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Untangle Sustainable Development Goal 8 through Data Visualization and HCI methods

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The journey of a thousand miles
begins with a single step.
– Lao Tzu

Abstract

Following the approval of the 2030 Agenda for Sustainable Development in 2015, sustainability became a hotly debated topic. In order to build a better and more sustainable future by 2030, this agenda addressed several global issues, including inequality, climate change, peace, and justice, in the form of 17 Sustainable Development Goals (SDGs), that should be understood and pursued by nations, corporations, institutions, and individuals.

In this thesis, we researched how to exploit and integrate Human-Computer Interaction (HCI) and Data Visualization to promote knowledge and awareness about SDG 8, which wants to encourage lasting, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. In particular, we focused on three targets: green economy, sustainable tourism, employment, decent work for all, and social protection. The primary goal of this research is to determine whether HCI approaches may be used to create and validate interactive data visualization that can serve as helpful decision-making aids for specific groups and raise their knowledge of public-interest issues. To accomplish this goal, we analyzed four case studies. In the first two, we wanted to promote knowledge and awareness about green economy issues: we investigated the Human-Building Interaction inside a Smart Campus and the dematerialization process inside a University. In the third, we focused on smart tourism, investigating the relationship between locals and tourists to create meaningful connections and promote more sustainable tourism. In the fourth, we explored the industry context to highlight sustainability policies inside well-known companies.

This research focuses on the hypothesis that interactive data visualization tools can make communities aware of sustainability aspects related to SDG8 and its targets. The research questions addressed are two: "how to promote awareness about SDG8 and its targets through interactive data visualizations?" and "to what extent are these interactive data visualizations effective?".

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Chapter 1

Introduction

In this chapter, we introduce the research background and the case studies of this thesis and present the research questions that drove the study. Finally, the structure of the thesis is presented.

1.1 Research background

Sustainability is a deeply discussed issue that particularly escalated in 2015 following the approval of the 2030 Agenda for Sustainable Development by the general assembly of the United Nations. This agenda highlighted a series of global problems, like poverty, health, inequality, climate change, peace, and justice, in the form of 17 Sustainable Development Goals (SDGs) addressed to achieve a better and more sustainable future by 2030 [96, 142]. These 17 SDGs (usually visualized with specific colors and icons, as depicted in Figure 1.1) should be known and therefore pursued by not only nations and governments but also all stakeholders, such as companies, institutions, and citizens [65].

However, the concept of Sustainable Development (SD) emerged in 1987 in the report "Our common future" published by the Bruntland Commission, where economic growth was linked to environmental stability. In particular, the report stated that SD is the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [37]. To

[1] https://www.un.org/sustainabledevelopment/news/communications-material/

FIGURE 1.1: The 17 Sustainable Development Goals.[1]

achieve this development, the report highlighted the necessity of a new phase of economic growth, as poverty was linked to inequality and environmental degradation. SD is taken into consideration within the HCI research field, as it is particularly relevant to humans and their life. Accordingly, in 2010 the Sustainable HCI (SHCI) area emerged. SHCI is defined as a "heterogeneous developing field of research, typically focusing on persuasive system design to influence users to behave and live more sustainably" [190]. In this context, DiSalvo et al. performed a literature review highlighting the main research topics of this new area in the form of five genres, named persuasive technology, ambient awareness, sustainable interaction design, formative user studies, and pervasive and participatory sensing [80].

Focusing on two of the previously mentioned research topics, denominated persuasive technology, and ambient awareness, Data Visualization is a powerful tool that can be exploited in both of them. Actually, Data Visualization is the representation of data in some systematic form to communicate the information extracted more clearly and effectively by exploiting the cognitive abilities of the human being and to create an efficient tool to amplify users' cognition, increase user awareness and support the decision-making process, highlighting patterns or abnormalities within the data [53, 88, 127, 146, 261, 269].

Moreover, nowadays, the number of information and data from different sources and in various formats is continually increasing, leading to the problem of how to represent this large amount of data and how the user can extract knowledge from them. Those data can result from a datafication process that aims to transform a phenomenon into data that can be studied and analyzed [166] or can be constantly generated consciously or unconsciously by every kind of people or Internet of Things (IoT) devices. For these reasons, the Data Visualization area has become increasingly important and widely studied in the literature to foster user awareness. However, there are still many studies in the literature that highlight the presence of open issues and challenges during the entire data visualization development process, such as i) the increasing amount of data to be displayed, ii) the way to represent them, iii) the avoidance of misinterpretation, iv) the creation of relevant knowledge and insight, and v) the final evaluation [24, 86, 220, 267]. Analyzing how users interact with and understand data could be essential to face some of the previously mentioned data visualization challenges. The interaction can be tangible [165, 59, 162], also making use of data physicalization ([257]), it can exploit Augmented, Virtual or Mixed Reality to make users feel more immersed and engaged with the data [222, 168] and it can be enjoyed through different types of smart devices, such as computers, smartphones, or wearable devices [111]. Hence, to better understand and analyze these interactions, the need to integrate the Data Visualization field with HCI arises. Nevertheless, one of the new challenges of HCI is making the visualization and analysis of big data usable by interested communities [82]. Data Visualization can, therefore, become a means of involving users. The reason for this is not only the desire to make knowledge accessible to all but also to make the users aware of the surrounding environment, which is increasingly interconnected, smart, and capable of producing large amounts of data from every kind of smart object. As introduced in [268], the user can engage with the provided data at different levels. In particular, the authors defined three levels of engagement: i) low engagement as simply being aware of the existence of the data, ii) medium engagement if the user actively explores the data to understand its structure and meaning, and iii) high engagement when a user reflects on or responds to the data.

As mentioned before, being aware of the environment is also important from a sustainability perspective. While the study from DiSalvo et al. ([80]) focuses on the identification of established genres in the SHCI, a more recent study from Hansson et al. analyzed the literature to also identify the most common SDGs [105]. In particular, in this systematic literature review, the authors analyzed a body of 71 papers from the SHCI area and classified them into the relative SDG. Their classification identified six SDGs: SDG 2 (zero hunger), SDG 7 (affordable and clean energy), SDG 9 (industry, innovation, and infrastructure), SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), and SDG 13 (climate action). Hence, building on these results where the economic facet doesn't appear and acknowledging the importance of economic growth that was already highlighted in the report "Our common future" mentioned before ([37]), we decided to focus our study on one of the 17 SDGs, i.e. SDG 8[2]. This Goal aims to promote lasting, inclusive, and sustainable economic growth, full and productive employment, and decent work for all. This SDG has several targets, so we decided to focus our attention on three of them:

- **green economy**[3], which can be linked to target 8.4. This target focuses on resource consumption to divide economic growth from the deterioration of the environment.
- **sustainable tourism**[4], which can be linked to target 8.9. This target focuses on identifying and enacting policies to promote sustainable tourism that also increases the foster awareness and knowledge of local culture.
- **employment, decent work for all and social protection**[5], which can be

[2] https://sdgs.un.org/goals/goal8
[3] https://sdgs.un.org/topics/green-economy
[4] https://sdgs.un.org/topics/sustainable-tourism
[5] https://www.ilo.org/global/topics/decent-work/lang--en/index.htm

linked to targets 8.5 and 8.8. Target 8.5 focuses on creating a productive workplace and decent work for all, regardless the gender, age, and disabilities, with equal pay. Similarly, target 8.8 aims at protecting workers' rights and promoting a secure and safe workplace for all, despite their origins.

1.1.1 Green Economy

The United Nations Environment Program defines the green economy as "a low-carbon, resource-efficient, and socially inclusive economy"[6]. Moreover, in this context, investments in resources, activities, and infrastructures made by private and public institutions can produce an increase in employment and income and enable carbon and pollution reduction, energy and resource efficiency, and prevention of biodiversity loss and ecosystem services. To increase awareness about this topic, we focused on the university community, made up of students, teachers, and technical-administrative staff, with the aim of raising awareness of related aspects, such as energy and paper saving. In particular, we analyzed two different case studies. In the first case study, we investigated the Human-Building Interaction between the community and a Smart Campus, while in the second case study, we provided information about the dematerialization process carried out by a University.

1.1.2 Sustainable Tourism

Sustainable tourism was defined by the World Tourism Organization as "tourism that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, the industry, the environment, and host communities" [7]. To increase awareness about this specific topic, we focused on sustainable tourism linked to authenticity and the relationship between tourists and locals.

[6] https://www.unep.org/regions/asia-and-pacific/regional-initiatives/supporting-resource-efficiency/green-economy

[7] https://sdgs.un.org/topics/sustainable-tourism

1.1.3 Decent work for all and social protection

Referring to the definition of the International Labor Organization, decent work means "opportunities for work that is productive and delivers a fair income, security in the workplace and social protection for families, better prospects for personal development and social integration, freedom for people to express their concerns, organize and participate in the decisions that affect their lives and equality of opportunity and treatment for all women and men" [8]. To increase awareness about this specific topic, we focused on sustainability in the corporate context.

1.2 Research hypothesis and questions

The purpose of this research concerns the integration between HCI and Data Visualization to design graphic visualizations able to increase awareness about a specific issue. In particular, this thesis follows the "research through design" approach as it aims to apply well-known HCI and visualization research methods to a series of different domains. Adding more details, the main focus of this research is to investigate which HCI methodologies can be exploited to design, and validate interactive data visualizations that can become effective tools to support specific communities for decision-making processes and increase their awareness of issues of public interest. In particular, we aimed at increasing awareness of SDG 8 and some of its targets (i.e, green economy, sustainable tourism, and decent work), which wants to "promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all".

In particular, this research focuses on the hypothesis that:
H1. Interactive data visualization tools can make communities aware of sustainability aspects related to SDG8 and its targets.

In validating H1, we went through two main research questions:

[8] https://www.ilo.org/global/topics/decent-work/lang--en/index.htm

- **RQ1. Design**. How to promote awareness about SDG8 and its targets through interactive data visualizations?
- **RQ2. Validation**. To what extent are the interactive data visualizations, resulting from RQ1, effective?

1.2.1 RQ1. Design

This first research question focuses on the creation of interactive data visualization tools exploiting well-known data visualization methods in order to make people aware of SDG8 and its targets. In particular, we explored different scenarios to better understand the features that can help during the design phase of such systems. To accomplish this goal, we exploited several designs and technologies, involving the target community of each case study.

1.2.2 RQ2. Validation

This second research question focuses on the validation of interactive data visualization tools to understand if the chosen design was effective and able to fulfill its duty, namely promoting awareness and knowledge about SDG8 and its targets. Hence, we wanted to validate our prototypes directly with the target users identified in each case study.

In this context, our research applied well-known methods to collect qualitative and quantitative data for two purposes: to validate the design and the systems' effectiveness and provide possible guidelines.

Starting from the definition inside ISO 9241-11:2018[9], effectiveness is depicted as "accuracy and completeness with which users achieve specified goals", so it is strictly related to the requirements of each case study.

[9] `https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-2:v1:en`

1.3 Thesis structure

This thesis illustrates the state of the art and our approach in relation to the mentioned research questions. In particular, each case study aims to answer both our research questions. The remainder of this thesis is structured as follows:

Chapter 2 presents the works done to increase awareness about the green economy topic, especially in terms of resource efficiency and energy saving in the Human-Building Interaction research field. The newly built Cesena Smart Campus of the University of Bologna was chosen as our case study, and therefore its community was selected as our target community. First, this chapter introduces the first system designed and developed to make the community aware of the campus' physical environment both in spatial terms (position of classrooms, laboratories, and offices) and in terms of sensors installed indoors for measuring environmental parameters. Then, it presents the second system to promote more sustainable and efficient use of those spaces (such as classrooms and laboratories) within the university campus.

Chapter 3 introduces the works done to increase awareness about the green economy topic, especially about dematerialization. Also, for this case study, we focused on the University of Bologna; consequently, its community was chosen as our target community. We designed and developed a system aimed at promoting the actions made by the University of Bologna to save papers by exploiting two different interactive infographics. This work was done in collaboration with members of the ITI/LARSyS group (Técnico, University of Lisbon, Lisbon, Portugal).

Chapter 4 presents the works done to increase awareness about sustainable tourism. In particular, it details the system designed and developed with the aim of promoting a more authentic touristic experience involving locals and tourists. To accomplish this goal, we focused on fostering a connection and interaction between those two communities.

Chapter 5 presents the works done to increase awareness about sustainability in the industry context. In particular, it focuses on creating awareness about internal corporate policies focused on employees. Hence, we developed a web-based system that engages users in a learning and reflection process about these policies. This work was done in collaboration with the Social Dynamics team at NOKIA Bell Labs (Cambridge, UK).

Chapter 6 concludes this thesis by summarizing each case study's obtained results and outlining future research and research vision.

Chapter 2

Case study: Human-Building Interaction

As mentioned in Chapter 1, one of the main targets of SDG8 is the green economy, which refers to a development model for sustainable growth with a low environmental impact. This chapter presents the work done to promote awareness about this topic, especially resource efficiency and energy saving in the Human-Building Interaction (HBI) research field.

To accomplish this goal, it was necessary to first identify the context and therefore the target community. The newly built Cesena Smart Campus of the University of Bologna was chosen to be our case study and, consequently, its community was chosen as our target community. As a first step, the university community had to be aware of the surrounding spaces. Hence, the first system designed and developed aimed to make them aware of the physical environment of the campus both in spatial terms (position of classrooms, laboratories, and offices) and in terms of environmental comfort based on sensors installed indoors for measuring environmental parameters, such as temperature, humidity, pressure, and air quality. Then, we designed and developed a second system to promote more sustainable and efficient use of those spaces (such as classrooms and laboratories) within the university campus. The rest of this Chapter is organized as follows. Section 2.1 introduces the concepts of Human-Building

Interaction and Smart Campus and the motivations behind these systems. Section 2.2 presents the main related works in the field of HBI and visualization for Smart Campuses. Section 2.3 illustrates the main assumptions behind the two systems. Sections 2.4, 2.4.3, 2.5 present the two systems designed and developed to answer the previous research questions and their evaluation. Finally, Section 2.6 summarizes the work and the main findings.

2.1 Introduction

In recent years, technological advancement, especially concerning 5G and advanced Internet of Things (IoT) devices, has increasingly led to the transition from building to smart building. Following the definition made in [38], when we talk about Smart Building, we refer to a building capable of adapting (not reacting) to its occupants' perception, comfort, and satisfaction, while keeping a high level of energy efficiency [75]. The ability to adapt comes from the increase in the number of smart devices and sensors installed inside the building. As a matter of fact, Smart Buildings have a building management system (BMS), a system that is able to monitor, regulate, and keep efficient its subsystems, e.g., HVAC (Heating, Ventilation & Air Conditioning) system, hot water system, or electrical monitoring system [123]. The data coming from the sensors are intended for the monitoring of the indoor condition by authorized personnel that can exploit the Building Information Modeling (BIM), a 3D digital model of the building that displays information for different kinds of stakeholders (e.g., planners, engineers, or managers) [252]. The BIM can be considered as a "digital twin" of the building exploited during the entire building lifetime [266], where the monitoring of the indoor conditions is fundamental for the satisfaction and comfort of the building's occupants [172].

Such a rich context calls for a specific investigation of the several dynamics that relate to the human, the buildings, and the urban landscape: Human-Building Interaction (HBI) is an interdisciplinary field that combines Human-Computer Interaction (HCI), Ubiquitous Computing, and Architecture and Urban Design

[6, 5]. Usually, studies in the HBI field exploit the data gathered from the sensors to start a discussion with the occupants with the final aim of improving their comfort, but, in the end, the actual data are not available to the people who live or work inside the building. In this context, we assume that, if visualized in a clear and intuitive way, the sensors' data can raise the target users' awareness of sustainability issues [217, 41] or can be helpful to communicate about comfort and energy use [265, 61, 176]. Therefore, increasing occupants' awareness can help them make more informed decisions that best suit their actual needs within the buildings. State of the art in this specific field shows that some previous works on HBI [7, 6] and on how to visualize smart building data [117, 114] have been already done, with the aim of improving the occupants' experience while exploiting building sensors data (with specific regard to those collecting environmental data, such as temperature and energy consumption). However, the possibility of increasing occupants' awareness of environmental conditions through specific HBI and data visualization strategies (targeting non-expert occupants) is not yet well investigated.

The analyzed building can also be a Smart Campus. In recent years, the term Smart Campus has become more and more widespread and investigated and exploited in several studies [198, 3]. The word campus refers to places (buildings and ground) where universities are situated. However, the term Smart Campus is not uniquely defined, and different concepts emerged [3] but always with the goal of improving the experience of the communities living in the indoor and outdoor spaces of the campus. Some researchers tried to define the term Smart Campus based on several approaches [174]. In particular, three main approaches emerged. The first approach is technology-driven. In this case, a Smart Campus is the result of the development of a digital campus, where IoT service providers [173] and cloud computing [63] are exploited. The idea that drives this approach is that items, commonly found in a university environment, should be converted into intelligent ones [46]. The second approach is tied to the smart city concept. The assumption behind this approach is that a Smart Campus has similarities with a Smart City. As a matter of fact, a Smart Campus can be seen as a self-contained little city with different functions, people, connections, and activities [198, 12]. Hence, adopting the same paradigm, a Smart Campus should exploit new technologies to help and support its community, made by users with different roles (students, professors, research, technical-administrative staff, etc.) [160]. Eventually, these users can become active players inside the Smart Campus and contribute to it through crowdsensing and/or crowdsourcing initiatives [215], [228]. Finally, the third, and last, approach involve an efficient use of resources. This is possible through the supply of environmental data (i.e., CO_2 and Particulate Matters (PM) [9], [262]) to the community [3] and through systems aimed at reducing costs and energy consumption to improve the life quality inside and outside the Smart Campus.

Hence, the birth and the evolution of Smart Campuses are linked to two different aspects. The first one is the availability and diffusion of technologies applied to the spaces able to produce and use data. The second one is the presence of a community made especially by digital natives who want to be actively part of campus life.

2.2 Background and Related Work

2.2.1 Human-Building Interaction

In recent years, the increment of smart buildings, with advancements in sensing and actuation systems, brought out the need for the HCI community to intervene and involve the user in the Human-Building Interaction (HBI) design practice [7]. Hence, recent studies have focused on this interaction to improve or facilitate the lives of smart building occupants [159]. In particular, Finnigan and Clear have analyzed how student occupants experienced spaces, how they evaluate them, and how the building management might improve considering the occupants [169]. Their case study was based on a smart university building in the UK equipped with BMS. They recruited 16 students for "building walks" and a speculative design workshop. Their findings concerning the students' experience inside a smart building provided insights into the design of building interaction within the University context.

Other examples involved the sensors and BMS to start a dialogue and resolve possible thermal comfort tensions inside shared spaces [93, 62]. Clear et al. developed ThermoKiosk, a system composed of survey devices (to express a subjective thermal comfort opinion), digital displays (to see the recorded data), and temperature sensors. This system exploited subjective comfort data to analyze how thermal comfort was perceived by occupants [62]. After three weeks of deployment, their findings from the qualitative studies highlighted how the interaction with the system changed the thermal comfort perception. Thermal comfort was also studied in [93], where von Frankenberg presented a 4-layer framework that aimed to resolve thermal comfort conflict inside shared spaces and provide fair decision-making, starting from a recorded event, such as environmental and individual biosignal sensor measurements.

The adoption of an innovative approach with the aim of motivating occupants to consider personal energy usage (having positive effects on their smart environments) is the basis of different studies. In particular, [134] proposed a gamification approach as a novel framework for smart building infrastructure. In particular, they introduce a strategy that incorporates humans-in-the-loop modeling by creating an interface to allow building managers to interact with occupants and potentially incentivize energy-efficient behavior. Moreover, such an approach has been enriched by deep learning training so as to improve estimations of occupant actions toward energy efficiency. Other studies focused their research goals and efforts on defining and adopting simulation strategies to analyze and predict occupants' behavior and then computing metrics and side effects from the smart buildings [141].

Summing up, previous works on HBI focused on improving the experience of building occupants by exploiting sensors data, especially those which collect data about temperature, energy usage, and individual (or subjective) data, leaving out the possibility of increasing occupants' awareness of environmental conditions inside a smart building.

2.2.2 Smart Building data visualization

Following the increasing presence of smart buildings, BIM and BMS have become increasingly relevant in facing the challenge of handling large, complex, and dynamic sensor data. In this context, Data Visualization is effective for the analysis and management of this information. In [114], Ignatov and Gade used a 2D digital map of the building to visualize the BIM sensor data. In particular, they created a visualization showing the dust accumulation in each room, exploiting a color scale from blue (lower) to red (higher) for the different accumulation levels. Instead, Natephra and Motamedi created a virtual 3D environment enjoyable through a head-mounted display to monitor indoor comfort. They showed, inside the environment, the information about temperature, humidity, and light as textual labels close to a relative icon to help monitor ing the indoor conditions [177]. The BIM visualizations were the subject of the review made by Ivson et al. [117]. In their review, they recognized three main types of BIM data visualizations: 2D CAD (e.g., schematic drawings, blueprints, maps), 3D CAD (e.g., actual shapes of physical entities), and charts (e.g., tables, hierarchies, graphs, diagrams, plots). Usually, these visualizations had five different scopes: (i) facility management; (ii) sustainability analysis; (iii) work execution; (iv) work planning; and (v) design review and clash analysis.

To summarize, despite the relevance of the role of occupants in relation to the smart building, the visualizations that display environmental data from BMS have a specific objective: monitor, manage or control the building [50, 49]. Hence, the challenge is how to design visualizations that target non-expert building occupants to provide clear and meaningful insights that can eventually foster their awareness.

2.2.3 Smart Campus data visualization

Considering Data Visualization as a tool to enable a better understanding of data in Smart Campus scenarios, dashboards can be an effective graphical user interface tool to provide at-a-glance views of the gathered data to users. In [230], authors created the Campus Energy Education Dashboard (CEED), a dashboard to visualize the energy consumed inside a university campus to improve energy efficiency and increase the knowledge of its occupants. CEED used a campus digital map to provide information about the building that consumes more energy and a bar chart to display the same information, exploiting both real-time and historical data. The system targets two distinct groups of users, providing analytic features for stakeholders and engagement features for students and staff.

Another example is Ubidots, a dashboard where smartphone data are collected and then visualized to monitor the mobility inside the campus [8]. In [149], Longre et al. proposed a model for the design of dashboards that display sensors data visualization in the context of a smart campus. In particular, they claim that the data displayed and the visualizations should take into consideration the users' roles. Sensor data could be environmental-related. For example, Hentschel et al. used a simple web dashboard to display data related to temperature and light intensity inside an office at the University of Glasgow [107]. Instead, USC AiR is a mobile application to display data about the air quality inside a campus. This application also exploits augmented reality to make users more engaged with those data and inspire them to contribute to the reduction of air pollution [223]. Similarly, Bujary et al. [39] resorted to augmented reality to lure users into using a pedestrian navigation application whose goal is also to gather quality environmental data on the premises of the University of Padua. The application is coupled with a web service providing a heatmap of collected historical values and their evolution over time. It was then expanded to be used even on smartwatches and with an algorithm able to generate the best routes considering also light and brightness beside the classic shortest path [41]. AlmaMap is another example of an application that displays environmental data, such as temperature, humidity, pressure, and particulate matter, gather from sensors inside a university campus, whose location is visible through the visualization of the campus map [217]. Tarabieh et al. used a map-based visualization, together with a bar chart, pie chart, and dial gauge, to provide data about the energy consumption on a university campus and to produce a behavioral change in the campus community [253].

Focusing on the issue of detecting and monitoring classroom occupancy, Sutjarittham et al. used data visualization techniques, like heatmap and line chart, to display attendance patterns during classes and the actual occupancy in the classrooms [251]. Inspired by this study, we pushed this approach further, providing a data visualization dashboard that not only visualizes the classrooms/labs' actual occupancy but also allows the user to easily perform visual comparisons to find the optimal course timetabling for real-time or medium- and long-term actions.

2.3 Research questions

Considering the background analyzed in the previous Section, we aimed to answer the two research questions, presented in Section 1.2, in the Human-Building Interaction context. In particular, concerning **RQ1**, we were interested in understanding how to promote green economy practices in a Smart Campus community through interactive data visualization tools. To do so, we investigated the following assumption:

- a user interface designed for a specific community increases occupants' context-awareness about environmental issues within a building, supporting them to make more informed decisions that best suit their needs;
- an interactive data visualization tool improves campus sustainability (in terms of energy saving) and safety (considering the COVID-19 restrictions and regulations).

Concerning **RQ2**, we wanted to evaluate the systems designed in the attempt to answer RQ1 by directly engaging the community of interest to understand if the design was effective for that specific community and extrapolate meaningful insights. In this case study, we defined effectiveness as the system's capability to visualize and communicate in a clear way the sensor data that should be understood by the users regardless of their expertise.

Hence, we proposed a smart campus system that exploits the three approaches mentioned in Section 2.1. In particular, we used smart environment technologies and IoT (first approach), and we engaged the campus community through crowdsourcing and crowdsensing activities (second approach) with the aim of efficient use of the resources to improve the life quality of the target community (third approach).

