Plan using 3D models as the basis for the creation of a simplified information system, allowing the insertion, retrieval and storage of heterogeneous data.

Chapter 5 - Discussion of the results: guidelines

5.1 - Guidelines for the documentation and management of Cultural Heritage using 3D models

Thanks to the application of different workflows to case studies, it is possible to draw up the records of cultural assets. For each one of them digital documentation and management change according to the characteristics and purposes of the actions taken on the specific asset. Therefore, different types of approaches for correct management will be defined.

Varying actions of conservation and/or exploitation arise in the management of a cultural asset depending on a specific phase of the life cycle: documentation, intervention, use, monitoring. Each procedure entails the interrelation between professional figures (figs. 1-2), with different level of knowledge in the use of digital methodologies for the documentation and Management of Cultural Heritage (MCH). The following figures can be schematised: manager or managing institution (M), generic professional (GP), specialised professional (SP) and general user (GU). The levels of knowledge of digital technologies are three (fig. 3): (Level of Knowledge 1 – LOK1) generic knowledge of methodologies and/or outputs, (Level of Knowledge 2 – LOK2) basic knowledge of acquisition and processing of the most common types of data (e.g. point clouds from terrestrial laser scanners), (Level of Knowledge 3 – LOK3) advanced and specific knowledge in certain methodologies and outputs.

The M generally has no direct experience in the use of digital methodologies, but he/she has a general knowledge of some of the most commonly used applications (e.g. laser scanning for 2D drawings). His background may not be directly related to scientific disciplines such as architecture or engineering and therefore his technical knowledge is limited to some more common outputs (LOK1).

The GP (architect, engineer, restorer...) has a greater knowledge of methodologies and their applications. He has direct experience of the most common ones, especially the use of TLS for data acquisition. In general, he/she knows which technology suits best the specific action

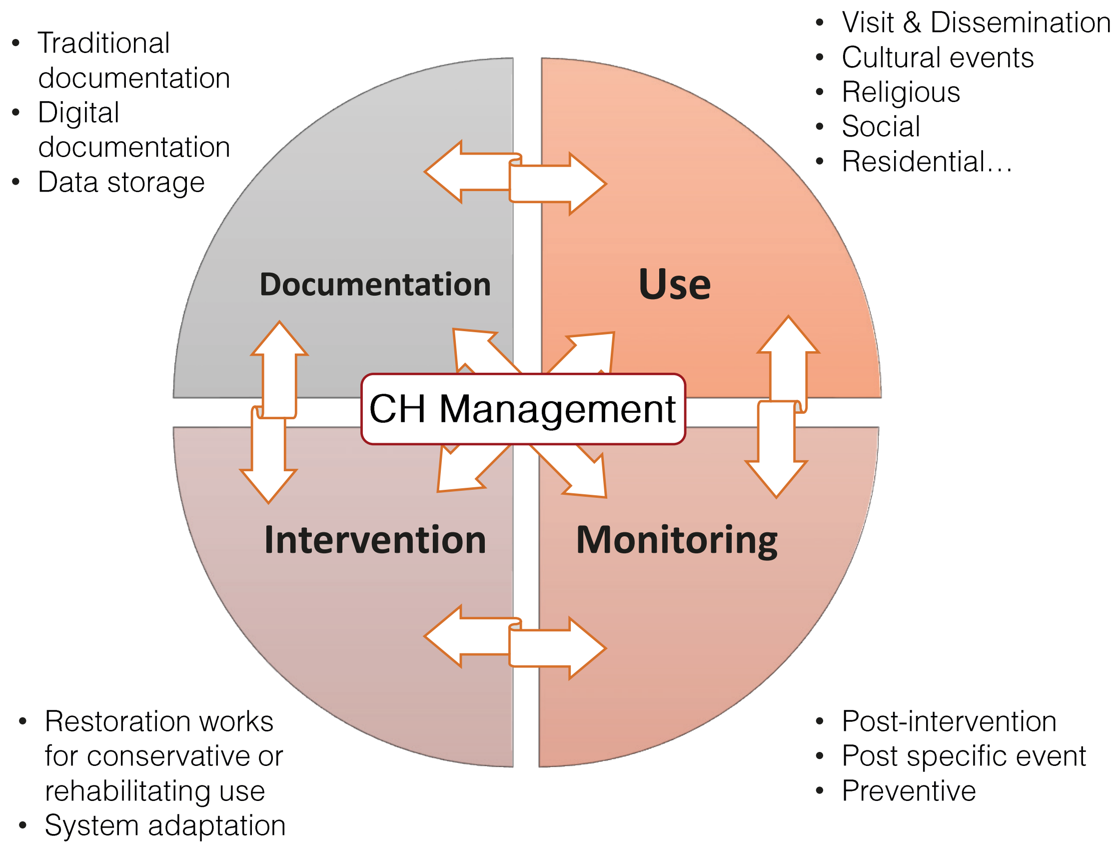

Fig. 1_ Life cycle of a cultural asset

Fig. 2_ Interrelation between the manager and professionals

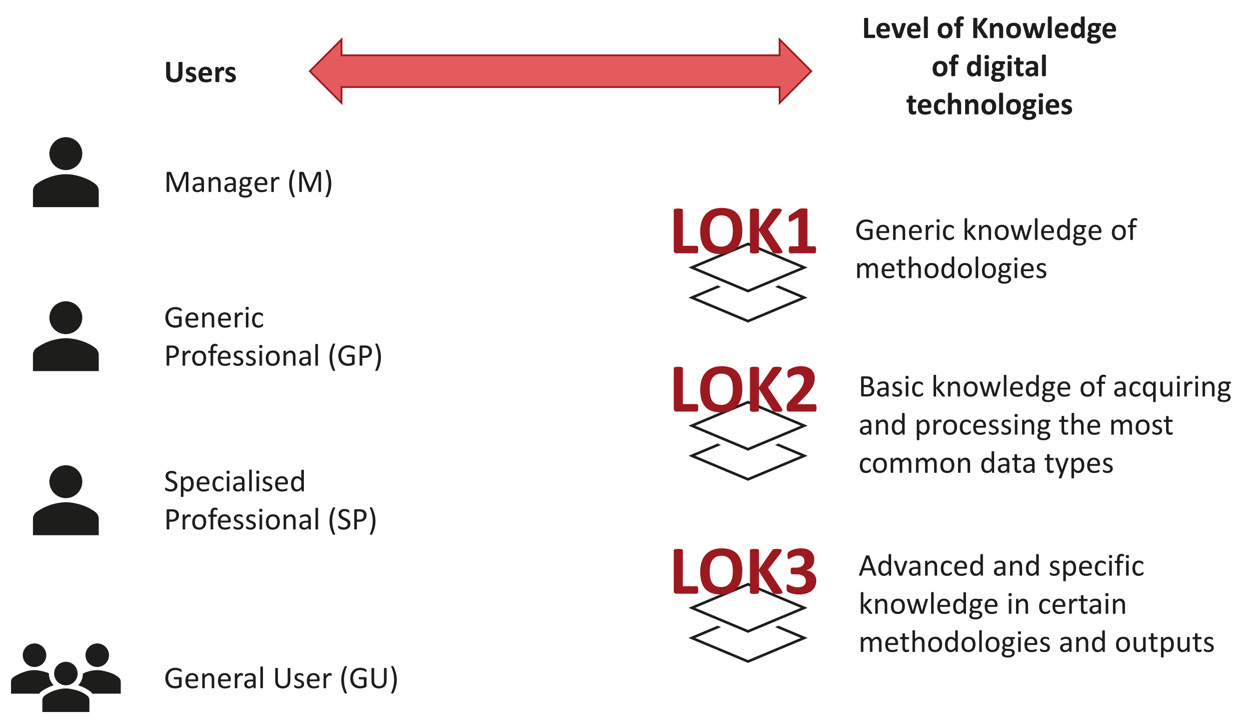

Fig. 3_ Level of Knowledge (LOK) of digital technologies

carried out, even if he/she is not an expert in data processing and the production of complex outputs, such as optimised models (LOK2).

The SP is familiar with one or two fields of application of digital methodologies, regarding the production of complex outputs, such as the creation of optimised reality-based 3D models, BIM models or 3D printing (LOK3).

The GU relates to the asset through the end products of digital methodologies, such as 3D models used for reconstructions, online visualisation and dedicated applications. He/she generally does not know the techniques for data collection and processing but has a basic knowledge of the outputs and their use (can be considered as a LOK1).

The LOKs defined above apply to those involved in the MCH to determine the end users of the proposed guidelines. For example, the documentation guideline is addressed to users with LOK1, while the compilation or data processing guidelines are addressed to users with LOK2 or LOK3.

In the analysis phase, in order to highlight the problems inherent to the MCH, the "life cycle of a Cultural Heritage" was defined (see paragraph 2.1), taking inspiration from the definition that applies to new materials and buildings, but adapted to CH. Recovering this concept, guidelines are proposed for each phase.

5.1.1 – Digital documentation

When planning the documentation of a cultural asset it is first necessary to assess its characteristics and combine them with the specific objectives of protection and enhancement. First, a specific spreadsheet is proposed, to be filled in for each cultural asset and its components, indicating its physical characteristics, ownership and accessibility, and listing the existing available documentation. The sheet suggests type and methods of digital documentation to be carried out according to the type of object studied and the action objectives The information contained in this sheet is not to be considered as descriptive and exhaustive of the monument. Instead, it is intended to provide the operator with some indications on how to proceed with the digital documentation. This sheet is therefore intended as a tool, not as a data archive document. However, it is important that it contains a reference to at least the Italian cataloguing system of the ICCD (Istituto Centrale per il Catalogo e la Documentazione - Central Institute for Catalogue and Documentation; ICCD, n.d.) or to the Italian Beweb cataloguing system of the Italian Episcopalian Institution (Conferenza Episcopale Italiana - CEI) (see paragraph 3.1), or any other institution in charge.

IDENTIFICATION DATA	
Name	
Location	
Country	
Region	
Province	
Municipality	
Address	
Number ICCD general catalogue	
CEI building code	
CEI card code	
ICCD link	
CEI link	
Other codes and institute	
Category	
Ownership	
Authority for the protection	
COMPILING DATA	
Authority / Contact person	
Role	
Date	
DOCUMENTAZIONE ESISTENTE	
Hardcopy Archive	
Digital - CAD file	
Scale detail	

Table 5.1_ Identification data

The evaluation sheet is made up of three sections:

- Identification data of the object and existing material;
- Physical-geometric characteristics of the object and the context;
- Objectives of the documentation or intervention for which documentation is required.

In the first section (table 5.1) there are some generic fields that report the basic data for the definition of the object of study, such as location, ownership, identification codes according to ICCD or CEI, etc. Among the characteristics of an asset, it is also necessary to list the digital documentation currently available, in order to assess the priorities for completing it (if, for example, scans are already present, but photographs are absent) or to plan monitoring.

In the second section (table 5.2) there are fields defining all those characteristics that will determine the choice for a specific digital documentation method. The parameters concern geometry, material, context conditions. Each parameter is assigned a positive or negative value and a multiplication coefficient depending on how much the characteristic can negatively or positively influence a given method. The user only has to enter the value 1 in the box provided

FEATURES			TLS	DP	DRONE
Exterior surveying	x	1	++	++	++
Interior surveying		0	++	+	---
Roofing surveying		0	-	-	+++
Object size	Small (cube size < of 1,5 metres)		-	++	---
	Medium (cube size between 2 and 15 metres)		++	++	-
	Large (cube size > of 15 metres)		++	+	+
	Urban complex		+	-	+++
Object shape	Regular and compact		++	++	++
	Significant width (> than 15 metres)		+	+	++
	Significant height (> than 8 metres)		+	---	+++
	Complex, with multiple planes (e.g. sculptural complexes)		++	-	-
Perimetral features	Free on all sides		++	++	++
	Partially free		+	+	+
	One-side free		+	+	+
Main building accessibility	Total		++	++	++
	Partial		+	+	+
	Danger of collapse		--	--	+++
	Inaccessible		+	-	+++
Context: presence of elements	Trees		-	-	--
	Permanent obstruction (furniture, street furniture, signage…)		--	--	-
	Buildings or immobile structures less than 2 metres from the facades		+	-	-
Surface material	Uniform or monochrome texture materials		++	--	--
	Reflecting material		-	+	+
	Opaque matte material, no monochrome, no uniform		++	++	++
Lighting condition	Excellent natural light		++	+	+
	Good natural light		++	-	-
	Low natural light		++	-----	-----
	Good artificial light		++	++	
			TLS	DP	DRONE

Table 5.2_ Parameters for survey technique

if the parameter is present or the value 0 if it is absent. In this way, particular characteristics, such as the presence of a certain material that negatively affects the result of the survey (e.g. a uniform, monochrome surface for digital photogrammetry), will lower the score for the corresponding method.

The result is a score for each of the three methods considered (Terrestrial Laser Scanner - TLS, Digital Photogrammetry - DP, Drone) which is compared with a table indicating the ranges in which it is advisable or not to use a certain method and why (table 5.3). This first result gives a general indication of the most suitable methodologies for the characteristics of a certain asset and for the part that needs to be surveyed (exterior, interior, roofing).

Range results	
x<5	Negative result or less than 5 points: the survey methodology is not suitable for the object to be surveyed. There are problems in the survey phase that make it impossible to apply (e.g. drone in small interior spaces) or do not allow correct results to be obtained from the point of view of geometric restitution, nor satisfactory for virtual reconstruction and visualisation for enhancement purposes.
5<x<10	Result between 5 and 10: The methodology can be applied to the object of study. However, there might be some criticalities to take into account during the survey and data processing operations (e.g. the lighting conditions for photogrammetric restitution or the size of the survey instrument in some inaccessible locations).
x>10	Result greater than 10: the methodology is well suited to the object of study. If the data are processed correctly, no errors should occur in the outputs.

Table 5.3_ Range results of the evaluation sheet

However, these should be considered together with the third part of the sheet, which is dedicated to the aims of documentation. This proposes the most common interventions and the methodologies that are best suited to each of them, in order to provide a general indication of how to proceed with documentation. The general nature of this indicative sheet is due to the fact that it is intended for the managers themselves (Ms with a LOK1) and not for the professionals who will carry out the survey (LOK2 or 3). The idea behind the sheet is to offer a tool to operators who intend to proceed with digital documentation for a specific purpose. In this way, they can use this first sheet to plan their documentation work or insert it in the calls for tender with providing the right requirements.

The third part of the sheet therefore proposes the main cases that arise for an administration in the MCH. The following categories of objectives have been considered (table 5.4):

Filling in the sheet allows the operator to choose some methodologies over others and to refer to professionals specialised in a particular field in case of special needs. The complete sheet is provided in Appendix 3. In order to verify the sheet on more typologies of CH and for different users, experts of CH sector in Italy and Spain were asked to fill in. The completed sheets are attached in Appendix 3. For each one a particular type of cultural asset was chosen and thanks to the compilation of the sheet a different type of digital documentation is proposed.

5.1.2 Storage of collected data

As already shown in the examples of the application of workflows to the selected case studies, the correct cataloguing and storage of the collected and processed data is of great importance.

In the guidelines we propose a standardised storage of raw data derived from laser scanning or photogrammetry and processed data such as 3D mesh models. The data conservation is divided into: (1) a scheme suggesting the correct data storage; (2) the compilation of sheets with the technical data of each file.

The scheme for the operator suggests, depending on the type of survey being undertaken, which parameters to introduce in the tender notices or agreement. It is linked to the indicative sheet on digital documentation and establishes the minimum quality standards that the data collected

Survey purpose	Possible outputs required	Suggested methodology
Creation of a database	The existing data are derived from traditional surveys and a database is needed to be used for general studies, for interventions or simple management operations. It is necessary to deepen the knowledge of a particularly complex artefact by studying its geometric and construction characteristics	Terrestrial Laser Scanner for very large, complex structures, with some unreachable parts (such as vaulted ceilings), while for smaller objects (less than 1.5 metres per side) the use of special laser scanners is recommended. For urban surveys or very large buildings, it is advisable to use a topographical survey for the correctness of the final drawings
Intervention – preliminary design or studies	2D drawings with a printable scale of 1:50/1:100 for the preparation of preliminary designs	Terrestrial Laser Scanner with low scanning resolution (2 cm at 10 metres) for simple, plastered structures; with medium resolution (1 cm at 10 metres) for complex structures and masonry
Intervention – structural restoration work, on masonry, etc.	2D drawings with a printable scale of 1:20, orthoimages for mapping with a given resolution depending on the type of intervention foreseen and the condition of the object (e.g. structural intervention with the need to map the position and size of cracks and lesions...)	TLS with medium resolution (1 cm at 10 metres) or high resolution (0.5 cm at 10 metres) for portions of particular interest for structural mapping or masonry deterioration. Digital photogrammetric survey to be integrated with the laser scanner survey. If the laser scanner is equipped with an internal camera, the photographs taken by the tool can be used for a general survey. However, for detailed surveys it is advisable to integrate a photogrammetric survey carried out independently of the laser scanner. In this case the final resolution of the orthoimages produced must be such as to allow a printable scale of 1:20 of the parts of interest for decay mapping or 1:10 for structural mapping according to specific requests of the professionals. For simple, plastered structures, photo-rectification is recommended
Intervention – replacement or duplicate of small objects	If there are special decorative or structural elements that need to be replaced or integrated into the restoration work, a model for 3D printing can be produced from similar elements or from a survey of the part where the gap is present	Digital photogrammetric survey and data processing for the production of a printable STL mesh model at 1:1 scale (with sufficient detail for full-scale printing)
Intervention – HBIM model	For interventions on large but structurally simple buildings (e.g. without complex slabs such as vaults or domes), or on more complex but small buildings structurally composed of easily standardised elements, the creation of a BIM model can be justified, if it is correctly set up also to ensure future management uses (e.g. visit control, plant monitoring, etc.). For complex buildings, the correct degree of simplification must be assessed. The level of detail required from the BIM model builder should be established before the assignment	Terrestrial Laser Scanner survey with low scanning resolution (2 cm at 10 metres) for simple, plastered structures; with medium resolution (1 cm at 10 metres) for complex structures and masonry walls
Monitoring	Schedule of survey campaigns to compare with previous and subsequent surveys and to monitor the evolution of the situation or part of the object	See corresponding in-depth section (cap. 5 – par XX)
Management – information system	To use a digital tool through which multiple actions can be carried out (archiving of documents, tracking of restoration work, monitoring, management of visits, etc.) it is possible to create a dedicated information system that is simplified (through the use of a BIM model) or complex (based on a 3D reality-based model)	In the case of a simplified information system, a Terrestrial Laser Scanner survey is sufficient for the construction of the base, to which detailed surveys can be linked
Dissemination	Digital reconstructions, historical phases, reproductions (3D printing): depending on the different outputs chosen, a different methodology may be needed	In general, a textured 3D model must be created for online visualisation (i.e. using digital photogrammetry); for full-scale 3D printing of small objects, digital photogrammetry is recommended; for 3D printing of small-scale reproductions, data obtained by Terrestrial Laser Scanner or digital photogrammetry can be used

Table 5.4_ Suggested methodology depending on the characteristics of the object

must reach. The following categories of digital products are outlined: point clouds obtained by Terrestrial Laser Scanner; orthoimages; 3D models obtained by digital photogrammetry; BIM models; STL mesh models. Specific standards will be proposed in section 5.1.6. The lack of standards and indications of this type has in fact been denounced by managers who find it difficult to catalogue and store the data correctly and therefore also in the subsequent retrieval of the same.

The scheme for the correct cataloguing and archiving of data guides the professional in charge of carrying out the survey and processing of data, and at the same time allows the manager to have an archive of digital products linked to the asset. Its correlation with the Management Plan will be analysed in section 5.2.

To introduce the cataloguing and storage indications, the levels that correspond to the degree of data processing are set as follows (fig. 4):

- Level of Storage 0 (LOS-0): contains the raw data collected with the survey operations. For point clouds from TLS, everything produced automatically by the scanner is entered (in its own format depending on the manufacturer), each cloud in PTX format without decimation and possibly a key plan containing information about the scanstation positions. For digital photogrammetry, the photos taken in RAW format are entered.
- Level of Storage 1 (LOS-1): contains the data on which some preliminary processing operations have been carried out, such as the clouds aligned (in the file format of the software used) and a global PTX file of the entire building or object. For the photogrammetry there are the photos on which some operations have been carried out, such as the white balance or the insertion of masks. Photos will be provided in TIFF format with non-destructive compression LZW.
- Level of Storage 2 (LOS-2): contains the main semi-finished outputs. A triangular mesh model is produced from the point clouds, saved in the format of the software

Guidelines

		TLS	DP
LOS-0	Raw data	- Original TLS format - PTX original sampling	- RAW format photos
LOS-1	Pre-processing	- Aligned point clouds - Total PTX	- TIFF format photos
LOS-2	Semi-finished output	- Master Model (triangular mesh), OBJ format	- DP software format - Model, OBJ format + texture
LOS-3	Output		

Fig. 4_ Levels of Storage (LOS) of digital data

used for triangulation and exported in OBJ format. For photogrammetry, level 2 contains the files in the format of the software and the final model exported in OBJ format with texture. This level also contains the CAD file in DWG format.

- Level of Storage 3 (LOS-3): contains the processing and final files obtained from the various types of workflows carried out, such as the model in STL format for 3D printing, the optimised OBJ models...

For each methodology, a subfolder is created in the general folder of a particular asset (fig. 5). This creates a simple archive containing all relevant information. In the case of management, the institution in charge must ensure the delivery of materials and the full availability for future use, at least of the LOS-0 files (raw data). This should be included in the agreement or in the call for tenders. In addition, each element data must be accompanied by the relevant detail sheet describing its characteristics, filled in by the professional in charge of the survey or processing. These detail sheets serve to correctly catalogue the data collected and processed, so that each entity is able to form a digital archive for each asset and integrate it with the ICCD cataloguing sheet. Cataloguing spreadsheet for common digital data (point clouds and mesh models) are provided in appendix 5.2.

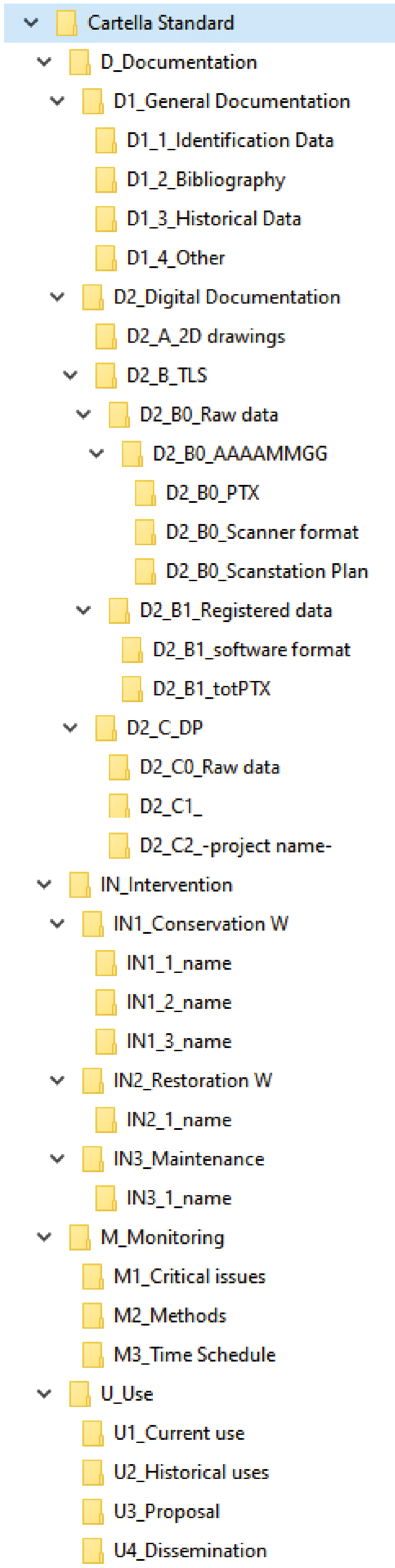

Fig. 5_ Example of a digital archive folder

5.1.3 Methods for acquiring and processing point clouds from Terrestrial Laser Scanners

The use of TLS for the acquisition of digital data in the form of point clouds is currently the most widely used technology in the academic and professional world for the survey of CH. Technological progress makes it possible to produce increasingly compact and less expensive surveying instruments used above all in the professional world (section 2.2.1).