2.4 Increase occupants' awareness to make informed decisions

The first system exploited low-cost sensors and smart technologies to augment the Cesena Smart Campus, one of the campuses of the University of Bologna, and produce hyperlocal data with which the user can interact through public displays to gain information about spatial-temporal phenomena. The term hyperlocal data refers to geolocalized information that can be available to the community members as a way to empower them and improve their interaction with the spaces. Moreover, we wanted to include the community as a way to make its members active participants in the exploration of the smart environment and make them benefit from the environment itself. This can be done through the interaction with the hyperlocal data by exploiting data visualization techniques, to provide information in a visual way [55].

2.4.1 Architecture

The system is composed of four components, as shown in Figure 2.1.

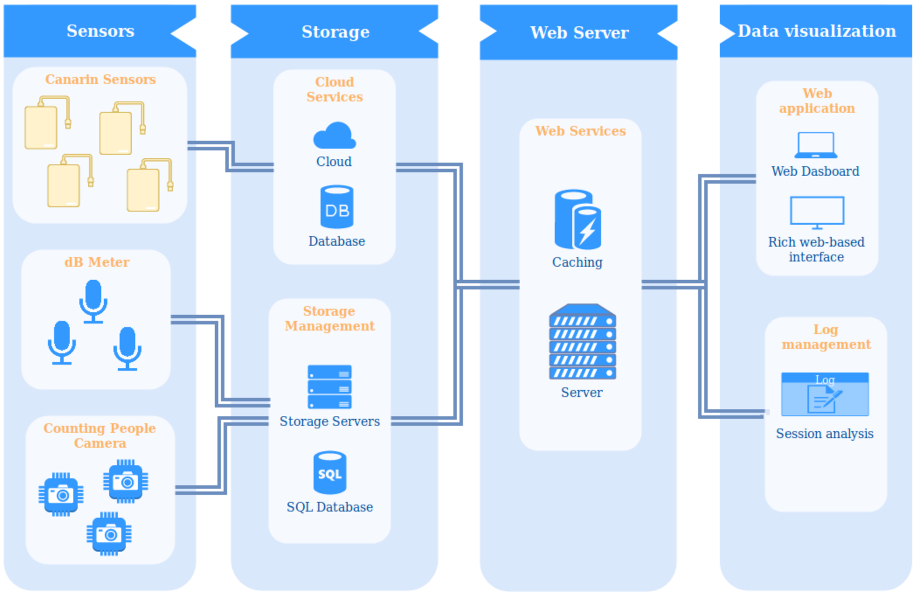

FIGURE 2.1: The architecture of the first smart campus system is made of four components: **i)** a sensor infrastructure with Canarin II, microphones, and cameras, **ii)** a database layer that stores the data collected by the sensors, **iii)** a web server, and **iv)** a Data Visualization layer with two web applications.

Sensors infrastructure

The first component is a sensors infrastructure aimed at increasing the sensors installed inside the campus and managed through a Building Management System (BMS) as a way to increase the sustainability of the newly built campus by monitoring and controlling CO_2, lights, and temperature inside the spaces. Our sensors (i.e., Canarin II [4]) were installed both indoors and outdoors and let us collect environmental measurements, such as temperature, air pressure, relative humidity, and air quality through Particulate Matter (PM 1.0, PM 2.5, PM 10.0). Adding more details, we placed three sensors station outside the building to investigate the different levels of pollution due to natural and urban phenomena, and other two stations inside the campus to monitor spaces that need to be controlled as the library warehouse, where books must be kept at the correct temperature and humidity so that they do not be damaged.

Database layer

The second component is the database layer, where the real-time data collected every 30 or 60 seconds (depending on the sensor) by our stations are stored in

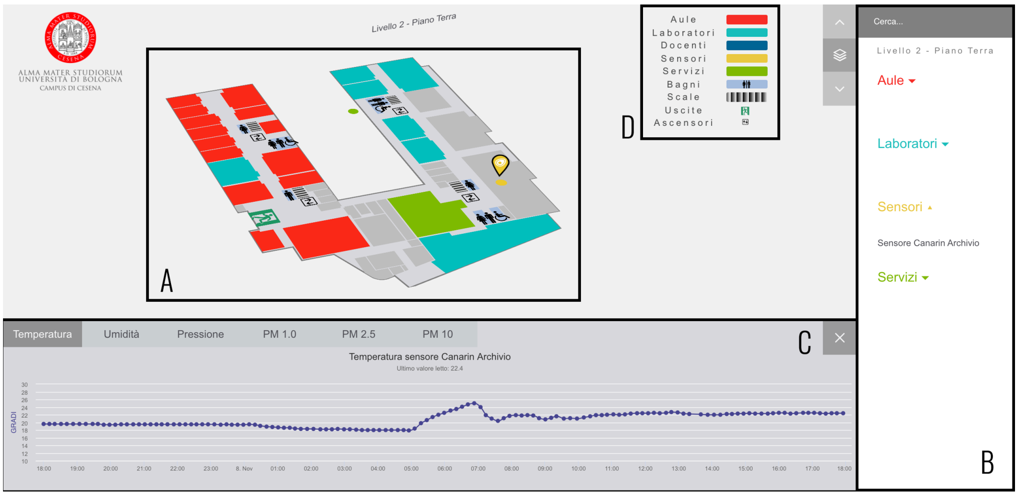

FIGURE 2.2: The system interface displayed when a user clicks on a sensor. **A** represents the floor where the sensor is located; **B** represents the sidebar with all the PoI listed; **C** represents the historical visualization of the temperature data gathered by an indoor sensor; **D** represents the legend with all the space typologies (e.g., classrooms, laboratories, offices, bathroom).

a MySQL database. Moreover, we also exploited the open data provided by the University of Bologna[1]. The open data contains information of interest to the community, and, in particular, we extracted the data about the lessons schedule. We decided to integrate this kind of information and use different data sources to bring a greater benefit to the university community in their activities on campus.

Web server

The third component is the web server, implemented using Node.js[2] and Express[3]. Moreover, we exploited libraries such as Socket.IO[4] to enable real-time, bidirectional, and event-based communication between the client and the server itself.

Data Visualization layer

Finally, the fourth and last component is the Data Visualization layer. This layer includes two web applications, both implemented using the standard web technologies (e.g., HTML5 and CSS3, JavaScript) and exploiting data visualization libraries such as D3.js[5] and Chart.js[6]. The main application is a rich web-based interface aimed to make the university community more aware of the spaces by letting them interact directly with a map of the campus and the hyperlocal data collected from our stations, as shown in Figure 2.2. This interface can be enjoyed through the public touchscreen display placed at one of the main entrances of the campus. Moreover, the user can interact with our interface in four different ways.

The map-based interaction. The focus and main component of the interface is a 2D map of the campus showing all the building's floors. As the Cesena campus had just been built, the university community didn't know the building and the spaces inside. After a brainstorming session, we decided to make the map the focus of the interface. This led us to have a direct link between the position of the sensors and their real-time data. We started from an open source project [150] that we modified to suit our needs. Through a click on the map, the user can select a specific floor of the campus and then see and interact with all the Points of Interest (PoIs). The interactive PoIs are classrooms, labs, and offices, while the non-interactive ones are facilities (e.g., toilets, elevators, and stairs). When a user selects a specific interactive PoI, its related information will appear at the bottom of the interface.

The search-based interaction. The user can also find the information through a search function that allows filtering the list of PoIs (in the right section of the interface, as shown in the left of Figure 2.2B) by keywords. This functionality was added to let the user search for a PoI without knowing the exact location.

[1]https://dati.unibo.it/
[2]https://nodejs.org/en/
[3]https://expressjs.com/
[4]https://socket.io/
[5]https://d3js.org
[6]https://www.chartjs.org

Once the user selects a PoI, the map will display and highlight its location and related information.

The interaction by categories. Staying in the right section of the interface (Figure 2.2B), the user can interact with the categories representing the different typologies of PoIs inside the campus. In particular, the identified typologies are five: i) classrooms, ii) laboratories, iii) professors' offices, iv) lessons and v) sensors. Once the user selects a category, the list will expand and shows all the related PoIs, and once the PoI is clicked, the map will display and highlight its location and related information.

The sensed data interaction. Finally, the user can interact directly with the data sensed by our sensors. In particular, we exploited data visualization techniques to display real-time data and historical data in an intuitive manner, as shown in Figure 2.2C. The main goal is to make the community aware of indoor and outdoor environmental conditions.

2.4.2 Evaluation

We evaluated our system through a mixed methods approach collecting and analyzing both quantitative and qualitative data. The quantitative data were, on one hand, collected automatically from the interactions made by the campus community with the public kiosk. On the other hand, we distributed a questionnaire to the community to better investigate the experience. The questionnaire was composed of 36 items, including 5-point Likert scale questions from 1 (strongly disagree) to 5 (strongly agree), multiple-choice questions, and open-ended questions. The qualitative data were taken from the observations and feedback requested in the questionnaire. We evaluated the qualitative feedback through the thematic analysis method. In particular, we involved the students from the Web Technologies course, enrolled in the Computer Science and Engineering bachelor's degree. We selected this target group as they were acquiring knowledge and skills in user experience and layout design. Hence, they were able to provide meaningful insights and feedback.

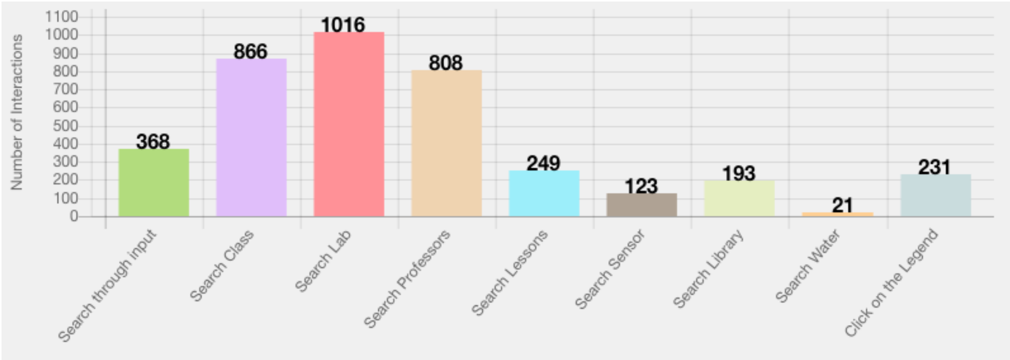

FIGURE 2.3: A bar chart displaying the nine more common actions done by the users when using the rich web interface. The chart is taken from our analysis interface.

Interaction analysis

We collected all the interactions with our kiosk made by the campus community for 30 days. In particular, to see how the community interacted with our interface, we focused on three aspects of the interaction: i) the duration of the interactions, ii) the object they interacted with (that could be, for example, a space in the map, the search bar or an element in the side menu), and iii) what they search for.

Starting from the duration of the interaction, we noticed that it lasted, on average, 1 minute and 45 seconds.

Concerning the object of interaction, we noticed that the majority of the community preferred to interact with the map-based interface (3495 interactions) rather than search a place with the side menu (1036 interactions) or with the search bar (368 interactions). These results proved the utility of providing hyperlocal data inside a map-based interface to display their spatial dimension.

Finally, regarding the searched content, the community mainly searched for laboratories (1016 interactions), classrooms (866 interactions), and professors' offices (808 interactions), as shown in Figure 2.3. This could be explained by the fact that the majority of the community is made up of students. Moreover, we noticed that only a few people looked at the data from sensors (123 interactions). To understand this number, we exploited the administered questionnaire that showed how some people recognized the utility of the data in providing new services to the community. However, at the same time, they highlighted the difficulty in reading raw data on the phenomena that can undermine the importance of the data itself.

Questionnaire analysis

We engaged a community of 135 students (80% males and 17.8% females) aged between 20 and 42. The majority of the respondents (93%) usually is on campus all working day of the week or at least all the day they had lessons.

Concerning our kiosk, 56% of users interacted at least once with it. In the questionnaire, we also investigated the reasons behind the answer. The motivations for the ones that never interact with the systems were mainly two. The first one is the "display blindness" issue [175], as 22 students never noticed the kiosk during their stay on campus. The second reason is the lack of interest in the system for 49 students, as they already knew where the classrooms or labs were located. We also investigated the usability, ease of finding information, and interactivity of the system. 38 students thought that the system was useful, 40 students that information was easy to find, and 45 that the interactivity was good. All the scores are reported in Figure 2.4. Moreover, we exploited the 5-point Likert scale to understand the goodness of experience. 76 students answered this question, and 36 rated their experience as 4 and 8 as 5.

Finally, we asked for some feedback and suggestions to further improve the experience of using our systems. Students were interested in the data we showed to exploit it for new services, such as providing information about empty classrooms or labs where it is possible to study.

2.4.3 Students' community involvement

After the evaluation presented in the previous Section, we wanted to investigate the possibility of including the students' community in the design process since they are the primary target audience of our system and the most significant part of a campus community. To do so and to test the usability of the system, we

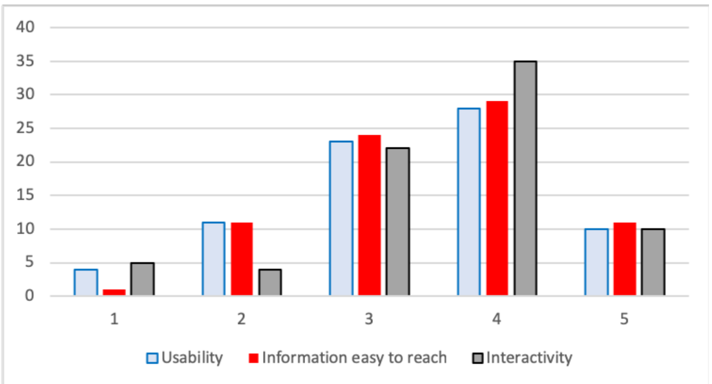

FIGURE 2.4: Students' rating on usability, ease of finding information, and interactivity, using a 5-point Likert scale

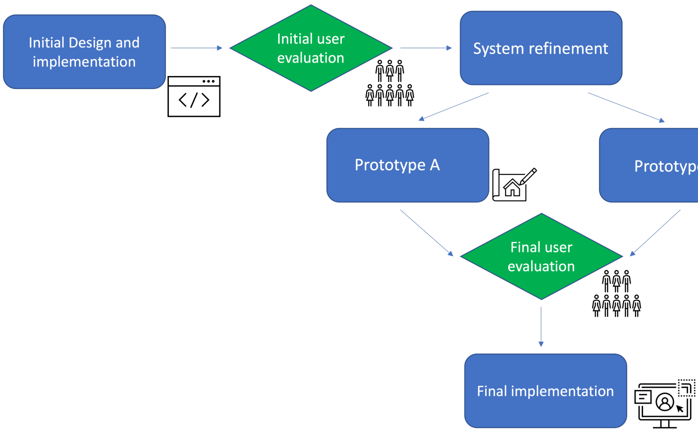

FIGURE 2.5: A flowchart showing the stages of the adopted methodology.

adopted a methodology based on an Iterative Design Cycle [182] composed of the following main different stages (as depicted in Figure 2.5):

1. an initial evaluation of the system through structured interviews and related results analysis (as detailed in 2.4.3);
2. the redesign of the system by the creation of two prototypes (Prototype A and Prototype B) (as detailed in 2.4.3);
3. a re-evaluation of the systems through the interaction with the prototypes (as detailed in 2.4.3);
4. the refinement of the initial system based on the new evaluation.

Interviews

In both the evaluation sessions (stages 1. and 3. in the above list), we engaged voluntary students in a structured interview. Standing in the proximity of the main entrance, we directly approached random students, asking them to participate in the study. When accepted, the researcher started the session by explaining the goal of the study, the voluntary nature of the participation, including the possibility of interrupting the interview at any moment, and, finally, she provided the participant with a paper informative consent detailing issues about data analysis and storage, in accordance with the European GDPR (General Data Protection Regulation).

The interviews were conducted by two different facilitators: one was directly involved in the dialog with the interviewees, while the other one annotated the words, gestures, and expressions of the interviewees. All interviewees faced the interview in the same conditions: they stood in front of the kiosk monitor with the same facilitators. Considering the tasks we asked them to perform, all the interviewees started from the system homepage and conducted the requested activities in the same order.

The interviews were structured into four phases:

1. personal questions, (Q1-Q3, in Table 2.1);
2. questions about the use of our system, (Q4, Q5, in Table 2.1);
3. two interaction tasks;
4. feedback: general questions on the system, Q6-Q11, in Table 2.1).

It is worth noticing that the questions of the structured interview (reported in Table 2.1) were inspired by our previous study [217]. In fact, since we already evaluated the overall system usability, interactivity, and the level of simplicity to reach the needed information (exploiting quantitative data), in this study, we wanted to focus specifically on qualitative data. In particular, thanks to the structured interviews, we were able to collect qualitative data to understand

TABLE 2.1: Questions asked during the interviews.

ID	Questions
Q1	How old are you?
Q2	To which gender identity do you most identify?
Q3	What is your course of study?
Q4	Have you ever interacted with the system?
Q5.a (experienced)	Why did you interact with the system? What did you look for?
Q5.b (inexperienced)	Why have you never interacted with the system?
Conduction of the two Interaction Tasks	
Q6	Do you think the system is useful?
Q7	What would you change in the system?
Q8	What information would you be interested in?
Q9	Have you noticed the sensors?
Q10	Do you think they are useful?

the critical issues related to the user interface and data visualization discovered while interacting with the system. For this reason, we just needed simple questions to engage the participants and collect feedback and comments instead of validated scales to measure specific dimensions.

The reason for Q4 was to divide interviewees into two different groups: the "inexperienced" users, in other words, those who had never interacted with the system before, and the "experienced" users, those who had already interacted with it. In fact, at the moment of the evaluation, the application was already installed for a while in the public kiosk available inside the Cesena campus, and students could freely interact with it. The division into such two groups is relevant in order to evaluate how intuitive the system was for the "inexperienced" users and how much it had impressed the "experienced" ones. Depending on this division, Q5 was different for "experienced" (Q5.a) and "inexperienced" (Q5.b) users.

For the interaction tasks, the thinking aloud protocol was exploited while testing the system's usability [183]. The facilitator asked the user to verbally express their thoughts during the interaction with the interface.

The initial user evaluation

We conducted 38 interviews with students afferent to the Cesena campus (I1-I38). The participants' sample was formed as follows: 8 (21%) females and 30

(79%) males, with ages ranging from 19 to 30, 30 (79%) bachelor students, 7 (18%) master students, and 1 Ph.D. student. The students were mostly from the Computer Science and Engineering area (31); the remaining were enrolled in different degrees, including architecture and biomedical engineering. It is worth mentioning that these percentages respect the student population structure in the Campus we have taken as our case study.

In this initial user evaluation, the interaction tasks were based on the following two scenarios:

1. The first scenario was "As a student, you would like to attend the lesson of the X class held by professor Y", where X was a lecture taking place that day, and Y was the relative professor's name. In this case, we wanted the user to find the right classroom.

2. The second scenario was "As a student, you have requested a reception with Professor Y. The meeting has been confirmed in her office", where Y was the professor's name. In this case, we wanted the user to find out an office.

It is worth noticing that the users were not explicitly told to find a place, but the activity to complete was hidden by describing a general scenario. In this way, we did not influence the interviewees or help them with the steps to complete the activity. In order to make a more accurate analysis, all users started from the home screen to perform the two tasks. Such interaction tasks had two purposes. Firstly, they allowed the users to interact in the first person with the system and answer the questions in a more concrete and precise way. Secondly, they help us see the problems arising in the usage and interaction.

Results. 14 interviewees (37%) were experienced users (Q4) as they had already interacted with the system: 7 of them out of curiosity, 4 of them searched a lab, a classroom, or an office, 2 of them to find available classrooms where to study, and 1 to see the arrangement of classrooms and bathrooms (Q5.a). 24 interviewees (73%) were inexperienced users (Q4): 9 of them never approached the system since they didn't understand its usefulness or its functionality, 6 of them weren't curious about it, 4 of them didn't see the monitor at the entrance, 4 already knew where to go, 1 said that it was difficult to use it, and 1 didn't interact with it for lack of time (Q5.b). This information allowed us to reflect on three issues: i) the project was not publicized; ii) the location of the monitor was not noticeable; perhaps the inclusion of a sign or pictures would have allowed students to notice the monitor; and iii) there was no guideline presenting how to interact with the system.

All participants were able to complete the interaction tasks. More problems arose with the first scenario because many users were not familiar with the system. For the same reason, the duration of the activities changed: the first one lasted from a minimum of one minute to a maximum of three minutes, while the second took less than a minute. These factors led us to think that the system, only after one use, was considered easy to use by the users and that they were able to understand how to reduce the search time by making fewer steps, thus finding the shortest way to perform the task. After the activities had been carried out and an overview of the system's functionalities was given, most participants thought it was useful (92%) (Q6).

Concerning Q7, many interviewees suggested having a list of the functionality on the homepage instead of the building map, as they didn't think it was an interactive system. I1 said: "I would like an introductory screen that quickly explains the system's features". Regarding the usability, many participants did not notice the search bar, which would have facilitated the two activities. I3 said: "The search should be better highlighted and more visible, with an icon that makes it more evident.". Moreover, some students suggested adding a wayfinding functionality with all the indications, like Google Maps. For many interviewees, it was important to find spaces (classrooms, library, open spaces) where to study or to wait for the beginning of a new lesson (Q8). I5 said: "It would be useful to include a function that indicates which classrooms are free at the time of the search", I9 said: "It would be useful to indicate which spaces are dedicated to students", I24 said: "It would be useful to indicate the hours of the library and if there are places available". Some participants believed it was nice to use the system to advertise the events organized by the university. In fact, I31 said: "It would be good to put the events on the screen". Concerning the sensors (Q9 and Q10), we found two different groups of interviewees. One group was interested in the sensors and their information. For example, I15 said: "I would like to have a description of the sensors with more detailed information for each of them, with also a global view.". A second group did not notice them or could not figure out what they were or represented.

Finally, 32 students (84%) were interested in having a mobile version to choose their course (to decrease the search time), geolocate the classrooms, and see free spaces. On the contrary, 4 participants claimed they would not use the mobile version because they are not fond of mobile apps.

The prototypes design

After the interviews' analysis, we focused on the sensors, attempting to understand how to improve the visualization of the data collected from them. To do so, we decided to create two different prototypes to see the preferred one. Three types of data were chosen based on previous interviews, i.e., based on what users expressed they wanted to see and what they felt was more meaningful regarding the sensors. Therefore we chose to represent data regarding temperature, brightness, and humidity. In these prototypes, we placed three images on the right side of the map, referring to the typology of the data collected. We decided to use images familiar to the user (i.e., images used in other applications or objects of everyday use) so s/he can understand their meanings by simply looking at them. In particular, we selected a sun for the light sensor, a thermostat for the temperature, and a droplet for the humidity.

Both prototypes had the same main screen of the system already deployed to avoid confusion. The only difference was the addition of the three icons on the

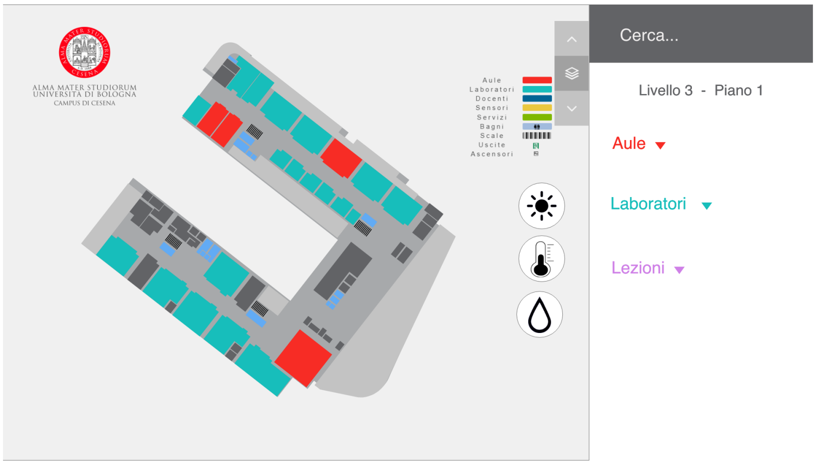

FIGURE 2.6: The homepage of the two prototypes with the three icons on the left that showed the three types of sensor data to visualize (brightness, temperature, and humidity).

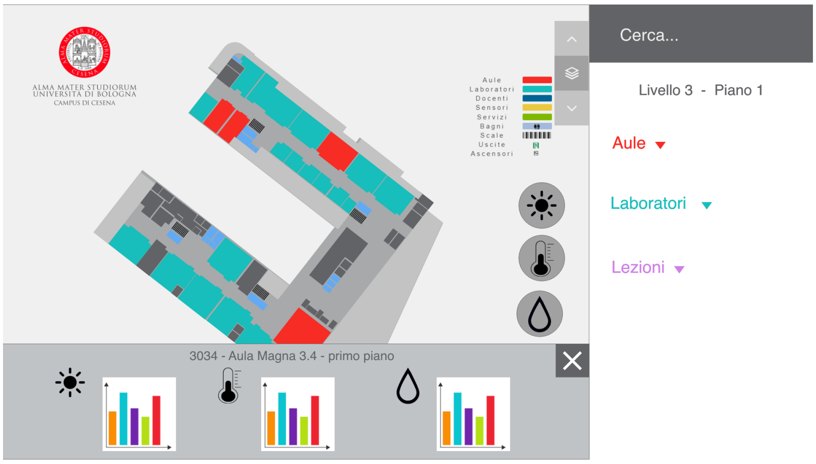

FIGURE 2.7: When a space is selected, the graphs for all the data will be displayed.

left that represented the sensors' data that it was possible to visualize (Figure 2.6).

Moreover, by clicking on each space in both of the prototypes, the user could see more detailed and historical information about the data collected through some graphs, as shown in Figure 2.7.

First Prototype. In the first prototype, we chose to visualize the current data coming from the sensors as a colored icon within the space where they were located (lab or classroom), as shown in Figure 2.8. By default, the sensors were not displayed but appeared when the user clicked on the relevant side icon. In this way, the user could choose how many sensors to visualize at the same time

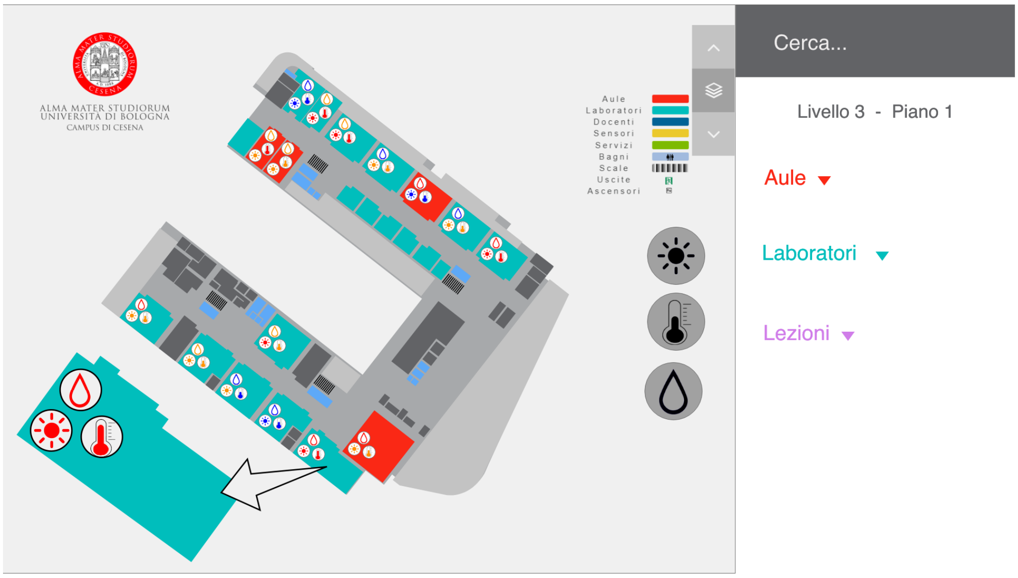

FIGURE 2.8: The UI of the first prototype with the three icons on the left selected. The three icons were all selected so each space has inside the three icons displaying the current value for each sensor, as shown in the zoomed space on the bottom left of the figure.

and have a general overview of all the floors. When an icon was selected, its color would change to gray to make the selection clearer. Instead, the color of the sensors' icon in each space would change based on the data collected. In particular, it would be red if the value was high, orange for a medium value, and blue for a low value. We have chosen these three colors as they are familiar to the user and are usually exploited to indicate high or low values.

Second Prototype. In the second prototype, we chose to color the spaces according to the data collected by the sensors. For example, if the user clicks on the brightness button, each classroom will change color according to the values of that sensor (Figure 2.9). The choice of colors is the same as in the first prototype. In this case, we decided to include a color legend to avoid confusing a user with the change of color. In this prototype, there was no possibility of seeing the data of all the sensors at the same time, so there was no general overview. The main difference from the first prototype concerns the data being shown differently. For example, in the first prototype, the sensors' data are displayed as icons inside their place (as shown in Figure 2.8), while in the second one, the value of the data colors the space (Figure 2.9). Moreover, in the first

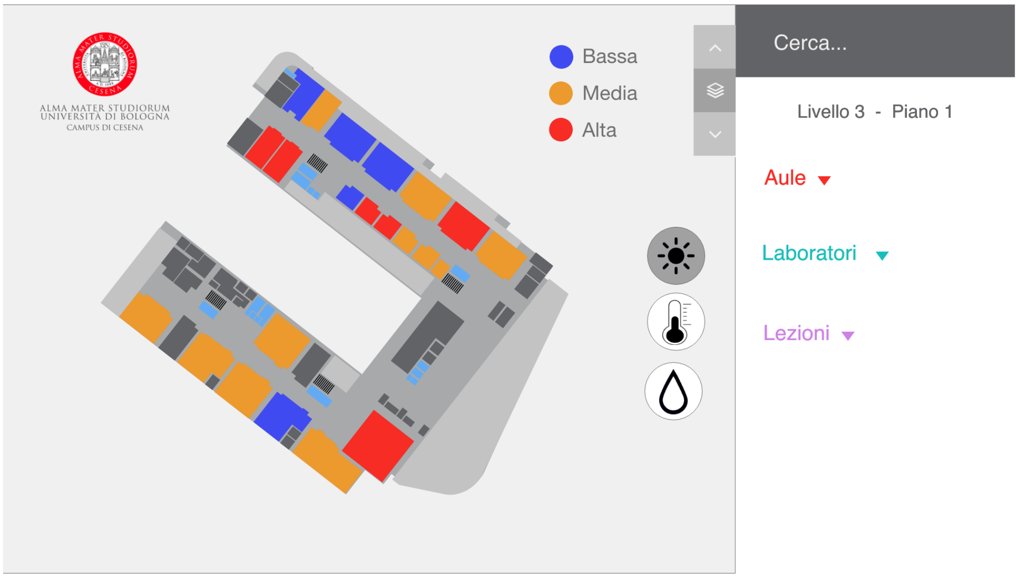

FIGURE 2.9: The UI of the second prototype with the brightness icons selected. Each space is colored based on the current data gathered by the brightness sensors. A legend for the color is also displayed to help the users and avoid confusion.

one, a user can see all the sensors at once, while in the second one, a user can see only one sensor at a time.

The final user evaluation

As already mentioned in 2.4.3, to analyze the usability and intuitiveness of the two prototypes, we conducted another series of interviews targeting students on campus. Therefore, the purpose of these interviews was to find the best solution between the two prototypes and to draw some conclusions on how the sensors' data should be displayed. The interview was carried out by the same two facilitators of the previous interviews. The use of the same facilitators, as well as for organizational reasons, brought three advantages: i) they already knew the difficulties encountered by the users in the previous interviews, ii) they were familiar with this mode of interviewing, and iii) in case a user who had already done the first interview came back, s/he would have felt at ease sooner, having already created a relationship of trust with them.

The adopted protocol was the same. The only difference was that the evaluation, this time, was focused on the two interactive prototypes instead of the whole system. Nonetheless, we visualized the interactive prototype on the same kiosk to not affect users' confidence in interacting with the system.

In this evaluation, we only defined one interaction task, and we asked participants to repeat it for both the prototypes. The interaction task was: "As a student, you would like to know the indoor conditions inside classroom X", where X was a classroom occupied by a lecture taking place that day.

Results We conducted 10 interviews with students afferent to the Cesena campus (I1-I10). The participants' sample was composed as follows: 3 (30%) females and 7 (70%) males, with ages ranging from 20 to 36, 4 (40%) bachelor students, and 6 (60%) master students. 8 interviewees were Computer Science students; 1 was a biomedical engineering student, and 1 a psychology student. It is worth noting that, at this stage of the presented study, we aimed to collect data devoted to a qualitative study. Involving 10 participants does not give us significant results from a statistical point of view, but they provide precious insights for a qualitative analysis of the obtained data. In fact, according to the literature [184], involving 5 users in testing a user interface and its interaction mechanism would result in the identification of an average number of interaction problems that is equal to 85% of all the problems in that user interface, and the 100% of the problems is averagely identified by engaging 15 users. Hence, 10 participants would detect the most significant issues with the analyzed user interface.

8 students had already interacted with the system (Q4), but half of them had never noticed the sensors. 7 of the interviewees thought it was useful to have information about environmental conditions collected by sensors in the spaces (Q10).

In general, the interviewees wanted to see information about the temperature (to find the room with the best temperature to stay inside) and light (to see the empty spaces). They weren't interested in the PM, as some of them didn't understand its meaning. Moreover, half of them (5) asked for a "presence sensor" to get data about the number of people inside a class/lab.

The prototypes were evaluated based on two dimensions: intuitiveness and satisfaction. The first one indicated that the colors, icons, and interface were easy to understand and use. Meanwhile, by satisfaction, we mean what the prototype left to the users, what was their first impression, if they liked the graphics, and all those feelings born in the user when using the prototypes. Analyzing and coding the interviews and the observations and field notes taken during the sessions, we can state that the first prototype was intuitive for 90% of the respondents, even if it did not completely satisfy all users (40% of them weren't satisfied). The second prototype was both intuitive and satisfactory for 70% of the interviewees. Even if this one was initially less intuitive it brought more satisfaction than the other.

For both prototypes, the students liked having the current data but thought that the visualization of historical data could be avoided.

Finally, from the interviews and the field notes, it emerged that 70% of the respondents preferred the second prototype. Even if they liked the first prototype because it had a global visualization of all three sensors, it brought several doubts about how to manage the space on the map. In fact, I4 said: "The visualization of all the sensors together is useful, but if there are more sensors, it would be difficult to read it because of the limited space.". Interestingly, I5 also said: "The second prototype might interest a general user more than a technician (the other prototype could be better for a technician) because this one is more intuitive." Concerning the intuitiveness of the two prototypes, there is no clear differentiation, but the satisfaction left by these prototypes was greater in the second one. In fact, I8 said: "This prototype (referred to the second one) is more beautiful, but, obviously, it is not possible to simultaneously visualize all three sensors on the global map. Although the first one is more intuitive, I like this one more, also because it gives me a rough outline of what I am looking for", also I1: "This prototype is easier. The legend is useful to understand what the colors refer to. I prefer this one because the colors have more impact than the other".

The choice of the preferred prototype was also influenced by their ability to process information related to the sensors' data. In this way, the final choice made it possible to deal also with the cognitive overload issue.

Final Implementation Based on the considerations made after the interviews, the second prototype was chosen for the final version of the system. However, based on the feedback received, some modifications concerning the icons and the colors were implemented. As a matter of fact, 80% of the respondents immediately figured out what the icons represented, although not all guessed the meaning of the colors. For this reason, in the final prototype, it was decided to keep the same icons and maintain the legend to indicate the colors' meaning. In fact, I2 says: "Thanks to the legend of the second prototype, I was able to understand immediately what the colors were referring to, something that I had not immediately understood in the first prototype". I3 also commented on the icon buttons: "The only lack for the icon buttons is the gray color when selected. In fact, you usually use that color to indicate that something is disabled. This could be confusing for the user". For this reason, in the final version, we decided to change the color for selecting and deselecting the icon buttons, as shown in Figure 2.10. This choice was also justified by the intention of limiting the cognitive overload of the users. For the same reason, we removed information considered unnecessary by the students, e.g., we eliminated the data about humidity.

Discussion and Limitations

All things considered, we can claim that this study has three main novel aspects. First, we exploited an iterative design cycle in a novel domain, that is HBI, actively engaging non-expert building occupants in the process (instead of expert users). Second, we translated the peculiar insights collected directly involving users into design recommendations. Third, with this work, we intended to fill the gap related to data visualization in the BIM context.

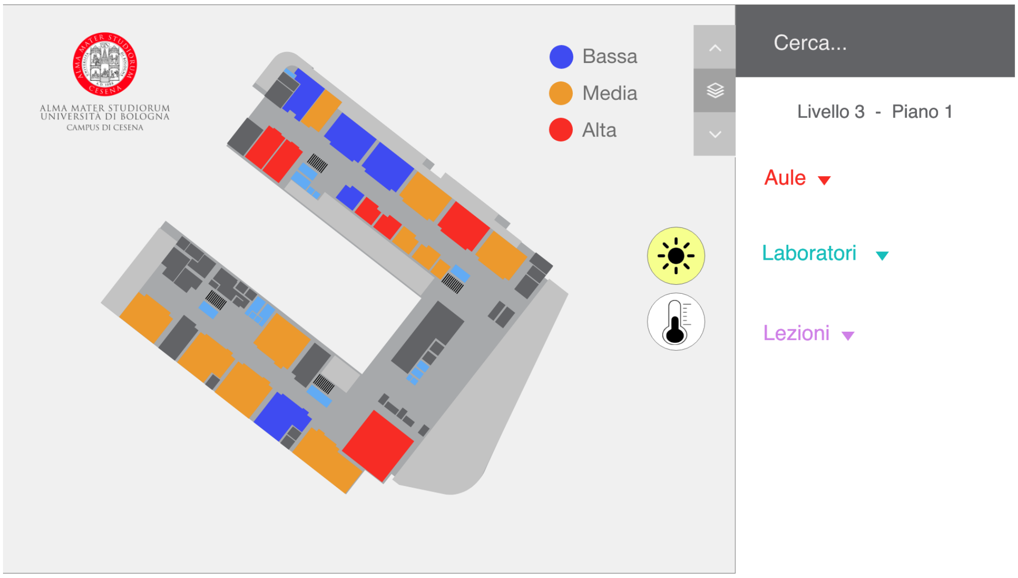

FIGURE 2.10: The UI of the final version created after the interviews starting from the second prototype. We kept the legend, and the icons for brightness and temperature, and we changed the color for the selected sensor.

From a practical perspective, we envision the possibility of using the system not solely for the initial purpose of finding the lecture hall or faculty offices but also for increasing awareness of the building's environmental conditions and, eventually, sustainability as a human value. In fact, Friedman defines the term human value as "what a person or group of people consider important in life" [94]. This broad notion is accompanied by a non-exclusive list of specific values named Human Welfare, Ownership and Property, Privacy, Freedom from Bias, Universal Usability, Trust, Autonomy, Informed Consent, Accountability, Courtesy, Identity, Calmness, and Environmental Sustainability [94]. In this study, we primarily focus on the last one: Environmental Sustainability.

However, including information about the current temperature and light can help students choose the best space to study or work in a group (i.e., the warmer or cooler classroom or an empty one where the lights are off). As a side effect, this will also ensure that students will not stop using the system once they become aware of classrooms/labs locations, engaging students over time. In terms of building environmental conditions, engaging the students in the interviews made us realize that the sensors most appreciated to increase awareness were the temperature and the brightness (which led us to remove the humidity). Moreover, interesting is the fact that most of the students pointed out the necessity of having a sensor for counting people inside each space. Finally, all the students also remarked on the importance of having a clear legend, as it helped them or confirmed what they thought about the meaning of the color. This last result is not surprising since it confirmed one of the 10 well-known Jakob Nielsen's usability heuristics: "recognition rather than recall" [181]. This heuristic reports that: "minimize the user's memory load by making elements, actions, and options visible. The user should not have to remember information from one part of the interface to another. Information reaquired to use the design (e.g. field labels or menu items) should be visible or easily retrievable when needed" [181].

From a framework perspective, we can draw some conclusions on the design of interfaces that aim to display indoor environmental conditions, using sensors installed inside public and shareable spaces, like a smart campus. Such gathered data are intended to be provided to a community of non-experts. These conclusions can be translated into a series of recommendations for the design of a map-based interface:

1. create a visualization designed considering specific target communities (students versus staff);

2. understand which sensors to display: before starting the design, it is essential to understand what types of sensors you have available and which are of interest to the target communities to create prototypes with only the necessary information;

3. provide a global map view of a single sensor at a time: this avoids cognitive overload for non-expert users;

4. choose between current data against historical data: avoid adding information that is of no interest to the target communities (in our case study, the historical data were considered useless to the students);

5. choose the right icons for the sensors: icons are more immediate but not always clear without an explanation;

6. choose colors for the data whose meaning is clear (i.e., worm and cold colors) and use colors to color the entire space to give an overall idea of the current situation;

7. use a legend: even if the icon or color seems clear, a visible legend is necessary;

8. add the name of spaces (if possible): not necessarily all users understand which space is only by looking at the map, so if the space allows you, add over the name.

Our work has two limitations that call for future work. First, the number of interviewed students was limited. This wasn't a problem for the usability test as Nielsen and Molich demonstrated that 50% of the major usability problems can be detected with only 3 users [185]. With 5 users, 90% of the most frequent usability problems can be detected. By most frequent problems, we mean those problems that occur with a frequency of at least 31% (that is an average problem frequency) [184]. As the number of participants increases, the percentage of problems with that frequency slightly increases because each new participant identifies problems already encountered by previous participants. However, the addition of participants also increases the probability of detecting problems with lower frequencies, which can be desirable or even significant. Future studies should include larger sample sizes to achieve more accurate findings. Nonetheless, analyzing in detail the obtained results, we can affirm that data provide valuable information, and such insights can be useful for developing cumulative knowledge [161].

Second, in our study, we only considered the student community, as they were the ones who most interacted with the monitor at the entrance. Replicating the study by integrating other communities, such as technical-administrative staff or faculty, could lead to new insights into the project as they may be interested in aspects not yet analyzed. As one interviewee suggested, the choice of the prototype could be different for the technical staff, implicating that the same data or info could benefit various communities if visualized in different ways [213].

2.5 Improve the Smart Campus sustainability and safety

The second system was designed, implemented, and deployed to assist administrative staff, ICT staff, faculty members, and, lastly, students in increasing the sustainability and safety of the Cesena Smart Campus. In particular, we exploited a responsive web-based dashboard to analyze data by interacting directly with a visual representation of them. Such data are related to the University timetabling and are the result of the aggregation/integration of different data sources, including University Open Data and data gathered by our IoT infrastructure. In fact, the IoT infrastructure enables the collection of real-time data about i) premises (i.e., classrooms and labs) occupancy thanks to a camera-based people counting service [172]; and ii) environmental conditions (e.g., air quality, temperature, humidity) through the Canarin II sensors stations [173]. We deployed such IoT infrastructure in 20 classrooms and labs. To present the potentialities of our approach, we investigated two cases: one related to sustainability and energy saving and the other related to safety and the new COVID-19 restrictions and regulations.

2.5.1 Architecture

The second system is composed of two core components: i) the IoT infrastructure to gather real-time classrooms/labs occupancy and environmental conditions, and ii) the Data Visualization web application. An overview of the overall architecture is depicted in Figure 2.11.

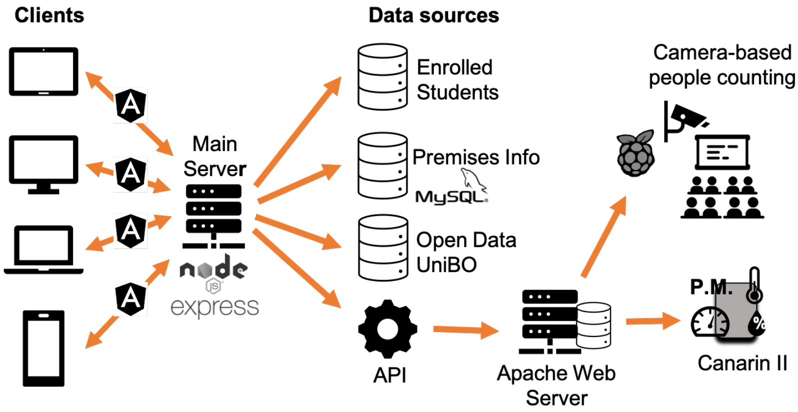

FIGURE 2.11: The system architecture.

IoT infrastructure

Our IoT infrastructure is composed of two elements: i) an edge-based system that exploits cameras for people counting, and ii) environmental conditions sensors stations to sense air contaminants, gathering formaldehyde, PM 1.0, PM 2.5, and PM 10 values, temperature, relative humidity, and air pressure. Focusing on the camera-based system for people counting, the main constituent of our architecture is the client side since almost the whole computation occurs there. In particular, the architecture is composed of three layers. (1) The data acquisition layer is devoted to the data acquisition, exploiting Intel RealSense D415 Depth cameras. The cameras are plugged-in (via USB) to a Raspberry Pi 4 model B, and we acquired 1280 x 720 pixel frame rate images every five minutes (this interval was set to better support the storing operations). (2) The prediction layer retrieves data from the cameras on the client-side and exploits a custom model based on YOLOv3 with the aim of predicting the number of people in a precise moment, dividing the image into regions, and predicting bounding boxes and probabilities for each region. In doing that, we exploit a transfer learning methodology. Once the prediction is done, the number of people predicted and the timestamp are stored in a file with a CSV extension. (3) The API layer, which, over HTTPS, responds to the needed information to the server requests. This three-layer architecture based on a *fat client-thin server* has four main advantages: higher scalability, working semi-offline, higher availability, and privacy compliance. Moreover, our edge-based transfer learning model allows obtaining an average accuracy equal to or greater than 91% (depending on the room layout). In our IoT infrastructure, we also integrated the Canarin II sensors stations [173]. Such stations allow monitoring of different environmental conditions, including formaldehyde, PM 1.0, PM 2.5, and PM 10 values, temperature, relative humidity, and air pressure. In our testbed, we deployed our infrastructure in 20 premises of the Cesena Campus, including 4 laboratories and 16 classrooms.

The web application

The Data Visualization web application we designed and developed is based on a client-server architecture, as shown in Figure 2.11. Regarding the server-side, we used Node.js[7] and the framework Express[8]. The server communicates with different data sources, such as i) open data provided directly by the University of Bologna to gain information about the courses and the class schedule inside the Cesena campus; ii) a MySQL database containing information (such as name, location, capacity) about classrooms and laboratories inside the campus; and iii) a database with information about the number of enrolled students for each teaching and courses of study. Moreover, our server exploits some APIs to obtain data about the actual presence of people inside a classroom or laboratory (gained by the camera-based people counting infrastructure) and the data about temperature, humidity, air pressure, and particulate matter from the Canarin II sensor stations [173]. This architecture allows us to easily extend it, including new data sources and sensors (through their API). The client-side was implemented with the Angular framework[9] and with the standard web-based languages, like HTML5, CSS3, and TypeScript[10]. Concerning the data visualization elements, we used some Javascript libraries like Google Charts[11] ,

[7]https://nodejs.org/
[8]https://expressjs.com/
[9]https://angular.io/
[10]https://www.typescriptlang.org/
[11]https://developers.google.com/chart

Chart.js[12], and D3.js[13] to make the charts interactive. Using these technologies, we were able to develop a responsive web-based application, enjoyable both from smartphones and tablets and larger screens (i.e., laptops).

The responsive web-based application has been designed as a dashboard that can be accessed both from smartphones, to have quick consultations (for example, to find empty classrooms or laboratories at a specific time), and from devices with larger screens to let the users perform more complex analyses. We designed the interface involving the target users in brainstorming sessions to gain insight into the information and data they needed and the interaction they would like to have to exploit the tool in order to make well-informed decisions. The application aims to improve the management of spaces and class schedules by means of five main functions/components that allow the user to visualize intuitive charts and perform analysis. Each page has a left-side vertical menu (where it is possible to select the specific component out of five) and a search input box on the top-right side. In the following, all the implemented components are presented in detail.

Overview. The homepage of our web application opens the overview component (Figure 2.12). This component displays a series of cards (e.g., three cards in Figure 2.12), each card shows information about a classroom or lab, including details such as the room capacity and the room occupancy (at the specified timestamp). If a lesson is currently taking place, the card also shows the name of the course, the professor's name, and the number of students enrolled. At the bottom of every card, there is a pictorial chart that highlights the occupation status of that room. The number of filled icons (out of five) represents the number of students inside the room in relation to its capacity. Adding more details, one filled icon corresponds to a room's actual occupancy lower than 1/4 (25%) of the room capacity, two filled icons correspond to an occupancy lower than 2/4 (50%), and so on; the fifth icon is used only to warn that the room current occupancy is equal or greater than the room capacity. Moreover, we take advantage

[12] https://www.chartjs.org/
[13] https://d3js.org/

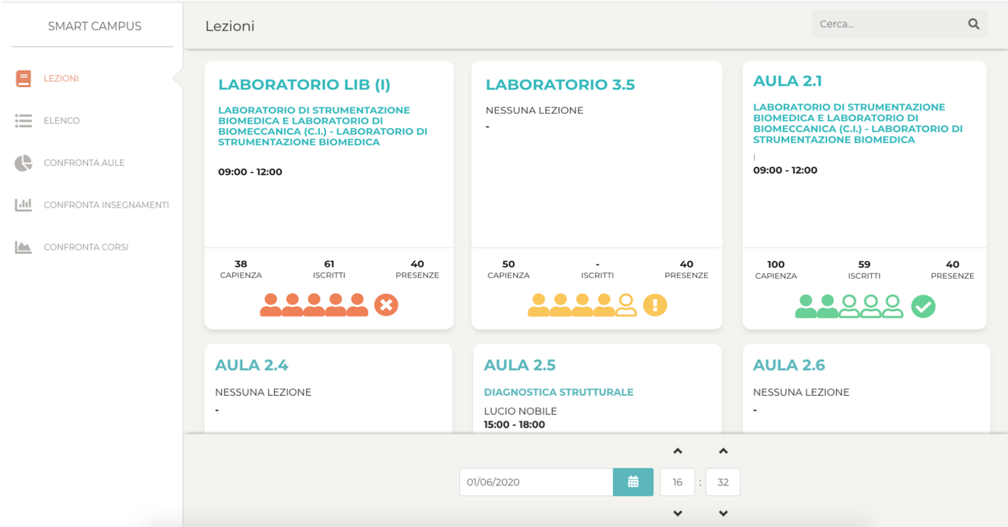

FIGURE 2.12: A screenshot of the system presenting the Overview component.

of colors (green, yellow, and red) to convey messages and easily draw attention to anomalies. Accordingly, if the classroom or laboratory is too crowded (i.e., actual occupancy equal to or greater than the facility capacity), all five icons are filled in red, with an error icon beside it. Instead, in a normal situation, i.e., the actual occupancy is between 25% and 75%, the chart is green (with two or three filled icons), and, finally, if the condition has to be monitored by operators, i.e., lower than 25% (one filled icon) or greater than 75% (four filled icons), the chart is yellow with an alert icon beside it.