During the acquisition phase, attention must be paid to the specific requirements of the institution in charge and the conformation of the object to be surveyed. Before starting to collect data, it is therefore advisable to plan the survey correctly in order to obtain data of the quality suitable for the purpose of the survey. First of all, it is necessary to consider the conformation of the object to be surveyed and pay particular attention to the geometric and height characteristics of the building. Apart from general considerations on the shape of the object to be surveyed and on the materials (see Appendix 3), three parameters affect the quality of a scan: (i) the resolution of the scan, (ii) the distance of the scanner head from the object and (iii) the angle of incidence of the laser light. The resolution of a scan (i) is a technical parameter that depends on the instrument and is determined before the scan is performed. It indicates the vertical and horizontal spacing between points at a given distance from the laser emission point. In the Leica ScanStation C5 scanner, for example, a medium resolution cloud has a resolution of 1 cm at 10 m, so the horizontal and vertical spacing between points 10 metres away from the scanner head is 1 cm. An increase in resolution means less spacing and also an increase in the number of points detected and therefore an increase in scanning time and PTX file size. The downside of too high resolution is therefore related to file processing, which can be unmanageable and therefore unusable. A lower resolution, on the other hand, leads to difficulties when aligning the scans, as the error in the cloud mesh increases, resulting in failing the alignment or obtaining a geometrically incorrect result. As the spacing between points increases with the distance of the object (ii) from the scanner head, this affects the spacing in a directly proportional way. The last parameter to take into account is the angle of incidence (iii), i.e. the angle between the laser beam and the normal to the surface scanned. As the beam tilts (and therefore the angle grows) the data is more sparse and erroneous points can be obtained (especially those that hit edges). The problem, therefore, is with very high façades, where the upper part, which is further away and hit at a greater angle of incidence, presents many errors in the rendering of the data, as well as for floors, as the height of the scanner is generally around 1.7 m, resulting in a bigger angle of incidence.

In the case where the point clouds are used for the construction of a mesh, there are some problems in the restitution. In order to find an optimal combination of these three described parameters, mesh construction tests were carried out on a series of samples extracted from the point cloud of the Mausoleum of Galla Placidia. Two series of samples were extracted: first ones from a single point cloud and second ones from the final point cloud (i.e., the one obtained from the alignment of all the scans). The single point cloud analysed was carried out with Leica ScanStation C5 at medium resolution (1 cm at 10 m). The instrument head is positioned 1.7 m above ground level and 3.3 m away from the main façade. Considering that the point cloud has a spherical shape and simplifying the façade as a vertical plane intersecting it, circular crowns are formed, characterized by the variation of the angle of incidence. Samples, approximated to squares of one metre by one metre, were extracted on the concentric crowns (with respect to the horizontal line passing through the scanner head). In this way, four samples belong to ranges of incidence angles varying between 0° and approximately 50°. As the distance increases, the number of points in each sample decreases and consequently the number of polygons. The

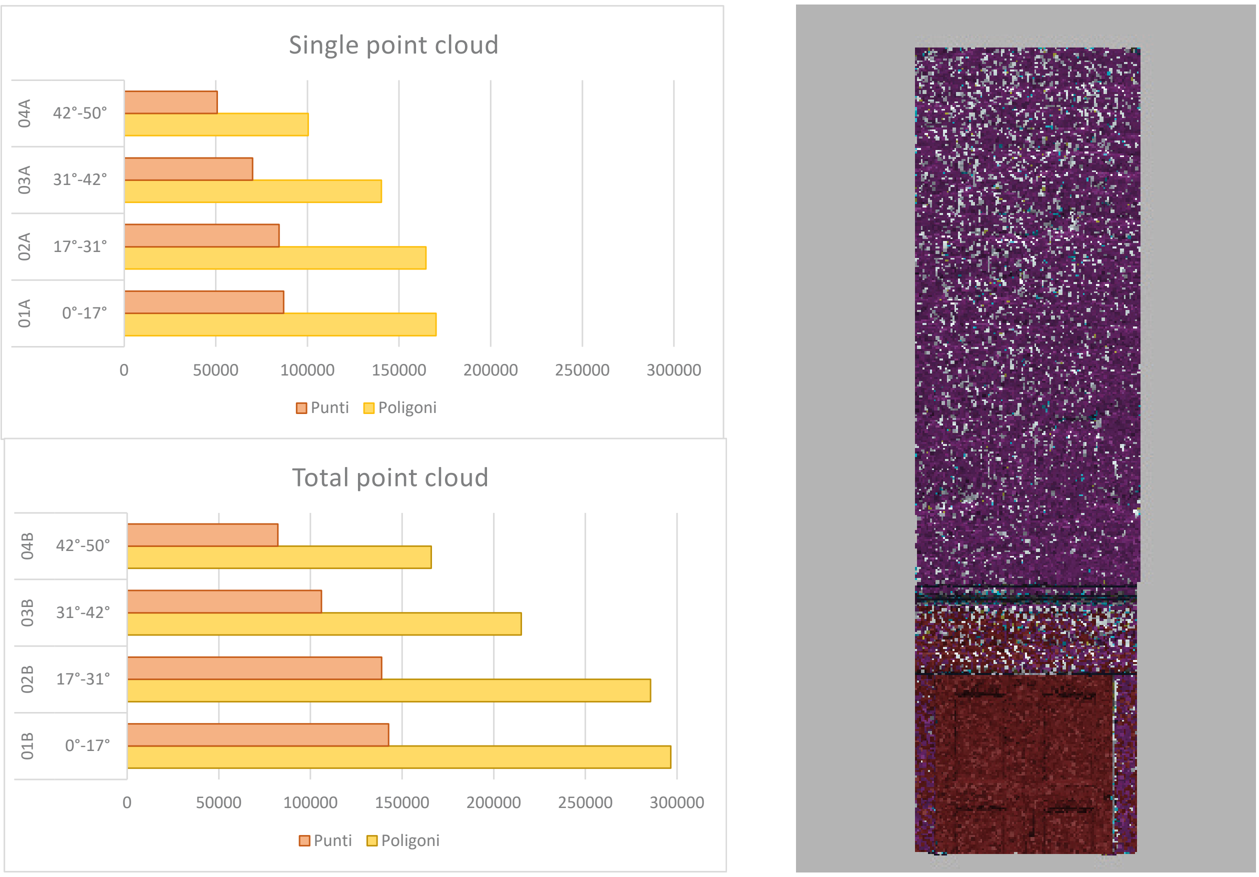

Fig. 6_ Relation between incidence angles and number of points and polygons per sample

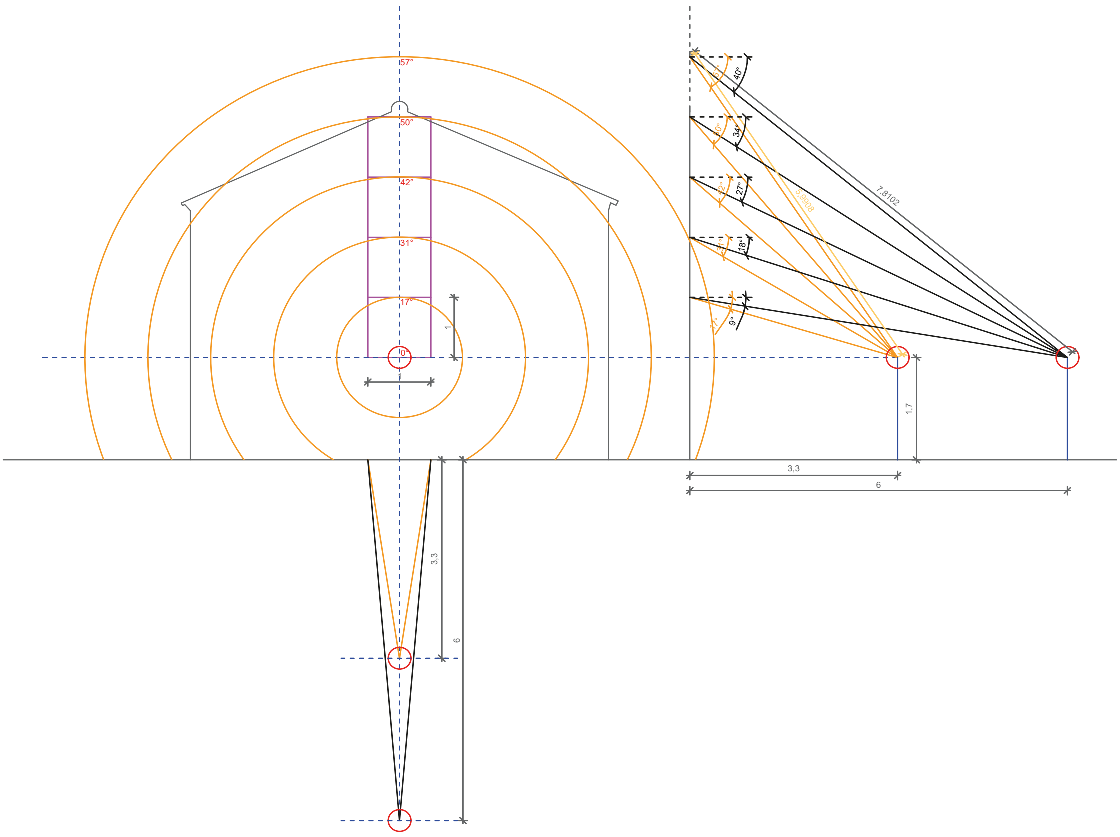

Fig. 7_ Relation between incidence angles and scanner distance from surface

decrease is not proportional as the function is represented by a curve. For each point sample, the mesh was created with the "Mesh Wizard" command of the Geomagic DesignX software at an average quality that did not alter the number of initial points. The samples from the single cloud were compared with those extracted from the total point cloud. This contained points from 8 clouds. However, some were removed as the source was too far from the object (the points were sparse). A total of 4 clouds formed the final cloud. For the second series of samples, the mesh was also constructed in order to compare the number of polygons obtained. As can be seen from the graphs (fig. 6), the data of the merged clouds is better than the single cloud samples, but in the most distant part the increase in the number of polygons is smaller than in the portions closer to the scanner head. Therefore, an increase in the number of scans of the same portion, in the upper parts, does not correspond to an effective increase in the number of valid points and polygons.

For the single cloud, in the case of non-homogeneous masonry (not plastered), more than 60° of angle of incidence the data is substantially unusable and can be removed by filtering the cloud, since the mesh shows many problems in the final rendering. This is especially true for fair-faced walls made of brick or stone elements that present a strong variability in the curvatures that describe their surface. For plastered walls the high angles of incidence therefore cause fewer problems and the data can be used.

In conclusion, these three parameters must be taken into account when designing the survey campaign in order to obtain the most optimal result for the purpose of the survey. In the case, for example, of a very high façade, we have seen that for a distance of the laser scanner from the wall of 3 metres with a resolution of 1 cm at 10 metres, the spacing between the points is about 3 mm, double that for a distance of 6 metres. However, as the distance increases, the angle of incidence decreases, improving the rendering in the upper portions of the façade. As the samplings have also shown, the combination of several clouds provides a greater number of points and polygons that are not erroneous. When planning the survey campaign, it is therefore necessary to set up a grid of scans whose positions are about three metres apart and possibly staggered. If detailed information on the upper part of the façade is required, it can be planned to take a number of scans from a greater distance (e.g. 6 metres) at twice the resolution, so that the spacing of the points is homogeneous and the angle of incidence is not too low (fig. 7). If a number of high detailed scans cannot be made for logistical or file management reasons, it can be convenient to scan with a higher resolution a limited area. In this way the PTX file will contain two clouds, one of which will have a narrower field of view. The advantage is a saving in terms of time (the scan takes less time and the scanner must remain in the same position, thus avoiding the operation of levelling the instrument) and a greater ease of management of the PTX file, which is less heavy than a high-resolution cloud.

If a topographic survey is carried out at the same time as the laser scanner survey, it must be ensured that the surveyed points are included in the scans. In addition to any topographic points, the points that will be used to connect future surveys to the base of the point cloud should be determined during the planning phase of the survey campaign. The base points must be part of the architecture, fixed points that can always be later referred to. In order to facilitate the operations of alignment of the scans and integration of the models derived from digital photogrammetry within the same reference system, it is advisable to use the Rad Coded Targets, automatically generated and recognised by the digital photogrammetry software Agisoft Metashape. This is if it is planned to carry out a photogrammetric survey at the same time as the laser scanner survey. Otherwise, HDS, black/white or spheres targets (the centre of which is automatically recognised by the software) can be used. Rad Coded Targets must be entered manually. Targets cannot be used as base points, as they are relative to each survey campaign and are removed at the end of the campaign.

Once the survey campaign has been planned on the basis of the data to be obtained, the characteristics of the building and the indications of the manager, it is possible to start with the acquisition of the data, which, in the event of very important gaps or errors, may be integrated in a subsequent phase, even if this must be limited.

As defined in the paragraph dedicated to the cataloguing of data (5.1.2), the point clouds in the original format of the laser scanner must be inserted in a specific folder that containing the PTX files without resampling. The downsampling can be done at a later stage of data processing, if a low detail mesh is to be created for example.

The first stage of point cloud processing involves the alignment of the scans, which today is done in some scanners automatically or semi-automatically with visual alignment and automatic target recognition. However, this automatic process sometimes does not allow the operator to check the scan data and the actual quality of the alignment for individual clouds, which in the case of complex objects can lead to errors. Furthermore, the process works best for simple buildings with e.g. large smooth surfaces (used for automatic alignment). In the case of manual alignment there is more control over the result, although obviously the data processing is much longer and can lead to operator errors.

In the case of the selected case studies, Leica Cyclone vv6-9 software was used. Geomagic DesignX v2016 software was chosen for point alignments of a portion of the mesh model. Before inserting the point clouds in the software, it is advisable to rename them so that the name contains a short abbreviation relating to the project (for example for the Neon Baptistery RA_NEON), the date of the survey in the format YYYYYMMDD, and a progressive number that corresponds to the key plan of the points taken: RA_NEON_20191204_01.

Once the alignment of all the clouds is finished, it is possible to start setting the total cloud (not unified) according to two directions: the first one follows the orientation of the cardinal points, while the second one follows an orientation chosen by the operator, aligned following for example the façade or the direction of the main development of the building. In this case, the workflow proposed is applied to the Neonian Baptistery of Ravenna. If a topographic survey is not available, as in the case of the Neonian, for the basic orientation of the laser scanner survey, the file in DWG format downloadable from the Ravenna Municipality website was chosen, which contains the orientation to the North. At the same time, in the IMP file of the Cyclone software, the total point cloud was oriented according to a chosen direction, so as to be convenient for the extraction of orthoimages (aligned with respect to the façade containing the entrance door). The various operations carried out serve to establish an origin and a direction of the axes for two main purposes: extraction of orthoimages with consequent creation of 2D drawings, use of a defined UCS as a basis for future insertion of other PTX files or for the use of coordinates for mesh models, etc. The definition of the two UCS (1, for the orientation for the extraction of elaborates, and N, for the orientation to the North) is carried out following some steps for which it is necessary to record the rototranslation matrix, so that it is always possible to redefine the correct orientation. The operations followed are detailed in Appendix 4.

The total point cloud in the Cyclone software IMP format has to be exported in PTX format (from Cyclone select the portion you want to export, File > Export to PXT format) and stored as a basis for future processing operations. It has been chosen in this basic workflow not to resample the clouds, nor to delete redundant points, or to merge the clouds in Cyclone in order to have an original raw file. These operations are carried out at a later stage before mesh creation with software that offers greater control over resampling characteristics and elimination of unnecessary or unreliable points.

Orthoimages can be extracted from the point cloud and imported into CAD for the creation of 2D drawings according to a manual drawing workflow. However, the cloud can also be used directly in the BIM environment, even if the programme handles heavy files poorly. In this case it is advisable to proceed with the unification and resampling of the clouds in order to obtain a more manageable cloud that can eventually be integrated with portions extracted from the high detail cloud. The procedure for the creation of the BIM file used as the basis of a simplified information system is described in section 5.2.

While creating of the digital archive, it is appropriate to record in a document the spatial coordinates of some natural points that can be used as a reference for subsequent surveys. In the case of the Neonian Baptistery, points belonging to the architecture and easily identifiable in it were extracted and then reported in a pdf document that can be easily consulted if there is no direct access to the point cloud during the survey campaign.

5.1.4 Photographic acquisition and processing methods

In recent years, the great development of Digital Photogrammetry (DP) software has made it possible to automate and speed up the process of three-dimensional reconstruction and the obtaining of a high-detailed texture from two-dimensional images. Given the much lower cost of the instruments necessary for data acquisition and the high level of automation of data processing, the methodology, initially developed for aerial and territorial applications, is now applied in the majority of CH surveys, both at large scale and in close-range applications. The increasing use of drones has also extended the applications of DP to archaeological sites, large buildings or inaccessible parts of them, which were previously surveyed with expensive and complex techniques using aircraft or balloons. However, as with any methodology, its effective application depends on certain environmental factors and the tools used. In these guidelines, the necessary indications are given for taking photographs so that orthoimages and mesh models of a certain quality can be obtained from them. As with the acquisition of point clouds from TLS, the raw data is very heavy and difficult to manage if it is too abundant, or leads to an erroneous reconstruction of the geometry if it is poor. Understanding the basic functioning of digital photogrammetry software is therefore necessary to conduct a photographic campaign whose data produces objects of a defined quality. While for point clouds the proposed standard is based on the resolution, distance and angle of incidence of the scans, in this case it is based on a parameter of pixels per inch (DPI) with a conversion table to the print scale, which then determines the resolution and detail readable from the orthoimages for subsequent use in, for example, pathologies mapping.

The workflow proposed is aimed at users with a LOK2, while detailed workflows on data processing for a LOK3 have been described in chapter 4 on the methodology applied in each specific case. In order to understand how to take photographs, from what distance and at what resolution, it is recommendable to start from the final result that we want to obtain, i.e. a certain number of DPI at a certain scale.

Before planning the survey campaign, it is necessary to summarise how the methodology works and which parameters and characteristics of the object and the contour affect the result, differentiating these parameters at geometric and texture level.

The main digital photogrammetry software uses Structure from Motion (SfM) for the construction of a 3D model from 2D images. This means that, using equations derived from photogrammetry and specific algorithms, they are able to calculate the spatial coordinates of a point provided it appears in at least two frames. From this basic principle of software operation derive the main characteristics that determine the correct execution of photographs and their processing. Digital photogrammetry techniques are classified as passive systems for measuring and reconstructing three-dimensional objects. The term "passive" refers to the role of light, which in laser scanners has an "active" role (it is the beam that strikes the surface and returns information to the instrument about the spatial position of a certain point). This means that, while laser scanners can operate and acquire data even in the absence of light, this is not possible for DP, where the photographs must have certain characteristics in order to obtain an accurate geometric reconstruction. The table 5.5 summarises the main conditions that can be encountered during the acquisition of photographs and suggests how to solve each problem.

Taking these considerations into account, it is possible to proceed with the planning of the survey campaign, combining the characteristics of the object and the contour with the purpose of the survey. Depending on the final scale to be obtained and the level of definition required, it is possible, knowing the characteristics of the camera with which the photos will be taken, to

Characteristics of the object to be surveyed	Ideal condition	Disadvantageous condition	Solution
Surface	Non-homogeneous material with many "features" easily identifiable in the images	Homogeneous monochromatic material (e.g. plaster): the software cannot find the right amount of homologous points needed for reconstruction	For homogeneous materials it is recommended to place a sufficient number of targets that help 3D reconstruction, which is not necessary in case of inhomogeneous materials.
Surface	Opaque material	Reflective or transparent material	Generally, in the architectural field, reflective or transparent elements are eliminated from the images by masking to avoid errors or longer processing times.
Dimensions	Small to medium size	Large dimensions (very long facades)	Division into portions and chunks, so that each one has a certain overlap with the adjacent ones, to allow subsequent alignment.
Shape	Compact, free of irregularities and deep parts not detectable in photographs	Portions with pronounced bas-relief: some parts are too dark or hidden, not identifiable from the photographs	Integration with detailed survey or modelling during post-processing phase
Environmental conditions	Ideal condition	Disadvantageous condition	Solution
Scene lighting	Overcast sky, but no rain or fog	Atmospheric conditions affecting lighting and atmosphere (rain, fog, object half lit by direct sunlight and half in shadow): possible incorrect alignment of photos or incorrect reconstruction of geometry, in correspondence with the transition between light and shadow; poor quality texture; risk of overexposed or underexposed photos	Take the set of photos when the object is completely in shadow; Small adjustments of images in pre-processing phase
Scene lighting	Homogeneous natural light	Lack of natural light, e.g. indoor: photos contain noise or are blurry	Use a longer exposure at the same time as a tripod to get perfectly in focus photos
Scene illumination	Uniform artificial light for which the radiometric characteristics are known	Not uniform artificial light (spotlights or lights with a strong coloured component)	Use natural light as much as possible: if exposure times are long, use a tripod.
Presence of elements in the contour	Free field	Presence of people, vegetation and other moving elements	Removal of unnecessary portions by image masking

Table 5.5_ Digital Photogrammetry conditions

have an estimate of the distance at which to take the photos to obtain a certain resolution. The Ground Sample Distance (GSD), the distance between the centres of two pixels measured on the ground, is used for this calculation. This distance refers to the ground because the formula is generally applied in aerial photogrammetry, but in the case of an architectural complex, the ground corresponds to the façade being photographed. The GSD represents the amount of terrain (or surface in general) contained in the single unit that makes up an image, i.e. the pixel. For example, if the GSD is 1 centimetre, this means that one pixel in the image represents one linear centimetre of the real object. By multiplying the value of the GSD by the total number of pixels in an image (linearly), the result is the linear dimension of the object represented in each photo. Using the reverse procedure, it is possible to find the distance from the object at which to take the photographs, establishing a final resolution and thus solving the equation. The parameters that come into play in the equation are:

- **d – Pixel size (mm):** This is a predefined feature of every camera; it depends on the size of the camera's sensor and the number of pixels it consists of. Generally, the sensor is a rectangle formed by a grid of square pixels;
- **f – Focal Length (mm)**: this parameter is set by the user (18 or 24 mm);
- **GSD (cm/pixel)**: GSD was defined as the constant ratio between d/D (pixel size/area covered).

The unknown is therefore **H - distance to object (height) (mm)**. Since the GSD is defined as GSDw= (H*Sw)/(f*Iw) = (H*d)/f (where Sw is the *Sensor width* and Iw is the *Image width*, also represented by the **d**) and knowing the other parameters we can derive H. We then need to establish a final resolution and scale, calculate for that scale the amount of surface area contained in the single pixel (D) and then find out at what distance to stand based on those imposed values.