List of Classrooms, Laboratories, Courses, and Teachings. The second component of our web application consists of four different lists, including all the classrooms, laboratories, courses, and degrees inside the Cesena campus, each list visualized in a card. The first two cards show the lists of the classrooms (in one card) and the laboratories (in another one) of the campus. Selecting one of them, the user can see the scheduled lessons through a simple list view or a timetable. For all the lessons already held in the selected classroom or laboratory, the list view also presented the pictorial chart described in the overview component, while, in the timetable, the same information is conveyed through the background color of the cell representing the lesson duration over time. Moreover, we wanted to provide the users with an analysis tool to monitor the number of lessons, hours of teaching, and percentage of usage of a given room

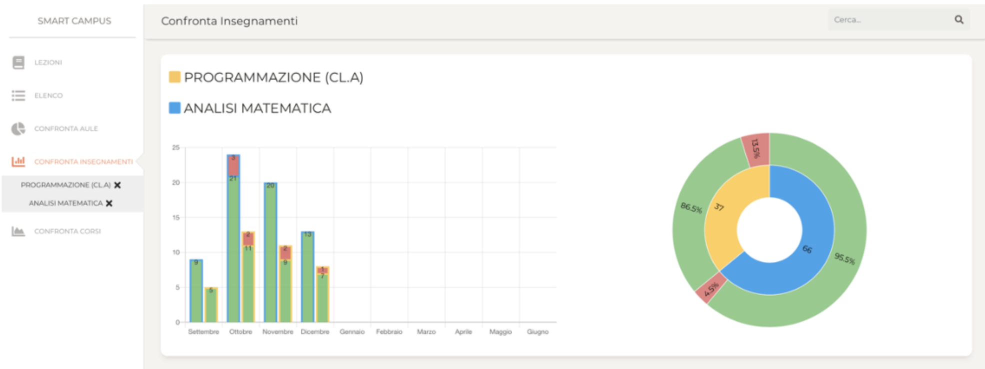

FIGURE 2.13: A screenshot of the system representing the Course comparison component.

(class or lab) through an easily understandable area chart. Lastly, we provide the user with the room location using the campus map in SVG format.

The third card in this component concerns the courses. For each of them, it is possible to see the general information, like the professor's name and the degree program to which it belongs. The scheduled lessons are available both in a text list and area chart visualization. The two visualizations use different visual techniques to display the same information: the attendance trend, the number of enrolled students, and the capacity of the classrooms or laboratories where the lessons are held. The attendance rate is visible through the pictorial graph, in the list view, and through the color of the relative point in the area chart. To provide an additional tool for analysis, a stacked bar graph, and a pie chart were included, presenting in green the percentage of spaces booked and actually used, in gray the percentage of lessons not yet held, and in red the percentage of spaces booked and not correctly used.

The fourth and last card of this component regards the degree program, both bachelor's and master's degrees, on the Cesena campus. For each degree program, we choose to display a list view of all of the courses, the relative professor, and a statistics page to visualize the correct usage of booked spaces. Also, in this case, we used a stacked bar chart and a pie chart with the same colors and meanings as the graphs described in the paragraphs above.

Classrooms and laboratories usage Comparison The third component of the web application concerns the comparison between two or more classrooms and laboratories in terms of the correct usage of space. As mentioned before, for each room (classroom and lab), we monitored the number of lessons and hours and the percentage of occupation. These elements provide a way to compare the effective usage of two or more distinct spaces. For each of the parameters considered, we used two different data visualization techniques (a line graph and a pie chart) to convey the same information so that the users can interact with the one that better reflects their demands. In particular, the line chart displays the number of lessons, hours, and the percentage of use in relation to the months of the year. Instead, the pie chart displays the same information but in relation to the total number of lessons, hours, and percentage of use.

Courses Comparison The comparison between two or more teachings/courses represents the fourth component of the application, and it is presented in Figure 2.13. To compare the different teachings, we used a stacked bar chart and a sunburst graph to display the differences in terms of the percentage of correct space usage and the number of lessons. The stacked bar chart uses the border color to identify the course it refers to (in Figure 2.13, yellow and blue), the green and red color of the bar to display the correct or incorrect usage of spaces, and the gray color for the lessons not yet held in relation to the months of the year. Concerning the sunburst graph, the first ring is divided according to the number of lessons for each teaching, while the second represents the percentage of correct and incorrect space usage for each teaching.

Degree programs Comparison Finally, the last component of our web-based application concerns the comparison of two or more degree programs. Also, in this case, we use the number of lessons and the percentage of correct and incorrect usage of spaces as parameters to compare the degree programs. We implemented a stacked bar chart and a sunburst graph to visualize the number of lessons and the usage of booked space. The meaning of the graphs and the use of border and bar colors are the same as in the course comparison component.

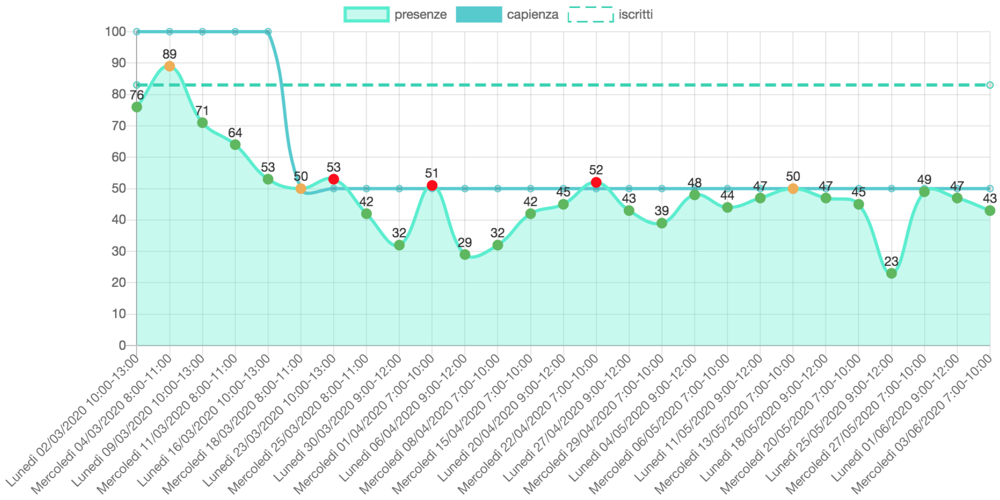

FIGURE 2.14: An area char representing the classroom occupancy values monitored during the COVID-19 pandemic, for a specific course.

2.5.2 Scenarios

To present the potentialities of our system in supporting premises management, we here present two scenarios. The first one focuses on using the data visualization system to verify the real-time occupancy considering the current COVID restrictions and regulations; the second is related to a medium/long-term monitoring of the classrooms/labs occupancy to increase the sustainability of the campus in terms of optimization of the energy consumption.

Scenario 1: real-time safety monitoring

The COVID-19 pandemic changed the way we experience any space and place, putting into effect social distancing measures. Considering University campuses, not always lessons can be taught in presence, but, if and when possible, in-person classes have to be taught in accordance with regulatory requirements and safety protocols. Different strategies have been adopted to ensure compliance with regulatory requirements and safety protocols. For example, the University of Bologna, to manage the capacity of each classroom/lab in the best possible way, developed a service that allows students to schedule the classes they plan to attend in two-week periods, specifying the attendance mode. Unfortunately, this strategy not always works as expected. For this reason, IoT can be exploited, along with similar solutions, to guarantee safety during in-person classes.

Exploiting our IoT infrastructure, and, in particular, the camera-based people counting system, we are able to monitor, in real-time, the number of students on a University premise. Thanks to our Data Visualization dashboard, we can obtain the actual classrooms/labs capacity (considering the current regulation) and visualize the room occupancy accordingly. This information is visible on the system home page in the overview component. In fact, the card allows us to immediately check the room occupancy in relation to the room capacity to ensure social distancing and safety. As an example, going back to Figure 2.12, used to present the overview components, it is possible to infer that: in lab LIB (on the left), the actual occupancy is greater than the actual capacity (red color and five filled icons), while in lab 3.5 (center) the actual occupancy is close to the maximum (yellow color and four out of five filled icon), and, finally, in lab 2.1 (on the right), the number of students in the room doesn't present any anomaly (green color and two out of five filled icons). When the pictorial chart becomes red (i.e., the room's actual occupancy is greater than the room's actual capacity), a notification is sent to the people responsible for the health and safety inside the campus.

Moreover, by integrating University's official data sources, the system can automatically update its data and visualize the information accordingly. As an example, in Figure 2.14, it is possible to see the impact of the decrease of the allowed room capacity value due to COVID-19 regulations regarding social distance (the allowed room capacity became 50, while it was 100 by design).

Scenario 2: medium/long term sustainability

As mentioned, defining a school/university timetabling is a complex task to solve [200]. With our approach, we are not interested in automatically solving such a problem but mostly in exploiting data visualization and IoT strategies to facilitate University staff in making the best decisions, considering also the campus sustainability. In fact, it has been proved that an efficient timetable could also reduce energy consumption and therefore increase the sustainability of the campus [244].

Our visual application has been designed to facilitate the discovery of not optimal classrooms/labs and course assignments on the basis of the real-time data collected by our IoT infrastructure. In fact, as presented also in Figure 2.14, by selecting one course, it is possible to analyze in detail the actual occupancy of the room during the course weeks in relation to the room capacity. Moreover, by selecting one specific value in the chart, it is possible to see a modal presenting the timetable of the other courses and see the classrooms (or labs) availability during that time slot (as shown in Figure 2.15). Considering, for example, that for the last three weeks, the number of students attending a course is usually half than expected, it is possible to "release" the assigned room and look for a smaller room that can host the students. This action can have an immediate impact on energy saving because a large space causes a higher level of heating and cooling loads if compared with a smaller one.

Moreover, through the course comparison component (that we previously presented exploiting Figure 2.13), it is possible to compare two courses, focusing on two values: the number of lessons that have achieved a satisfactory occupancy value in relation to the room capacity, and the number of lessons that prompted an anomaly. These visualizations could help the administrative staff to change the classroom for those lessons having an attendance rate much lower or greater than the room capacity, leading to an improvement in space management on our campus.

2.6 Discussion and conclusion

In this Chapter, we introduce our approach to making a campus community aware of topics related to the green economy, giving them the opportunity to make more informed decisions. In particular, our case study was based on

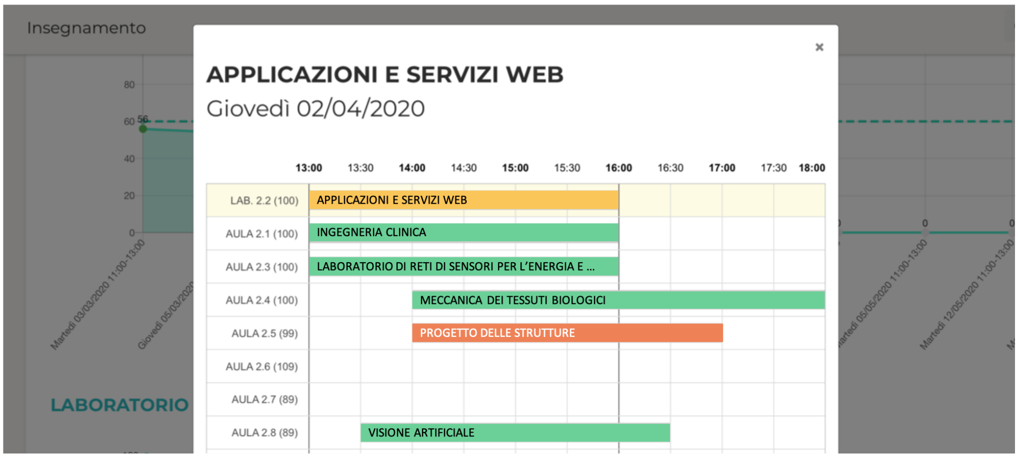

FIGURE 2.15: Timetable to compare classroom (or lab) availability and perform an exchange to improve sustainability.

Human-Building Interaction between a Smart Campus (building) and its community.

To verify the assumptions presented in Section 2.3, we designed, developed, and evaluated two different systems in the context of the newly-built Cesena Smart Campus, one of the campuses of the University of Bologna. The results are here summarized and discussed.

A user interface designed for a specific community increases occupants' context awareness about environmental issues within a building, supporting them to make more informed decisions that best suit their needs. Concerning the first research question (RQ1), with our system, we wanted to prove the importance of having a community that not only passively benefits from the system but also exploits it to become aware of its effects on environmental comfort and community itself. To demonstrate that, we designed a system made of an IoT infrastructure and a public installation. In particular, the sensors collect the environmental information displayed in the interface enjoyable through the public installation, through which the community can interact with hyperlocal data. After the development of the system, we evaluated it through a mixed methods approach involving the campus community. We analyzed both quantitative data from the system log (more than 10.000 interactions) and the questionnaire administered to 135 students and qualitative data from the feedback requested in the questionnaire. Then, we wanted to increase occupants' awareness of environmental conditions inside a smart building and address two main research challenges. Firstly, several studies about building data visualization used environmental conditions data only for monitoring, managing, or control, without taking into account the non-expert building occupants' needs and awareness. Secondly, if focusing on the area of HBI, previous studies focused on improving the experience of building occupants by exploiting sensors' data, especially those collecting data about temperature, and energy usage, leaving out the possibility of increasing occupants' awareness of environmental conditions. To fill these two gaps, we performed a study engaging users (non-expert building occupants) in the design of a system able to visualize sensed data and increase the users' awareness. To this end, we initially evaluated the system through structured interviews, and then we revised the map-based interface and prototyped two different versions, integrating the users' comments and suggestions. Finally, the users were engaged in the re-evaluation of the systems. This allowed us to refine the system based on the new insights and implement a final version.

An interactive data visualization tool improves campus sustainability (in terms of energy saving) and safety (considering the COVID-19 restrictions and regulations). We presented an integrated approach that combines IoT infrastructures (e.g., a camera-based people counting service and sensors for environmental conditions monitoring) and Data Visualization strategies to i) ensure safety, and ii) improve the sustainability of a University campus. As a testbed, we deployed our approach in the Cesena (smart) campus, one of the campuses of the University of Bologna. It is worth noting that the system was initially designed with the main goal of facilitating University staff to monitor premises occupancy and improve the course timetabling accordingly, increasing Campus sustainability. Nonetheless, with the start of the COVID-19 pandemic, it shows its potential to monitor safety aspects introduced with the actual regulations and constraints. As future work, we plan to integrate a machine learning module in our web application that uses the data gathered during the first year of deployment to suggest timetabling recommendations to improve Campus sustainability and safety.

Chapter 3

Case study: Dematerialization

As mentioned in Chapter 1, one of the main targets of SDG8 is the green economy, which refers to a development model for sustainable growth with a low environmental impact. This Chapter presents the work done to promote awareness about this topic, especially about dematerialization. To accomplish this goal, it was necessary to first identify the context and the target community. Also for this case study, we focused on the University of Bologna and, consequently, its community was chosen as our target community. We designed and developed a system aimed at promoting the actions made by the University of Bologna to save papers. The rest of this Chapter is organized as follows. Section 3.1 introduces the importance of sustainability and SDGs, and, in particular, the necessity of paper reduction. Section 3.2 presents the main related works about information visualization to communicate sustainability issues and engage communities. Section 3.3 illustrates the main assumption behind our system. Section 3.4 describes the design, the architecture, and the implementation of the whole system, focusing, in particular, on the design and implementation of two web infographics, while Section 3.5 presents its evaluation involving users from the University community. Finally, Section 3.6 summarizes the work and the main findings.

3.1 Introduction

Humanity is facing several global challenges, including those related to poverty, hunger, inequality, climate change, decent employment, and peace and justice. As mentioned before, in 2015, the general assembly of the United Nations defined a universal call to action, titled *Transforming our world: the 2030 Agenda for Sustainable Development*, which aims to address these major challenges in order to achieve a better and more sustainable future for all [179, 142]. It also presented the 17 SDGs as targeted actions to mobilize global efforts to end poverty, protect the planet and ensure that all people enjoy peace and prosperity by 2030 [179, 142].

As mentioned before, the SDGs seek worldwide actions among governments, businesses, and civil society. Since its definition, the agenda was adopted by 193 states at the United Nations and all governments worldwide have agreed to its goals. Nonetheless, its success relies heavily on actions and collaborations by all actors. Accordingly, fundamental is the effort of companies and institutions to align their strategies as well as to measure and manage their contribution to the realization of the goals [65], as stated by Ban Ki-moon, Secretary-General: "Companies can contribute through their core activities, and we ask companies everywhere to assess their impact, set ambitious goals and communicate transparently about the results" [65]. Likewise, universities in Europe and around the world are crucial to global sustainable development [14].

In this context, the University of Bologna puts in place different strategies and actions to achieve the SDGs, focusing, in particular, on four dimensions: teaching, research, third mission, and institution [27]. At the same time, the University is undertaking actions to reduce its impact on the environment. One of these actions aims to reduce the use of paper, embracing the *paperless* concept [108]. The idea behinds this concept is really simple: attenuating the papermaking environmental impact by managing documents (creation, modification, storage and retrieval) only (or mostly) in digital form, and the impact of this strategy has been investigated in different contexts, such as office [197, 1], classroom [13, 74], University and campus [116, 132, 216], and society [164, 102].

The paperless movement has a two-fold significant positive effect on sustainable development. Firstly, it allows for promoting the sustainable use of terrestrial ecosystems and sustainable management of forests, combating deforestation (according to SDG 15). Indeed, forests are a critical foundation to assure sustainable development, reducing the risk of natural disasters, including floods, droughts, landslides, and other extreme events, and mitigating climate change through carbon sequestration, contributing to the balance of oxygen, carbon dioxide, and humidity in the air and protect watersheds, which supply 75% of freshwater worldwide [178]. Moreover, forests are crucial for food, water, wood, energy, biodiversity, and health [205], nonetheless, they are experiencing deforestation and degradation. From 2000 to 2013, the global intact forest landscape area decreased by 7.2%, a reduction of 919,000 km^2 [210]. People cut down 15 billion trees each year and the global tree count has fallen by 46% since the beginning of human civilization [68]. Paper production is one of the main players behind deforestation: 50% of the world's industrial logging is transformed into paper [20]. In fact, despite we entered the digital era, the global demand for paper products has actually increased in the last decades (with a global increase of 3% per year), evidenced by the more than 350 million tons produced annually [25, 242, 76].

Secondly, reducing the amount of paper used will benefit the environment since the papermaking process is toxic, resource-intensive, and uses chemicals and pollutants that are creating major health issues and environmental degradation. Moreover, the process required to obtain paper pulp (the primary material used for papermaking), together with the disposal of paper waste products are the major contributors to greenhouse gas emissions [242]. As a consequence, the pulp and paper industry is one of the largest energy consumers, greenhouse gases (GHG), and pollutant emitters among manufacturing industries. Studies have assessed that the production of one ton of paper results in circa 950 kg of carbon dioxide (CO_2) equivalent greenhouse gases (GHG) emissions (on average) [248].

In this scenario, technology, and in particular, interactive systems, have been proven to be a useful tool to increase user awareness about sustainability topics and strategies, and, consequently, to foster behavior change [92]. Drawing on previous studies on sustainable HCI (e.g., [85, 80, 83]), Data Visualization (e.g., [211, 109, 208]), and public installations to increase awareness (e.g., [263, 23, 118]), we designed a system that exploits different technologies, mixing digital and reality (as detailed in [214]). Here, we detail the design and the evaluation (engaging people from the University community) of one specific component of the system: the web-based application to visualize interactive infographics. In particular, this study focus on the evaluation of two different interactive infographics, designed to exploit different styles and techniques, to extract insights related to the design of infographics to increase awareness about sustainability issues.

3.2 Background and Related Work

Several scholars investigated the use of interactive visualizations, including both data visualization and infographics, to provoke reflections on sustainable behaviors and behavior change. For example, in [229], the authors present the use of an infographic (the Double Pyramid of the Barilla Center for Food and Nutrition) to promote healthier and more sustainable food consumption. After an evaluation phase, results show that nutritional messages do have a significant influence on users involved in the test [229].

In [131], the authors investigated the intuition to design for persuasion. In doing that, they designed two ambient displays as desktop widgets representing a user's computer usage time but in different visual styles: a *coralog* (because coral reefs are currently being destroyed by the rapid increase in the amount of CO_2 dissolved in the ocean and the elevated sea surface temperatures) and a *timelog*.

Holmes designed artworks that display the real-time usage of key resources such as electricity in order to prove if such an approach can offer new strategies to conserve energy in the home and workplace [109]. In particular, the media art, called *7000 oaks and counting*, is composed of a sequence of animated clips using a series of tree images that correspond to the carbon loads in the building. The trees reflect seasonal variation: fall, winter, spring, and summer [109].

The *Imprint* project aimed to bring data into discussions about paper usage and waste [211]. The project displays in a touch-sensitive LCD display 5 visualizations: i) a tag cloud that collects commonly printed words and can serve as a summary of the popular concepts; ii) a visualization to show how popular a given community member is; iii) a visualization that clusters workers based on the documents they printed; iv) a pie chart which aggregates the time that printers are working versus their idle times; a visualization depicts the total amount of energy used to power Imprint itself [211].

In [226], Rist et al. have focused their study on various types of interactive energy visualizations, with particular attention on how the user behavior and, consequently, his/her energy consumption changes on the basis of the exploited visualization. They used the Fogg Behavior Model ([92]) to categorize interactive visualizations ranging from charts to pictorial or gamified visualizations. They aimed to prove that visualizations can increase users' awareness and motivate them to reduce their energy consumption.

Another project presents the visualization of an augmented bin with the relative facebook application that puts users in front of their conscious and unconscious behaviors concerning their waste management [64, 256]. This study insists on the social component, which relies on every user's desire to be accepted by the community and his/her sense of guilt and shame once he/she realizes his/her waste. To improve users' awareness and behavior, they use an approach based on gamification with a weekly visualization for every user. This visualization displays the user's recycling achievements and food waste savings in the form of a tree and gold bars.

To engage public participation and make them aware of not only sustainable issues but also the complexity of sustainable development, in [10], Antle et al. designed and developed a game on a multi-touch interface on public venues. They used the concept of collaborative learning to create a game for seven years old and older people to show them the complexity of balancing the environment and human needs. To verify that the gameplay leads the user to be aware of the difficulties in sustainable development, they used a survey based on 13 questions [11]. The idea of using a public display for people to interact and increase their awareness is not new. Similarly, in [195], Odom et al. present the design and the implementation of an Eco-Visualization in situated displays. The context was a campus community where they implement a dynamic visualization to create competition between dormitories. The main goal was to change the students' long-term behavior regarding energy and resource consumption. They believed that situated displays could create a more engaging experience, which can lead to better consumption habits.

An interesting project is the *Go and Grow* system that presents a living visualization to increase users' awareness and ensure a more active lifestyle [29]. The system uses personal data, like steps taken from a tracker, to properly water a living plant. Also, the authors have provided an online dashboard to have an alternative way to visualize the data. The system wanted to prove that abstract or living visualizations are more emotionally engaging and, accordingly, more capable of producing a behavioral change.

The artwork *A Conversation Between Trees* has been designed with the purpose of establishing a live connection - or conversation - between a distant tree in the Atlantic forest and a local tree at each venue (one of the three selected arts centers located in different UK forests) [118]. The artwork visualizes sensor data, captured and streamed live from each tree on two large displays. Between these visualizations, the "climate machine" is located, an unusual device that visualizes recorded and predicted global CO_2 levels by slowly burning circular graphs onto large circular disks of recycled paper. Moreover, visitors can also experience a walk in the local UK forest during which they can use a mobile phone to capture and visualize images of the forest and answer questions about their feeling about being in the forest [118]. This installation represents an example of "ecologically engaged art" to open up, stimulate and frame the public debate around sustainability [80].

All these examples provide the power of interactive visualization to promote sustainable behavior. Inspired by them, we designed our system.