If, for example, we want to obtain an image with a resolution of 300 DPI and a final scale of 1:20 (taking into account the graphic error relative to each scale), we know that 10 mm of the work corresponds to 200 mm of the real object and approximately 118 pixels of the image (300 DPI = 118 pixels/cm). Therefore, each pixel of the work corresponds to 1.667 mm (200 mm / 118 = 1.693 mm). If the size of a pixel in the sensor is 0.0084 mm (depending on the camera model) and the shooting focal length is kept at 18 mm, H can be obtained by inverting the GSD equation:

0,0084 mm : 1,667 mm = 18 mm : H

H = (18 mm * 1,667 mm) / 0,0084 mm = 3572 mm

The maximum distance H from the object where the camera is to be placed is approximately 3.6 metres.

In order to facilitate the calculation of the distance from which to take the photos, a spreadsheet has been developed through which, by entering the scale, the resolution, the characteristics of the sensor, the distance is provided and vice versa (table 5.6).

However, with this calculation we obtain the distance for a certain resolution and scale that we impose on the single frame and not on the final product, i.e. the orthophoto exported by the photogrammetry software. Once the object has been scaled and oriented, if we are in the final

FINAL SCALE	1 to	**10**		
	10 mm =	100	mm	
FINAL RESOLUTION		**300**	DPI	
PIXEL PER CM		118		
d – Pixel size (mm): This is a predefined feature of every camera; it depends on the size of the camera's sensor and the number of pixels it consists of. In fact, the sensor is a rectangle formed by a grid of square pixels		**0,00388**	mm	
GSD – (mm/pixel): amount of area contained in the linear distance between two centres of two adjacent pixels		0,846667	mm/pixel	
f – Focal Length (mm): this parameter is set by the user (18 or 24 mm)		**18**	mm	
H - distance to object (height) (mm)		3927,835	mm	**3,9 m**
GSDw= (H*Sw)/(f*Iw) = (H*d)/f		0,846667		

Table 5.6_ Automatic distance for a given scale, resolution, d, f

stage of data processing, i.e. we have already produced the texture, Agisoft Metashape allows us to export orthoimages of custom views at a certain resolution. If the photos are taken at approximately the same distance as previously calculated with the correct overlap and processed in medium quality, i.e. without pixel reduction or resampling, we can extract an orthophoto with the detail established at the beginning.

Once these preliminary considerations about the purpose and final quality of the survey have been made, one can proceed to set targets in the survey campaign. These will be used to orient and scale the resulting model. In fact, the geometric reconstruction performed by the software does not provide information on the scale and orientation of the object. In close-range photogrammetry it is not recommended to use GPS coordinates if available in the photos, as the accuracy for such close-up shots is lower. In the case of the Agisoft Metashape software, Rad Coded Targets are automatically provided by the software in a pdf. The targets have portions of an annulus around a central circle and each combination of portions corresponds uniquely to a number. They are automatically recognised by the photogrammetry software but must be entered manually in the point cloud software. A correct arrangement and an adequate number of targets contributes to a higher accuracy of the position of tie points found by the software. The workflow differs slightly depending on whether or not a TLS survey is present. If it is present, it is sufficient to assign the point cloud coordinates to the targets (already oriented according to the indications of section 5.1.3). In the absence of a TLS survey, it is necessary to use a direct survey, obtaining a lesser accuracy. Therefore, a topographic survey and/or TLS is recommended. The targets should be placed on flat surfaces and in sufficient number for the reconstruction (taking into account that they will then also appear in the texture, covering part of the surface). Once the targets have been placed and the target numbers have been entered in the eidotypes, the photo set can be prepared. A "set" means the series of shots taken and processed together. Depending on the computer efficiency in processing data, each set varies in dimensions and number of photographs. As the correct execution of the photographs implies the success of the subsequent data processing, it is important to take the photographs according to the following precautions: position of the camera with respect to the object (i), overlapping (ii), shooting parameters (iii). The position of the camera (i) must be as perpendicular as possible to the surface being photographed, since as with the laser scanner, the angle of incidence is also a fundamental factor here. If a photo is taken perpendicular to the surface, the sides will be detected at a lower angle of incidence. If it is too low, the software has more difficulty in recognising homologous points between photos. For this reason, it is important to have a good percentage of overlap (ii) both horizontally and vertically (minimum 60% horizontally and 80% vertically; each point must appear in at least two frames, preferably in 5).

With regard to the shooting technique (iii), the following parameters must be set manually and kept fixed for each set of photographs: ISO, aperture, focal length, as well as saving the photographs in RAW format and at the highest resolution available.

- The ISO should be kept as low as possible (100 for outdoor spaces with lots of light, 200 for indoor spaces with less light), because as the ISO sensitivity increases, so does the noise in the photos.
- The aperture (given by f focal length/stop) should be set at the beginning of the set and kept fixed (by setting Aperture Priority). The aperture value should be kept low (i.e. the denominator should be high) in order to have a greater depth of field, resulting in a photo that is entirely in focus.
- The focal length should be set as short as possible, in a range between 18 and 80 mm, trying to avoid telephoto lenses and fish-eye lenses. The focal length should be kept fixed during the whole set; it can be varied during the set only in particular cases, such as very high facades when moving from the lowest to the highest part of the facade, although it can be convenient to work for different chunks each time the focal length is varied. As the distance between the shooting point and the photographed surface increases, the GSD also increases (each pixel in the image covers a greater linear length of the photographed surface). To keep the GSD value constant, it is necessary to increase the focal length. In this way, each photo will cover the same portion of the photographed area and the resolution will therefore be almost constant. To get better shots it is then necessary to decrease the angle of incidence, moving away from the object as you go up in photographing the façade.

Once the survey campaign has been completed, the materials collected shall be catalogued and archived according to the indications given in paragraphs 5.1.2 and 5.2. In particular, photos in RAW format belong to level 0, TIFFs adjusted in the white balance, exposure, etc. belong to level 1 and so on.

For the subsequent treatment of the data, some detailed examples of workflows are proposed in chapter 4, while a specific reference can be found in the official guide downloadable from the website of the major DP software, such as Agisoft Metashape.

5.1.5 Monitoring planning through digital documentation

The monitoring of a CH differs substantially depending on the portion of the building concerned and what is to be monitored. In order to plan correct monitoring, it is necessary to:

- identify the critical points or points affected by interventions, define their characteristics and the changes to monitor;
- Define the correct digital (or other) documentation methodology for monitoring;
- define the monitoring schedule.

Point (1) therefore corresponds to the study of the characteristics of the artefact and its surroundings in order to highlight, list and describe those parts of the object of study which require continuous monitoring. These may have emerged during the analysis phases, such as, for example, unresolved degradation pathologies for which the state of activity and speed of degradation is to be monitored, or to check the effectiveness of the interventions carried out over time. Critical issues also include those features of the surroundings that may influence the degree of conservation of the building, such as seismic risk or natural disasters specific to each area. By highlighting the characteristics to be monitored, it is possible to define the type of monitoring, distinguishing between: (i) preventive, (ii) pre-intervention, (iii) during intervention, (iv) post-intervention. Preventive monitoring (i) is due to the presence of a certain characteristic, mainly related to the context, for which it is intended to intervene before it occurs. For example, in the case of an earthquake or other natural disaster, the monitoring planned and carried out before the occurrence of such a disaster allows to have documentary information on the pre-earthquake status in the cases of possible reconstruction, or structural monitoring to verify the changes due to the earthquake. This documentation composes part of the digital historical archive linked to each asset. In fact, all the documentation carried out in a monitoring action must be linkable to the digital archive based on the point cloud, as defined in section 5.1.3. It is therefore essential that each future survey is oriented according to the reference system chosen and adopted as the basis. The other three types of monitoring (pre- (ii), during (iii) and post-intervention (iv)) are linked to a specific intervention action (conservation, rehabilitation or ordinary maintenance) for which it is desired to document the state before the intervention, the state during the various phases of the intervention and the state afterwards, according to predefined time intervals in order to see the evolution of a particular criticality or pathology and the effect that the intervention has had on it. Furthermore, in the case of ordinary maintenance work, monitoring the course of a particular pathology allows the interventions themselves to be planned more effectively, planning the intervention times correctly. In the case study of the cupola of the Small Baths of Hadrian's Villa (see paragraph 4.2.4) a type of monitoring through digital survey was applied during and after the intervention. The pre-intervention situation was already documented and served as the basis for alignments and comparisons. During the intervention, instead, various laser scanner and photogrammetric surveys were carried out in each phase, which were useful for the following purposes: creation of a digital archive relating to the intervention; help in the design phases and variations during construction; use for simulation and structural analyses.

The manners of monitoring (2) are decided according to the type of criticality highlighted or the intervention planned (both are part of the specific section of the Management Plan as defined in section 5.2). If the method chosen for monitoring is one of the digital documentation methodologies analysed above, it is necessary to carry out the survey following certain considerations for the subsequent insertion of the data in the created database. In particular, the important aspect in the monitoring methodology is the reference in the spatial coordinates to the point cloud chosen as the basis and contained in the Management Plan (according to the indications of section 5.1.3). In that way, the comparison is immediate because it belongs to the same reference system. As seen in point (1), the most common cases of monitoring refer to changes in the shape of the artefact and/or in the state of conservation of the surfaces. Both can occur due to natural events or planned interventions. In the case of shape changes, the methodology mainly used is the TLS, for a structural analysis involving the elaboration of a crack pattern (unless of course there are particular situations in which structural monitoring requires high precision and therefore the use of specific systems to measure and control the cracks, for example, depending on the indications and specific detailed requests of the restorer or structural engineer).

On the other hand, to monitor the situation of the pathologies of degradation of a façade or the effectiveness of a treatment carried out during a restoration, it will be necessary to carry out a photogrammetric survey at regular intervals with relative textures of sufficient quality to identify the pathologies and differences in the progress of degradation (printable at a scale of 1:20, 1:10 or higher for particular details). An example of this type of survey was carried out on the floor of the Panteón (see section 4.2.2), for which two photogrammetric surveys conducted one year apart were compared. The second survey was oriented and scaled using the reference coordinates of the base system and then the two orthoimages were exported at the same scale so that they could be superimposed or compared easily, in order to highlight the differences and the course of degradation, visible, for example, in the glazing. With more advanced techniques depending on the specialist doing the work, it is then possible to compare point clouds or meshes (also automatically with modelling software that performs alignment by points or surfaces) to analyse the deviation of the two surfaces. In this way, following the indications given on the minimum quality of mesh models (number and length of the side of the polygons) it is possible to compare portions of detail and see the differences and contribute to the formation of the digital archive relating to an asset.

Each intervention or criticality highlighted determines the time schedule of the various types of monitoring, based on the level of criticality and urgency defined in the analysis and on the type of criticalities. More specific indications about restoration monitoring can be found in Della Torre (2005). In the case of preventive monitoring (meaning a monitoring for preventive conservation; Van Balen, 2005; Della Torre, 2020), the level of urgency is assigned on the basis of the probability of occurrence of the event and the consequences it would have on the building; this also determines the time interval with which to carry out the surveys (e.g. for earthquakes, depending on the seismic characteristics of the area, annual intervals are envisaged; for other types of natural disasters monitoring may be quarterly or six-monthly to coincide with the seasonal change and monitor the object in all situations). The pre-intervention monitoring (ii) must be general (both in the object of the survey and in the quality), since it is used to assess the criticality and the speed of degradation. In that way, it is possible to define the type and urgency of the intervention. It should be planned for the whole building (depending clearly on the resources available) at a medium-low quality, and then detailed documentation should be carried out only for the portions highlighted as critical and in need of intervention. For these reasons, it can be planned at relatively short intervals (3 months), as its execution must be of the expeditive type, for a maximum restitution scale of 50. The time schedule of monitoring during an intervention is adapted to the phases of the intervention itself (e.g. before and after the application of a cleaning product, etc.). In post-monitoring there is a first phase of one year with two or three measurements (at 3, 6 and 12 months, for example), while the subsequent phases are determined by the results of the first monitoring, which assesses the effectiveness of the intervention in eliminating or slowing down the pathology. Depending on this assessment, future monitoring can be planned (table 5.7). To summarise:

Monitoring actions	1 - identify the critical points or points affected by interventions, define their characteristics and the changes to monitor	2 - define the correct methodology of digital (or other) documentation for monitoring	3 - define the time interval of monitoring

Types of monitoring	Preventive M.: due to the presence of a certain characteristic linked to the context (earthquake, natural criticalities...)	Pre-intervention M.: document the structural and surface situation to correctly plan interventions	M. during intervention: documentation during the various phases of the intervention to assess its effectiveness and to create a digital archive	Post-intervention M.: documentation of the post-intervention situation in order to assess effectiveness and durability.
Time planning	Depends on the level of urgency (determined by the probability of the event occurring and the effects it would cause on the building)	Referred to the entire building or complex in order to determine the criticalities and interventions to be carried out; can be carried out at 3-month intervals, with medium-low quality. The critical points identified will be subject to detailed surveys depending on the urgency of the intervention.	Depends on the various phases of the intervention	Post-intervention documentation is carried out at 3-6-12 months; the next is planned on the basis of the results of the first year's monitoring (effect of the intervention in eliminating or slowing down a deteriorating pathology)

Table 5.7_ Monitoring indications

5.1.6 Standard and digitisation

In the previous paragraphs the most common types of digital products have been analysed in detail, such as point clouds, photographs, 3D models, orthoimages. For each of them have been proposed acquisition, cataloguing and processing characteristics that become standards for the digitisation of CH. The aim is to provide minimum levels of quality control for the data obtained from the main digital methodologies used by the academic and professional world for digitisation according to the purpose of the survey.

As seen in the introduction to the thesis research and in the state-of-the-art analysis, such standards and regulations are mostly used in BIM, while guidelines for digitisation, cataloguing and archiving of digital products related to CH are lacking. Through the experience gained on the case studies, these guidelines provide as many tools as possible for the quality control of the data collected and processed, for their effective cataloguing, archiving, conservation and use.

The table 5.8 summarises the proposed indications divided by type of data, related to the main purpose of the acquisition and processing which determines the minimum quality.

5.2 Management planning using 3D models

The proposed indications work well if they are taken into account by the administration responsible for management and applied in the phases of the life cycle. These must be included in a document that contains all the indications to be implemented in each phase, the specifications for intervention and the programming of monitoring, all types of intervention, both conservation and documentation. This document is inspired by the *Plan Director* in use by the Spanish administrations, which contains all the information related to an asset, such as identification data, interventions carried out and a planning of future actions. The difference is to combine this document with digital technologies and the use of 3D models. A simplified information system is therefore proposed based on a BIM model that serves as a vehicle for the input of existing and future data on the asset. The BIM model is in fact based on a point cloud taken as a geospatial reference base. Therefore it allows all data to be linked to the correspondent portions of the building or object. Since the BIM workflow is widespread in professional environments, such an information system is more likely to be applied on many more occasions than other information systems. These, while offering many essential tools for management and intervention, also require an IT infrastructure created ad hoc, which can hardly be designed for all types f cultural assets, for which managers have limited resources. The experiences made by the writer in the past years on the information system created for the restoration of the Neptune Fountain in Bologna (Apollonio, Ballabeni et al., 2018) and with the SACHER project (Smart Architecture for Cultural Heritage in Emilia-Romagna; Apollonio, Rizzo et al., 2017) (see section 2.2.3) have served as a basis to further simplify the procedure proposed in the thesis. However, there remains the possibility in the future to integrate the information or to transform such a simplified system into

Data	Methodology used to obtain data	Data format and database creation
Point cloud	Obtained by TLS; Grid of 3x3 m scans at 1 cm resolution at 10 m. For façades higher than 6 m (see the angles of incidence in the image 5.XX), distance of 6 m and double resolution.	-Point clouds in each instrument proprietary format; -Single point clouds in PTX format not decimated; -Total non-unified point cloud in PTX format with insertion of two customised UCSs
Point cloud	Obtained from digital photogrammetry: depends on object size, photo pixels, photo quality, processing quality, photo quantity, PC characteristics. Considering a medium PC (8 GB RAM) and HIGH quality processing (no resampling on the photo), for an object distance between 3 and 6 meters (depending on the calculation related to GSD and print scale) the minimum number of photos is between 2/3 and 3/3 of the linear length (10 m -> 7/10 photos).	-Original software format file -Undecimated point cloud in PTX format
Triangular mesh model	HIGH: between ½ and 1/5 of the number of points in the cloud MEDIUM: 1/15 LOW: 1/45 High quality for the Master Model; lower qualities derived from decimation of the Master Model for processing where lower quality is required	OBJ + texture (TIFF)
Optimised mesh model	From HIGH (master model) automatic retopology at 50%, global remesh to have homogeneous triangle edge length, optimization to quadrangular mesh and texture reprojection in Agisoft Metashape -> max 1,000,000 polygons depending on initial data (1/10-1/20 of the number of polygons of the master model); If further optimisation with manual retopology, map baking for insertion into game engines -> max. 10,000 polygons (proportional to initial data).	OBJ + texture (TIFF) + maps (PNG, targa)
Orthoimage	From cloud management software, export at 300 DPI. If the program does not automatically calculate the number of DPIs and does not relate them to a certain scale of representation, use the Pixel-Scale spreadsheet (Table 5.9). Cyclone does not allow you to export at a certain scale and definition, it requires the number of pixels in the image, but when inserting it into AutoCAD, if the unit of measurement is in metres, it automatically scales the image (in this case the check on the number of pixels should be done to be sure of having a minimum resolution).	TIFF format Reference coordinates to base point cloud
Orthoimage	From digital photogrammetry software: it is usually possible to export at a certain scale. Otherwise, you can use the same table as above, 5.9	TIFF format Reference coordinates to base point cloud
3D print model	High Quality - objects with complex shapes such as sculptures: average full-scale model edge length -> 2 mm (printing up to 2:1 scale) High Quality - objects such as buildings with large, smooth, uniform portions and small, complex-shaped portions (building facades with decorative point elements) average edge length of full-scale model for smooth portions -> 100 mm, decorative parts 50 mm (printing up to scale 1:20)	STL format in full and reduced print scale

Table 5.8_ Proposed indications for digitisation standards

	WIDE (cm)	HEIGHT (cm)	
OBJECT DIMENSIONS	**10**	**5**	
PLOT SCALE	1 to **50**		
DIMENSIONS ON PAPER (cm)	20	10	cm
PAPER RESOLUTION		**300**	DPI
PIXEL PER CM		118	pixel/cm
TOTAL EXPORTED IMAGE PIXELS	**2362 x 1181**		**pixels**

	WIDE (cm)	HEIGHT (cm)	
OBJECT DIMENSIONS	**10**	**5**	
PLOT SCALE	1 to **50**		
DIMENSIONS ON PAPER (cm)	=(B2*100)/D3	=(D2*100)/D3	cm
PAPER RESOLUTION		**300**	DPI
PIXEL PER CM		=D5/2,54	pixel/cm
TOTAL EXPORTED IMAGE PIXELS	**=B4*D6 x =D4*D6**		**pixels**

Table 5.9_ Pixel-Scale and formulas

a specific information system. For this reason, the indications provided in the guidelines follow (as was the case for the SACHER Project) the regulations and indications provided by the ICCD, so that the compilation information can be easily integrated with the general file in the ICCD catalogue.

The use of the Management Plan for each cultural asset should follow a shared approach at national and international level to follow in a standardised way the digitisation indications on which the European Commissions are focusing. In the present proposal the Management Plan is a written report linking each section to the corresponding data, and through the compilation of which the digital archive is created for each asset and based on the simplified information system in a BIM environment. The instructions and technical indications for the correct acquisition and cataloguing of data have been anticipated in the previous sections and are now outlined in the proposed index of the Management Plan report.

The Management Plan is divided into four macro-areas based on the phases identified in the life cycle of the asset: (D) Documentation, (IN) Intervention, (M) Monitoring, (U) Use.

Documentation (D) includes all the data already existing or acquired relating to the manufact for which the plan is to be drawn up and a proposal for future documentation. Therefore, the documentation includes both the identification data of the object, and the digitised archive data, and finally the data relating to the digital documentation. As explained in detail in section 5.1.1, the constitution of such a digital archive follows certain instructions for its creation and the technical cataloguing of the data entered, especially digital data (see sheets for the correct cataloguing of point clouds, mesh models, etc.). It is in turn divided into:

- D1 – General Documentation
- D2 – Digital Documentation
- D3 – Other typologies of documentation

- D4 - Time planning of documentation actions

The part of the Management Plan that describes the macro area of the Documentation (D) must correspond to the subdivision made with the folders that contain the corresponding materials (see section 5.1.2). Future documentation actions must be correctly classified according to type, oriented with respect to the base point cloud, and clearly indicate the date of acquisition and/or processing.

The second macro-area, concerning Interventions (IN), is divided into interventions carried out and those to be carried out. In this case, too, the operations can be distinguished according to their typology:

- IN1 - Conservation work
- IN2 - Restoration work
- IN3 - Ordinary maintenance

Each section contains data on each intervention carried out (technical reports, analysis data, etc.) and a planning calendar for future interventions or cycles of interventions (e.g. for maintenance). If an intervention establishes the use or acquisition of digital data, the relevant reference folder must be created in the Documentation section.

The third macro area contains indications concerning Monitoring (M). In this area the critical points are identified. For each of them a monitoring method and the time schedule are established. Each criticality must therefore consider three aspects: Type of criticality; Type of monitoring proposed and/or carried out; Monitoring plan (modality and time schedule), as better defined in section 5.1.5.

The last macro-area, relating to Use (U) describes the current uses of the asset and the possible future uses, in accordance with: the legislation in force for its protection and enhancement; the conservation conditions of the manufact; the compatibility of the proposed use with the characteristics of the asset; the possible modifications or interventions that should be carried out in the case of the insertion of a new compatible use.

The Management Plan report should describe the data and indicate the link to the folder containing it, following an index of this type:

D - Documentation

- D1 - General documentation:
    - D1_1 - Identification data (following or quoting the ICCD cataloguing form)
    - D1_2 - Historical data: (i) Summarised historical report with links to specific existing bibliography and archive material; (ii) Archive material (if digitised, otherwise list of archives, references, location... of each material); (iii) Photographic material (relating to inspections carried out)
    - D1_3 - Reference legislation for the protection, conservation and enhancement of the asset
    - D1_4 - Other general documents related to the identification of the asset
- D2 - Digital documentation: this section lists the existing or acquired digital data, describing the technical characteristics of their acquisition and processing:
    - D2_A_Digital documents (in digital format or digitised) such as technical drawings, plans, sections…

D2_B_Terrestrial Laser Scanning: describes the existing data by means of the technical sheets and the characteristics of the cloud of reference points, assumed as the basis for the creation of the BIM model and for the connection of the models performed in subsequent phases

D2_C_Digital Photogrammetry

D2_D... other types of digital data

D3 - Other type of documentation: this section reports any other data that cannot be included in the previous categories.

D4 – Time schedule of documentation actions

IN - Interventions

IN1 - Conservation work

IN1_1 - Cleaning of external surfaces

IN1_2 - Conservation work on wall surfaces

IN1_3 - ...

IN2 - Restoration works

IN2_1 - Structural work

IN2_2 - New buildings

IN2_3 - ...

IN3 - Ordinary maintenance

IN3_1 - Supply installations (water, electricity, heating, etc.)

IN3_2 - Security installations (access, surveillance, fire protection system, etc.)

IN3_3 - ...

M - Monitoring

M1 - Critical issues identified

M2 - Monitoring methods

M3 – Time schedule of monitoring

U - Use

U1 - Current use (contains administrative documents related to current use)

U2 - Historical uses

U3 - Proposals for new uses and degree of compatibility

U4 - Dissemination strategies

In addition to the proposed index, the subdivision, cataloguing and archiving of the data is provided through a standard folder that can be used for application to any other cultural asset.

5.3 Dissemination strategies through 3D models

As analysed in the state of the art and proposed in the case study experiments, there are many uses that can be made of 3D models for the dissemination of CH (see section 2.3).

In recent years, exploratory applications proposed by museums have been further boosted during the 2020s in the months of mobility restrictions, especially through the use of virtual replicas for remote exploration. The user, already interested in virtual reproductions, has become more demanding with regard to their quality and accessibility. The offer must therefore keep up with the level of quality required by the general and specific public. Certainly, what emerges from the guidelines is the need to create a base which constitutes the digital archive for each asset.

In table 5.9 the main outputs that can be used for dissemination to the general public (analysed in detail in section 2.3). For each output the main uses for dissemination are listed, linked to the methodologies with reference for technical details as analysed in section 5.1.1.

The strategies proposed for the use of 3D models in the dissemination of aspects related to CH can be of great help to institutions, especially if small or unknown to the general public. The valorisation of CH and the dissemination of its historical and artistic aspects must be included in the Management Plan (in fact it appears in the proposed index). Inclusion in the plan implies a greater commitment on the part of the manager, on the one hand in the use of fundings in documentation actions, on the other hand it allows for better use of these resources. In fact, some strategies and some outputs have a low cost compared to the degree of dissemination that can be achieved in return. Therefore, depending on the available resources, each institution must assess which strategies to adopt for dissemination through 3D models (table 5.10) and include them in the Management Plan.

Uses of 3D models	Possible uses for dissemination
(1) Physical reproduction	3D printing with a defined scale factor; Replicas of current or previous states, anastylosis (i); Replicas of museum collections for the creation of tactile models (ii); Replicas of artworks to lend to other museums (iii); Creation of museum gadgets and home 3D printing (iv).
(2) Digital reproduction for online visualisation	Publication on online platforms for visualising 3D models; Creation and publication on the official website.
(3) Digital reproduction for virtual exploration	Creation of applications and serious games for exploring and understanding CH with videogame mode.
(4) Digital reproduction as an educational tool	Possible original state and transformations; Anastylosis; Production of audiovisual content for education and dissemination (guides, in-depth content); Creation of applications to support guided tours.
(5) Virtual and Augmented Reality	First-person remote exploration of the current situation or digital reconstructions; Virtual tours with in-person guidance; Educational video.

Table 5.10_ Possible uses of 3D models for dissemination

Conclusions

The proposed guidelines help the different types of users in the Management of Cultural Heritage. Thanks to the experimentation on case studies, it was possible to determine standards and workflows for each phase that are adapted to the Level of Knowledge of digital technologies and methodologies. Given the variety of Cultural Heritage and the complexity of the management phases, it is necessary to experiment and apply guidelines and standards on as many case studies as possible, in order to refine the guidelines themselves, as will be underlined in the future research lines outlined in the next chapter.

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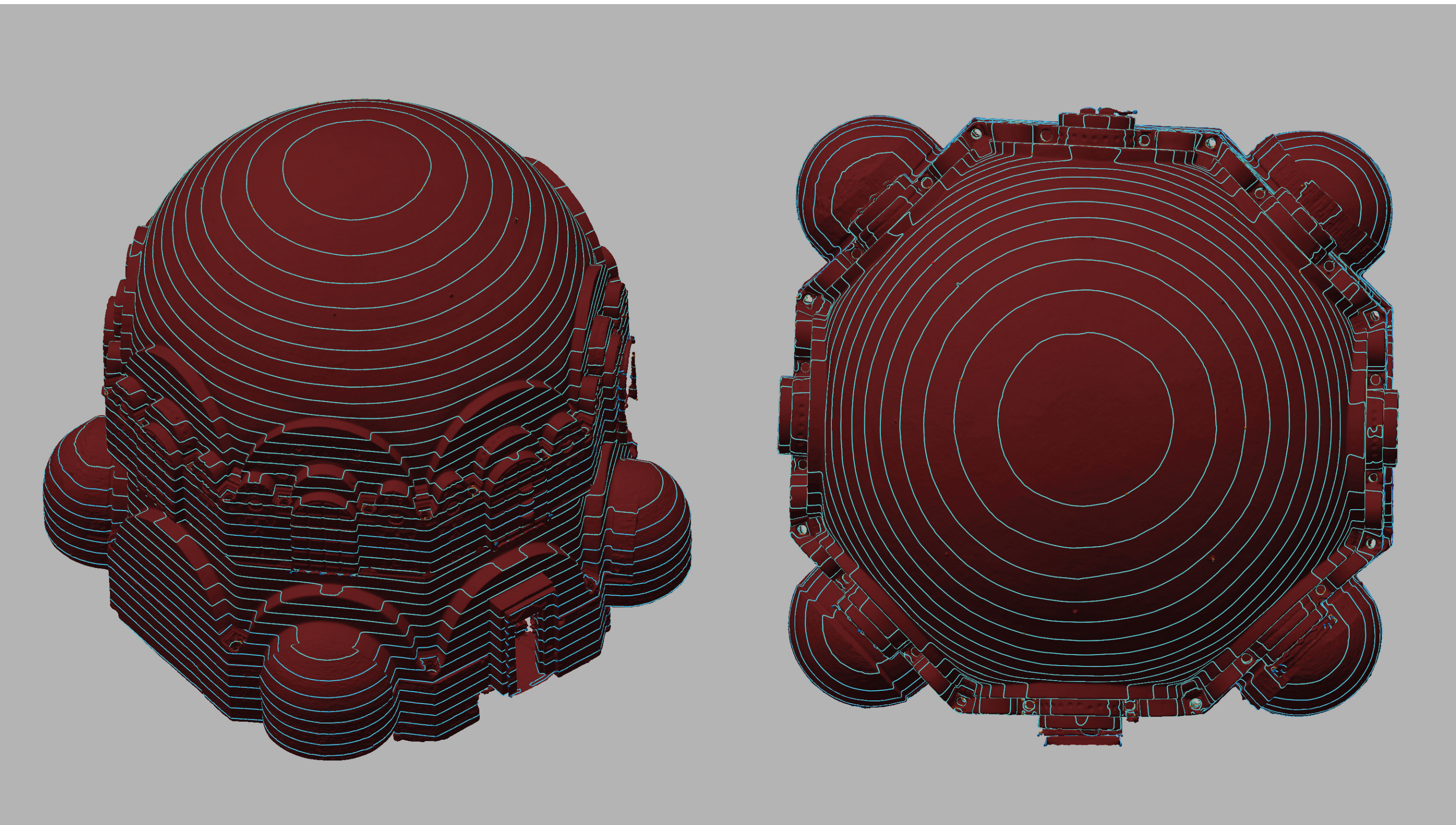
Sections on the 3D model of the interior on the Neonian Baptistery, Ravenna (Italy)

Chapter 6

Conclusions and future lines of research



Chapter 6 - Conclusions and future lines of research

The study of the state of the art (see chapter 2) showed that the research field of digital technologies applied to Cultural Heritage (CH) is wide, interdisciplinary and continuously expanding. From a technical point of view, data acquisition equipment is becoming more and more efficient, improving the quality/price ratio and opening up to the professional world. Data processing methodologies are becoming more and more automated, reducing processing time and the skills required for processing, and again becoming common practice in the professional world. The most promising solutions, although still with a strong experimental component, come from the integration of different methodologies, borrowed from similar sectors (engineering, videogames). Still limited are effective solutions for the management of CH through 3D models. Recent experiences with information systems offer valid tools for management phases, but they require a huge investment for the creation of a dedicated IT platform, which often is left behind by the administrations at the end of the project.

It is clear that, while on the one hand European and national digitisation programmes are pushing towards the use of digital technologies and 3D models, on the other hand they are still lacking in indicating standards for data acquisition and processing that effectively control the quality of digital products and indicate good practices for centralised and coordinated management at supranational level. In addition, the indications for the use of 3D models by Europe belong almost exclusively to the field of dissemination, while some Member States carry out standardisation study projects related to their own local scope (see chapter 3). It is therefore difficult for all the actors involved to communicate and manage the digitisation plan in a choral way, when the aim of standardisation should be to facilitate management and dialogue among the wide variety of institutions dealing with CH (at global level too, such as UNESCO).

Moreover, the duality between the academic and professional worlds is still a big unsolved issue. On the one hand scholars are constantly studying solutions to technical issues (concerning methodologies for data documentation and processing). On the other hand, professionals interact with the managers of CH without having precise references for the execution of their work. Lastly, managers find difficult to use 3D models in the management.

The thesis research aimed to propose guidelines to fill this gap with specific standards and good practices for the correct use of 3D models in CH management. The indications provided derive from the analysis of each aspect and phase of the whole CH management cycle, taking into account both the users involved and their knowledge levels with respect to digital methodologies. The proposed standards and best practices for data gathering and processing are therefore based on the experimentation of digital data documentation and processing workflows applied to multiple case studies (chapter 4) and adjusted to the level of knowledge of the user. The thesis is therefore based on a comprehensive analysis of all aspects, actions and interactions generated by CH management, linking each aspect to the use of digital models. The interdisciplinary and global vision approach to the issue allows to provide tools for practical application in the management cycle (chapter 5).

Future research in the field must therefore focus on the subject with the same interdisciplinary and inclusive approach to all facets of the management cycle. Some lines of research and application of procedures arising from the analyses are proposed:

- adoption of standards and good practices, similar to those proposed in the thesis, at an international European level;
- continuous experimentation on the highest number of different typologies conforming CH, in order to provide greater adaptability of the guidelines to the great variety of cultural assets. In fact, standards and procedures must undergo an iterative process of application, so that they are improved through repeated and continuous machine learning experimentation. Effective standards and procedures will facilitate data exchange and help to improve and coordinate digitisation actions;
- automatic classification of raw data (point clouds, images) to divide them into elements, using segmentation and labelling processes. In this way, the database used for management is not just a repository of heterogeneous data but becomes a relational information system.
- processing of collected data. Using a relational information system identified in the previous point, strategies and methods for integrating heterogeneous data, optimisation and classification standards are identified.

Lastly, given the wide variety of disciplines involved, the high number of digital products available today and the increasing level of quality required by users, it is essential to accompany research and digitisation actions with adequate dissemination of results and procedures, involving different professionals and creating the right conditions for the training of professionals capable of managing CH through the correct use of 3D models.

CAPITOLO 6 - CONCLUSIONI E FUTURE LINEE DI RICERCA

Lo studio dello stato dell'arte (v. cap. 2) ha evidenziato come il campo di ricerca delle tecnologie digitali applicate ai Beni Culturali sia ampio, interdisciplinare e in continua espansione. Dal punto di vista tecnico, le strumentazioni di acquisizione dei dati diventano sempre più efficienti, migliorando il rapporto qualità/prezzo e aprendosi al mondo professionale. Le metodologie di processamento dei dati sono sempre più automatiche, riducendo i tempi di lavorazione e le capacità necessarie per il processamento e anche in questo caso diventano pratiche diffuse nel mondo professionale. Le soluzioni più promettenti, sebbene ancora con una forte componente sperimentale, si hanno dall'integrazione di metodologie differenti, prestate da settori affini e applicate con successo alla documentazione digitale del Patrimonio Culturale (come l'utilizzo dei game engines o dell'ambiente BIM). Ancora però limitate sono le soluzioni efficaci per la gestione dei Beni Culturali tramite i modelli tridimensionali. Le recenti esperienze dei sistemi informativi offrono validi strumenti per determinate fasi della gestione, prevedendo però un ingente investimento per la creazione di una infrastruttura informatica dedicata, che comporta spesso un rapido abbandono da parte delle amministrazioni alla conclusione del progetto.

È evidente quindi che mentre da un lato i programmi europei e nazionali per la digitalizzazione spingono verso l'utilizzo delle tecnologie digitali e dei modelli 3D, dall'altro sono ancora carenti nell'indicare standard per l'acquisizione e il processamento dei dati che controllino efficacemente la qualità dei prodotti digitali e che indichino buone pratiche per la gestione centralizzata e coordinata a livello sovranazionale. Inoltre, le indicazioni di utilizzo dei modelli 3D da parte dell'Europa appartengono quasi esclusivamente all'ambito divulgativo, mentre alcuni Stati Membri portano avanti progetti di studio di standardizzazione relativi al proprio ambito regionale (v. cap.3). Tutti gli attori in gioco hanno quindi difficoltà a comunicare e gestire il piano di digitalizzazione in maniera corale, quando invece l'obiettivo di una standardizzazione dovrebbe essere quello di favorire la gestione e il dialogo nella grande varietà di enti e istituzioni che si occupano dei Beni Culturali (anche a livello mondiale, come l'UNESCO).

Sia su piccola che su grande scala permane la dualità tra mondo accademico e mondo professionale, spesso non comunicanti tra di loro. Da una parte il mondo accademico, in costante aggiornamento e studio delle tematiche trattate nella tesi (come le metodologie di documentazione e processamento dei dati digitali), mentre dall'altra il mondo professionale, che interagisce con i gestori dei Beni Culturali senza avere riferimenti precisi per l'esecuzione del proprio lavoro. I gestori, invece incontrano difficoltà nell'utilizzo dei modelli tridimensionali, sia perché ne trovano difficile l'uso applicato alla gestione, sia perché non sempre ne conoscono le potenzialità.

La ricerca di tesi ha inteso proporre linee guida per riempire questo vuoto, sia dal punto di vista di standard specifici che di buone pratiche per il corretto utilizzo dei modelli 3D nella gestione del

Patrimonio Culturale. Le indicazioni fornite derivano dall'analisi di ogni aspetto e fase dell'intero ciclo di gestione di un Bene Culturale, tenendo in considerazione sia gli utenti coinvolti che i loro livelli di conoscenza rispetto alle metodologie digitali. Le proposte di standard e buone pratiche per la raccolta e il processamento dei dati si basano quindi sulla sperimentazione dei workflow di documentazione e processamento dei dati digitali applicati a molteplici casi studio (v. cap. 4) e si adattano al livello di conoscenza dell'utente finale. La tesi si basa quindi su un'analisi completa di tutti gli aspetti, le azioni e le interazioni generate dalla gestione dei Beni Culturali, collegando ogni aspetto all'uso dei modelli digitali. L'interdisciplinarità e l'approccio di visione globale alla questione permettono di fornire strumenti di applicazione pratica nel ciclo di gestione (v. cap. 5).

Future ricerche nel campo devono quindi concentrarsi sull'argomento con lo stesso approccio interdisciplinare e inclusivo di tutte le sfaccettature del ciclo di gestione. In particolare, si propongono alcuni filoni di ricerca e di applicazione di procedure che scaturiscono dalle analisi e dal percorso di tesi:

- adozione di standard e buone pratiche similari a quelle proposte nella ricerca di tesi a livello di raccomandazioni europee;
- sperimentazione continua sul più alto numero di tipologie differenti che conformano il Patrimonio Culturale, per fornire una maggiore adattabilità delle linee guida alla grande varietà di Beni Culturali. Infatti, standard e procedure devono essere sottoposti a un processo iterativo di applicazione al Patrimonio Culturale, in modo che vengano messi a punto grazie alla ripetuta e continua sperimentazione automatica, di tipo *machine learning*. Standard e procedure efficaci favoriranno l'interscambio di dati e contribuiranno a migliorare e coordinare le azioni di digitalizzazione;
- classificazione automatica di dati grezzi (nuvole di punti, immagini) per la suddivisione in elementi, mediante processi di segmentazione e assegnazione di etichette. In tal modo, il database utilizzato per la gestione non è solo un repository di dati eterogenei, ma diventa un sistema informativo di tipo relazionale.
- elaborazione dei dati raccolti. Utilizzando un sistema di tipo relazionale individuato al punto precedente, si individuano strategie e metodi di integrazione di dati eterogenei, standard di ottimizzazione e di classificazione.

Infine, data la grande varietà di discipline coinvolte, l'alto numero di prodotti digitali oggi disponibili e il crescente livello di qualità degli stessi richiesto dagli utenti, è fondamentale accompagnare le ricerche e le azioni di digitalizzazione con un'adeguata diffusione e divulgazione di risultati e procedure, coinvolgendo i diversi professionisti e creando le condizioni giuste perché si formino delle figure professionali capaci di gestire i Beni Culturali tramite il corretto utilizzo dei modelli tridimensionali.

CAPÍTULO 6 - *CONCLUSIONES Y LÍNEAS FUTURAS DE INVESTIGACIÓN*

El estudio del estado del arte (capítulo 2) mostró que el campo de investigación de las tecnologías digitales aplicadas al Patrimonio Cultural es amplio, interdisciplinario y en continua expansión. Desde el punto de vista técnico, las herramientas de adquisición de datos son cada vez más eficaces, mejorando la relación calidad/precio y abriéndose al mundo profesional. Las metodologías de procesamiento de datos están cada vez más automatizadas, lo que reduce el tiempo de procesamiento y los conocimientos necesarios para utilizarlas, contribuyendo a su difusión en el mundo profesional. Las soluciones más prometedoras, aunque todavía con un fuerte componente experimental, provienen de la integración de diferentes metodologías, tomadas de sectores afines y aplicadas con éxito a la documentación digital del Patrimonio Cultural (como el uso de motores de juego o el entorno BIM). Son todavía limitadas las soluciones eficaces para la gestión del Patrimonio Cultural mediante modelos tridimensionales. Las experiencias recientes con los sistemas de información ofrecen herramientas válidas para ciertas fases de la gestión, pero requieren una enorme inversión para la creación de una infraestructura informática dedicada, lo que a menudo conduce a un rápido abandono por parte de las administraciones al finalizar el proyecto.

Es evidente que, mientras por un lado los programas de digitalización europeos y nacionales impulsan el uso de las tecnologías digitales y los modelos 3D, por otro siguen sin indicar normas de adquisición y tratamiento de datos que controlen eficazmente la calidad de los productos digitales e indiquen buenas prácticas para una gestión centralizada y coordinada a nivel supranacional. Además, las indicaciones para el uso de modelos 3D por parte de Europa pertenecen casi exclusivamente al ámbito de la divulgación, mientras que algunos Estados miembros llevan a cabo proyectos de estudio de normalización limitados a su propio ámbito regional (capítulo 3). Por tanto, es difícil que todos los actores implicados comuniquen y gestionen el plan de digitalización de forma coral, cuando el objetivo de la normalización debería ser fomentar la gestión y el diálogo entre la gran variedad de instituciones que se ocupan del Patrimonio Cultural (incluso a nivel mundial, como la UNESCO).

Tanto a pequeña como a gran escala, se mantiene la dualidad entre el mundo académico y el profesional, que a menudo no se comunican entre sí. Por un lado, el mundo académico, que está en constante actualización y estudio de los temas tratados en la tesis (como las metodologías de documentación y tratamiento de datos digitales), mientras que por otro lado el mundo profesional, que interactúa con los gestores del Patrimonio Cultural sin tener referencias precisas para la ejecución de su trabajo. Los gestores, por su parte, tienen dificultades con el uso de los modelos tridimensionales, tanto porque les resulta difícil aplicarlos a la gestión como porque no siempre conocen su potencial.

La investigación de la tesis tenía como objetivo proponer directrices para llenar este vacío, tanto desde el punto de vista de las normas específicas, como de las buenas prácticas para el correcto uso de los modelos 3D en la gestión del Patrimonio Cultural. Las indicaciones proporcionadas se derivan del análisis de cada aspecto y fase de todo el ciclo de gestión, teniendo en cuenta tanto los usuarios implicados como sus niveles de conocimiento respecto a las metodologías digitales. Las normas y las mejores prácticas propuestas para la recogida y el tratamiento de datos se basan, por tanto, en la experimentación de flujos de trabajo de documentación y tratamiento de datos digitales aplicados a múltiples casos prácticos (capítulo 4). La tesis se basa, por tanto, en un análisis exhaustivo de todos los aspectos, acciones e interacciones que genera la gestión del Patrimonio Cultural, vinculando cada aspecto al uso de modelos digitales. El enfoque interdisciplinario y de visión global del tema permite proporcionar herramientas de aplicación práctica en el ciclo de gestión (capítulo 5).

Por lo tanto, la investigación futura en este campo debe centrarse en el tema con el mismo enfoque interdisciplinario e inclusivo de todas las facetas del ciclo de gestión. En particular, se proponen algunas líneas de investigación y aplicación de procedimientos derivados de los análisis y el recorrido de la tesis:

- adopción de normas y buenas prácticas similares a las propuestas en la investigación de la tesis a nivel de recomendaciones europeas;
- experimentación continua sobre el mayor número de tipologías diferentes de Bienes Culturales, para proporcionar una mayor adaptabilidad de las directrices al Patrimonio Cultural. Las normas y los procedimientos deben someterse a un proceso iterativo de aplicación, de modo que se perfeccionen mediante la experimentación repetida y continua del aprendizaje automático. Unas normas y procedimientos eficaces facilitarán el intercambio de datos y ayudarán a mejorar y coordinar las acciones de digitalización;
- clasificación automática de datos brutos (nubes de puntos, imágenes) para descomponerlos en elementos, mediante procesos de segmentación y etiquetado. De este modo, la base de datos utilizada para la gestión no es sólo un depósito de datos heterogéneos, sino que se convierte en un sistema de información relacional;
- tratamiento de los datos recogidos. A partir de un sistema de tipo relacional definido en el punto anterior, se identifican estrategias y métodos de integración de datos heterogéneos, normas de optimización y clasificación.

Por último, dada la gran variedad de disciplinas implicadas, el elevado número de productos digitales disponibles en la actualidad y el creciente nivel de calidad exigido por los usuarios, es imprescindible acompañar las acciones de investigación y digitalización con una adecuada divulgación de los resultados y procedimientos, implicando a diferentes profesionales y creando las condiciones adecuadas para la formación de profesionales capaces de gestionar el Patrimonio Cultural a través del correcto uso de los modelos tridimensionales.

Capítol 6 - Conclusions i línies futures d'investigació

L'estudi de l'estat de l'art (capítol 2) va mostrar que el camp d'investigació de les tecnologies digitals aplicades al Patrimoni Cultural és ampli, interdisciplinari i en contínua expansió. Des del punt de vista tècnic, les ferramentes d'adquisició de dades són cada vegada més eficaç, millorant la relació qualitat/preu i obrint-se al món professional. Les metodologies de processament de dades estan cada vegada més automatitzades, la qual cosa reduïx el temps de processament i els coneixements necessaris per a utilitzar-les, contribuint a la seua difusió en el món professional. Les solucions més prometedores, tot i que encara amb un fort component experimental, provenen de la integració de diferents metodologies, preses de sectors afins i aplicades amb èxit a la documentació digital del Patrimoni Cultural (com l'ús de motors de joc o l'entorn BIM) . Són encara limitades les solucions eficaces per a la gestió del Patrimoni Cultural per mitjà de models tridimensionals. Les experiències recents amb els sistemes d'informació oferixen ferramentes vàlides per a certes fases de la gestió, però requerixen una enorme inversió per a la creació d'una infraestructura informàtica dedicada, la qual cosa sovint conduïx a un ràpid abandó per part de les administracions al finalitzar el projecte.

És evident que, mentres per un costat els programes de digitalització europeus i nacionals impulsen l'ús de les tecnologies digitals i els models 3D, per un altre seguixen sense indicar normes d'adquisició i tractament de dades que controlen eficaçment la qualitat dels productes digitals i indiquen bones pràctiques per a una gestió centralitzada i coordinada a nivell supranacional. A més, les indicacions per a l'ús de models 3D per part d'Europa pertanyen quasi exclusivament a l'àmbit de la divulgació, mentres que alguns Estats membres duen a terme projectes d'estudi de normalització limitats al seu propi àmbit regional (capítol 3) . Per tant, és difícil que tots els actors implicats comuniquen i gestionen el pla de digitalització de forma coral, quan l'objectiu de la normalització hauria de ser fomentar la gestió i el diàleg entre la gran varietat d'institucions que s'ocupen del Patrimoni Cultural (inclús a nivell mundial, com la UNESCO).