3.3 Research questions

Considering the background analyzed in the previous Section, we aimed to answer the two research questions, presented in Section 1.2, in the context of the promotion of dematerialization actions. In particular, concerning **RQ1**, we were interested in understanding how to promote the effort protracted over the last years by the University of Bologna for addressing the SDGs and, among other things, towards more sustainable use of forests, reducing the waste of paper. To do so, the focus is to design two interactive infographics employing different graphical styles and navigation mechanisms. In relation to **RQ2**, we wanted to evaluate the two infographics engaging members of the University of Bologna to gain insight into the most effective features. In this case study, we defined effectiveness as the system's capability to visualize and communicate in a clear way these dematerialization actions. These efforts should be known by all the members of the university community.

3.4 Methods

3.4.1 The context

In accordance with the paperless and dematerialization movements, during the last years, the University of Bologna employed several strategies to reduce paper consumption. Due to the University's size, which counts a community of more than 92.000 individuals including students, faculty, and staff, spread over

5 cities, each initiative has a strong impact on sustainability. This impact can be calculated in terms of: i) the number of trees "saved" (i.e., the amount of wood that would be required to produce the given amount of paper); ii) kilograms of CO_2 , a value that measures the CO_2 from burning fossil fuels, methane from paper decomposing in landfills and short-lived climate pollutants, including forest carbon storage loss from logged forests. These values have been estimated considering, for each paperless action, the number of paper sheets not used thanks to the dematerialization strategies, and the "Paper Calculator"[1], a web-based tool that allows calculating the estimated environmental impacts of different paper choices using a science-based methodology grounded in life cycle assessment.

Moreover, to make the effort more tangible to its community, the University governance decided to plant new trees on terrains nearby two newly built campuses; the number of trees that will be planted represents a percentage of the total number of trees saved avoiding the use of paper. This action has two positive effects: it allows the University community to enjoy a tangible result of the paperless strategies, becoming more aware of the University effort, and, moreover, the trees will benefit the Campus area in terms of pollution (CO_2 sequestration) and noise attenuation capability.

3.4.2 System overview

To stimulate reflections related to the sustainable strategies undertaken by the University of Bologna, we designed and implemented a system that takes advantage not only of online rich content related to the paperless effort (exploitable using different devices) but also of the outdoor new green areas that will be created, so as to collect location-based measures and provide personalized visualizations. The whole system comprises different components (exploiting different technologies), as presented in Figure 3.1 and briefly presented in the next paragraphs (more details can be found in [214]).

[1] https://c.environmentalpaper.org/

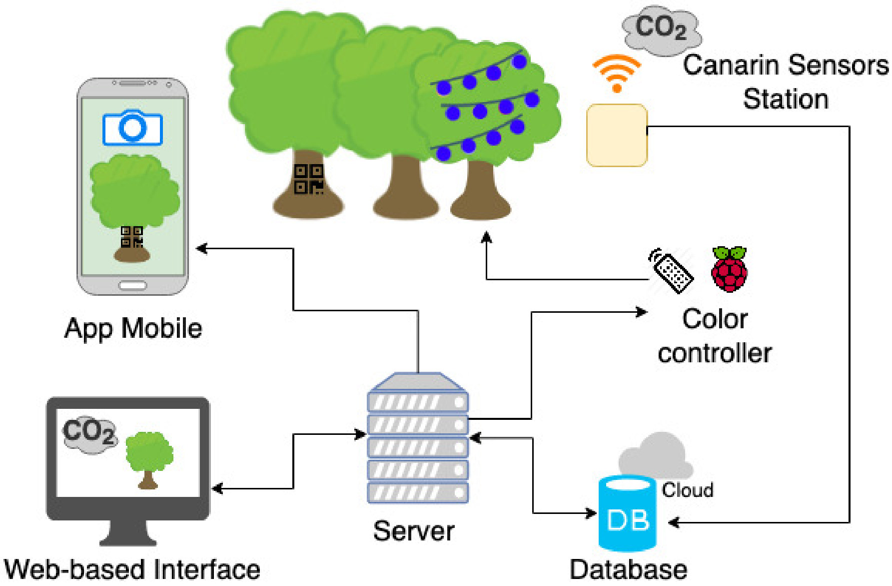

FIGURE 3.1: The system architecture.

The system includes a sensors infrastructure deployed in the Campus green areas where the trees will be planted to collect data on environmental conditions such as particulate matter (PM 1.0, PM 2.5, and PM 10), carbon dioxide (CO_2), and carbon monoxide (CO), nitrogen dioxide (NO_2) and ozone (O_3), formaldehyde, temperature, related humidity, and air pressure. All these sensors are encapsulated in the Canarin II sensors station [262]. The idea is to use these data to provide up-to-date information about the environmental conditions through online content (exploitable from different devices) and an in-situ installation.

Using the gathered sensors' data, we intend to provide an in-situ public installation in the Campus green area, equipping a tree with RGB color LED string lights. The color of the lights will change accordingly to the level of pollution detected in real-time (e.g., "red" if the detected pollution level is critical; "blue" if the detected pollution level is in the range considered as not critical but not so low; and so on).

To link the planted trees with the digital contents of the web application, we prototyped a mobile application (both for Android and iOS devices) able to read specific QR-code markers (placed on the tree) and provide AR information about the real-time environmental condition (i.e., pollution level) together with details about the paperless actions the University is undertaking, while exploring the campus green area.

The last key component in our developed system is represented by the web-based interface that is the focus of this investigation.

3.4.3 The Web-based Interactive Infographics

This work is unfolding alongside a growing interest in using ICT and information visualization to promote sustainable development. Technology has proven to be a useful tool for increasing user awareness about sustainability topics and fostering behavior change. This is particularly true considering interactive systems that provide targeted information and can lead to a process of decision-making, persuading, and influencing the users [92]. In this scenario, Information Visualization (InfoVis), defined as the use of visual representations provided through the use of computers to amplify the user's cognition by leveraging human visual capabilities to make sense of abstract information, has become increasingly relevant [98]. The information is displayed using attributes, such as color, shape, or size, specifically designed to reveal new data or to highlight relationships between the data that may not be noticed at first sight [135]. Interesting is the specific case of infographics (information graphics) where elements of data visualization are combined with design to disseminate data in an attractive and aesthetic fashion [106]. The final aim is always the same, making sense of data and increasing awareness about a specific issue.

Along the same lines, we decided to exploit information visualization, and, in particular, infographics, to provide informative rich content related to the different initiatives the University of Bologna is carrying out in favor of the dematerialization process and in accordance with the paperless movement. To this end, two interactive infographics have been designed and evaluated to exploit different techniques and styles.

The design process

To design the infographics, we carried out two distinct brainstorming sessions:

- one involving four researchers in Human-Computer Interaction (HCI) and data visualization at the department of Computer Science, University of Bologna (CS group);
- the other one engaging three researchers and experts with a background in storytelling, and web and graphic design from the Interactive Technologies Institutes, Madeira (ITI group).

Both sessions lasted circa two hours and a half and began with 10 minutes of introduction to explain the context and the available data. In particular, we asked them to design an infographic including the following information (as design constraints):

1. the number of years the University is carrying out the paperless initiatives;
2. the three main categories used to group the paperless initiatives, i.e., process innovation, dematerialization, and digital communication;
3. for each category, an overview of the specific implemented projects;
4. for each project: name, description, number of sheets not used, number of trees "saved", CO_2 not produced during the papermaking process and stored by the saved trees, and the number of years that activity has been running.

At the end of the two sessions, each group selected one idea to be refined and implemented. From the CS group, the emerged infographic mainly exploits interactivity and animations, using the metaphor of leaves on a tree (where each leaf - circle - represents a project), in an incremental single-page layout; while, from the ITI group, the selected infographic mostly exploits storytelling and aesthetic, recalling correlations between the saved trees (as the result of the paperless actions) and the new Campus green areas, in a horizontal layout, where the story is told using different static frames. For these reasons, we named the first one "Animated infographic" and the second one "Aesthetic infographic".

Infographics implementation

Both the designed infographics have been implemented by exploiting well-known web-based technologies, such as HTML5, CSS3, and Javascript-based libraries. Considering the "Animated infographic", we also take advantage of JQuery UI[2] and D3.js[3] to manage the animations and positioning of the virtual leaves, and frameworks, as Bootstrap[4]. All used images are in scalable vector graphics (SVG) format.

Both the infographics implement a three-layer logic to present content: 1. in the main page it is possible to see an overview of all the categories, 2. then, it is possible to select a category and have an overview of all the projects in such a category, and, finally, 3. data related to a specific project are presented when selected. The main three screens of the two interactive infographics are presented in Figure 3.2 and Figure 3.3, respectively. In particular, in both figures, the first screenshot presents the main page with the general overview of the three categories, the second one presents the overview of the projects related to the "dematerialization" ("Dematerializzazione" in the Italian language) category, and the last one presents details about the "Digital thesis" ("Tesi digitali" in the Italian language) project.

As depicted, the main page of the "Animated infographic" (on the left of Figure 3.2) shows the metaphorical tree with the projects-leaves, the three macro-categories, and the timeline. The user can then select one category (highlighted with the yellow color in the central screen in Figure 3.2) so as to activate (using AJAX) the information container at the bottom of the page. Finally, the user can select one single project to visualize its details (on the right of Figure 3.2). This

[2]https://jqueryui.com/
[3]https://d3js.org/
[4]https://getbootstrap.com/

interface exploits an incremental single-page layout for a vertical-based navigation experience. Moreover, to engage users, we exploited a combination of illustrations, text, and other animated elements to add movement and catch the user's eye.

Adding more details, the "Animated infographic" is made of different animations to trigger the idea of incremental growth of the projects. The user's attention is captured by different animations executing one after the other. In order, the elements that appear are: i) a bare tree at the center of the screen, ii) the year of the project on the right of the screen in the timeline, iii) the project category will be highlighted on the left of the screen, iv) the leaf of the tree related to that year, and v) the number of trees saved that year and the related CO_2 inside the clouds. This series of animations is repeated for each of the four years presented.

The same three layers logic is employed in the "Aesthetic infographic" where, instead, the interaction is based on three static (not animated) frames that provide the different levels of details in a horizontal-based navigation fashion (as shown in Figure 3.3). In this infographic, the main idea is to show the green area of the campus (with the campus building in the background), creating a narrative link between the paperless initiatives and the trees planted in the renewed green area. Unlike the "Animated infographic", in this infographic, the interaction with the elements leads to a new interface every time.

3.5 The evaluation

Developed the two infographics, we engaged users in an evaluation, as presented below.

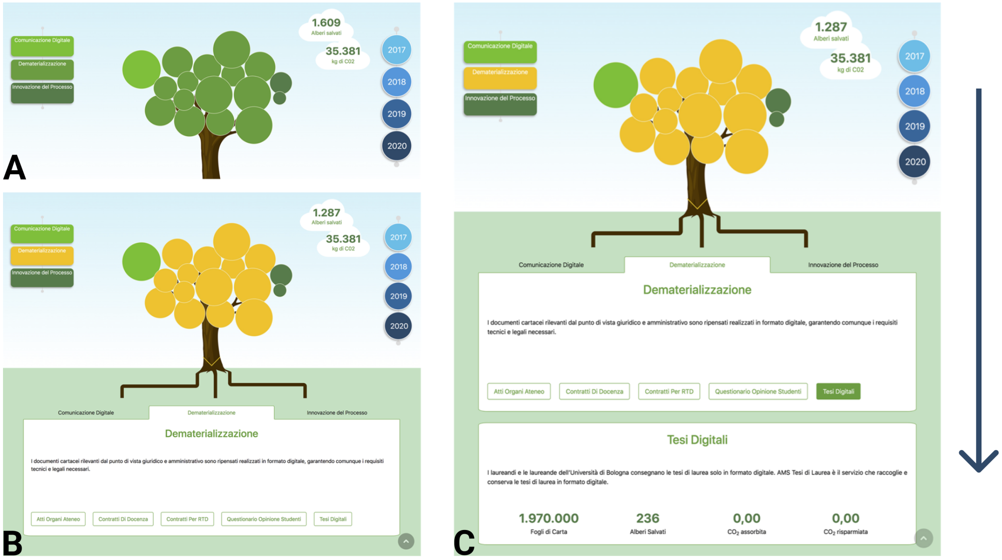

FIGURE 3.2: The "Animated infographic" vertical-based navigation. **A** is the main page where each leaf of the tree represents a project, **B** shows the information of the project category clicked, and **C** shows the information about a single project.

3.5.1 The methodology

To evaluate the two infographics, we developed an online questionnaire (using Google Forms) in order to collect feedback from the University community (including undergraduate, graduate, and Ph.D. students, faculty, and staff members), the one that will benefit from the visualizations.

The issue of evaluating infographics has been investigated in different studies (see, for example, [207, 106, 264]. As a framework to drive our evaluation, defining which dimensions to analyze, we put into practice the one presented in [148]. In such a study, the authors present a user study conducted on two versions, i.e., one interactive and one static (a simple snapshot of the interactive one) of a series of three infographics related to weather forecasts, university ranking, and countries' well-being. Going through a detailed process, the authors observed that users expressed clear preferences for interactive infographics. Drawing on this outcome, the goal of this study is different: comparing two different interactive infographics that differ in the design and graphic style, and level of interactivity and storytelling, while presenting the same data to detect any significant difference in their perceived characteristics. Nonetheless, we

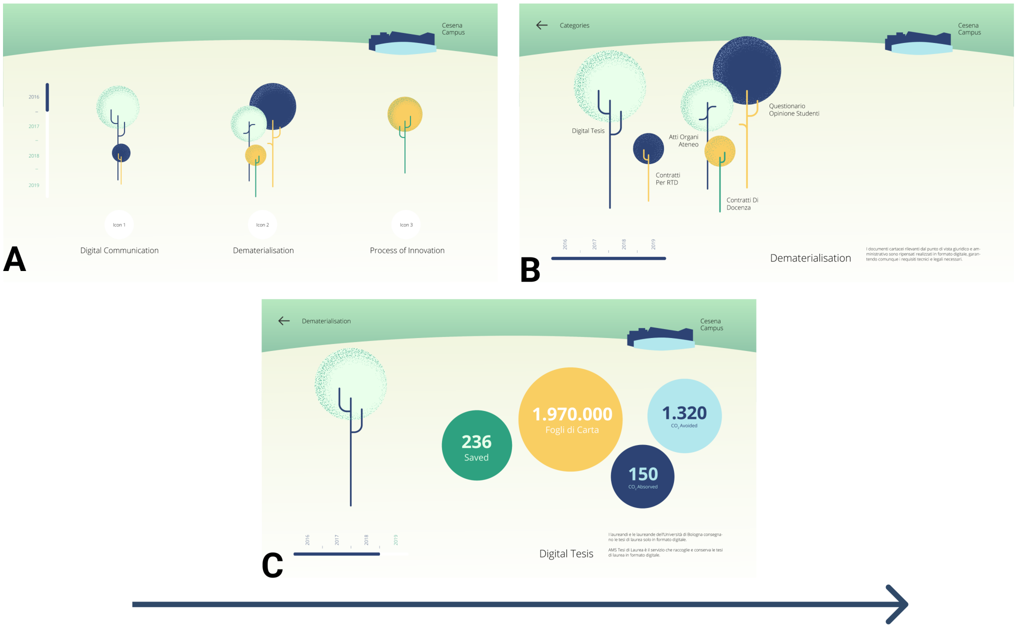

FIGURE 3.3: The "Aesthetic infographic" horizontal-based navigation. **A** is the main page where each tree represents a project, **B** shows the information of the project category clicked and the projects belonging to that category using the metaphor of tree, and **C** shows the information about a single project. Each interaction lead to a brand new interface.

opted to draw on their study and to employ the resulting model for the assessment of the different qualities (inspired by the "Visualization wheel" [43]) as the framework for our investigation. In particular, for each infographic, we were interested to investigate: i. six **information quality dimensions** (i.e., sinteticity, clarity, informativity, intuitivity, attractiveness, elegance), measured using a 6-points ordinal Likert-scale (1 - strongly disagree; 2 - disagree; 3- somewhat disagree; 4 - somewhat agree; 5 - agree, 6 - strongly agree); and ii. six **design quality issues** (i.e., essentiality/redundancy, abstraction/figuration; functionality/decoration; density/lightness; originality/familiarity; multidimensionality/monodimensionality), measured using an ordinal Likert-scale from 1 (first dimension) to 9 (second, opposite, dimension) (e.g., 1 - essentiality to 9 - redundancy and 5 - neutral). All the details about these dimensions and issues are presented in Locoro et al. study [148].

The questionnaire encompassed four sections:

1. general info: items related to the users, such as gender, age, background,

and role inside the University community (i.e., undergraduate, graduate, and Ph.D. student, faculty member, staff member);

2. "Animated infographic": we provided respondents with screenshots of the infographic, and we asked them to evaluate the dimensions of interest by answering the information quality items plus the design quality items. Moreover, we provided them with the link to the working infographic and asked them to answer contextual questions (two), looking for the answers interacting with the infographic. An example of the question is: "How many paper sheets have been avoided thanks to the digitization of the *Tesi Digitali* project?";

3. "Aesthetic infographic": this section comprises the same items as the previous one, considering the corresponding screenshots. Also, in this case, we provided respondents with the working link to the infographic, and we asked them the task of interacting with the infographic and writing the answer to the proposed two questions (different from the ones presented in the previous section);

4. Awareness questions: to collect preliminary insights on the relevance of such infographics considering the possibility of using them as a tool to foster environmental awareness, we asked users if they feel more aware of environmental issues after having interacted with the infographics (to be answered by selecting a value on a 5-points ordinal Likert-scale - strongly disagree; disagree; neutral, agree, strongly disagree).

For each of the information quality items and design quality issues, besides the official term, some synonyms or a definition were presented to the respondents in order to disambiguate their intrinsic meaning as much as possible.

We provided all respondents with the same sequence of questions, while the items for each question were presented in a randomized order.

3.5.2 The participants

45 University members answered the questionnaire, recruited inviting CS students enrolled in the Web Technologies class (Bachelor's Degree in Computer Science) and faculties/staff members, using the snowball sampling method. All respondents are part of the University of Bologna community. The participants' sample is characterized as follows: 23 (46%) female and 22 (44%) male, with ages ranging from 19 to 64, with 29 (64%) with an age between 19 and 25; 13 (29%) undergraduate students, 18 (40%) graduate students, 3 (7%) Ph.D. students (for a total of 34 students out of 45), 7 (15%) Faculty members and 4 (9%) staff members (for a total of 11 "non-students"). The students are mostly from CS (26); the remains are enrolled in different degrees, including environmental sciences, psychology, education, economics, and marketing.

3.5.3 Results and discussion

The collected data were analyzed to highlight emerging insights, comparing the two infographics and the different dimensions, grouped by information quality issues and design quality issues.

Before performing the below-presented analysis, for all the statistical tests, we applied standard procedures of statistical hypothesis testing by adopting a confidence level of 0.95 and a significance level of 0.05. In particular, we computed Pearson Correlation between the dimensions (expressed with a value from -1 - negative correlation, to +1 - positive correlation) to test the null hypothesis: *there are no significant correlations between the proposed dimensions*. Results show a positive correlation with all the couples of dimensions with a p-value < 0.05.

Information quality issues analysis

Figure 3.4 displays the values assigned by the participants to the two infographics, considering the information quality issues analysis. It is possible to observe that the majority of participants considered both the infographics informative, clear, and synthetic. In particular, aggregating the "positive" answers (4 - somewhat agree, 5 - agree, and 6 - strongly agree), we can notice a similar trend for the two infographics and the following dimensions (considering the animated and the aesthetic infographics respectively): informativity, 82% and 73%; intuitivity, 67% and 64%, sinteticity, 84%, and 82%; clarity, 71%, and 71%. Besides that, two interesting issues emerged: in general, the aesthetic infographic appears more elegant and attractive if compared with the interactive one. In fact, 69% of users positively agreed with the attractiveness dimension of the aesthetic infographic (versus 44% if focusing on the animated infographic). Moreover, the elegance dimension provided interesting insights. If we check the aggregate amount of positive values, we have that 53% and the 67% of respondents found the infographics (the animated one and the aesthetic one, respectively) elegant; but if we focus on the values obtained by the animated one, it is possible to notice that 31% of users selected strongly agree and 22% selected agree, solidly asserting the elegance characteristic of such an infographic.

Figure 3.5 presents a table where each cell represents the number of participants who selected the same pair of values to answer the same question for both infographics. The selected score is represented by the number of columns for the animated infographic and the number of rows for the aesthetic infographic. To better explain with an example, taking the first table in Figure 3.5, and considering the value in column 4 and row 2 (that is 2), this can be read as: two users assigned the score 4 (#column) to the animated infographic and the score 2 (#row) to the aesthetic one. Interestingly, the cells in the diagonal (the green cells in Figure 3.5) represent the number of users who assigned the same score to both the infographics, while the cells in its immediate proximity (the yellow cells in Figure 3.5) represent the number of users who assigned similar value (with a difference of +1 or -1) to the two infographics. As an example, considering the second table (i.e., elegance), the cell in column 4 and row 5 is telling us that 7 users selected the value 4 (somewhat agree) for the animated infographic and the value 5 (agree) for the aesthetic infographic. An interesting result to highlight is that, for each question, the number of users in the diagonal (i.e., the number of users who selected the same score for both the infographics) and in its immediate proximity (i.e., the number of users who assigned similar score +/-1 to both the infographics) represents the majority of users. In other words, the majority of the users didn't find any difference or just a little difference (+/-1) comparing the two infographics, considering a specific information quality issue. To better see this result with the data, the number of users considering the yellow plus the green cells represents: informativity, 87%; elegance, 69%; attractiveness, 58%; intuitivity, 73%; sinteticity, 96%; clarity, 78%.

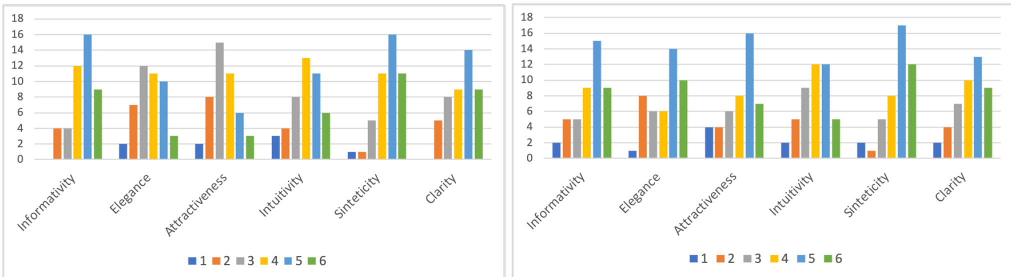

FIGURE 3.4: Information quality dimensions. The distribution of the respondents' value (from 1 to 6): animated infographic (right) and aesthetic infographic (left)

Score Aesthetic infographic (rows) / Score Animated infographic (columns)

Informativity

	1	2	3	4	5	6
1	0	1	1	0	0	0
2	0	2	0	2	1	0
3	0	0	2	3	0	0
4	0	0	1	3	4	1
5	0	1	0	4	8	2
6	0	0	0	0	3	6

Elegance

	1	2	3	4	5	6
1	0	0	1	0	0	0
2	1	3	0	2	2	0
3	1	0	4	1	0	0
4	0	2	3	1	0	0
5	0	2	1	7	2	2
6	0	0	3	0	6	1

Attractiveness

	1	2	3	4	5	6
1	0	0	2	2	0	0
2	1	1	2	0	0	0
3	1	1	2	2	0	0
4	0	4	2	2	0	0
5	0	2	5	4	4	1
6	0	0	2	1	2	2

Intuitivity

	1	2	3	4	5	6
1	0	0	1	1	0	0
2	1	2	2	0	0	0
3	2	0	2	2	1	2
4	0	1	1	7	2	1
5	0	1	1	3	6	1
6	0	0	1	0	2	2

Sinteticity

	1	2	3	4	5	6
1	1	1	0	0	0	0
2	0	0	0	1	0	0
3	0	0	4	0	1	0
4	0	0	1	5	2	0
5	0	0	0	5	8	4
6	0	0	0	0	5	7

Clarity

	1	2	3	4	5	6
1	0	1	0	1	0	0
2	0	2	1	1	0	0
3	0	1	3	0	2	1
4	0	1	2	3	3	1
5	0	0	2	3	5	3
6	0	0	0	1	4	4

Score Animated infographic

FIGURE 3.5: Information quality dimensions. The number of participants who selected the same couple of answers: the column represents the animated infographic score while the row represents the aesthetic infographic score

To have a complete overview of the relevance of all the dimensions per infographics, we computed the median value for each dimension and plotted these data on a radar chart. The outcome is depicted in Figure 3.6 where it is well visible how the elegance and attractiveness dimensions are impacting more the aesthetic infographic, while clarity seems better in describing the animated infographic. In particular, concerning the animated infographic, on average, they scored for Informativity ($\mu = 4.5$, $\sigma = 1.2$, Med = 5), Elegance ($\mu = 3.6$, $\sigma = 1.3$, Med = 4), Attractiveness ($\mu = 3.4$, $\sigma = 1.3$, Med = 3), Intuitivity ($\mu = 4.0$, $\sigma = 1.4$, Med = 4), Sinteticity ($\mu = 4.6$, $\sigma = 1.2$, Med = 5), Clarity ($\mu = 4.3$, $\sigma = 1.3$, Med = 5). Concerning the aesthetic infographic, on average, they scored for Informativity ($\mu = 4.3$, $\sigma = 1.4$, Med = 5), Elegance ($\mu = 4.2$, $\sigma = 1.5$, Med = 5), Attractiveness ($\mu = 4.1$, $\sigma = 1.5$, Med = 5), Intuitivity ($\mu = 3.9$, $\sigma = 1.3$, Med = 4), Sinteticity ($\mu = 4.6$, $\sigma = 1.3$, median=5), Clarity ($\mu = 4.2$, $\sigma = 1.4$, Med = 4).