Tant a xicoteta com a gran escala, es manté la dualitat entre el món acadèmic i el professional, que sovint no es comuniquen entre si. D'una banda, el món acadèmic, que està en constant actualització i estudi dels temes tractats en la tesi (com les metodologies de documentació i elaboració de dades digitals), mentres que per un altre costat el món professional, que interactua amb els gestors del Patrimoni Cultural sense tindre referències precises per a l'execució del seu treball. Els gestors, per la seua banda, tenen dificultats amb l'ús dels models tridimensionals, tant perquè els resulta difícil aplicar-los a la gestió com perquè no sempre coneixen el seu potencial.

La investigació de la tesi tenia com a objectiu proposar directrius per a omplir este buit, tant des del punt de vista de les normes específiques, com de les bones pràctiques per al correcte ús dels models 3D en la gestió del Patrimoni Cultural. Les indicacions proporcionades es deriven de l'anàlisi de cada aspecte i fase de tot el cicle de gestió del Patrimoni Cultural, tenint en compte tant els usuaris implicats com els seus nivells de coneixement respecte a les metodologies digitals. Les normes i les millors pràctiques propostes per a l'arreplega i el tractament de dades es basen, per tant, en l'experimentació de fluxos de treball de documentació i tractament de dades digitals aplicats a múltiples casos pràctics (capítol 4) i adaptats al nivell de coneixements de l'usuari final. La tesi es basa, per tant, en una anàlisi exhaustiva de tots els aspectes, accions i interaccions que genera la gestió del Patrimoni Cultural, vinculant cada aspecte a l'ús de models digitals. L'enfocament interdisciplinari i de visió global del tema permet proporcionar ferramentes d'aplicació pràctica en el cicle de gestió (capítol 5).

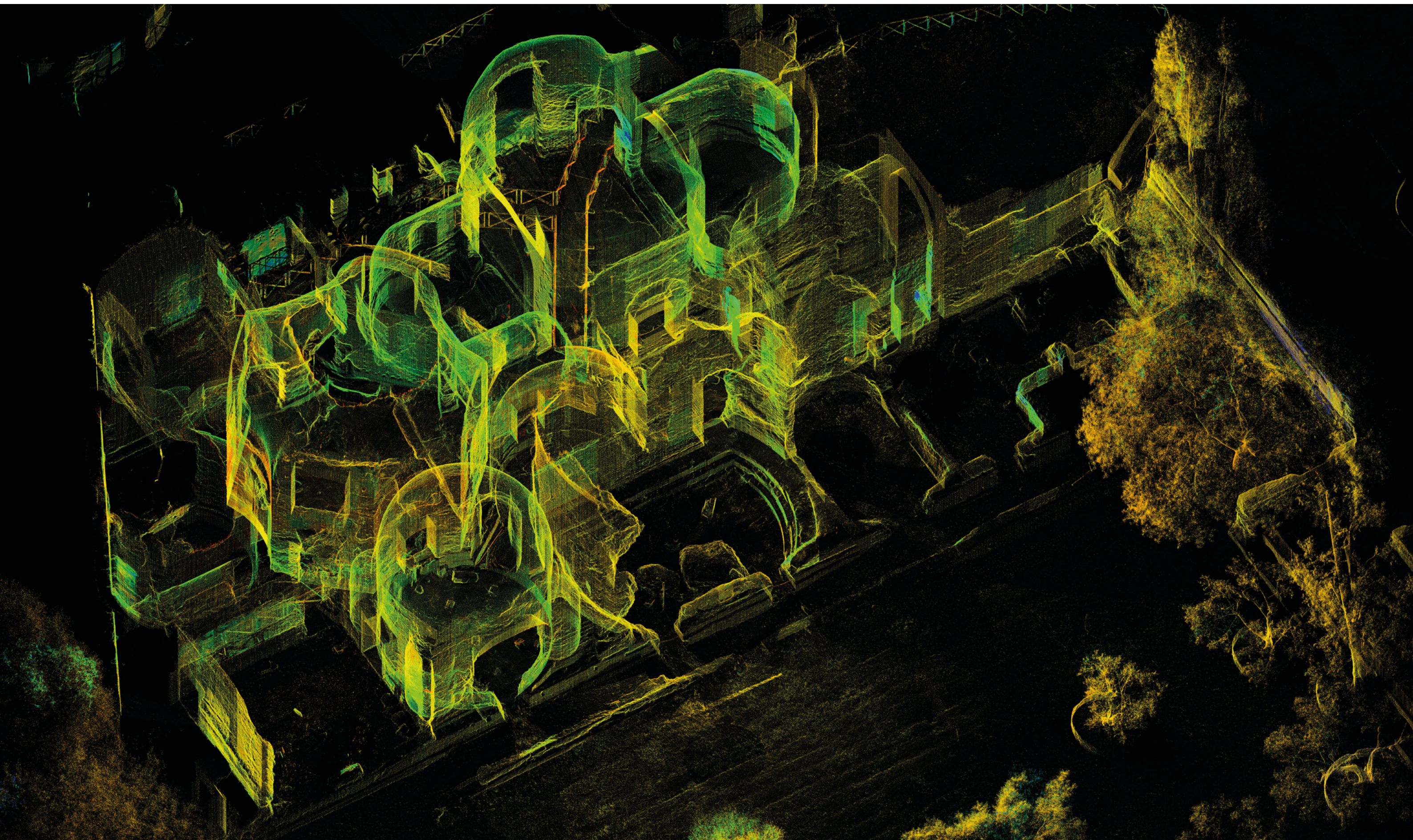
Per tant, la investigació futura en este camp ha de centrar-se en el tema amb el mateix enfocament interdisciplinari i inclusiu de totes les facetes del cicle de gestió. En particular, es proposen algunes línies d'investigació i aplicació de procediments derivats de les anàlisis i el recorregut de la tesi:

- o adopció de normes i bones pràctiques semblants a les propostes en la investigació de la tesi a nivell de recomanacions europees;
- o experimentació contínua sobre el nombre més gran de tipologies diferents que conformen el Patrimoni Cultural, a fi de proporcionar una major adaptabilitat de les directrius a la gran varietat de Béns Culturals. De fet, els estàndards i els procediments han de sotmetre's a un procés iteratiu d'aplicació, de manera que es perfeccionen per mitjà de l'experimentació repetida i contínua de l'aprenentatge automàtic. Uns estàndards i procediments eficaços facilitaran l'intercanvi de dades i ajudaran a millorar i coordinar les accions de digitalització.
- o classificació automàtica de dades brutes (núvols de punts, imatges) per a descompondre'ls en elements, per mitjà de processos de segmentació i etiquetatge. D'esta manera, la base de dades utilitzada per a la gestió no és només un depòsit de dades heterogènies, sinó que es convertix en un sistema d'informació relacional;
- o tractament de les dades arreplegats. A partir d'un sistema de tipus relacional definit en el punt anterior, s'identifiquen estratègies i mètodes d'integració de dades heterogènies, normes d'optimització i classificació.

Finalment, donada la gran varietat de disciplines implicades, l'elevat nombre de productes digitals disponibles en l'actualitat i el creixent nivell de qualitat exigit pels usuaris, és imprescindible acompanyar les accions d'investigació i digitalització amb una adequada divulgació dels resultats i procediments, implicant diferents professionals i creant les condicions adequades per a la formació de professionals capaços de gestionar el Patrimoni Cultural a través del correcte ús dels models tridimensionals.

Point cloud of the Small Baths complex in Hadrian's Villa, Tivoli, Rome (Italy)

Appendix



Appendix 1

Workflow for model and texture optimization applied to RA_AND_chap_ceiling (II survey).

Software used: Agisoft Photoscan, Leica Cyclone, Luxology Modo.

File Agisoft Photoscan: RA_AND_chap_TOT.psx

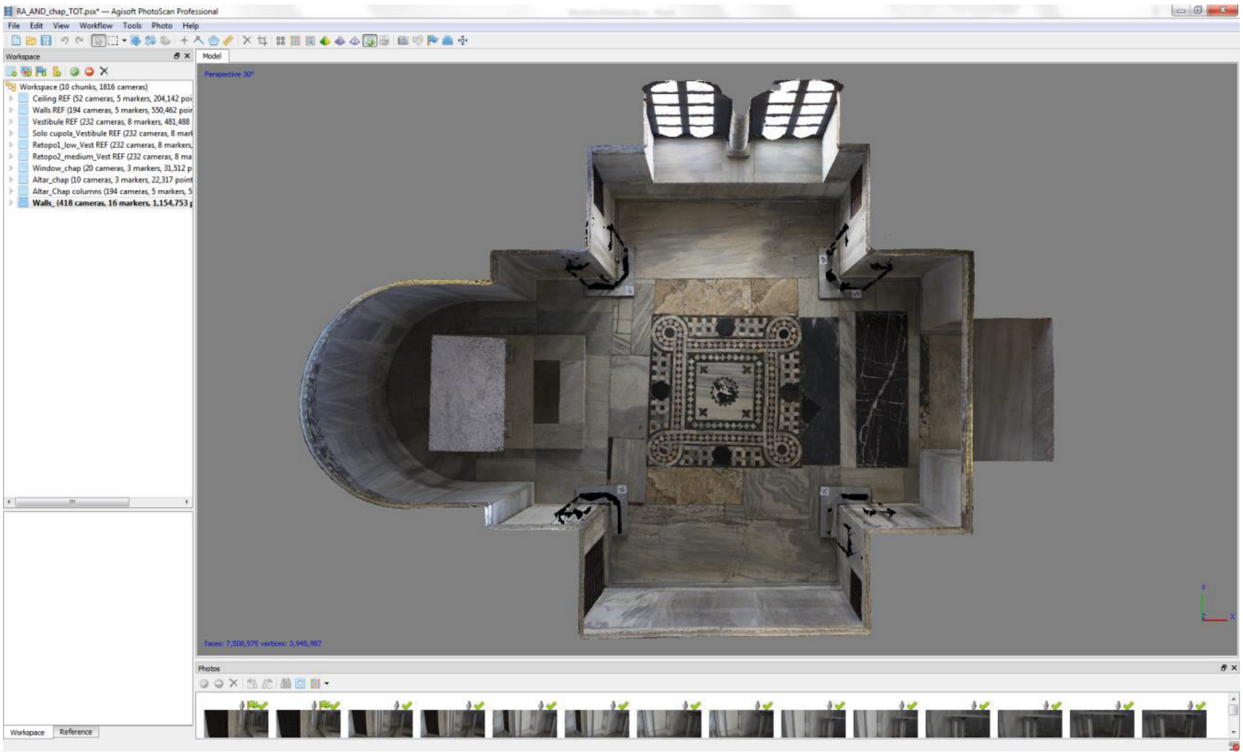
It contains 3 different chunks:

- Ceiling REF (52 cameras, 5 markers, 204 142 points)
- Walls REF (194 cameras, 5 markers, 550 462 points)
- Vestibule REF (232 cameras, 8 markers, 481 488 points)

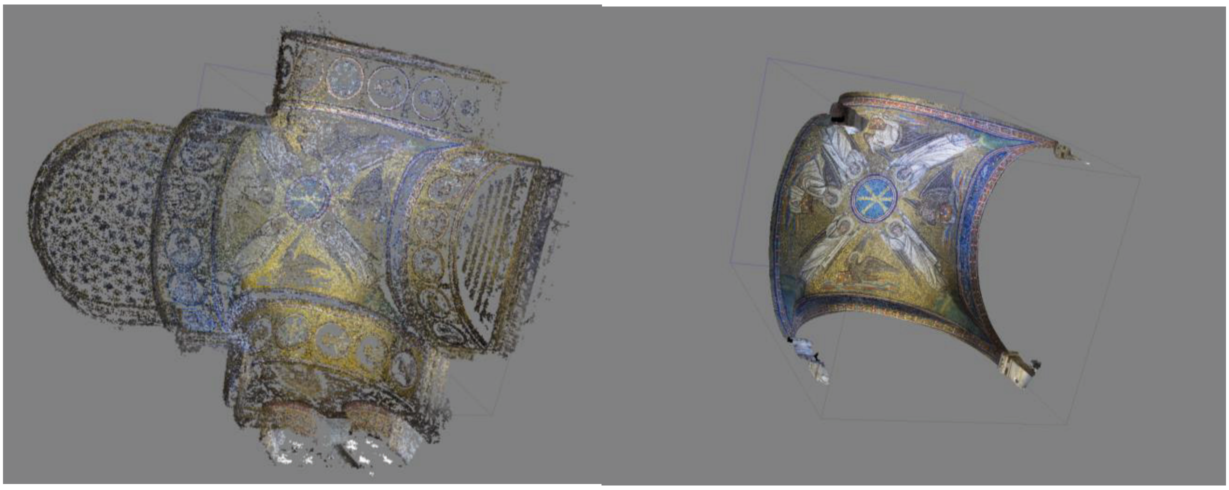
Each chunk has been referenced by taking coordinates of markers from the point cloud in Leica Cyclone, so the chunks appear already aligned. Before the merge, it is opportune to clean some part of the mesh that could generate erroneous match.

Some parts, like the window and the altar, have been processed separately and added in a second time, to avoid a bad quality of the texture due to overexposed or underexposed photos.

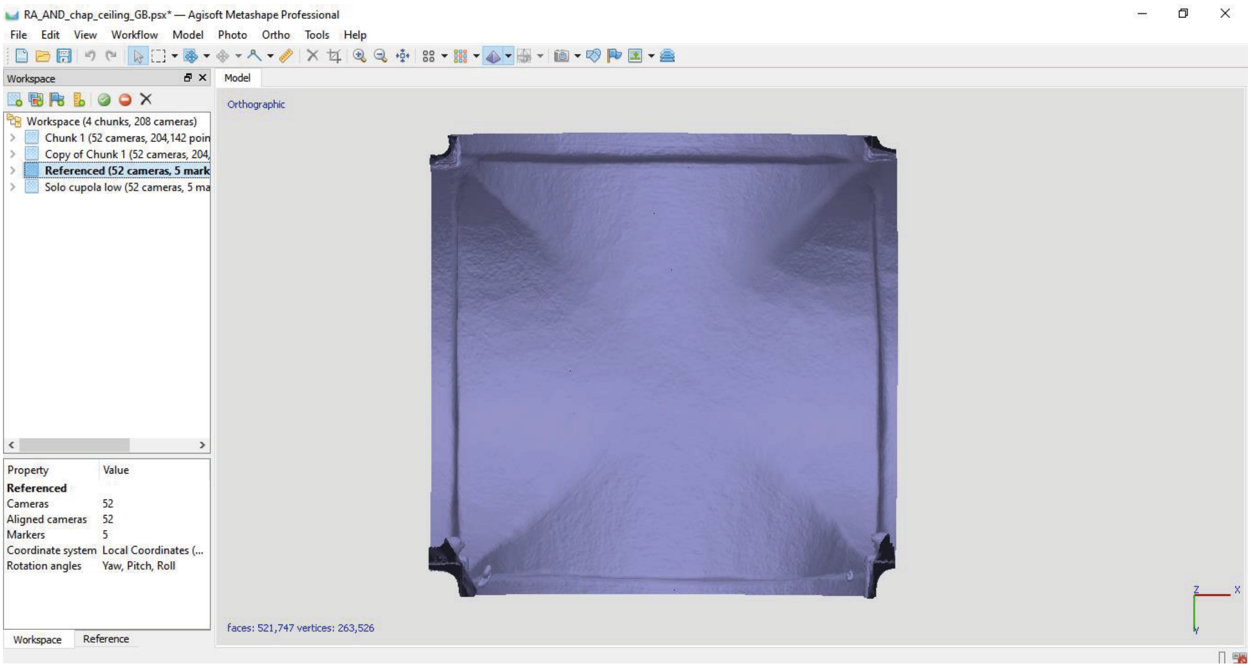
1) Follow Photoscan workflow from alignment to texture production, inserting reference coordinates from a TLS point cloud (or other measurements taken).



2) Duplicate the final chunk and process only a small part, here the upper part of the dome.

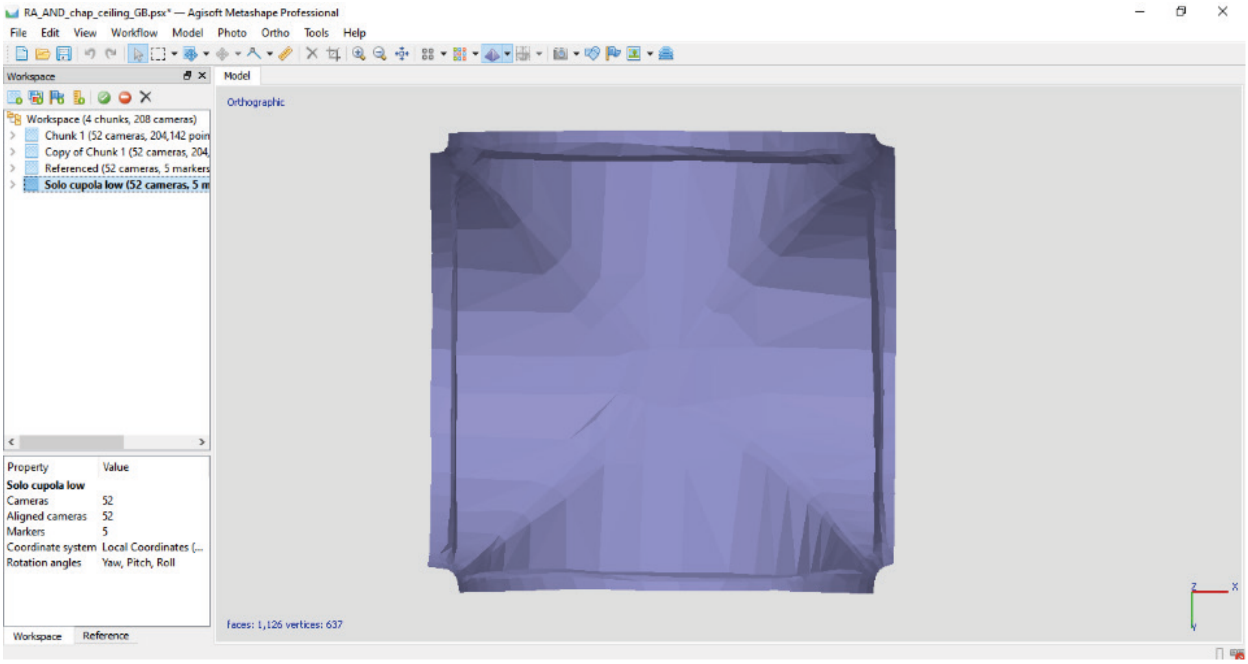


3) Export the model in OBJ format with texture.



4) Import in Luxology Modo: Import… > Import as static mesh, meters.

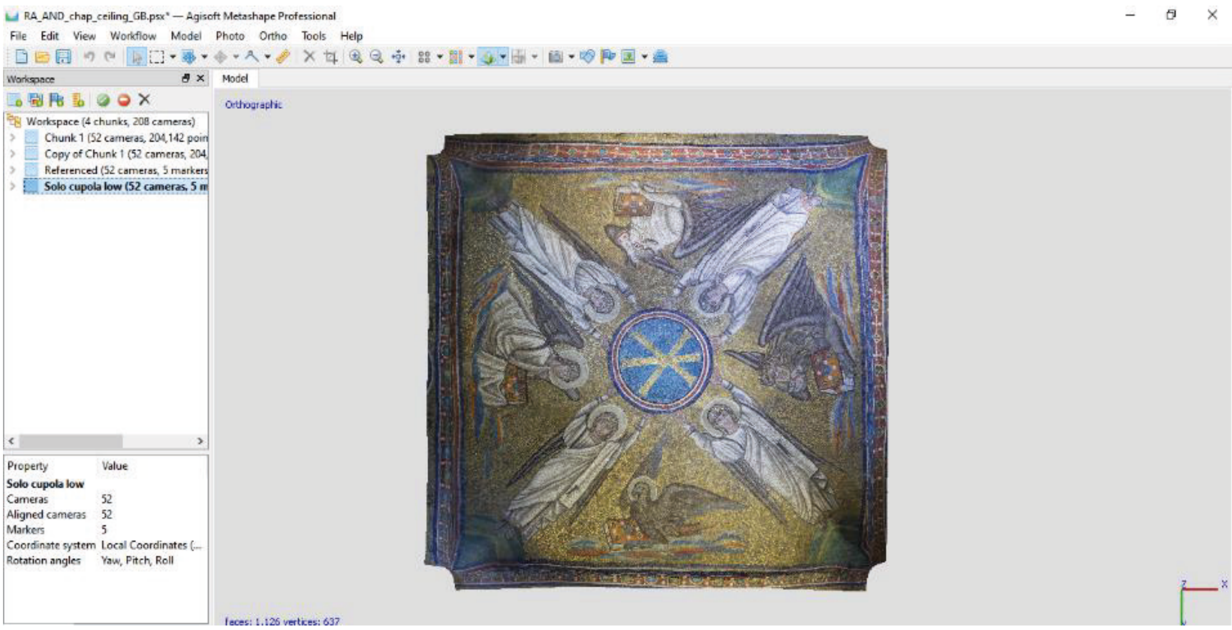
5) With first an automatic and then a manual retopology reduce and optimize the polygons that compose the mesh exported from Agisoft Photoscan.



6) Create an UV map.

7) Export from Modo only polygons in OBJ format.

8) Reimport in Agisoft Photoscan and calculate the texture on new low poly model (keeping uv).

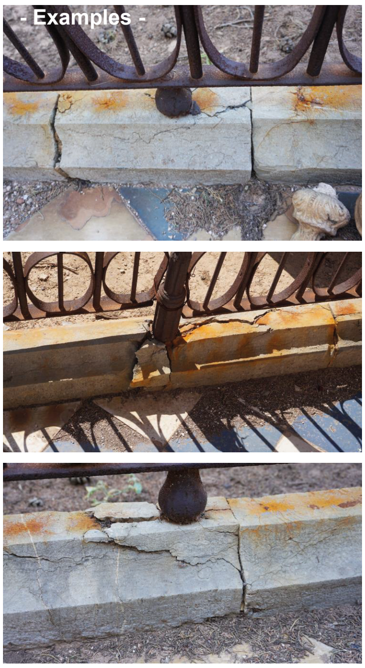


Now the model has a very low numbers of polygons and a high-quality texture that can be further improved by texture baking in Luxology Modo.

APPENDIX 2

Workflows for the creation of specific elements in a HBIM environment

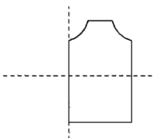
(1) The limestone kerb supporting the external railing is made up of elements with a regular section profile, but of different lengths one from another. For this reason, it was decided to create a “railing based” family by activating only the part of the supporting kerb, and then using the section profile created in CAD and having the possibility of generating the model during the same insertion. In this way, following the real partition, all the elements were recreated, to which the corresponding catalogue code was linked in the “Mark” section and the state of preservation and the main pathologies in the “Comments” section (rust stains of the railing, cracks, lesions, detachment of portions due to swelling of the metal, lack of mortar joints, displacement from the original position).