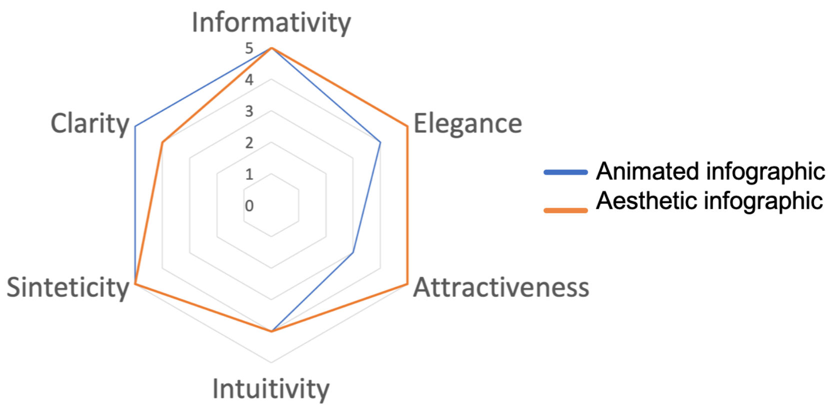

FIGURE 3.6: Information quality dimensions. The median values obtained by the two infographics.

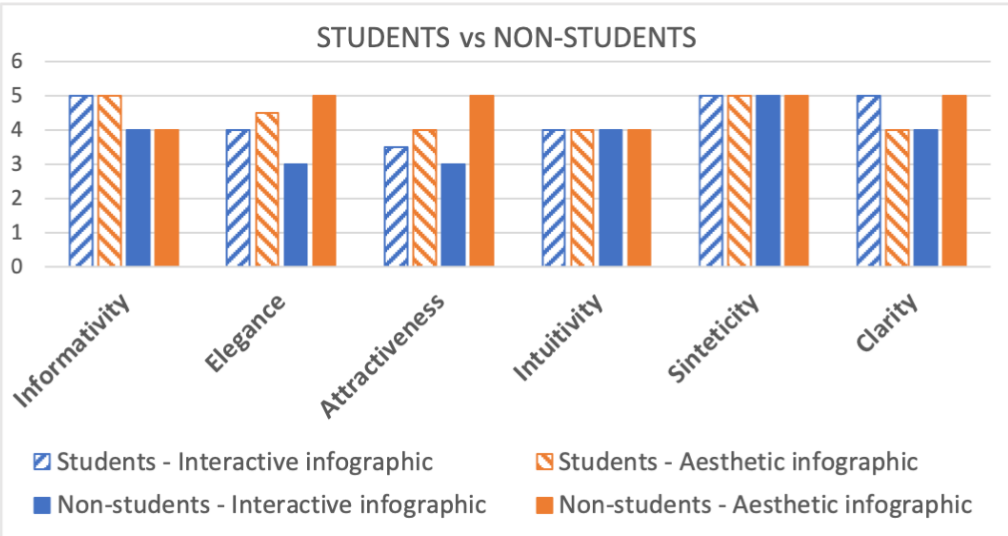

FIGURE 3.7: Information quality dimensions. The median values obtained by the two infographics, grouped by students and non-students.

Moreover, assessing the different backgrounds and ages of the involved participants and their role within the University community, we decided to divide the collected results considering students (undergraduate, graduate, Ph.D.) and non-students (faculty and staff members). The outcome, considering the median value is presented in Figure 3.7. It is interesting to notice that for the intuitivity and sintenticity issues, the median values are exactly the same for all the groups, while for the other dimensions, it doesn't seem to emerge as a common trend. Considering the elegance and attractiveness dimensions, non-students seem to provide more distant scores than students when comparing the two infographics. Surprisingly, when focusing on informativity, it is possible to notice that students agree on the same score for both the infographics and, in the same way, non-students.

3.5.4 Design quality issues analysis

To analyze the design quality issues, we exploited the same statistical analysis and visualization presented for the other dimensions. In particular, Figure 3.8 presents the distribution of the selected value (from 1 to 9) for each question regarding the animated infographic. Conversely, Figure 3.9 presents the same chart but uses the data related to the aesthetic infographic. As already mentioned in Section 3.5.1, each question is defined with two opposite issues, so, for example, the first question (Question 1) goes from 1 (Essentiality) to 9 (Redundancy). All the questions and the related design quality issues are briefly presented in Table 3.1.

For each question, the order bars are colored based on the selected score (as defined in the legend). In these two charts, we grouped the number of participants who selected the same value, considering each question.

The outcome shows that the users seem to perceive the animated infographic as denser (56% of users selected a value from 1 to 4 in question 4) than the aesthetic one that is considered more light (49% of users selected a value from 6 to 9 answering to the same question); conversely, the aesthetic infographic is considered more original (values from 1 to 4 in question 5) by 71% of respondents (vs 44% for the animated one), and more essential (78% vs 60%, question 1).

TABLE 3.1: Questions and related design quality issues

Questions	Design quality issues
1	Essentiality - Redundancy
2	Abstraction - Figuration
3	Functionality - Decoration
4	Density - Lightness
5	Originality - Familiarity
6	Multidimensionality - Monodimensionality

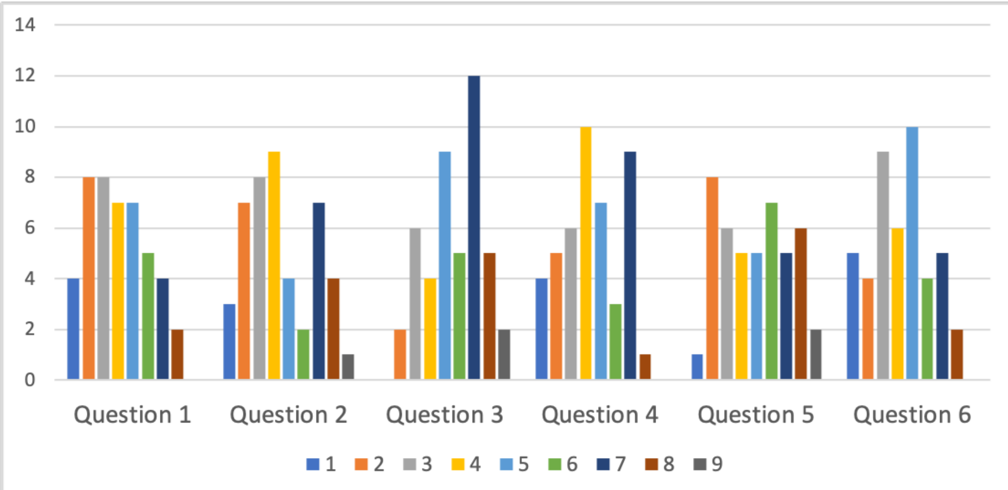

FIGURE 3.8: Design quality issues. The distribution of the respondents' value (from 1 to 9) for the animated infographic.

To better understand the outcome, we computed the median values for these issues and plotted such values in the radar charts depicted in Figure 3.10. To add more details, the visualized median values are calculated using a dataset created considering two values for every single question. In other words, in the radar chart, the two issues that are visualized in opposite positions are the two issues concerning the same question (es. question 1 - Essentiality and Redundancy) and we calculated the two values as one the opposite of the other in a scale from 1 to 9 (for example, if the user selected 2, it means that the infographic is perceived strongly essential - value 8, than Redundancy - value 2). It is the same as having two distinct questions, both from 1 to 9, but negatively correlated.

Analyzing the radar char in Figure 3.10 at the top, we can claim that the issues that better describe the animated infographic, in contrast with the aesthetic

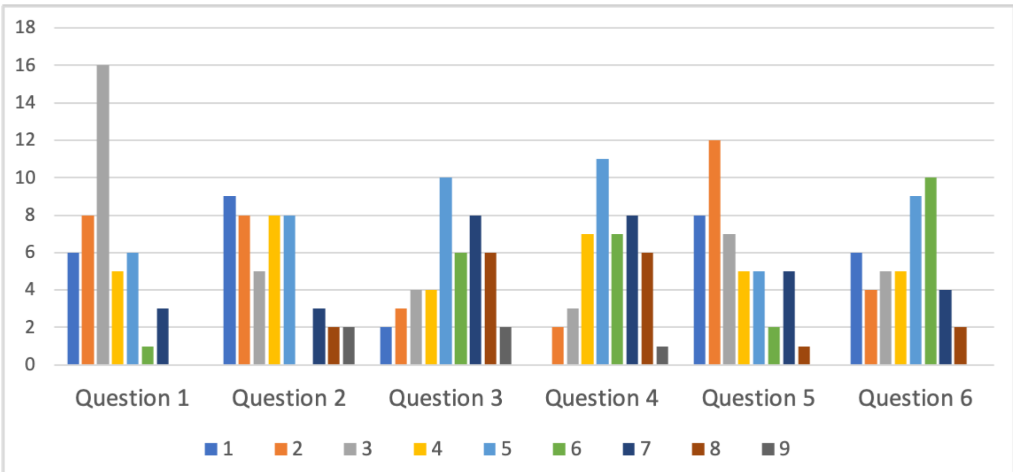

FIGURE 3.9: Design quality issues. The distribution of the respondents' value (from 1 to 9) for the aesthetic infographic.

one, are: multidimensionality, and lightness. On the contrary, the aesthetic infographic seems better described by originality and essentiality.

As we did for the infographic quality dimensions, we grouped the gathered data considering students and non-students; the outcome is presented in Figure 3.10 at the bottom. It is interesting to notice that, for the students, the shape of the radar chart is very similar to the one considering all respondents, on the contrary, the chart grouping the answers of non-students is different. Besides that, it is possible to see that essentiality and originality remain the design qualities that better describe the aesthetic infographic. Focusing on the non-students values, a new interesting dimension for the animated infographic emerges as relevant: functionality.

3.5.5 Awareness-related issues analysis

We recall that in the questionnaire we included two open questions for each infographic where we asked users to compute a task. The task was related to looking for a piece of information relevant inside the infographics (either animated or aesthetic) and reporting it correctly. No significant differences were reported between the two infographics. In fact, almost all the users answered in the right way considering the four questions (with the percentage of correct answers varying from 88% to 93%).

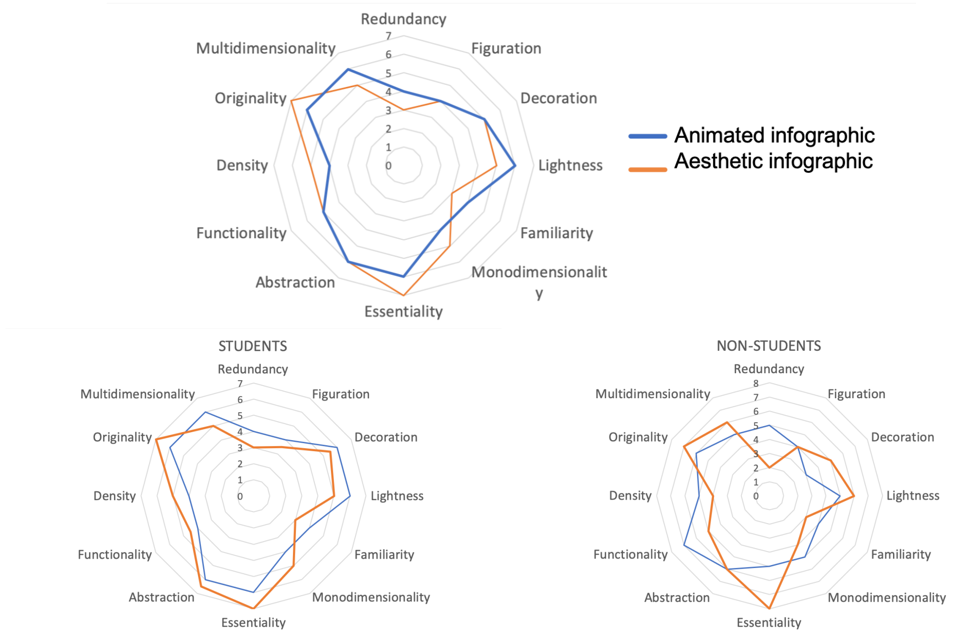

FIGURE 3.10: Design quality issues. The median values obtained by the two infographics, grouped by all (on the top), students, and non-students (on the bottom)

Moreover, we concluded the questionnaire by asking if the user was feeling more aware of environmental issues after having interacted with the infographics (to be answered by selecting a value on a 5-points ordinal Likert scale). The majority of participants answered in a positive way: 22 (49%) agree and 17 (38%) strongly agree, out of 45 respondents.

3.6 Discussion and conclusion

One of the main goals of this study was to promote the effort protracted by the University of Bologna toward paper reduction. To answer the research questions, we designed two interactive infographics (i.e., animated and aesthetic), and we evaluated them using as a framework the model presented in [148] in order to find if a significant correlation exists between the users' perceived qualities and dimensions, and the implemented design. The evaluation showed us that both infographics were effective.

Moreover, the evaluation outcome highlights interesting results. First of all, it is possible to claim that both interfaces obtained high scores when considering the information quality dimensions, validating our design decisions. Adding more details, the animated infographic was perceived as clearer (clarity dimension) than the aesthetic one, conversely, the aesthetic infographic was perceived as more elegant (elegance dimension) and attractive (attractiveness dimension). Regarding the design quality issues, we can maintain that the issues that better describe the animated infographic are multidimensionality, and lightness, while the aesthetic infographic seems better described by originality and essentiality.

Since we engaged the University community, we decided to analyze the collected data grouping them based on students and non-students. Interesting results and some differences seem emerging. For example, for the design quality issue, focusing on the non-students' values and the animated infographic, the functionality dimension comes into play, not really interesting when considering all the data. Instead, considering the information quality dimensions, non-students seem to provide more distant scores than students, while comparing the elegance and attractiveness dimensions for the two infographics.

These preliminary results echo the outcome obtained by [148] confirming the fact that differences exist in the way groups with different characteristics perceived infographics. Moreover, with this case study, we provide exploratory evidence regarding the possibility to use interactive infographics as a tool to foster awareness about environmental issues in a University community.

This study comes with limitations, which in turn pose some important avenues for future research. First of all, to provide significant pieces of evidence the sample of users involved in the study should be enlarged and more variegated in terms of background and age. This is particularly true considering the non-student members that in this study represented only 24% (11 out of 45). Enlarging the dataset will also allow performing other analyses considering more than one dimension (gender, background, and so on). Another limitation of our study is related to measuring the perceived increase of awareness about environmental issues, including the post-usage retention of information. In this study, we asked users to interact with the infographics just for the time to find the content to answer the task. A more comprehensive study should be performed focusing on measuring awareness.

Chapter 4

Case study: Sustainable Tourism

As mentioned in Chapter 1, one of the main targets of SDG8 is sustainable tourism, which takes into consideration the environment, society, and the economy of the places. As deeply investigated in the literature, there is a link between authentic experiences and sustainable tourism, which provides benefits for both locals involved in the offer of the experience and tourists [91, 209, 250, 258]. This Chapter presents the work done to promote a more authentic touristic experience involving locals and tourists. The rest of this Chapter is organized as follows. Section 4.1 introduces the context and motivations behind the system. Section 4.2 presents the main related works about sharing economy, connections between locals and tourists, 360° VR to foster playful interactions, user studies in touristic 360°VR contexts, and recommendations in tourism. Section 4.3 illustrates the main dimensions we wanted to investigate and which were the basis of the system. Section 4.4 describes the design, the architecture, and the implementation of the whole system. Sections 4.5, 4.6, 4.7 analyzed the main studies conducted. Finally, Section 4.8 summarizes the work and the main findings.

4.1 Introduction

As the world becomes increasingly interconnected, new and emerging technologies shape the landscape of tourism and hospitality [15, 170]. The hospitality sector's core competency is all about creating connections (connecting people, places, and cultures), and emerging trends in information and communication technology (ICT) can play a crucial role [113, 238]. Indeed, the widespread diffusion of mobile devices has provided new opportunities to access multiple sources of information in a ubiquitous, location-based, and continuously connected fashion, changing the way we experience tourism-related services [71, 124, 128]. All this information exchange is leveraged by a participatory culture that underlies practices such as user-generated content, social media sharing, and creation, and crowdsourcing [33, 203, 259]. The digital exchange of information not only impacts how people plan a trip but also provides emerging opportunities in how we access tourism services [71]. In this light, the tourism and hospitality sector is embracing extended reality and immersive technologies, including virtual reality (VR) and augmented reality (AR), offering innovative services and playful experiences, both in situ (exploiting location-based technologies) or remotely. These experiences provide virtual representations of touristic places, with the final aim to increase the likelihood of physically visiting such sites in the future [57, 79, 120, 139, 151, 221, 240]. Extended reality can, in fact, facilitate tourists in accessing valuable information and increasing their knowledge about touristic destinations while enhancing the tourist experience with different levels of entertainment, such as playfulness, inspiration, liveliness, collectivity, and surprise [97, 136, 196]. While such immersive technologies have been strongly exploited in the Cultural Heritage context, they have not been explored as extensively in the context of hospitality services.

In this context, we investigated the possibility of taking advantage of mobile computing and extended reality to provide visitors with the possibility to enjoy "authentic" travel experiences mediated by locals. "Authenticity" is a concept that has been introduced by MacCannell in the 1970s to investigate tourist motivations and experiences [156]. MacCallen argues that most tourists seek authenticity but are frustrated in their attempts because the tourism industry, in the endeavor to exploit this desire, creates inauthentic environments as set up frontstages. Reenacted folklore dances or themed restaurants, for example, mimic authenticity instead of being genuine [202].

Thanks to the widespread use of digital and networked technologies, locals today are taking the matter into their own hands, communicating directly with the visitors, proposing meaningful interactions, as well as authentic and experientially oriented opportunities [201].

Our research effort embraces the opportunity to design and evaluate participatory hospitality services as a playful urban experience, bringing together local hosts with visitors through a direct exchange of authentic information, proposing to foster connectedness and empathy through an immersive interactive playful experience[1].

Extending on the "SharePortugal" desktop-based web platform, based on a 2D flat visualization [44], the authors created ShareCities, a 360° mobile VR playful immersive tool to support hosts and visitors' exchange of information about a touristic destination. Drawing on the idea of playable cities [115, 187, 186], ShareCities exploits contemporary ubiquitous locative mobile technologies and 360° VR as means of creating meaningful connections between people and places [60]. Through the "playable cartography" concept, Clarke argues how "aesthetic and design methods can enhance a sense of community by placing an emphasis on personal, autobiographical location-based narratives as a means of capturing and sharing the multitude of emerging and individual identities of those who inhabit cities and township" [60]. Moreover, Desmet and Hekkert ([77]) elaborate on the "aesthetic experience" as "a product's capacity to delight one or more of our sensory modalities." Inspired by these ideas, we designed ShareCities, exploiting playable cartography and the esthetic qualities of the

[1]With the term "experience", we intend "how a user interacts with and experiences a digital system. It includes a person's perceptions of utility, enjoyability, ease of use, and efficiency." (source: https://dictionary.cambridge.org/dictionary/english/user-experience).

system to favor a visitor's playful encounter with an urban touristic destination. The graphics and colorful aspects of the VR 360° rendition are supposed to positively engage users through a virtual representation of the hosts' rooms and messages, inviting users to enter the virtual space. Such a virtual space is personalized by the locals and should engage the visitors in playful treasure hunts for clues and suggestions left in the room for them to find. Hence, by engaging with ShareCities, visitors can playfully interact with authentic and unmediated information provided by locals and distributed in their virtually rendered apartments. Moreover, visitors can use the platform to respond to messages, ask for further information and asynchronously initiate a dialogue[2] with locals. Considering previous findings, establishing meaningful points of dialogue and sharing opportunities that bring benefits to both residents and tourists still needs inquiry.

Hence, we carried out three different studies. Initially, we took a first step, necessary to achieve this overall goal, by focusing on the visitors' experience. We initiate this exploration by evaluating and comparing two distinct visitors' approaches (with different degrees of immersion).

Then, we present an experiment to investigate the possibility of using personalized 360° rooms to foster curiosity and affinity as the first step to initiating a conversation between tourists and locals before the actual face-to-face meeting. The final goal is to design a system that explores novel interactions to create connections between locals and tourists to facilitate authentic travel experiences mediated by locals.

Finally, we take our research study a step further by presenting an analysis of three *proximity*-based people-to-people recommendation criteria. To add more details, this study is framed within a research framework aimed to investigate

[2]We use the term dialogue to refer to "a conversation between two or more persons" (source: `https://www.dictionary.com/browse/dialogue`); and we refer to a conversation as "an informal inter-change of thoughts, information, ideas or opinions about a particular issue, etc., by spoken words or other nonoral means of communication" (source: `https://www.dictionary.com/browse/conversation`).

the *proximity* concept as an enabler for authentic tourism in the context of the sharing economy.

4.2 Background and Related Work

In this Section, we presented the main works and studies that inspired our approach. In particular, we will focus on three aspects: i) the sharing economy concept, ii) the connections and interactions between locals and tourists, and iii) the recommendation in touristic contexts.

4.2.1 Sharing economy

Sharing economy can be considered an umbrella term as different scholars analyzed the concept and gave a broad set of definitions [2]. On this basis, Acquier et al. proposed an organizing framework that placed the sharing economy at the intersection of three areas: access economy, platform economy, and community-based economy [2]. Each of these three areas focused on different initiatives: access economy concerns the share of underutilized resources or skills to enhance their use; platform economy is related to a decentralized exchange between peers through digital platforms; while the community-based economy is about the coordination through forms of interaction that are non-contractual, non-hierarchical or non-monetized [2]. As a matter of fact, the sharing economy has been deeply investigated in the last decades, especially in the tourism context [171, 56], with a particular focus on Peer-to-Peer (P2P) accommodation [138] thanks to the increase of providers, such as AirBnB and Couchsurfing. In this context, this economic principle has been enabled by the evolution of technology and Web 2.0, which have influenced and eased the creation of trust between host and guests through digital connections, especially in the home exchange [45].

4.2.2 Creating connections between tourists and locals through technology

Nowadays, tourists aim to experience the authenticity of the place they visit. One way to feel it is to get in touch with the local people, feel the human contact and experience their lifestyles. Paulauskaite et al. ([201]) demonstrated, through a qualitative analysis based on some interviews with Airbnb guests, that co-created experience, thanks to the sharing of spaces or local information between the local and the tourist, leads to feeling the authenticity of the travel and increase the tourist's immersion in the experience. In the attempt to understand how to make this experience more authentic and memorable in the context of in-situ guided tours, Zatori et al. ([277]) also used a quantitative analysis through a questionnaire. In particular, they found that the interaction between tourists and local guides is positively related to the authenticity and memorability perceived, as they reflect the local culture. This insight is accentuated by Richards ([225]), who reasoned on the concept of being or living like a local, which states that tourists want to become involved in the daily life of the visited place. Such a condition is reachable through the exchange of culture, knowledge, and so on. To foster this exchange, several companies have exploited the use of crowdsourcing, developing web-based and mobile applications that put visitors in direct contact with locals. This contact can happen directly through questions and answers as in "The Loqal"[3] mobile app or "Spotted by Locals,"[4] also built on the same rationale. Both services provide tourists with an offline guide to locals' favorite places, avoiding the touristic ones. Similarly, applications such as "Traveling Spoon,"[5] "Withlocals,"[6] and "Cool Cousin"[7] aim to put tourists and locals in direct contact, offering walking or guided tours, culinary experiences, disclosing interests and even the jobs of the locals, to give the visitors the opportunity to get to know them better. Moreover, Locavores ([276])

[3]https://loqal-app.com/

[4]https://www.spottedbylocals.com

[5]https://www.travelingspoon.com/

[6]https://www.withlocals.com/

[7]https://www.coolcousin.com/

mobile application provides tourists with authentic food and experiences, facilitating encounters with locals and exchanging information about their respective cultures. Locals register their profile on the platform, and, based on that, they will be matched with the tourists' preferences [276]. In conclusion, regardless of the exploited device (web platform or mobile application), the flourishing of these commercial applications demonstrates that tourists care for meaningful and authentic experiences and find them through connection and direct information exchange with locals.