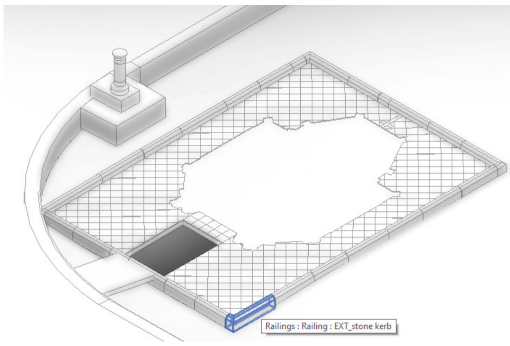


1. Stone kerb

- **Material**: limestone
- **Different length and shape** for each element, same section profile
- **Main Pathologies**:
  - **Damage with detachment** of substantial parts (mainly due to the expansion of the oxidised metal supports)
  - **Rust stains**;
  - **Small cracks**;
  - **Displacement** of some elements from the original position

➢ **Restorers needs**:
- total number of pieces
- length of each piece
- total surface area
- pathologies related to each element





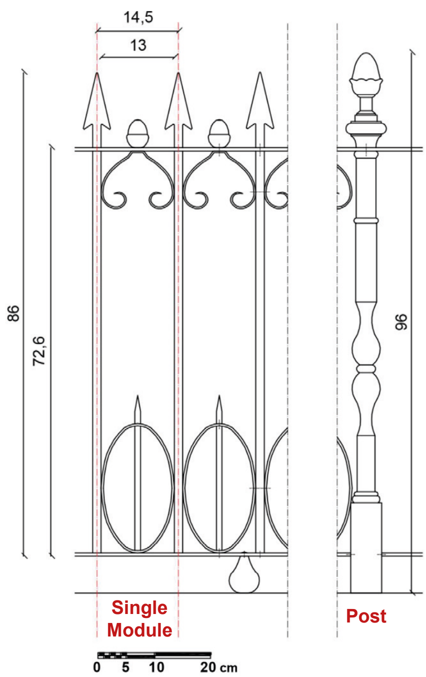
C	D	E	F	G	H	I
Description	Base Level	Mark	Cou	Length	Comments	Material -
Bordillo	0Se	0Se-Bo-S-02	1	0.76 m		Limestone
Bordillo	0Se	0Se-Bo-W-06	1	1.01 m		Limestone
Bordillo	0Se	0Se-Bo-W-07	1	1.26 m		Limestone
Bordillo	0Se	0Se-Bo-N-01	1	0.79 m		Limestone
Bordillo	0Se	0Se-Bo-N-05	1	0.92 m		Limestone
			5	4.74 m		
Bordillo	0Se	0Se-Bo-E-06	1	0.82 m	Grieta	Limestone
Bordillo	0Se	0Se-Bo-E-07	1	0.34 m	Grieta	Limestone
Bordillo	0Se	0Se-Bo-S-03	1	0.27 m	Grieta	Limestone
Bordillo	0Se	0Se-Bo-S-04	1	1.00 m	Grieta	Limestone
Bordillo	0Se	0Se-Bo-W-01	1	0.93 m	Grieta	Limestone
Bordillo	0Se	0Se-Bo-N-06	1	0.74 m	Grieta	Limestone
Bordillo	0Se	0Se-Bo-E-03	1	0.96 m	Grieta	Limestone
Bordillo	0Se	0Se-Bo-E-04	1	1.15 m	Grieta	Limestone
			8	6.22 m		

(2) The iron railing that surrounds the chapel in an enclosure is composed of 11 sectors separated by posts and formed by modules that are repeated in the decorations. The main pathologies affecting the railing are oxidation (spread over the whole surface), loss of some elements and disconnection of others. It was important for the restorers to know the total number and condition of each element so that they would know where and how to intervene. It was therefore decided to reproduce the current conformation in the BIM model, respecting the changes in shape, but maintaining the possibility of selecting each element individually, reporting its characteristics and condition. Each sector was created as a surface, using the "in-site mass" command and the point cloud as a basis for recreating the actual geometric conformation. Then the mass was divided vertically into the number of modules in each sector (which varies according to position) using the automatic function, so that the subdivisions could be used to position the elements that recreate the modules. Here it was decided to create by extrusion and rotation operations from the CAD profile four different adaptive models: the main poles of division between one sector and another, the minor poles of separation between one module and another, the internal elements and the horizontal bar. The models are adaptive because they can be easily adapted to the shape of the surface and can be easily modified to suit different applications. Each element is thus individually selectable, so that the relevant information can be added or displayed, and automatically listed by the Schedule command of the software according to parameters chosen by the user.

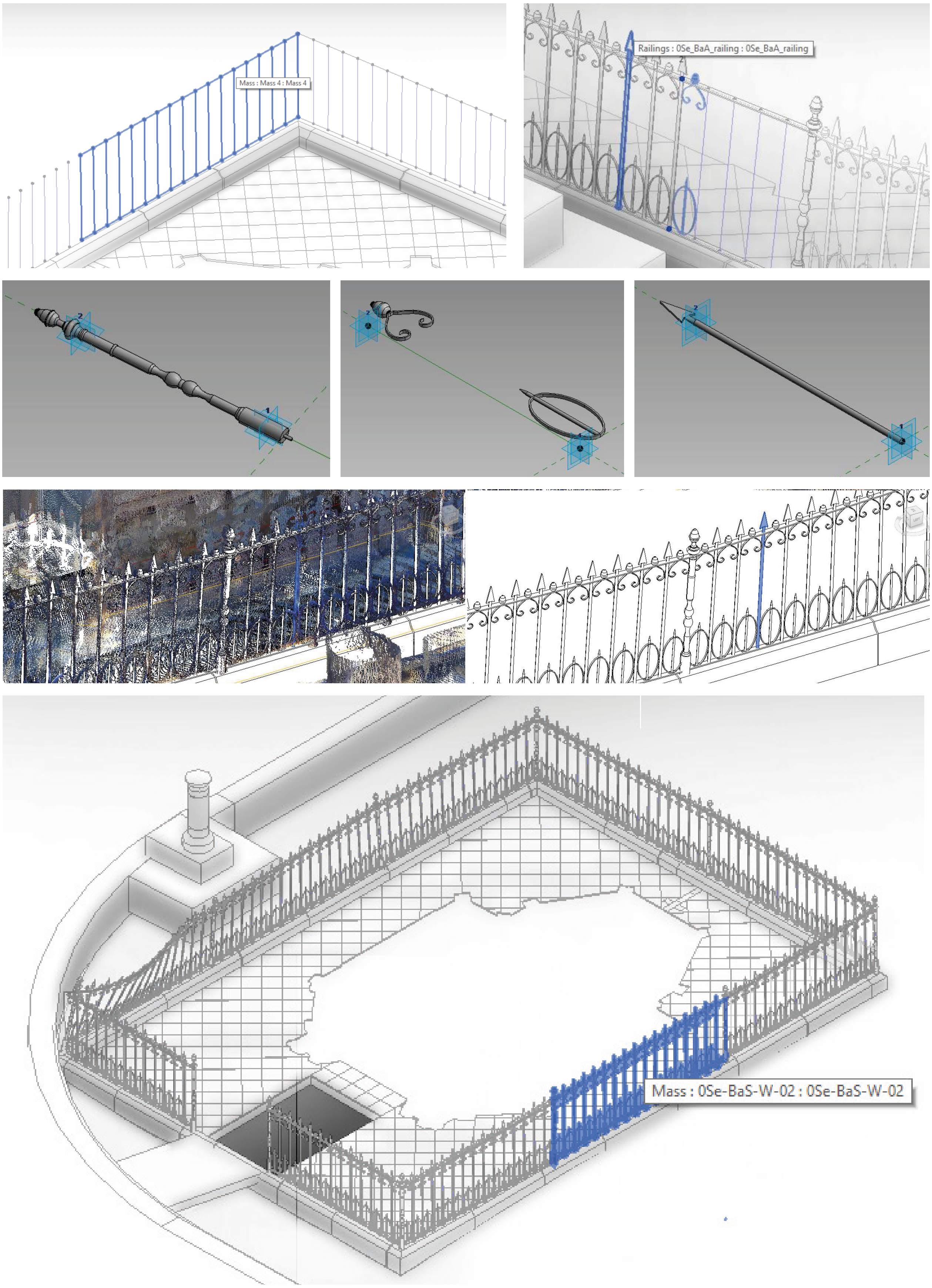
2. Railing

- **Material**: metal, iron
- **Main Pathologies**:
  - Oxidation;
  - Loss of supports, verticality and shape;
  - Lack of elements

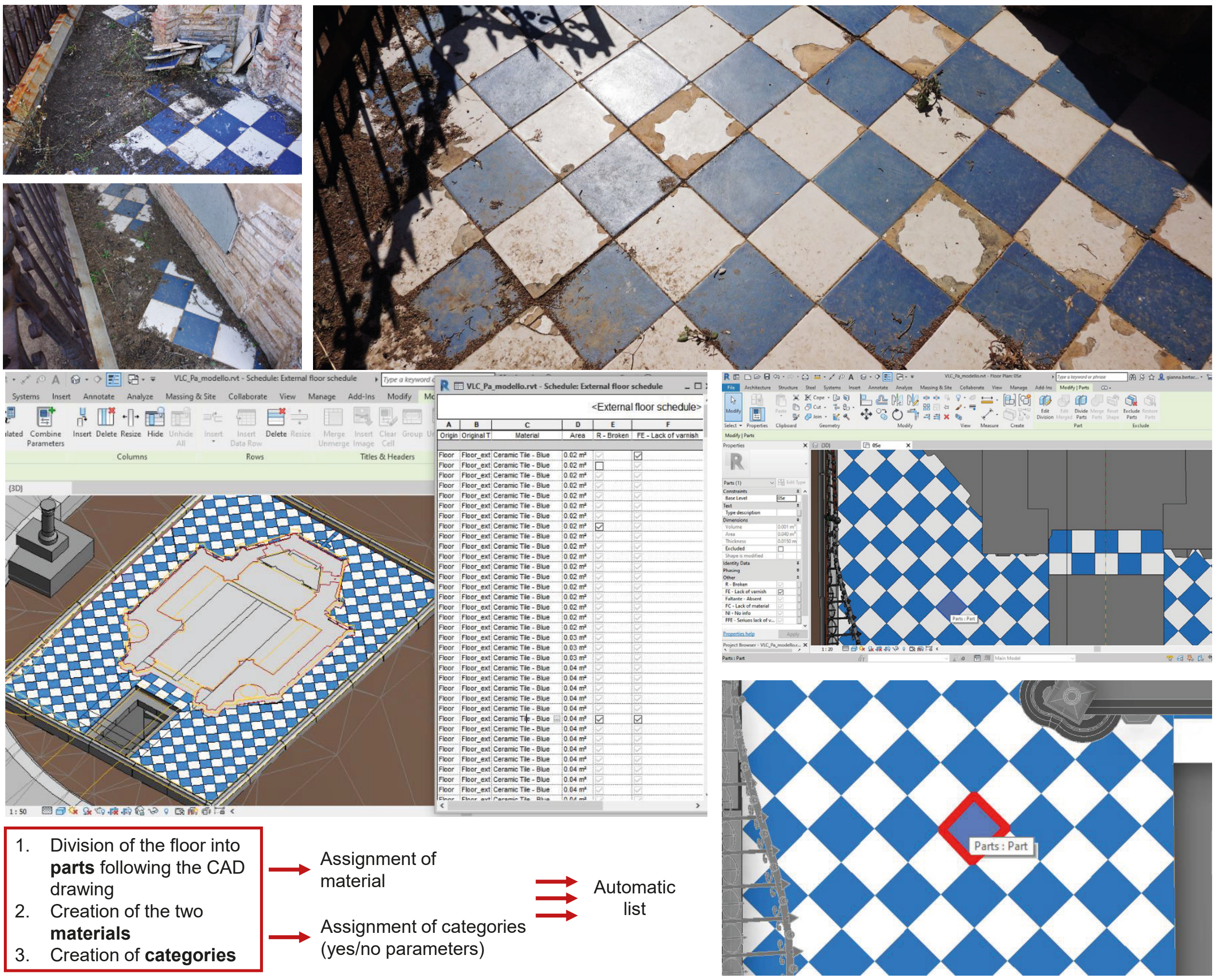
- **Restorers needs**:
  - Number and condition of each individual element;
  - Where and how to intervene and restore the original condition;
  - Number and position of broken or missing elements



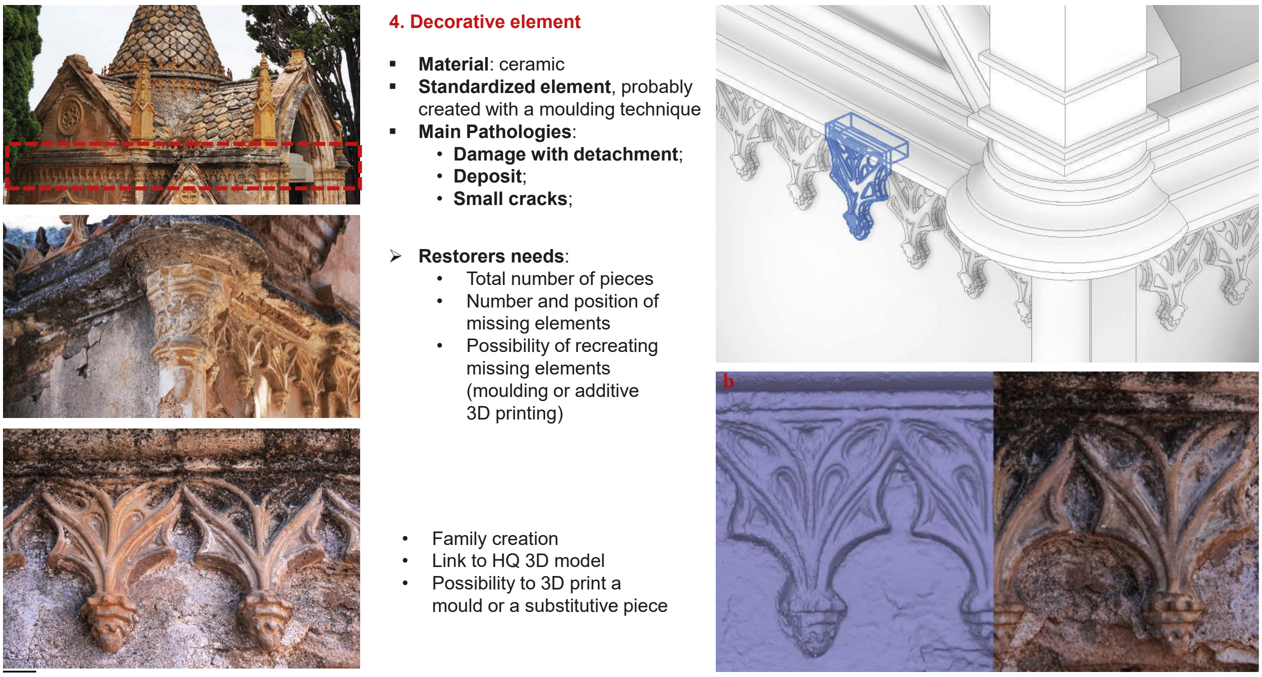
2. Railing


Mass : Mass 4 : Mass 4
Railings : 0Se_BaA_railing : 0Se_BaA_railing
Mass : 0Se-BaS-W-02 : 0Se-BaS-W-02

(3) The external floor consists of white and blue glazed ceramic tiles arranged in a chessboard pattern. In the back of the building the tiles form a cross pattern. In this case too it was necessary to know the total number of tiles of each colour and the pathologies affecting them in order to correctly estimate the restoration or replacement operations. The tiles are affected by cracks, lack of glazed surface and lack of ceramic paste. In order to transfer the information into the BIM model, it was decided to create the layer of the external floor and then to divide it into parts following the CAD drawing (this operation can also be done directly from the point cloud, but it is longer and more complex than using the CAD drawing). By using the “Create parts” command, the actual floor conditions were then recreated so that each element with his characteristics could be listed automatically. The state of conservation was inserted as a yes/no parameter (each listed pathology was or was not present in each tile). By selecting a part one can then know which is the corresponding material, the area (some partial tiles are divided along the diagonal) and enter the pathologies manually by simply activating or not the corresponding parameter (a compilation operation that can also be done by non-expert users in BIM modelling). This is also useful in future monitoring, as the same information can be entered after the restoration, by adding some parameters such as “Replaced” or “Restored”, in order to see the evolution of the post-restoration condition.



(4) For the decoration, the needs of the restorers were similar to the previous cases (number of elements, state of preservation, position...), but with the additional need to link the simplified BIM model to a high detail model for possible 3D printing (if they choose to replace missing elements or to create the mould to be used for replacing). Therefore, in order to keep the BIM model light, it was decided to model a very simplified version of the decoration and to activate a local link connected to the high detail model in OBJ format and the STL model ready for 3D printing. In this way it is possible to create a simple archive of models and data always linked to the BIM model.



APPENDIX 3

Spreadsheet for digital documentation. LOK 1

IDENTIFICATION DATA

Name	
Location	
Country	
Region	
Province	
Municipality	
Address	
Number ICCD general catalogue	
CEI building code	
CEI card code	
ICCD link	
CEI link	
Other codes and institute	
Category	
Ownership	
Authority for the protection	

COMPILING DATA

Authority / Contact person	
Role	
Date	

DOCUMENTAZIONE ESISTENTE

Hardcopy Archive	
Digital - CAD file	
Scale detail	

DATI IDENTIFICATIVI

Denominazione	
Localizzazione	
Stato	
Regione	
Provincia	
Comune	
Indirizzo	
Numero Catalogo generale ICCD	
Codice immobile CEI	
Codice scheda CEI	
Link ICCD	
Link CEI	
Altro tipo di codice e istituto	
Categoria	
Proprietà	
Ente competente per la tutela	

DATOS IDENTIFICATIVOS

Nombre	
Ubicación	
País	
Región	
Provincia	
Municipalidad	
Dirección	
Número Catalogo general ICCD	
Codigo immueble CEI	
Codigo ficha CEI	
Enlace ICCD	
Enlace CEI	
Otro tipo de código identificativo e institución	
Categoría	
Propiedad	
Organismo competente de la tutela	

DATI COMPILAZIONE

Ente / Compilatore	
Ruolo	
Data	

DATI COMPILAZIONE

Organismo / Recopilador	
Rol	
Fecha	

DOCUMENTAZIONE ESISTENTE

Cartacea	
Digitale - disegno CAD	
Scala - dettaglio	

DOCUMENTACION EXISTENTE

Documentación en papel	
Documentación Digital - archivo CAD	
Escala - detalle	

NAME

Parameters: 0=no, 1=yes

FEATURES			TLS	DIGITAL PHOTOGRAMMETRY	DRONE
Exterior surveying	x	1	++	++	++
Interior surveying		0	++	+	---
Roofing surveying		0	-	-	+++
Object size	Small (cube size < of 1,5 metres)		-	++	---
	Medium (cube size between 2 and 15 metres)		++	++	-
	Large (cube size > of 15 metres)		++	+	+
	Urban complex		+	-	+++
Object shape	Regular and compact		++	++	++
	Significant width (> than 15 metres)		+	+	++
	Significant height (> than 8 metres)		+	---	+++
	Complex, with multiple planes (e.g. sculptural complexes)		++	-	-
Perimetral features	Free on all sides		++	++	++
	Partially free		+	+	+
	One-side free		+	+	+
Main building accessibility	Total		++	++	++
	Partial		+	+	+
	Danger of collapse		--	--	+++
	Inaccessible		+	-	+++
Context: presence of elements	Trees		-	-	--
	Permanent obstruction (furniture, street furniture, signage…)		--	--	-
	Buildings or immobile structures less than 2 metres from the facades		+	-	-
Surface material	Uniform or monochrome texture materials		++	--	--
	Reflecting material		-	+	+
	Opaque matte material, no monochrome, no uniform		++	++	++
Lighting condition	Excellent natural light		/	+	+
	Good natural light		/	-	-
	Low natural light		/	-----	-----
	Good artificial light		/	+++	/
			Terrestrial Laser Scanner	**Digital Photogrammetry**	**Drone**

The spreadsheet contains formulas for each methodology and exterior, interior, roofing. The formula consists of a sum of parameters, each of which is increased or reduced by a factor represented in the correspondent column.

Fora example here are the formulas for the EXTERIOR

TLS formula: =SUM(2*C3)+(2*C4)+(-1*C5)+(-1*C6)+(2*C7)+(2*C8)+(1*C9)+(2*C10)+(1*C11)+(1*C12)+(2*C13)+(2*C14)+(1*C15)+(1*C16)+(2*C17)+(1*C18)+(-2*C19)+(1*C20)+(-1*C21)+(-2*C22)+(1*C23)+(2*C24)+(-1*C25)+(2*C26)+(0*C27)+(0*C28)+(0*C29)+(0*C30)

DP formula: =SUM(2*C3)+(1*C4)+(-1*C5)+(2*C6)+(2*C7)+(1*C8)+(-1*C9)+(2*C10)+(1*C11)+(-3*C12)+(-1*C13)+(2*C14)+(1*C15)+(1*C16)+(2*C17)+(1*C18)+(-2*C19)+(-1*C20)+(-1*C21)+(-2*C22)+(-1*C23)+(-2*C24)+(1*C25)+(2*C26)+(1*C27)+(-1*C28)+(-5*C29)+(3*C30)

DRONE formula: =SUM(2*C3)+(-3*C4)+(3*C5)+(-3*C6)+(-1*C7)+(1*C8)+(3*C9)+(2*C10)+(2*C11)+(3*C12)+(-1*C13)+(2*C14)+(1*C15)+(1*C16)+(2*C17)+(1*C18)+(3*C19)+(3*C20)+(-2*C21)+(-1*C22)+(-1*C23)+(-2*C24)+(1*C25)+(2*C26)+(1*C27)+(-1*C28)+(-3*C29)+(0*C30)

NAME

Parameters: 0=no, 1=yes

FEATURES			TLS	DIGITAL PHOTOGRAM METRY	DRONE
Exterior surveying		0	++	++	++
Interior surveying	x	1	++	+	---
Roofing surveying		0	-	-	+++
Object size	Small (cube size < of 1,5 metres)		-	++	---
	Medium (cube size between 2 and 15 metres)		++	++	-
	Large (cube size > of 15 metres)		++	+	+
	Urban complex		+	-	+++
Object shape	Regular and compact		++	++	++
	Significant width (> than 15 metres)		+	+	++
	Significant height (> than 8 metres)		+	---	+++
	Complex, with multiple planes (e.g. sculptural complexes)		++	-	-
Perimetral features	Free on all sides		++	++	++
	Partially free		+	+	+
	One-side free		+	+	+
Main building accessibility	Total		++	++	++
	Partial		+	+	+
	Danger of collapse		--	--	+++
	Inaccessible		+	-	+++
Context: presence of elements	Trees		-	-	--
	Permanent obstruction (furniture, street furniture, signage…)		--	--	-
	Buildings or immobile structures less than 2 metres from the facades		+	-	-
Surface material	Uniform or monochrome texture materials		++	--	--
	Reflecting material		-	+	+
	Opaque matte material, no monochrome, no uniform		++	++	++
Lighting condition	Excellent natural light		/	+	+
	Good natural light		/	-	-
	Low natural light		/	-----	-----
	Good artificial light		/	+++	/
			Terrestrial Laser Scanner	**Digital Photogram metry**	**Drone**

NAME

Parameters: 0=no, 1=yes

FEATURES			TLS	DIGITAL PHOTOGRAM METRY	DRONE
Exterior surveying		0	++	++	++
Interior surveying		0	++	+	---
Roofing surveying	x	1	-	-	+++
Object size	Small (cube size < of 1,5 metres)		-	++	---
	Medium (cube size between 2 and 15 metres)		++	++	-
	Large (cube size > of 15 metres)		++	+	+
	Urban complex		+	-	+++
Object shape	Regular and compact		++	++	++
	Significant width (> than 15 metres)		+	+	++
	Significant height (> than 8 metres)		+	---	+++
	Complex, with multiple planes (e.g. sculptural complexes)		++	-	-
Perimetral features	Free on all sides		++	++	++
	Partially free		+	+	+
	One-side free		+	+	+
Main building accessibility	Total		++	++	++
	Partial		+	+	+
	Danger of collapse		--	--	+++
	Inaccessible		+	-	+++
Context: presence of elements	Trees		-	-	--
	Permanent obstruction (furniture, street furniture, signage…)		--	--	-
	Buildings or immobile structures less than 2 metres from the facades		+	-	-
Surface material	Uniform or monochrome texture materials		++	--	--
	Reflecting material		-	+	+
	Opaque matte material, no monochrome, no uniform		++	++	++
Lighting condition	Excellent natural light		/	+	+
	Good natural light		/	-	-
	Low natural light		/	-----	-----
	Good artificial light		/	+++	/
			Terrestrial Laser Scanner	**Digital Photogram metry**	**Drone**

Parameters for interior and roofing.

Survey purpose	Possible outputs required	Suggested methodology	Selection
Creation of a database	The existing data are derived from traditional surveys and a database is needed to be used for general studies, for interventions or simple management operations. It is necessary to deepen the knowledge of a particularly complex artefact by studying its geometric and construction characteristics	Terrestrial Laser Scanner for very large, complex structures, with some unreachable parts (such as vaulted ceilings), while for smaller objects (less than 1.5 metres per side) the use of special laser scanners is recommended. For urban surveys or very large buildings, it is advisable to use a topographical survey for the correctness of the final drawings	
Intervention - preliminar design or studies	2D drawings with a printable scale of 1:50/1:100 for the preparation of preliminary designs	Terrestrial Laser Scanner with low scanning resolution (2 cm at 10 metres) for simple, plastered structures; with medium resolution (1 cm at 10 metres) for complex structures and masonry	
Intervention – structural restoration work, on masonry, ecc.	2D drawings with a printable scale of 1:20, orthoimages for mapping with a given resolution depending on the type of intervention foreseen and the condition of the object (e.g. structural intervention with the need to map the position and size of cracks and lesions...)	Terrestrial Laser Scanner with medium resolution (1 cm at 10 metres) or high resolution (0.5 cm at 10 metres) for portions of particular interest for structural mapping or masonry deterioration. Digital photogrammetric survey to be integrated with the laser scanner survey. If the laser scanner is equipped with an internal camera, the photographs taken by the tool can be used for a general survey. However, for detailed surveys it is advisable to integrate a photogrammetric survey carried out independently of the laser scanner. In this case the final resolution of the orthoimages produced must be such as to allow a printable scale of 1:20 of the parts of interest for decay mapping or 1:10 for structural mapping according to specific requests of the professionals. For simple, plastered structures, photo-rectification is recommended	
Intervention – replacement or duplicate of small objects	If there are special decorative or structural elements that need to be replaced or integrated into the restoration work, a model for 3D printing can be produced from similar elements or from a survey of the part where the gap is present	Digital photogrammetric survey and data processing for the production of a printable STL mesh model at 1:1 scale (with sufficient detail for full-scale printing)	
Intervention – HBIM model	For interventions on large but structurally simple buildings (e.g. without complex slabs such as vaults or domes), or on more complex but small buildings structurally composed of easily standardised elements, the creation of a BIM model can be justified, if it is correctly set up also to ensure future management uses (e.g. visit control, plant monitoring, etc.). For complex buildings, the correct degree of simplification must be assessed. The level of detail required from the BIM model builder should be established before the assignment	Terrestrial Laser Scanner survey with low scanning resolution (2 cm at 10 metres) for simple, plastered structures; with medium resolution (1 cm at 10 metres) for complex structures and masonry walls	
Monitoring	Schedule of survey campaigns to compare with previous and subsequent surveys and to monitor the evolution of the situation or part of the object	See corresponding in-depth section (cap. 5 – par XX)	
Management – information system	To use a digital tool through which multiple actions can be carried out (archiving of documents, tracking of restoration work, monitoring, management of visits, etc.) it is possible to create a dedicated information system that is simplified (through the use of a BIM model) or complex (based on a 3D reality-based model)	In the case of a simplified information system, a Terrestrial Laser Scanner survey is sufficient for the construction of the base, to which detailed surveys can be linked	

DATI IDENTIFICATIVI

Denominazione	Chiesa di Sant'Apollinare
Localizzazione	
Stato	Italia
Regione	Emilia-Romagna
Provincia	Ravenna
Comune	Russi
Indirizzo	Piazza Farini 18
Numero Catalogo generale ICCD	800266405
Codice immobile CEI	
Codice scheda CEI	
Link ICCD	https://catalogo.beniculturali.it/detail/ArchitecturalOrLandscapeHeritage/0800266405
Link CEI	
Altro tipo di codice e istituto	
Categoria	Bene Architettonico
proprietà	Ente religioso cattolico
Ente competente per la tutela	Soprintendenza per i Beni Architettonici e Paesaggistici per le province di Ravenna Ferrara Forlì-Cesena e Rimini

DATI COMPILAZIONE

Ente / Compilatore	Simone De Giglio -simonedegiglio@gmail.com
Ruolo	architetto
Data	11/09/2021

DOCUMENTAZIONE ESISTENTE

Cartacea	Bibliografia di riferimento
Digitale - disegno CAD	Catasto
Scala - dettaglio	

DENOMINAZIONE

Parametri 0=no, 1=sì

CARATTERISTICHE

			TLS	PHOTOGR	DRONE
Rilievo ambienti esterni	x	1	++	++	++
Rilievo ambienti interni		0	++	+	---
Rilievo coperture		0	-	-	+++
Dimensioni dell'oggetto di rilievo	Piccole (lati del cubo < di 1,5 metri)	0	-	++	---
	Medie (lati del cubo tra 2 e 15 metri)	0	++	++	-
	Grandi (lati del cubo > di 15 metri)	1	++	+	+
	Complesso urbano	0	+	-	+++
Forma dell'oggetto di rilievo	Regolare e compatta	1	++	++	++
	Grande sviluppo in larghezza (> di 15 metri)	1	+	+	++
	Grande sviluppo in altezza (> di 8 metri)	0	+	---	+++
	Complessa, con piani multipli (es. complessi scultorei)	0	++	-	-
Caratteristiche perimetrali	Libero su tutti i fronti	0	++	++	++
	Parzialmente libero	1	+	+	+
	Libero su un fronte	0	+	+	+
Accessibilità struttura principale	Totale	0	++	++	++
	Parziale	1	+	+	+
	Pericolo crollo	0	--	--	+++
	Inaccessibile da terra	0	+	-	+++
Presenza di elementi nel contesto	Alberi	0	-	-	--
	Ostruzioni permanenti (mobili, arredo stradale, segnaletica…)	1	--	--	-
	Edifici o strutture immobili a meno di 2 metri dalla superficie	1	+	-	-
Materiale superficie	Materiali con texture uniforme e monocromi	1	++	--	--
	Materiali riflettenti	0	-	+	+
	Materiale opaco, non monocromo, non uniforme	0	++	++	++
Condizioni illuminazione	Ottima illuminazione naturale	1	++	+	+
	Media illuminazione naturale	0	++	-	-
	Scarsa illuminazione naturale	0	++	-----	-----
	Buona illuminazione artificiale	0	++	++	

Documentazione con Terrestrial Laser Scanner	Documentazione con fotogrammetria digitale	Documentazione con drone
10	**4**	**6**

Example of a compiled spreadsheet

DATI IDENTIFICATIVI

Denominazione	Palazzo San giacomo
Localizzazione	
Stato	Italia
Regione	Emilia-Romagna
Provincia	Ravenna
Comune	Russi
Indirizzo	Via Carrarone Rasponi
Numero Catalogo generale ICCD	
Codice immobile CEI	
Codice scheda CEI	
Link ICCD	
Link CEI	
Altro tipo di codice e istituto	
Categoria	Bene Architettonico
proprietà	Comune di Russi
Ente competente per la tutela	Soprintendenza per i Beni Architettonici e Paesaggistici per le province di Ravenna Ferrara Forlì-Cesena e Rimini

DATI COMPILAZIONE

Ente / Compilatore	Simone De Giglio – simonedegiglio@gmail.com
Ruolo	Architetto
Data	11/09/2021

DOCUMENTAZIONE ESISTENTE

Cartacea	Bibliografia di riferimento
Digitale - disegno CAD	banca dati del comune
Scala - dettaglio	1:100

DENOMINAZIONE

Parametri 0=no, 1=sì

CARATTERISTICHE			TLS	PHOTOGR	DRONE
Rilievo ambienti esterni		0	++	++	++
Rilievo ambienti interni	x	1	++	+	---
Rilievo coperture		0	-	-	+++
Dimensioni dell'oggetto di rilievo	Piccole (lati del cubo < di 1,5 metri)	0	-	++	---
	Medie (lati del cubo tra 2 e 15 metri)	1	++	++	-
	Grandi (lati del cubo > di 15 metri)	0	++	+	+
	Complesso urbano	0	+	-	+++
Forma dell'oggetto di rilievo	Regolare e compatta	0	++	++	++
	Grande sviluppo in larghezza (> di 15 metri)	0	+	+	++
	Grande sviluppo in altezza (> di 8 metri)	1	+	---	+++
	Complessa, con piani multipli (es. complessi scultorei)	1	++	-	-
Caratteristiche perimetrali	Libero su tutti i fronti	1	++	++	++
	Parzialmente libero	0	+	+	+
	Libero su un fronte	0	+	+	+
Accessibilità struttura principale	Totale	1	++	++	++
	Parziale	0	+	+	+
	Pericolo crollo	1	--	--	+++
	Inaccessibile da terra	0	+	-	+++
Presenza di elementi nel contesto	Alberi	0	-	-	--
	Ostruzioni permanenti (mobili, arredo stradale, segnaletica...)	0	--	--	-
	Edifici o strutture immobili a meno di 2 metri dalla superficie	0	+	-	-
Materiale superficie	Materiali con texture uniforme e monocromi	1	++	--	--
	Materiali riflettenti	0	-	+	+
	Materiale opaco, non monocromo, non uniforme	1	++	++	++
Condizioni illuminazione	Ottima illuminazione naturale	0	++	+	+
	Media illuminazione naturale	1	++	-	-
	Scarsa illuminazione naturale	0	++	-----	-----
	Buona illuminazione artificiale	0	++	++	

Documentazione con Terrestrial Laser Scanner	Documentazione con fotogrammetria digitale	Documentazione con drone
13	0	4

Example of a compiled spreadsheet

DATOS IDENTIFICATIVOS

Nombre	Presa "El Salto"
Ubicación	
País	España
Región	Andalucía
Provincia	Córdoba
Municipalidad	El Carpio
Dirección	CO-3107, 14620 El Carpio, Córdoba
Número Catalogo general ICCD	
Codigo immueble CEI	
Codigo ficha CEI	
Enlace ICCD	
Enlace CEI	https://www.juntadeandalucia.es/boja/2003/174/d17.pdf
Otro tipo de código identificativo e institución	BOJA nº 174 del 10 de septiembre de 2003, página 19.793
Categoría	Bien de Interés Cultural - Monumento
Propiedad	Ayuntamiento de El Carpio
Organismo competente de la tutela	Consejería de Cultura/ Junta de Andalucía

DATI COMPILAZIONE

Organismo / Recopilador	Sandra Beato Pérez
Rol	Restaurador
Fecha	26/09/2021

DOCUMENTACION EXISTENTE

Documentación en papel	Archivo Municipal
Documentación Digital - archivo CAD	
Escala - detalle	1:1000

NOMBRE

Parámetros: 0=no, 1=sí

CARACTERISTICAS			TLS	Fotogram. digit.	DRON
Levantamiento exterior		0	++	++	++
Levantamiento interior	x	1	++	+	---
Levantamiento cubiertas		0	-	-	+++
Dimensiones del objeto de estudio	Pequeñas (lados del cubo < de 1,5 metros)		-	++	---
	Medianas (lados del cubo entre 2 y 15 metros)		++	++	-
	Grandes (lados del cubo > de 15 metros)		++	+	+
	Complejo urbano	1	+	-	+++
Forma del objeto de estudio	Regular y compacta		++	++	++
	Gran desarrollo en anchura (> de 15 metros)		+	+	++
	Gran desarrollo en altura (> de 8 metros)		+	---	+++
	Compleja, con planos múltiples (conjunto escultórico)	1	++	-	-
Características perimetrales	Libre en todos los lados	1	++	++	++
	Parcialmente libre		+	+	+
	Libre en un lado		+	+	+
Accesibilidad estructura principal	Total	1	++	++	++
	Parcial		+	+	+
	Peligro de derrumbe		--	--	+++
	Inacesible por tierra		+	-	+++
Presencia de elementos en el contexto	árboles		-	-	--
	Obstáculo físico (mobiliario, mobiliario urbano, señalización...)	1	--	--	-
	Edificios o estructuras no removibles a menos de 2 metros de la superficie a levantar		+	-	-
Material superficial	Materiales con textura unitaria y monocromos		++	--	--
	Materiales reflectante		-	+	+
	Material opaco, no monocromo, no unitario	1	++	++	++
Condiciones de iluminación	Excelente iluminación natural	1	++	+	+
	Media iluminación natural		++	-	-
	Escasa iluminación natural		++	-----	-----
	Buena iluminación artificial		++	++	

Documentación con Terrestrial Laser Scanner	Documentación con fotogrametría digital	Documentación con dron
9	4	5

Example of a compiled spreadsheet

DATOS IDENTIFICATIVOS

Nombre	Castillo y murallas de Cullera
Ubicación	
País	España
Región	Comunidad Valenciana
Provincia	Valencia
Municipalidad	Cullera
Dirección	Pujada Castell, s/n, 46400 Cullera, Valencia
Número Catalogo general ICCD	
Codigo immueble CEI	
Codigo ficha CEI	
Enlace ICCD	
Enlace CEI	
Otro tipo de código identificativo e institución	46.21.105-015
Categoría	Bien de interés cultural
Propiedad	Ayuntamiento de Cullera
Organismo competente de la tutela	Museos históricos de Cullera

DATI COMPILAZIONE

Organismo / Recopilador	Jose Anaya Visbal
Rol	Arquitecto
Fecha	26-09-2021

DOCUMENTACION EXISTENTE

Documentación en papel	Archivo histórico de Cullera
Documentación Digital - archivo CAD	Archivo histórico de Cullera
Escala - detalle	1:1000

NOMBRE

Parámetros: 0=no, 1=sí

CARACTERISTICAS			TLS	Fotogram. digit.	DRON
Levantamiento exterior	x	1	++	++	++
Levantamiento interior		0	++	+	---
Levantamiento cubiertas		0	-	-	+++
Dimensiones del objeto de estudio	Pequeñas (lados del cubo < de 1,5 metros)	0	-	++	---
	Medianas (lados del cubo entre 2 y 15 metros)	0	++	++	-
	Grandes (lados del cubo > de 15 metros)	0	++	+	+
	Complejo urbano	1	+	-	+++
Forma del objeto de estudio	Regular y compacta	0	++	++	++
	Gran desarrollo en anchura (> de 15 metros)	0	+	+	++
	Gran desarrollo en altura (> de 8 metros)	0	+	---	+++
	Compleja, con planos múltiples (conjunto escultórico)	1	++	-	-
Características perimetrales	Libre en todos los lados	1	++	++	++
	Parcialmente libre	0	+	+	+
	Libre en un lado	0	+	+	+
Accesibilidad estructura principal	Total	0	++	++	++
	Parcial	1	+	+	+
	Peligro de derrumbe	0	--	--	+++
	Inacesible por tierra	0	+	-	+++
Presencia de elementos en el contexto	árboles	1	-	-	--
	Obstáculo físico (mobiliario, mobiliario urbano, señalización…)	0	--	--	-
	Edificios o estructuras no removibles a menos de 2 metros de la superficie a levantar	0	+	-	-
Material superficial	Materiales con textura unitaria y monocromos	1	++	--	--
	Materiales reflectante	0	-	+	+
	Material opaco, no monocromo, no unitario	0	++	++	++
Condiciones de iluminación	Excelente iluminación natural	1	++	+	+
	Media iluminación natural	0	++	-	-
	Escasa iluminación natural	0	++	-----	-----
	Buena iluminación artificial	0	++	++	

Documentación con Terrestrial Laser Scanner	Documentación con fotogrametría digital	Documentación con dron
9	1	4

Example of a compiled spreadsheet

DATOS IDENTIFICATIVOS

Nombre	
Ubicación	
País	Ecuador
Región	Sierra
Provincia	Pichincha
Municipalidad	Sangolqui
Dirección	Calle Riofrio y Garía Moreno
Número Catalogo general ICCD	
Codigo immueble CEI	BI-17-05-01-000-000160
Codigo ficha CEI	
Enlace ICCD	
Enlace CEI	
Otro tipo de código identificativo e institución	
Categoría	Bien de interes Patrimonial
Propiedad	Municipio de Rumiñahui
Organismo competente de la tutela	Municipio de Rumiñahui

DATI COMPILAZIONE

Organismo / Recopilador	INPC
Rol	Ente gubernamental, que promueve, difunde y gestiona la preservación, conservación y salvaguardia del patrimonio cultural material e inmaterial.
Fecha	2010

DOCUMENTACION EXISTENTE

Documentación en papel	Si
Documentación Digital - archivo CAD	Si (solo plantas arquitecónicas)
Escala - detalle	1-100

NOMBRE

Parámetros: 0=no, 1=sí

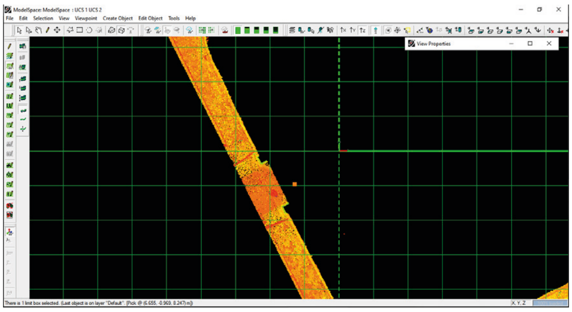
CARACTERISTICAS			TLS	Fotogram. digit.	DRON
Levantamiento exterior	x	1	++	++	++
Levantamiento interior		0	++	+	---
Levantamiento cubiertas		0	-	-	+++
Dimensiones del objeto de estudio	Pequeñas (lados del cubo < de 1,5 metros)		-	++	---
	Medianas (lados del cubo entre 2 y 15 metros)		++	++	-
	Grandes (lados del cubo > de 15 metros)	1	++	+	+
	Complejo urbano		+	-	+++
Forma del objeto de estudio	Regular y compacta		++	++	++
	Gran desarrollo en anchura (> de 15 metros)	1	+	+	++
	Gran desarrollo en altura (> de 8 metros)		+	---	+++
	Compleja, con planos múltiples (conjunto escultórico)		++	-	-
Características perimetrales	Libre en todos los lados		++	++	++
	Parcialmente libre	1	+	+	+
	Libre en un lado		+	+	+
Accesibilidad estructura principal	Total		++	++	++
	Parcial	1	+	+	+
	Peligro de derrumbe		--	--	+++
	Inacesible por tierra		+	-	+++
Presencia de elementos en el contexto	árboles		-	-	--
	Obstáculo físico (mobiliario, mobiliario urbano, señalización...)		--	--	-
	Edificios o estructuras no removibles a menos de 2 metros de la superficie a levantar	1	+	-	-
Material superficial	Materiales con textura unitaria y monocromos	1	++	--	--
	Materiales reflectante		-	+	+
	Material opaco, no monocromo, no unitario		++	++	++
Condiciones de iluminación	Excelente iluminación natural		++	+	+
	Media iluminación natural		++	-	-
	Escasa iluminación natural		++	-----	-----
	Buena iluminación artificial	1	++	++	

Documentación con Terrestrial Laser Scanner	Documentación con fotogrametría digital	Documentación con dron
10	**6**	**4**

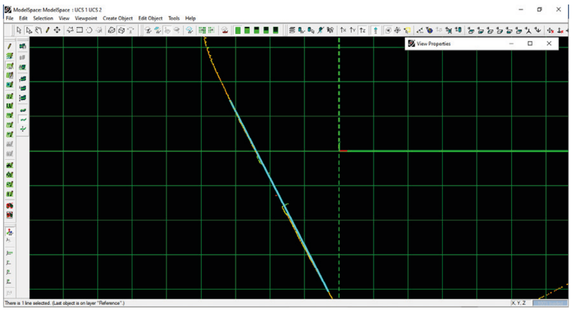
Example of a compiled spreadsheet

APPENDIX 4

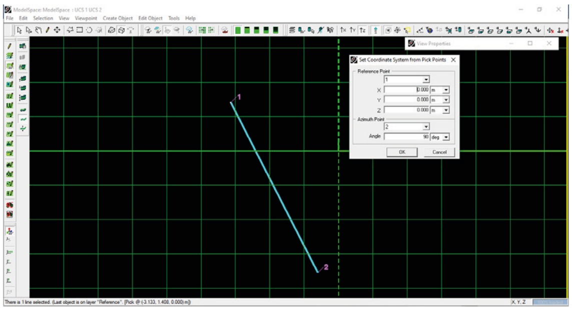
Creation of reference UCS in Leica Cyclone and Autodesk AutoCAD



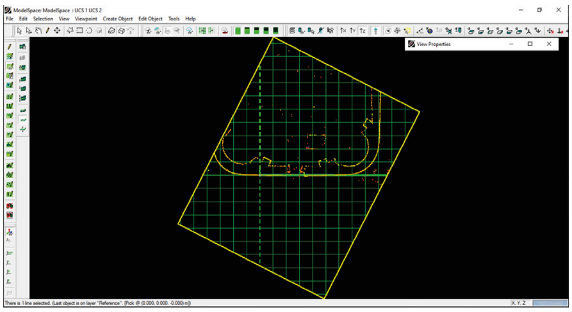
First of all, the origin and direction of the UCS1 axes must be defined in Cyclone. Starting from the default situation (UCS oriented according to the scanner position in the scan used as Home during alignment, fig. 1), associate the Original Reference Plane with the Cutplane and display only a 1 cm slice (Tools > Cutplane > Set from Active Ref Plane and then Tools > Cutplane > View Slice).



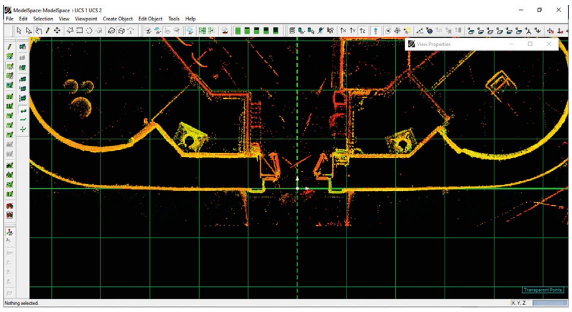
With the Multi-Pick Mode select two points that belong to the main direction of the facade and create a segment (Create Object > From Pick Points > Line Segment, fig. 2).



Select the Line segment, right click, Edit Properties and change the Z coordinates of the Start Point and End Point to be equal (0.00). The segment created is used to set UCS1: select the first vertex of the segment, View > Coordinate System > Set from Points... and set the Azimuth Point angle to 90 degrees (fig. 3).

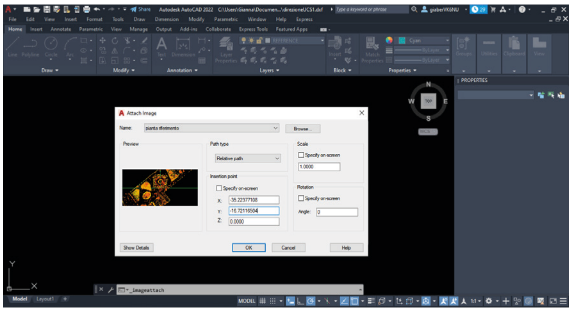


Finally, align the Reference Plane with the new UCS (Tools > Reference Plane > Set to UCS) (fig. 4).