4.2.3 360° VR to foster playful interactions

In the last few years, 360-degree virtual reality (360° VR) has gained more and more attention in the travel and leisure industry, both from the academic and business domains. Quite often, 360° VR is designed to work with head-mounted displays (HMD) to make the experience more immersive. However, recently, 360° VR technologies gained attention in the mobile ecosystem, thanks to the fast and vast diffusion of smartphones. In this context, some studies investigated the use of 360° VR technologies in the tourism sector. For example, 360° VR has spread in tourism-related applications to attract tourists and let them experience the chosen destination even before their actual travel [221]. Some studies were conducted in the tourism context to understand if mobile 360° videos, soundscapes, and HMD VR could positively influence the user experience concerning new travel destinations and heritage sites, which can lead to enjoyment and amusement [84, 125, 129]. Moreover, Dionisio et al. ([78]) investigated users' perception of a mobile application that uses location-based storytelling and mobile VR to enhance the tourists' experience of the urban destination, providing them with an entertaining way to explore some of the locations and learn about the local culture. Similarly, Yasmine's Adventures lets users playfully experience a Berlin inner city neighborhood through mobile 360° VR panoramas and local anecdotes [188]. To evaluate their approach, the authors exploited a questionnaire also including items from the Flow Short Scale ([158]) and the Positive and Negative Affect Schedule scale

(PANAS) ([67]). Moreover, they conducted semi-structured interviews to probe participants' impressions of the overall experience. In their preliminary study, the authors also confirm the application improves the relatedness and the playful exploration of the surroundings. These systems are inspiring examples of successful tourists' engagement through urban playful interaction. With the COVID-19 pandemic, most tourism companies and agencies have moved their activities online, offering virtual experiences to mitigate the monetary loss since tourism was one of the most affected industries [101]. Lots of museums have created virtual exhibitions using 360° VR so that users could watch them from the couch at home during the lockdown [232]. The COVID-19 outbreak has increased concerns and anxiety among tourists, and the use of VR could mitigate them [180]. Finally, virtual 360° environments are also exploited for commercial use. For example, the IKEA virtual reality experience[8] lets the users see and experience the home with the help of an HMD. The application offers some playful and useful interactions when, through a simple click, the user can change the color of cabinets and drawers. Another commercial example is InmobiliAR[9]. InmobiliAR is an app that allows the clients of a real estate agency to see the apartments and take a virtual 360° VR tour directly from the street. These applications were an inspiring start for our adaptation of the existing application ([44]), exploring the playful benefits of immersive technologies and evaluating the impact of such technologies in contrast with the 2D application.

4.2.4 User studies in the touristic 360° VR contexts

Several studies investigated the user experience of VR in tourism [104, 143, 147]. In our project, we narrow the focus to the evaluation of 360° VR environments. A virtual 360° environment is often used in tourist contexts to engage and immerse the potential tourists in their destination before and during the actual trip. Hence, Rahimizhian et al. ([221]) intended to understand if

[8]https://present.digital/ikea/
[9]http://www.inmobiliar.com.mx/

360° videos could positively influence the tourists' attitude and behavior toward the destination. After conducting an online questionnaire, they found that the 360-degree videos about Hong Kong could affect the tourists' satisfaction and, therefore, their trip and the electronic word of mouth about the destination. Moreover, in the literature, some studies that compare 360° VR in mobile devices and HMD both in private and public contexts are presented to understand how target users perceive them. For example, Kelling et al. ([125]) showed that 360-degree videos positively offer a new travel destination or experience. Still, the participants in their study preferred to enjoy it in private contexts due to their social and cultural backgrounds. The same conclusion was drawn by Dionisio et al. ([78]), as they found out through questionnaires and interviews that 360° VR was positively perceived by the participants of the study, as it can create an enjoyable experience. In conclusion, 360° VR improves the attitude of tourists toward the destination, especially if it can also be used in private contexts. In this context, as a novel contribution, we investigated the possibility of exploring 360° VR together with esthetic experiences and playful interaction to engage tourists in looking for information in virtual rooms.

4.2.5 Recommendation in Tourism

To improve the touristic experience, recent works have deeply investigated the use of recommendation systems, especially in suggesting new Points of Interest (PoI) to tourists. An example of a travel recommendation is PhotoTrip, which suggests to tourists some unexpected and not mainstream Points of Interest [40]. In particular, it used social networks, crowdsourcing, and gamification to provide relevant photos and information about cultural heritage locations and improve the response quality of the system. In [275], Yochum et al. analyzed the Location-based recommendations in the tourism context. In particular, they found that they can be divided into two categories: stand-alone location recommendations and sequential location recommendations. The first group includes suggestions for a single location after taking into account the needs and preferences of the users, their location history, or their trajectories. The second group suggests a set of locations that creates a travel route especially based on geotagged social media content or GPS trajectory. The social media photos were also exploited by Figueredo et al. in [90] in order to create a series of tourism attractions and recommend them to the user. Additionally, they used Convolutional Neural Network and fuzzy logic to extrapolate the scene profile from the photo and create the tourist profile based on the preferences to execute the recommendation. The effectiveness of the system was evaluated against ground truth and showed that 90% of the attractions provided could be considered relevant for each validation user's profile.

Recently, some studies have investigated the benefits of serendipity in recommendation systems even in the tourism domain. In [167], Menk et al. aimed to surprise the users with serendipitous recommendations of places exploiting their degree of curiosity and education. In their study, the authors extracted information from social networks (e.g., Facebook app) to predict curiosity and choose the most suitable places. Finally, they evaluated the recommendation system with users, asking them to rate each suggested place using 3 questions (5-point Likert scale) to measure the level of accuracy, serendipity, novelty, and textual feedback to rate the users' satisfaction. From the evaluation, they demonstrated how the system was able to provide novel, surprising or serendipitous recommendations with a good level of accuracy.

To summarize, previous works on recommendations in the tourism domain focused on suggesting new and possibly unexpected places to tourists, often exploiting their social media presence and preferences. In our case study, we decided to change the approach and focus on recommending people, in particular, locals. Hence, we wanted to suggest three locals' profiles: (i) the one that best suited each tourist in terms of similarity of interests; (ii) the nearest one in terms of geographic proximity; and (iii) a random one to further investigate the concept of serendipity. It is worth noting that people-to-people recommendation criteria have been deeply investigated in different contexts than tourism, particularly in dating apps [206, 137] and social media networks [103, 274].

4.3 Research questions

Considering the background analyzed in the previous Section, we aimed to answer the two research questions presented in Section 1.2 in the context of smart and sustainable tourism. In particular, concerning **RQ1**, we were interested in understanding how to promote the creation of authentic experiences and meaningful connections between locals and tourists. In particular, we were interested in investigating:

- how an immersive 360° VR visualization contrasts with a 2D visualization;
- what implication for the design of playful information-sharing hospitality platforms we can draw from the study conducted on visitors' experience of ShareCities;
- the possibility to use personalized 360° rooms to foster curiosity and affinity as the first step to initiate a conversation between tourists and locals before the actual face-to-face meeting;
- three different criteria to provide tourists with meaningful recommendations of the locals' rooms and, eventually, foster an authentic tourism experience.

In relation to **RQ2**, we wanted to evaluate the platform engaging potential future tourists to gain insight into the most effective features. In this case study, we defined effectiveness as the system's capability to connect locals and tourists through the creation of a meaningful connection between them in order to finally promote sustainable tourism.

4.4 The ShareCities platform

ShareCities has been conceived as a case study to investigate the possibility of exploiting esthetic experiences to establish meaningful points of dialogue and sharing opportunities that bring benefits to both residents and tourists. We

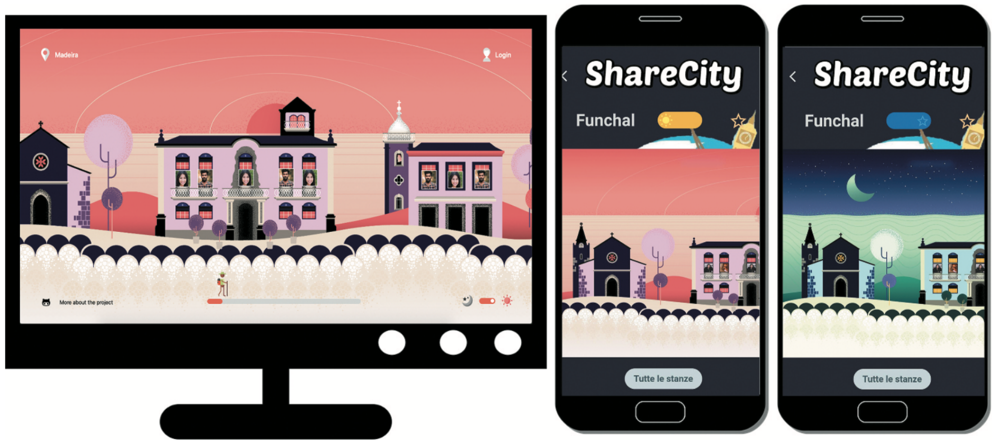

FIGURE 4.1: The desktop-based web app (on the left), and the mobile app (on the right).

initiated such an investigation by designing and implementing SharePortugal, a desktop-based web application described in [44]. The desktop-based web application provides the following functions:

- tourists and locals need to register to become part of the community and enjoy the services. The created account can be used both in the desktop-based web version and in the mobile app;
- once logged, it is possible to select a city to explore; each city has a homepage presenting, in a virtual fashion, the monuments, buildings, and peculiarities that characterize such a city, explorable through a horizontal scroll, as shown in Figure 4.1 (left side). Moreover, it is also possible to change the background style of the image (night or day) and vice versa;
- images representing the local's avatar or photos are visible in the city building windows. By selecting the picture in the window, tourists can see the customized virtual room of a specific local, together with information about the person and the provided touristic services, authentic information about the city, and read and leave messages in the room;
- locals can customize the virtual room, adding personal information, photos, posters, messages that the visitors can find, information about the city, changing the wall color and pattern, and so on.

As anticipated, the local's virtual room includes not only visual elements to reveal the personality and interests of the person but also textual information, such as the telephone number and the e-mail, and the possibility to leave messages on a visible communication board. Through the playful experience of leaving messages in the room and receiving answers, the host and visitor have the possibility of initiating a conversation leading to a virtual or face-to-face dialogue. This information exchange would benefit both residents and tourists. The residents will benefit by having an opportunity to meet new people from different cultures and initiate a connection, and eventually, dialogue, with them before deciding to host them or to meet them face to face. A visitor, on the other hand, by getting to know the host, could develop a better understanding of their host and their culture, which in turn could foster empathy and facilitate meaningful exchange (which can be beneficial to the locals in several manners: cultural of goods, of information, etc.). When navigating a virtual room using such a system, the user can only see its static 2D image.

The existing platform is composed of i) a web application targeting the locals and ii) a mobile application that targets tourists, as presented in Figure 4.2.

4.5 Effects of an immersive 360° VR visualization

To enhance visitors' playful interaction with locals through information sharing and asynchronous message exchange, we extended the SharePortugal 2D-based visualization web system into the 3D ShareCities mobile application. The new mobile app explores the smartphone 360° VR potential of interacting in real-time with the urban and digital space of the city and providing tourists with aesthetic immersive experiences. The design of the mobile application was inspired by the desktop visualization, which was made responsive, to have consistency between the two systems. The mobile application has been implemented in Flutter[10], a mobile UI framework that allows building native apps on iOS and Android from a single codebase. The app features several functions:

[10] https://flutter.dev/

- Log in - once logged in, tourists (as well as locals) will see the list of available cities, ordered by the distance from the user who is navigating the app, taking advantage of the built-in GPS sensor. We also exploited the smartphone time zone to change the city background, from day to night (and vice versa), which should also privilege the information shared (if happening during the day or at night).
- (Selected) City Home - considering the city homepage (same as the desktop-based web app), the user is presented with the graphically rendered facade of several iconic buildings of the selected city (Figure 4.2, right side). The visitor can enter a room of the building by touching the avatar/picture of a host, which is visualized on the windows of the buildings (as depicted in Figure 4.2). In the mobile ShareCities, we exploited the location-based nature of the smartphone to order the avatars on the windows by their proximity to the user; the same approach is used when selecting the "See all hosts' rooms" button, which shows all the available rooms, ordered by their proximity.
- Room view - inside the rooms, visitors can read messages and reviews left by other tourists who came in contact with the same host, including scores (i.e., "stars"). To visualize such details (public messages and reviews) and other host information, such as the touristic services/places s/he recommends, the user can touch the buttons on the left side of the screen. To create an immersive experience, we implemented the local's room as a 360° VR panorama representing the local's room. Exploiting the smartphone's built-in gyroscope sensor to map the user's viewpoint, the tourist can look around the virtual room by simply rotating the smartphone, feeling to be "inside" the room. To generate the 360° image sphere, we used the viewer provided by the Panorama plugin[11].

[11] https://pub.dev/packages/panorama

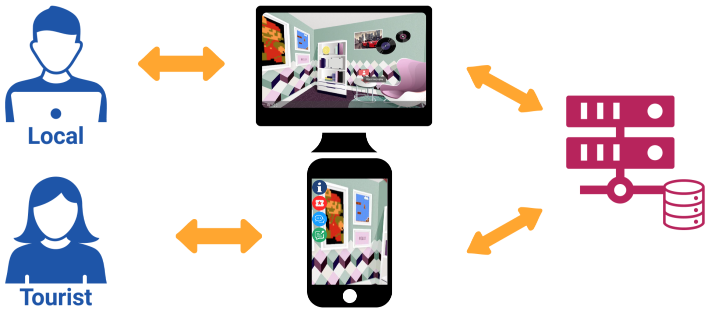

FIGURE 4.2: ShareCities architecture: it is a client-side architecture where the server gets the data from the database and communicates with the clients. We have two applications: one web-based, which targets the locals, and the other mobile-based, which targets the tourists.

4.5.1 Evaluation

Methodology

This study's primary intent is to shed light on the use of mobile 360° VR strategies to support playful information sharing between locals and tourists. To better frame our goal, we investigated the following assumptions:

- in the ShareCities hospitality service, an immersive 360° VR has a positive influence on the visitor's experience in contrast with a 2D visualization;
- the design of playful information-sharing hospitality platforms has some implications on the visitor experience of ShareCities.

With the main focus of investigating these assumptions, we designed an experiment to collect qualitative and quantitative data. We exploited a within-subjects study and questionnaires as a self-report method. In particular, we were interested in comparing the visitors' user experience as they visualize the local's virtual room using a 360° VR immersive panorama (gyroscope-based view) with the 2D approach, which uses a flat image. Both approaches were tested using the ShareCities mobile version, using a smartphone; we developed two versions of ShareCities mobile: one presenting the virtual room with 2D flat images, the other one exploiting 360° VR panoramas. To statistically validate the outcome, we defined our overall null hypothesis (H0) as follows: *"no difference is perceived between using a 360° VR versus a 2D visualization of the hosts'* *room while experiencing emerging hospitality services through the mobile app."* Since the two questions and H0 revolve around the concept of "immersion", we designed the questionnaire to measure immersion, and its related constructs, such as flow and presence. Moreover, usability is a measure of how comfortable the users felt with the system and interface design. And finally, engagement to understand if we had succeeded in fostering playful interactions among system users. Existing literature abounds in validating scales to measure the above constructs. In the following, we describe the validated scales we adopted for our study and discuss the motivation behind the specific selection.

The questionnaire

The questionnaire scales

Usability. Usability is a core term in HCI and a relevant property of a system that could impact the user experience of the evaluated software [112]. For this reason, we opted for including a few questions to measure the system usability of both the 2D and the 360° mobile VR ways to explore a virtual room. Among the vast literature on usability evaluation [152], ASQ [144], SUMI [133], we opted for the System Usability Scale (SUS) [34] composed of 10 simple questions so not to overload the participant. Although its characteristics (such as reliability, effectiveness, and the number of scales) have been extensively discussed [19, 18, 28], it is widely used by HCI practitioners thanks to its simplicity and efficiency, and researchers are still confirming its validity in comparison with other scales [35, 145, 247]. In fact, SUS proved to be particularly relevant and reliable to compare and evaluate the usability of two versions of an application that are based on different technologies [35]. Focusing on this dimension, the H_{0U} we test if: *"no difference in usability is perceived between using a VR versus a 2D visualization of the hosts' room while experiencing emerging hospitality services through the mobile app."*

Engagement. Engagement, which can be defined as the ability to engage and sustain user engagement in digital environments, is crucial to fostering the dialogue between locals and tourists. Analyzing the existing literature [140, 191], we decided to focus on self-reporting scales since such a strategy allows participants to describe their own experiences [119, 193, 192, 271], and, finally, we opted for the short form of the User Engagement Scale (UES-SF) [194], using only 12 items to investigate four dimensions: focused attention, esthetic appeal, perceived usability, and reward factor. The short version encompasses all of our evaluation needs in measuring user engagement while reducing the study participant's fatigue (as recommended in [194]. Focusing on this dimension, the H_{0E} we test is: *"no difference in engagement is perceived between using a VR versus a 2D visualization of the hosts' room while experiencing emerging hospitality services through the mobile app."*

Immersion. Immersion is a multidimensional concept that has been extensively investigated when designing and evaluating virtual environments (VE). Immersion can relate to interaction with the technology itself [241] or to the users' feelings when immersed in the system [273]. Considering the former one, immersion can be defined as a psychological state of being enveloped by and interacting with an environment that allows users a continuous stream of experiences [273]. In VE, immersion has been achieved using wearable devices such as HMD and/or large displays and cave environments that isolate the users from the real context [31, 121, 231]. While the concept of immersion has been analyzed in web browsers contexts [235] and smartphones [58, 130], the relevance of context while using a smartphone is just starting to be explored [17, 58, 78, 130, 188]. Kim coins the concept of "contextual immersion" [130] which keeps into account the context-awareness typical of mobile systems [130]. Despite our study not being focused on AR, but rather on 360° VR panorama, we adopted Kim's framework since it allows us to investigate different properties valuable in measuring immersion in our mobile scenario. We relied on Choi et al. [58] to investigate the interactive and immersive experience of using 360° VR content on the mobile platform by selecting some items (i.e., 3, 17, 20, 30, 80, 81, 82) from [254]. While the Tcha-Tokey et al. ([254]) questionnaire was designed for a head-mounted display game study, nonetheless, some items can be adapted to a smartphone-based 360° VR scenario, as proved by Choi et al.

Dimension	**Scales/Questionnaires**	**Items**
Usability	System Usability Scale (SUS) [34]	All items (#10)
Engagement	User Engagement Scale (UES), short version [194]	All items (#12)
Immersion	Framework for context immersion in mobile augmented reality [130]	Interface (1, 2, 4); Sensory (1,3); Involvement (1, 3, 5, 9, 10); Motivation (1, 2, 5, 10); Mobility (4); Reality: (2)
	Questionnaire to Measure the User Experience in Immersive Virtual Environments [254]	3 (engagement), 17 (immersion), 20 (immersion), 30 (flow), 80 (open question), 81 (open question), 82 (open question)
		Total items: #45

TABLE 4.1: Details about the composition of the questionnaire to evaluate the system.

Constructs	**Kim** [130]	**Tcha-Tokey et al.** [254]
Interface	Interface (1, 2, 4)	–
Sensory	Sensory (1, 3)	–
Involvement	Involvement (1, 3, 5, 9, 10)	3 (engagement), 17 (immersion)
Motivation	Motivation (1, 2, 5, 10)	–
Mobility	Mobility (4)	–
Reality	Reality: (2)	20 (immersion)
Sense of Comfort	–	30 (flow)

TABLE 4.2: Defined dimensions related to the immersion complex concept.

[58]. Focusing on this dimension, the H_{0I} we are testing is: *"no difference in immersion is perceived between using a VR versus a 2D visualization of the hosts' room while experiencing emerging hospitality services through the mobile app."*

The comprehensive questionnaire.

In the end, the questionnaire was comprised of 45 items, divided into four groups: 10 items to measure the app usability using SUS [34]; 12 items to investigate engagement using UES-SF [194]; 23 items to understand immersion as a multidimensional concept, including 16 items extracted from the framework for context immersion in mobile augmented reality [130], and seven from the questionnaire presented in Tcha-Tokey et al. ([254]). Table 4.1 details the selected items for each framework. Since the experiment was conceived as a within-subject study, we created the final questionnaire considering 45 as the maximum acceptable number of questions to minimize respondent fatigue [22].

To evaluate immersion, we grouped all the items into six constructs: interface, sensory, involvement, motivation, mobility, reality, and sense of comfort (as presented in Table 4.2).

Participants' answers followed a 5-point Likert scale (1 – Strongly disagree; 2

– Disagree; 3 – Neither agree nor disagree; 4 – Agree; 5 – Strongly agree). At the end of the questionnaire, three open-ended questions concluded the study: "What were the positive aspects of the experience? What were the negative aspects of the experience? Could you share some suggestions for improvements? (i.e., 80, 81, 82 in [254]). All the items were translated into Italian to facilitate participants (regarding SUS, we used [28]) and adapted to our case study when possible. The questionnaire was pilot tested for content ambiguities on a small sample of users (three) with different backgrounds. After the pilot test, a few items were reworded (or supplemented with comments).

The study protocol

To design the evaluation, we tested ShareCities for mobile devices in two versions, one with a 360° VR immersive panorama of the host's virtual room and the other showing just a static image of it (the 2D-based version). To eliminate individual differences between experimental conditions, each participant tried both versions. In addition, we applied a counterbalancing strategy to avoid ordering effects, asking half the participants to start with the 360° immersive version and the other half with the 2D version. The experiment was performed in September 2020, in Cesena (Bologna, Italy), following the COVID-19 recommendations and restrictions both at the national and regional levels. We engaged one participant at a time, and the two researchers and the participant wore the mask all the time. To avoid participants installing the two versions of the app, we used one of the lab smartphones, and we sanitized the device (and the desk) at the beginning of every new session. Each session lasted 30 minutes, including: a brief introduction to the study and the app goal, the two app evaluations, and the related two questionnaires. In particular, each participant evaluated one app and, afterward, answered a questionnaire; then, they repeated the two activities (evaluation and questionnaire) for the other version of the app. To answer the questionnaire, we provided students with two QR codes to allow them to answer using their devices in a small room outside of the lab (to avoid putting pressure on or influencing them with the researchers' presence). Considering the method, one researcher was assisting the participant, while the other was transcribing the participants' comments and recording the hidden transcript (facial expressions) and user interaction issues that were experienced.

Participants

We engaged digital natives and, in particular, students attending the "Mobile Programming" course during the third year of the bachelor's degree in Computer Science (Cesena campus, University of Bologna). The call for participation was shared online using the course mailing list, and participation was voluntary. Due to COVID criticalities, access to users was limited. A total of 15 students (5 females and 10 males), ranging from 21 to 32 years old (avg = 23), answered our call, still allowing us to collect relevant data [42, 219]. All the participants were informed that participation in the study was voluntary and that they could refuse or discontinue their participation at any time for any reason.

Findings

In the following subsections, we present the results and findings from the study. In describing the findings, we call "2D" the version of the visualization that makes use of the 2D static/flat image, while "VR" is the one using a 360° VR panorama to represent the virtual local room. To answer our H0s, we also computed the Wilcoxon Matched-Pairs Signed Ranks Test nonparametric statistical test that compares two paired groups to establish if they are statistically significantly different from one another, exploiting the median values [157].

Usability.

Following the SUS recommendations, we calculated the average total score for both applications. The outcome was positive ("excellent") for both versions: the 2D version obtained an average total score of 91.3 (out of 100), while the VR version got an average score of 91.5 (out of 100). Considering these scores, it seems that the immersive peculiarity of the VR version slightly influenced

Engagement sub-dimensions	**2D**	**VR**
Focused attention (FA)	3.09	4.07 (+0.98)
Perceived usability (PU) (reverse coded)	4.93	4.87 (-0.06)
Aesthetic appeal (AE)	3.78	4.44 (+0.66)
Reward factor (RF)	3.78	4.51 (+0.73)
	3.88 (overall value)	4.38 (overall value)(+0.50)

TABLE 4.3: The average score for both versions obtained using UES-SF.

(positively) the perceived usability of the overall system, which was already high. Both apps were perceived as original, visually appealing, and simple to use without requiring the users to perform complex tasks. This outcome is also confirmed by computing the Wilcoxon Matched-Pairs Signed Ranks Test, obtaining a p-value = .3869 > α = 0.05, meaning that we can not reject our H_{0U}.

Engagement.

We calculated and then compared the UES-SF scores for both versions of the app. As detailed in H. L. O'Brien et al. ([194]), an overall engagement score can be calculated by adding all of the items together and dividing the sum by twelve. The data had a high level of internal reliability with a Cronbach's α value of 0.82 and 0.90, respectively. As a result, considering a scale from 1 to 5, the VR version obtained a higher score (4.38) than the 2D one (3.88). Table 4.3 shows the score grouped by the four relevant sub-dimensions; it is possible to notice minimal differences between the two versions, confirming the results obtained using SUS. While the 2D version scores slightly higher in Usability, the Attention Focus (FA), Esthetics (AE), and rewarding Factors (RF) positively impact the user's engagement with the 360° VR version. FA (circa 1) reports on the higher difference. Analyzing the data using Wilcoxon Matched-Pairs Signed Ranks Test, we have the confirmation that we can reject our H_{0E} (p-value = .01922 < α = 0.05), and we can assert that the introduced VR function impact (positively) the level of engagement.

Immersion.