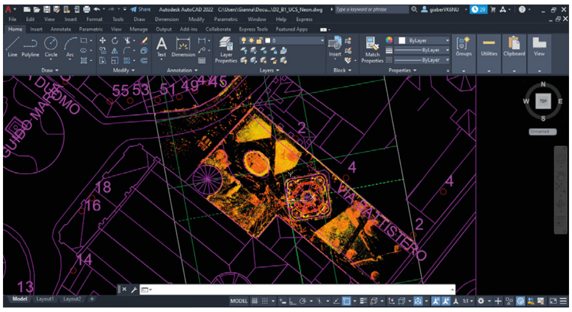


Now you can move the origin to the chosen point as the centre of the threshold by selecting a point, moving the Reference Plane to the point (Tools > Reference Plane > Set Plane Origin at Pick Point) and then View > Coordinate System > Set From Reference Plane (fig. 5).

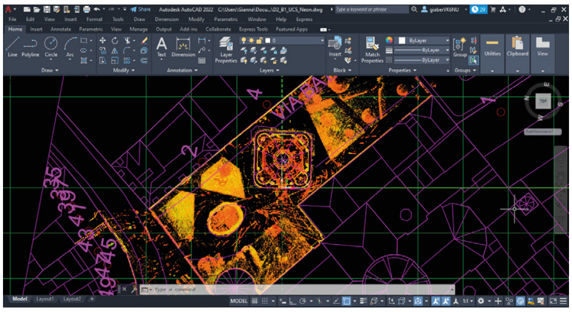
The current UCS must be saved (View > Coordinate System > Save/Edit Coordinate System). Select the previously created segment, change the coordinates of the start and end point to match the origin of the axes and a predefined length along the X axis, and then export it in DXF format (File > Export).



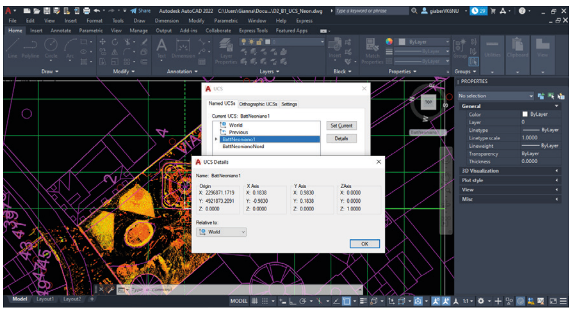
At the same time, an orthoimage of the plan is exported (File > Export...) and inserted in the CAD file containing the segment (at the time of insertion, the X and Y coordinates of the translation contained in the TWF file generated by Cyclone must be entered, while the scale remains equal to 1) (fig. 6).



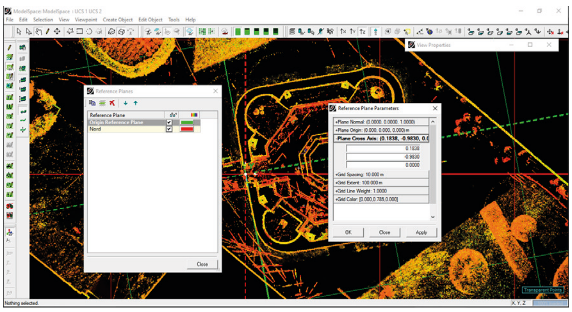
Now you can copy the orthoimage and the segment into the CAD file of the CTR and proceed with the creation of the two UCS. After aligning the orthoimage and the segment with the CTR, the UCS is selected and moved to the origin point of the segment (fig. 7), then the UCSMAN command is used to rename the current UCS with the addition of North.



Finally, the UCS1 corresponding to the orientation chosen in the cloud is also inserted: by selecting the UCS, the X axis is rotated so that it corresponds to the direction of the segment and the new UCS is saved (fig. 8).



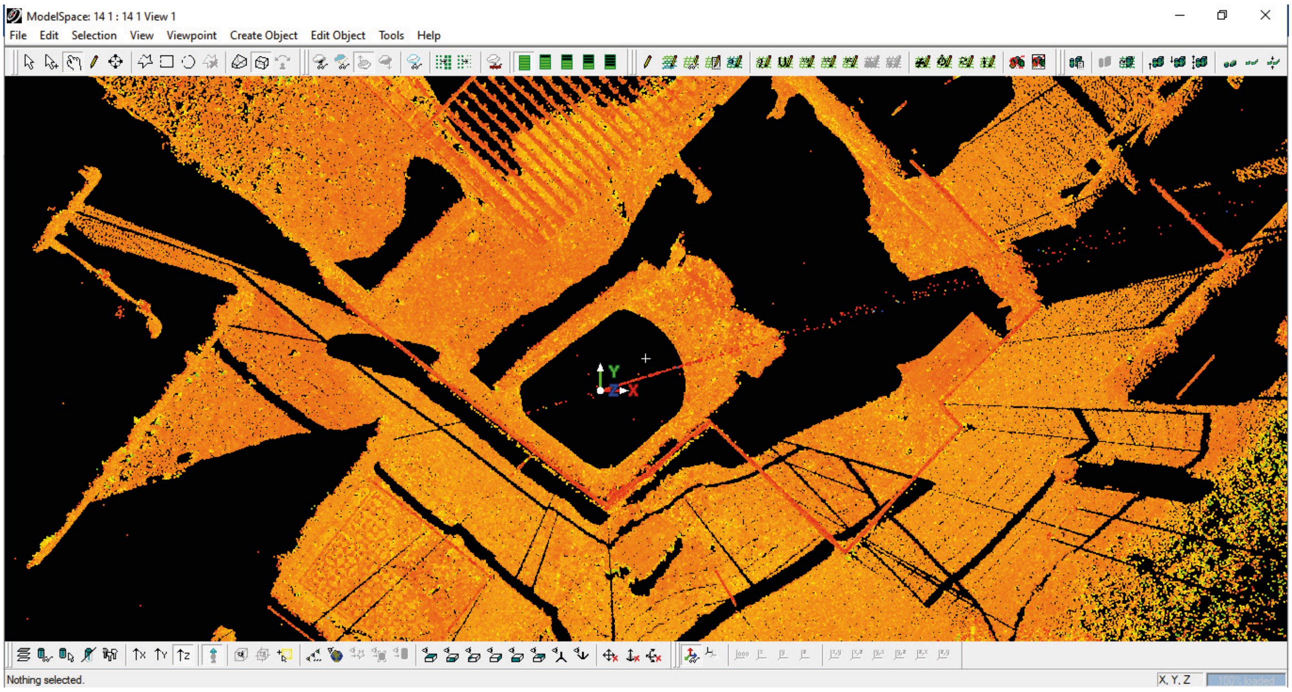
At this point you can also insert the North orientation in Cyclone. By copying the Reference Plane and activating it, the direction of the Plane Cross Axis must be changed (from the Reference Plane properties and the X and Y coordinates that give the direction of the new X axis must be entered, which can also be obtained from AutoCAD in the UCS details, 009-010) and then the new UCS North must be saved. The XY coordinates make up the rototranslation matrix (in this case only rotation since the origin is the same point).



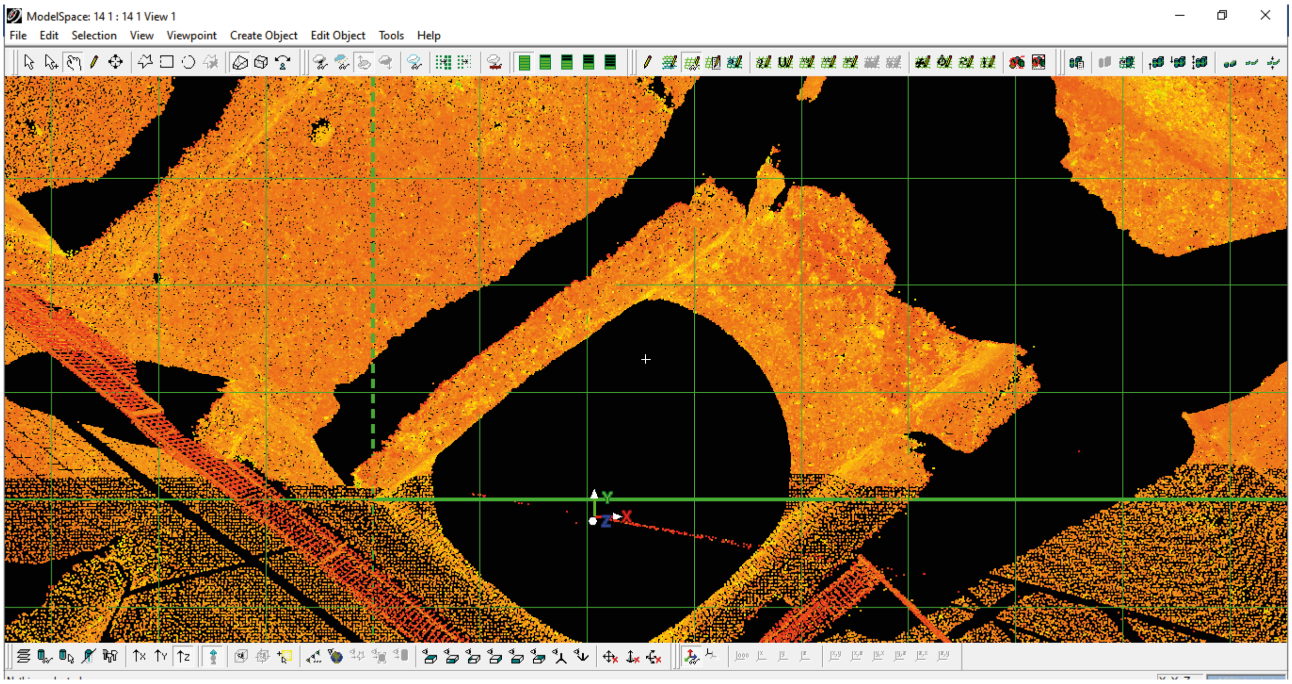
The reference segment used in Cyclone must be selected and copied to ControlSpace. This is because Cyclone automatically arranges a Scanworld according to the axes that correspond to the position of the Home ScanWorld laser scanner; therefore, if a new alignment is made (e.g. if a new cloud is added) the UCS created in the ModelSpace are lost, but can be restored using the same procedure as before through the reference segment (explained below).

Leica Cyclone 6.0
How to maintain a defined UCS after a new registration.

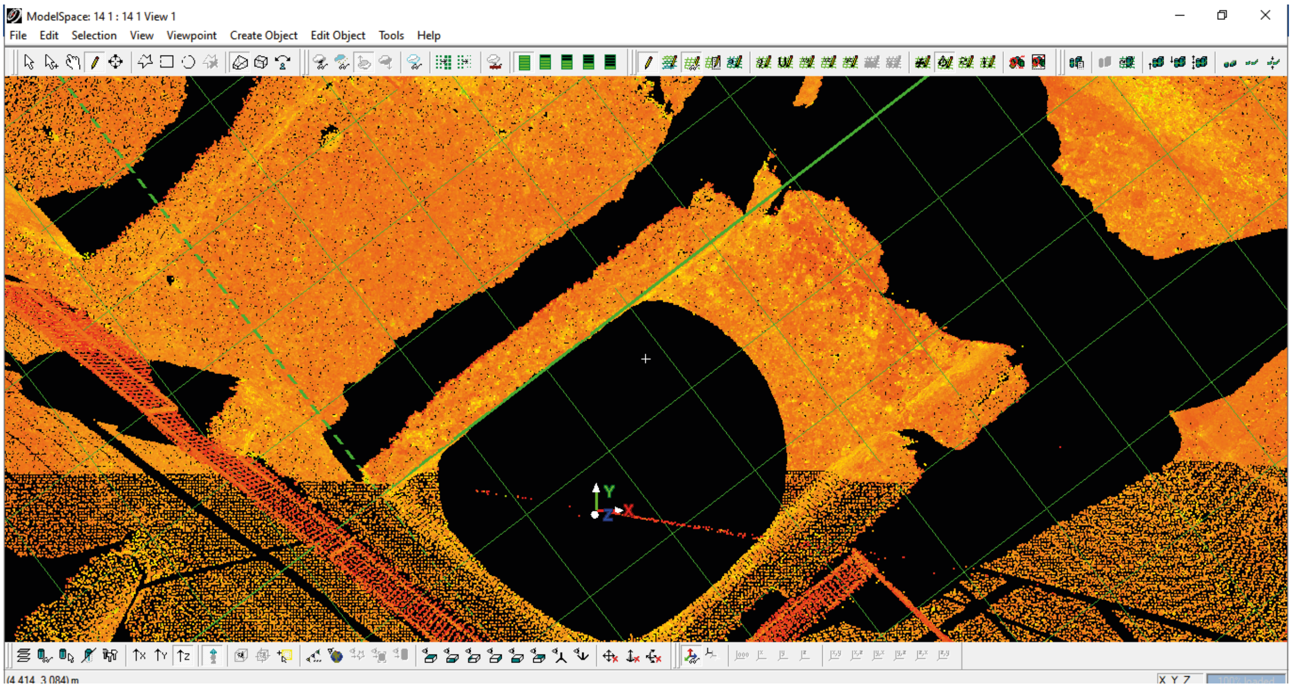
1) In the main final point cloud define a new User Coordinate System.



First method: **using a reference plane.**
Copy and activate a new reference plane. Select a point that will become the origin of the plane. Tools > Reference Plane > Set Plane Origin at Pick Point > Deselect.
Set the Orthographic and Top View

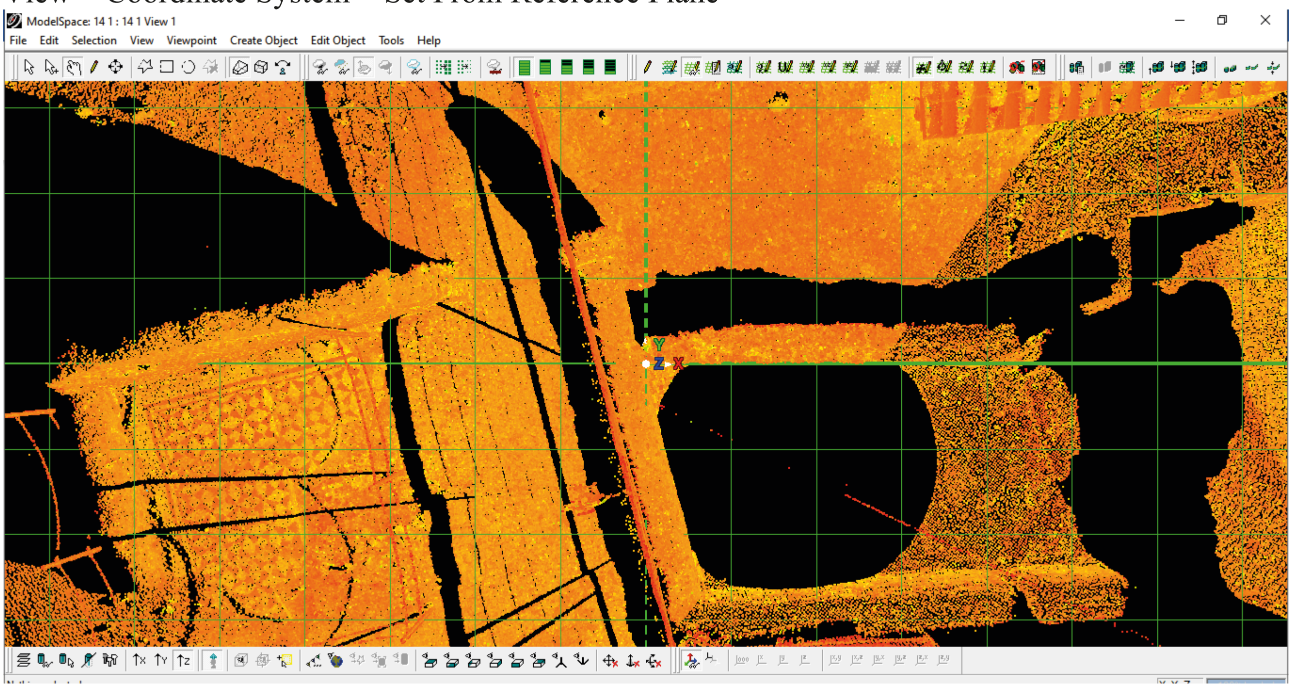


Tools> Reference Plane > Rotate

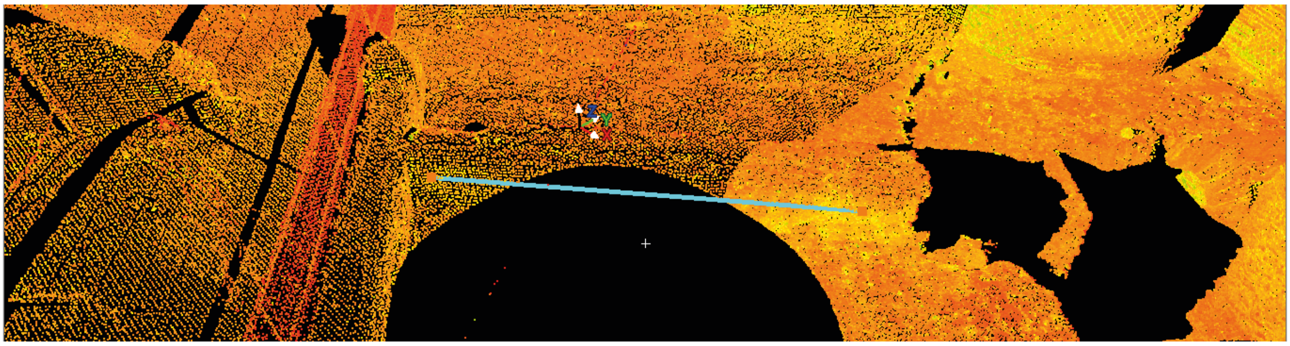


Tools > Reference Plane > Align View to Active Plane

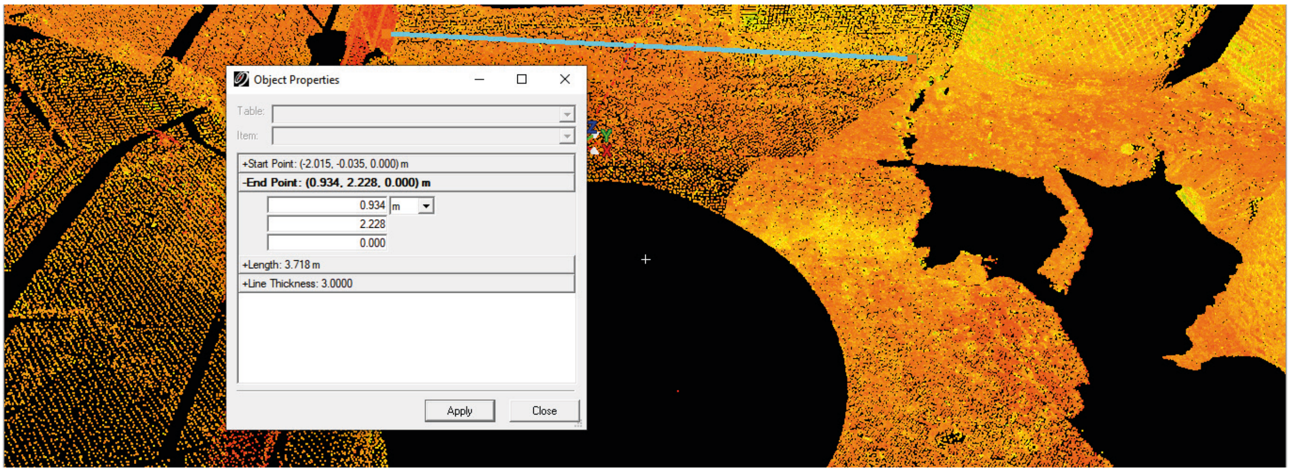
View > Coordinate System > Set From Reference Plane



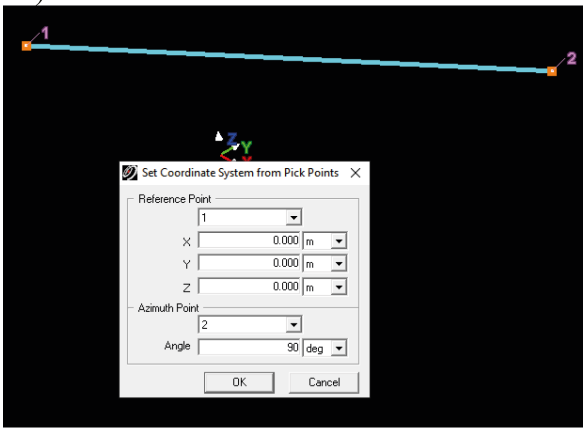
Second method: **using a segment line.** Select two points on the plane (a wall for example) that will become the direction of the X axis.
Create Object > From Pick Points > Line Segment



Select the line segment > Right click > Edit Properties > Change the Z coordinates of the first and second point to 0.000 (or another number, but it has to be the same in the two points).



Select the two vertices of the line segment > View > Coordinates System > Set from Points… (Angle 90).



2) Now select the Line segment created to set the UCS and copy it to Control space (Tools > Registration > Copy to Control Space).

3) After the new registration, the Coordinate System will be automatically set to the Default Home Head Scan. Select the two vertices of the Line segment and View > Coordinates System > Set from Points… (Angle 90).

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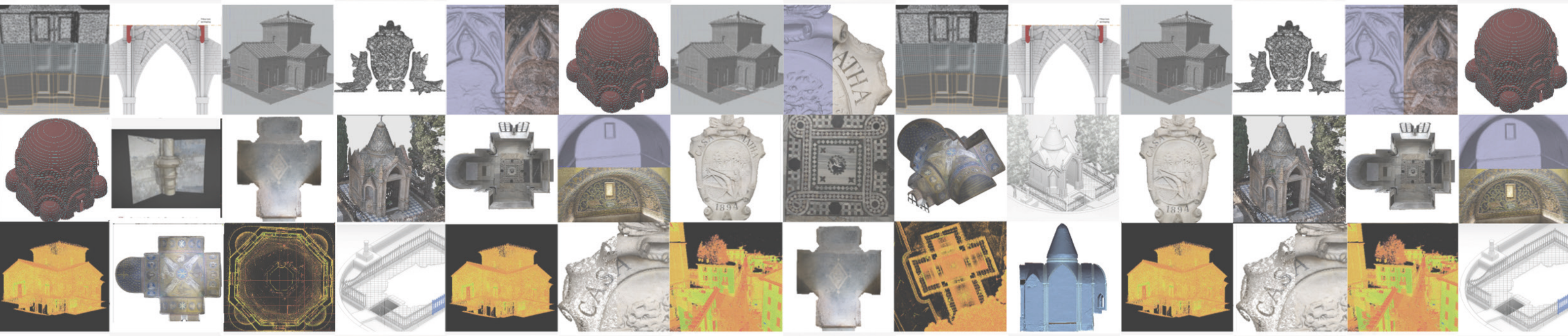

Guidelines for the Management of Cultural Heritage using 3D models for the insertion of heterogeneous data

Linee guida per la Gestione del Patrimonio Culturale tramite l'utilizzo di modelli tridimensionali per la raccolta di dati eterogenei

Directrices para la Gestión del Patrimonio Cultural a través de modelos tridimensionales como repositorios de datos heterogéneos

Coordinator of PhD Programme
Prof. Roberto **Pasini**

Supervisor
Prof. Luca **Cipriani**

Supervisor
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