To evaluate immersion, we exploited the six constructs presented in Table 4.2, i.e., interface, sensory, involvement, motivation, mobility, reality, and sense of

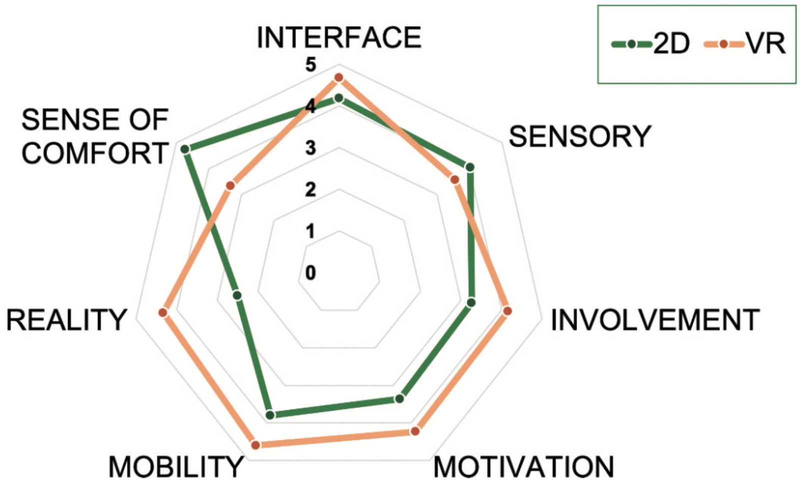

FIGURE 4.3: A radar chart presenting the average value obtained for each dimension composing immersion, for the two app versions (2D vs VR).

comfort. Figure 4.3 presents an overall view of the obtained outcome. In the following, each construct is analyzed in detail.

Interface. Regarding the interface construct, we evaluated how the interface can facilitate the acquisition of information. Its sub-dimensions were considered, in particular, three questions were analyzed: *finding the information requires me a lot of effort (reversed for the analysis), I was very efficient in finding the information, and navigating the room didn't require me any effort*, with a Cronbach's α value of 0.71 and 0.65, respectively. Comparing the two versions of the app, most users performed better information acquisition with the 360° VR version, even though it required a higher effort for a few participants. In general, the VR version scored an average of 4.67 (var = 0.03) versus the 4.18 (var = 0.01) of the 2D (see Figure 4.3). Focusing on our H_{0I}, computing the Wilcoxon Matched-Pairs Signed Ranks Test proved that the interface' construct positively influences the sense of immersion ($p = .001904 < \alpha = 0.05$).

Sensory. To analyze the sensory construct, we considered two sub-dimensions: I exclusively used vision to survey or search the environment, and I extensively used a touch-sensing function to survey or search the environment. It emerged that participants were more prone to exploiting the touch-sensing function in the 2D version than in the VR one (an average value of 4.7 vs 3.3, with a variance of 0.20 and 1.69, respectively). This can be explained considering that touch was the only modality to navigate the 2D visualization. Considering the vision to search the environment, both the apps obtained a similar result (3.3 vs 3.8, with a variance of 1.29 and 1.36, respectively), aligned with the fact that both the interfaces needed an extra sense (i.e., touch-sensing and movement, respectively). In both the sub-dimensions, the high computed variances between the scores tell us that, likely, participants interpreted the meaning of the question in different ways. Moreover, the statistical analysis using Wilcoxon Matched-Pairs Signed Ranks Test confirms that, in this case, we can not reject the null hypothesis ($p = .1126 > \alpha = 0.05$). Accordingly, it seems that vision and touch do not discriminate in the way the two apps are perceived.

Involvement. According to Kim's contextual immersion framework ([130]), the involvement construct is composed of seven sub-dimension: the sense of being involved, the real-time awareness of the virtual environment, and with the local's identity, concentration, the level of interaction with information in the environment, the satisfaction with the displayed information, the engagement with the visual elements, and the level of immersion in the system in relation with the external environment. Two other sub-dimensions, the involvement of the visual aspects of the virtual environment and the level of not awareness of things happening around (items 3 and 17 of [254]), were added to better investigate the involvement provoked by an immersive virtual environment. To verify the internal correlation between these seven sub-dimensions we computed Cronbach's α value, obtaining a sufficient internal correlation (0.61 for 2D and 0.79 for VR). Focusing on the 360° VR version, participants provided positive scores (on average, 4.32, var = 0.04) for 6 out of 7 questions. In particular, only one question, *"I become so involved in the environment that I was not aware of things happening around me"* (n. 17 in [254]), scored close to 3 (3.2, var = 1.62). We decided to include this question to investigate the extent to which the 360° VR panorama let users "forget" about the real environment. Since the smartphone mediates the VR experience, this result is rather positive since the real environment in the background was not invisible to the user, but still did not interfere with the experience. The 2D version scored lower (on average, 3.27, var = 0.58), with a lower score of 2.67 (var = 1.29) in the *"sense of being involved in the virtual environment."* It is interesting to highlight the high variance value. In a second analysis, we noted that those who tried the 2D version first were inclined to give it a higher score than those who tested it as the second option. Focusing, in particular, on the real-time awareness of the virtual environment and the local identity sub-dimension, we can report that the VR version obtained a higher score than the 2D one (average values: 4.33 and 3.53, variances: 1.29 and 0.91). The two aggregate construct average scores are presented in Figure 4.3. Moreover, the Wilcoxon Matched-Pairs Signed Ranks Test confirmed that the involvement sub-dimension positively impacted the experience of the app, as shown by the data (p-value = .003436 < α = 0.05).

Motivation. The motivation construct is composed of four sub-dimensions: moving in the room I acquired information, I felt an intimacy with the person, I really enjoy the visualization/navigation task, and I developed empathy toward the person in the room. The average value obtained by the 2D version is 3.67 (var = 0.23), versus 4.23 for the VR version (var = 0.11). As a confirmation of this difference, we computed the Wilcoxon Matched-Pairs Signed Ranks Test obtaining p-value = .001784 < α = 0.05, allowing us to reject H_{0I}. This outcome corroborates the relevance of the 360° VR environment in supporting the participant's playful and meaningful interactions with the system.

Mobility. The mobility construct includes just one sub-dimension: it was possible to see real-time situations while moving. With this item, we wanted to measure if the user experienced any positive or negative issues due to real-time visualization of the digital room. We obtained the following average values: 4.6 (var = 0.37) for the VR version and 3.8 (var = 0.16) for the 2D version. To ascertain if the null hypothesis can be accepted or rejected, we computed the Wilcoxon Matched-Pairs Signed Ranks Test. The output p-value = .005576 < α

= 0.05 proves that we can reject H_{0I}, in favor of the VR version.

Reality. The reality construct includes two sub-dimensions: visualizing the scenes helps me to acquire spatial recognition and information about the real environment, and I felt physically fit in the virtual environment. Since we used items from different frameworks (see Table 4.2), we computed Cronbach's α obtaining a good internal consistency (0.76 for 2D and 0.61 for VR). The VR version obtained an overall average score of 4.3 (var = 0.04) versus 2.5 (var = 0.25) of the 2D room based one. Also, in this case, we can reject H_{0I} because computing the Wilcoxon Matched-Pairs Signed Ranks Test, we obtained a p-value = .0006859 < α = 0.05.

Sense of comfort. To investigate whether the user felt comfortable moving the smartphone in real space to navigate the VR room, we exploited item n. 30 of Tcha-Tokey et al. ([254]): I was not worried about what other people would think of me. This sub-dimension is correlated with the concept of flow, the sense of being absorbed by a task to such a degree that one forgets about time and place [69]. The data shows that half of the users didn't care about other people's judgment (answering positively – agree and strongly agree), while two felt neutral and four felt worried (average value = 3.3, var = 1.69 versus average value = 4.73, var = 0.20 of the 2D version). Computing the Wilcoxon Matched-Pairs Signed Ranks Test, we obtained a p-value = .00596 < α = 0.05, resulting in the rejection of the H0I but in favor of the 2D version.

Qualitative data.

To collect qualitative data, we exploited three open questions, as detailed in *"The comprehensive questionnaire."* We analyze the qualitative data through the thematic analysis approach. In the following, details about the outcome are provided.

Positive aspects. In general, both apps obtained positive feedback. Positive aspects of the 2D app are related to: visual aspects of the interfaces (5 mentioned this aspect out of 15 participants), ease of use (6 out of 15), the concept (5 out of

15), the possibility to navigate the host's room (1 out of 15). In particular, one user claimed that the navigation of the 2D version is more straightforward because the VR version was too slow in reacting to the user's inputs; another user reported that s/he prefers the 2D version because it is possible to navigate the room without "moving." Positive comments regarding the VR app regarded: the visual aspects of the interfaces (4 mentioned this aspect out of 15 participants), ease of use (4 out of 15), the concept (4 out of 15), and the possibility of navigating the room through 360° VR (14 out of 15) which connects directly with our assumptions. To give a better idea of the participants' feelings regarding the VR app, we report here some quotes from the users' interviews: *"I like a lot the possibility to explore the virtual room. In a way that is consistent with the movements made in the physical room"; "I liked being able to see a person's room from the inside," "I found the room that moves with you captivating, so as and the possibility of knowing in advance the person you are asking formation from," and "the ability to navigate the room in virtual/augmented reality is really interesting and gives the feeling of total immersion, and I find it very intuitive!."*

Negative aspects. Some negative aspects of both versions of the app were highlighted. Regarding the 2D app, the negative feedback was mostly related to: unclarity of some initial interface interaction (i.e., clicking on the hosts' avatars to access the room, or scrolling down the city buildings, via the horizontal slider) (2 participants mentioned this aspect out of 15 participants); disappointment with the interaction, finding it too static (8 out of 15). Contrariwise, no negative issues were reported by 4 out of 15 users. The VR app collected a few negative feedback: unclarity of interaction with the icons on the windows (1 out of 15); gyroscope-related technical issues – 4 out of 15 users noticed that if at the beginning of the navigation tasks, the smartphone was not perpendicular to the ground, the user needs to correct the spatial perception in the 360° scene; no possibility to interact (selecting or zoom in/out) with objects in the virtual room. Finally, no negative issues were reported by 6 out of 15 users.

Users' suggestions. Analyzing users' suggestions for both apps, we collected some interesting ideas, some more general and others more specific. One user suggested including the possibility of directly talking with the hosting person, maybe exploiting vocal messages (for both 2D and VR apps); one user suggested having more than one room per host and giving the visitor possibility to navigate from one room to another (e.g., by clicking on the room door, the user can enter in another room) (for both 2D and VR apps); two users suggested to add interactive objects in the room (360° VR only); another user suggested to add hints to help users to understand how to interact with the city homepage (for both 2D and 360° VR apps); a user suggested to allow to choose the room visualization, if static or 360° (360° VR). Interestingly enough, one participant, after trying the 2D version as the first trial, s/he wrote: "The system doesn't exploit at all the smartphone potentiality, but I have no idea how to improve it." This comment indicates how young users' have expectations with smartphones.

Discussion and limitations

In relation to our assumptions, the findings point out the positive influence of the 360° VR visualization on the visitor's experience of ShareCities. ShareCities, in fact, exploits VR immersive esthetics, engaging the users through one or more of their sensory modalities, inviting them to experience the city and its hosts' suggestions in a playful and esthetically pleasurable way. The graphics and colorful aspects of the AR renditions positively engage users; the virtual representation of the hosts' personalized rooms and the asynchronous messaging exchange invite visitors to enter the virtual space and immerse themselves in a playful treasure hunt for clues and authentic information on the hosting city. In the following section, we discuss the findings in detail against related work and each specific dimension of the experience.

Usability.

Usability scored high across both apps (91.3 and 91.5 out of 100), even slightly higher with the 360° VR. The immersive peculiarity of the 360° VR version positively influenced its usability. We can hypothesize that the participants' age, which corresponds to our target users (digital natives), affects the positive results. Digital natives rely on smartphones for many activities, including travel and tourism. Similarly, mixed reality is becoming an exciting and familiar mode of interaction. While in 2017, Nisi et al. ([188]) and Dionisio et al. ([78]) reported users feeling awkward manipulating their phones in public to view 360° VR content, our study confirms that nowadays, ease and comfort in performing these actions is growing [110].

Engagement.

Regarding engagement, the 360° VR app scored slightly higher than the 2D one, on all factors, except perceived usability (PU). To better understand this result that seems contradictory with the one presented above (SUS), it is worth mentioning that PU, framed in the engagement context, focuses on measuring the negative effect experienced as a result of the interaction and the degree of control and effort expended [194]. While a slightly lower PU score is understandable as a 2D room interaction is simpler and requires less effort than a 360° VR one, we like to call attention to one of our users' comments on the 2D app, mentioning that such an app seemed to miss the opportunity to exploit the smartphone capabilities. This expectation is aligned with recent studies investigating the increasing number of mobile apps exploiting smartphone built-in sensors (e.g., GPS) and AR/VR to provide touristic services [66, 151, 221, 260]. These recent studies confirm that, nowadays, digital native travelers have expectations about the possibility of interacting in mixed reality through mobile apps for tourism. Moreover, regarding "immersive contextual" interaction [130], attention focus (FA), which is considered as "feeling absorbed in the interaction and losing track of time" [194], scored higher for the VR app. This is a positive result itself as it confirmed our design intention to enhance playful "immersive" interaction.

Immersion.

We analyzed the immersion dimension considering the context-awareness property of the smartphone ecosystem to measure contextual immersion [130]. In doing so, we defined six constructs.

Interface. Both versions performed well regarding the evaluation of the interface, intended as ease of use in acquiring information. A slight majority preferred the 360° VR version, while a minority found it more cumbersome. This is understandable considering the effort needed to manipulate the smartphone to find the host's information placed around the room, in contrast with the 2D version, where the information is immediately visible and easier to retrieve. This result aligns with the perceived usability (PU) results (UEA-SF scale). On the other hand, 14 out of 15 users expressed positive feedback about the 360° VR navigation, confirming digital natives' comfort in using MR technologies, echoing recent studies in the education context [163, 237]. The visual aspect of the interface and its ease of use were considered positive aspects of both the 2D and the 360° VR versions.

Sensory. The scores obtained from the sensory construct analysis disclosed that vision and touch senses don't discriminate the way the two apps are perceived. The motivation can be three-fold. First, vision is highly exploited in both versions. Secondly, in both apps users can interact with the environment using touch albeit in a different way: in the 2D version, the user mostly uses the horizontal scroll, while in the 360° VR the touch is used to zoom in/out. Thirdly, both the questions have high internal variance among the scores, probably suggesting that the participants interpreted the meaning of the questions differently, and, consequently, the data show inconsistency. Considering these motivations, we can conclude that further investigations are needed to better assess the sensory role in fostering playful interactions.

Involvement. The involvement construct allowed us to investigate relevant issues considering our goal to foster playful interaction among tourists and locals. The output confirms that users found the 360° VR app more "involving" than the 2D one (4.32 vs 3.27), with a difference of 1.05 in favor of the 360° VR version. The involvement construct includes, among others, a sub-dimension questioning to what extent the app supports real-time awareness about the location, and identities of people, objects, as well as environmental elements. The VR version obtained a higher score than the 2D one (4.33 vs 3.55, respectively). This is a relevant output considering that our design aims at fostering playful interactions among tourists and locals, and eventually building empathy between the two. Moreover, one participant expressed the desire to start a live conversation with the hosts. S/he articulated that while visitors explore the room, the host could be available for questions, for example, over a virtual phone line. While we only hypothesized this function, this user already expressed the desire for it. Other two participants claimed an interest in interacting with the objects in the room to discover further information about the host's identity, while another would like to visualize more objects or details related to the owner. We believe these comments support the app's potential to foster dialogue among visitors and hosts.

Motivation. The analysis of the motivation constructs highlighted that 360° VR supports playful and meaningful engagement, confirming our intent. First, it confirms how 360° VR technologies can facilitate information acquisition. In fact, the item moving in the room I acquired information obtained an average value of 4.4 versus 3.3 for the 2D version. Secondly, the VR version fostered playful interaction. In fact, the item I really enjoy the visualization/navigation task obtained an average score of 4.67 versus 3.35 for the 2D version. As a secondary effect, this result provides evidence that the 360° VR navigation didn't distract the user, but acted as an amplifier of the host information. Thirdly, on average, users felt intimacy with the room host, again confirming our design aim. In fact, the two items I felt an intimacy with the person and I developed empathy toward the person in the room got an average value close to 4 versus 3.2 for the 2D version. Moreover, one participant reported, as a positive aspect, that s/he really liked the possibility of knowing a person in advance (thanks to the room exploration) before asking for suggestions about the city. This feedback reinforces our intuition to use 360° VR to design a system able to benefit the visitors through information exchange with the room's host.

Mobility. The mobility construct measures the possibility of accessing real-time information about the environment. The 360° VR version obtained an overall higher score than the 2D one offering its relevance for fostering playful interactions. The result was surprising, as both apps were experienced through a mobile device. Nonetheless, it is interesting to point out that some users perceived the 2D version as a good compromise to obtain real-time information without delay or inconsistencies, which, on the contrary, can be encountered by navigating the VR room using the built-in gyroscope. Accordingly, four users pointed out technical issues with the gyroscope as a negative aspect of the system. This outcome confirms the high technological expectation of digital natives while enjoying a mobile immersive application.

Reality. With the reality construct, we investigated if the user felt the virtual environment was real. In this case, results strongly state that the 360° VR app was able to increase the acquisition of spatial recognition and information about the real environment, as also the feeling to be physically fit in the virtual environment, obtaining an average score of 4.3 vs 2.5. This outcome is the confirmation that we designed an immersive system, able to create the psychological sensation of being in an alternate space, a feature VR technology should have by design [26].

Sense of comfort. The sense of comfort needs to be considered when designing a system that requires the user to perform physical movements in a public space. Indeed, this sub-dimension is clearly correlated with the concept of flow, the sense of being absorbed by a task to such a degree that one forgets about time and place [69]. The general result confirms that users seemed comfortable using and waving their smartphones in real public spaces to engage with the application. We like to connect this positive result with the changing habits of digital natives, and how the existence of mixed and extended reality applications for public space is becoming mainstream. Said that, a few users still declared that they are worried about other judgments, confirming that the sense of comfort can affect the ease of smartphone use and gesture performance in engaging with extended realities in public spaces. Echoing with [17, 188], we can conclude that this is an issue that needs to be considered while designing mobile 360° VR environments.

Limitations The main limitations of this work are related to the experiment sample, in terms of size, background, and nationality. Size: we were able to engage only 15 participants due to the current COVID-19 pandemic and the related restrictions and lockdown periods. This number can still provide valid results, as detailed in Preece et al. [219] and Caine [42], but, indeed, engaging a greater number of participants can strengthen the obtained results. The uniform background of the users might produce bias. All the engaged users were enrolled in the Computer Science bachelor's degree. Considering previous literature discussing the increasing diffusion of VR technologies in mobile applications ([151]), we can assume that this condition didn't affect the obtained results. Nationality: all the participants were Italian. Also, in this case, we are confident in thinking that this condition did not strongly affect our study due to the nature of the application. However, to validate our assumptions, a future experiment with a larger number of digital natives with different backgrounds and nationalities should be performed.

4.6 Effects of personalized 360° rooms

In the previous study presented above, we learned that:

- today's generation of tourists relies on smartphones for many activities, including travel and tourism, while mixed realities are becoming an exciting and almost familiar mode of interaction. Nonetheless, designing for 360° VR technologies is still in its infancy, and guidance is needed to avoid discomfort while performing movements with the smartphone in public spaces;

- the 360° VR version empowered the acquisition of information about the host's identity and personality, allowing the visitors to eventually build empathy and intimacy. Moreover, the 360° VR mobile app allowed users to create a mental image of the room, increasing the feeling to be physically in the virtual room;
- direct exchange and potential dialogue are a welcome possibility for visitors exploring the hosts' environment. While we only hypothesized the possibility of providing synchronous dialogue between visitors and hosts through the exploration and annotation of the room, some participants clearly expressed the desire for it;
- focusing on immersion, the sensory construct requires further investigation to understand its effects on fostering playful interaction through 360° VR technologies, while interface, involvement, motivation, mobility, and reality positively influence the user's perception of the VR version. On the contrary, we can confirm that the sense of comfort negatively influences the VR experience.

Based on these findings, we built our next study. In particular, we wanted to shed light on the use of 360° personalized virtual rooms to create connections and a sense of affinity, and eventually, empathy, between tourists and locals. The final goal is to increase the likelihood of physically visiting the touristic place in the future and experiencing authentic travel interactions mediated by locals. To better frame our goal, we defined the following assumption: "*The use of 360° VR personalized rooms facilitate the creation of connections, affinity, and empathy between the tourist and the local*".

Hence, we personalized each room so the tourist is able to understand the personality and interests of the owner. For example, in Figure 4.4, a tourist can see that the host of the room likes football and is a fan of the Cesena football team.

FIGURE 4.4: The mobile version of two personalized rooms (Matteo's and Luca's rooms).

We can also infer that the room owner is passionate about history, as he has a photo of the eldest and most famous library in the city of Cesena, and he is a fan of Tiziano Ferro, an Italian singer. Accordingly, the room was customized considering the following *persona*: *Matteo is an architect and lives with his girlfriend and beloved dog. He is very extroverted and likes to meet new people. He loves his city and knows a lot about its history and, in particular, about its historic buildings. He can walk the street of Cesena and talk about it for hours. He walks with his dog, sometimes stops to talk to tourists, helps them find their way, and gives them tips. Sometimes they end up going to a cafe and having coffee while he explains to them all about the wonderful Cesena*. Following the same strategy, we defined other two personas and personalized each room accordingly.

4.6.1 Evaluation

To evaluate ShareCities considering the visitor point of view, we designed an experiment to collect qualitative and quantitative data. The experiment was carried out for three weeks in December 2020 at the Interactive Technologies Institute (ITI, Funchal, Portugal) in compliance with the COVID-19 national regulations and safety measurements.

The study protocol and methodology

We engaged one participant per session. The session was comprised of four different moments: introduction, app interaction, questionnaire, and interview.

Introduction (circa 10 minutes): we welcomed each participant and presented the system, explaining what s/he will be asked to do and the length of the experiment (from 45 to 60 min max). In particular, we asked participants to experience the app's functionalities as a (future) tourist and to imagine that they are planning a visit there, and would like to obtain some information about the city and the local customs before arriving. Moreover, we clarified that participation in the study was voluntary, and they could refuse or discontinue their participation at any time for any reason. We also asked for their consent to collect and store (anonymously) the data for research purposes only. We specified that the data are processed following the European regulation on Privacy GDPR of 25/05/2018, which integrates the Legislative Decree 30 June 2003 n. 196 "Code regarding the protection of personal data" guaranteeing the total anonymity of the participants.

App interaction (circa 10 minutes): the participant was free to explore and interact with the mobile application as a "future" tourist, focusing on Cesena. We created three personalized 360° VR rooms to describe the interests and personalities of three local hosts from Cesena: Matteo, Anna, and Luca. To perform the test, we provided the participant with a lab smartphone (Galaxy Tab S7), so as to avoid asking to install the app on a personal smartphone.

Questionnaire (circa 20 minutes): when the user feels ready, s/he stopped using the app and could start answering the questionnaire. It was comprised of six sections (presented in the following order): 1. an introductory part to confirm the interest in participating in the experiment and storing and analyzing the data (in accordance with GDPR); 2. three open questions to write a description (few paragraphs) of each host and her/his preferences, and six true/false questions regarding the customized information and elements visualized into the 360° VR room; 3. nine questions related to the sense to be connected with the locals and three questions about how much the user feels to be close to each host's profile (affinity); 4. 12 questions related to the experience (User Engagement Scale - UES - short version [194]); 5. eight questions related to the sense of discomfort, immersion, and flow (extrapolated from [255]); 6. four questions about the user, i.e., nationality, age, gender, and background. The questions in sections 3., 4. and 5. were presented in the form of a five-point Likert scale (from Strongly Disagree to Strongly Agree). Each participant answered the questionnaire, accessible using a QR-code link and available on Google Forms, using a personal smartphone.

Interview (circa 5 minutes): after the questionnaire, the researcher performed a quick interview asking questions concerning the best/worst part of the experience and suggestions to improve the experience.

The study protocol was pilot-tested with three participants. Such preliminary tests didn't highlight any concerns or issues, so we proceeded with the official experiment.

Participants

We engaged 19 users who were recruited via the institute mailing list. The age ranges were divided as follows: 24-29, 9 users; 30-35, 8 users; 36-42, 1 user; >42, 1 user. Regarding gender, we engaged 11 males and eight females. The participants' background was variegated, from computer science and engineering to design, psychology, and management. Regarding nationality, all the participants were Portuguese, and only 2 of them had already heard about Cesena before the experiment.

Results and discussion

In this Section, we present the obtained results and the related discussion, in an attempt to investigate our assumption.

Engagement.

First of all, we analyzed if participants feel engaged by the app (section 4. of our questionnaire), exploiting the UES (User Engagement Scale) short version [194]. Results in the form of the average and the standard deviation values for each item considering all the participants are depicted in Figure 4.5. The average values range from Strongly disagree (1) to Strongly agree (5). From the data, we can claim that, in general, the users enjoyed interacting with the system and feel engaged. Only one item obtained a score close to 3 (neutral). Such an item investigated the possibility for the app to appeal senses. This could be due to the fact the app primarily engages only one sense: the one related to the visual elements.

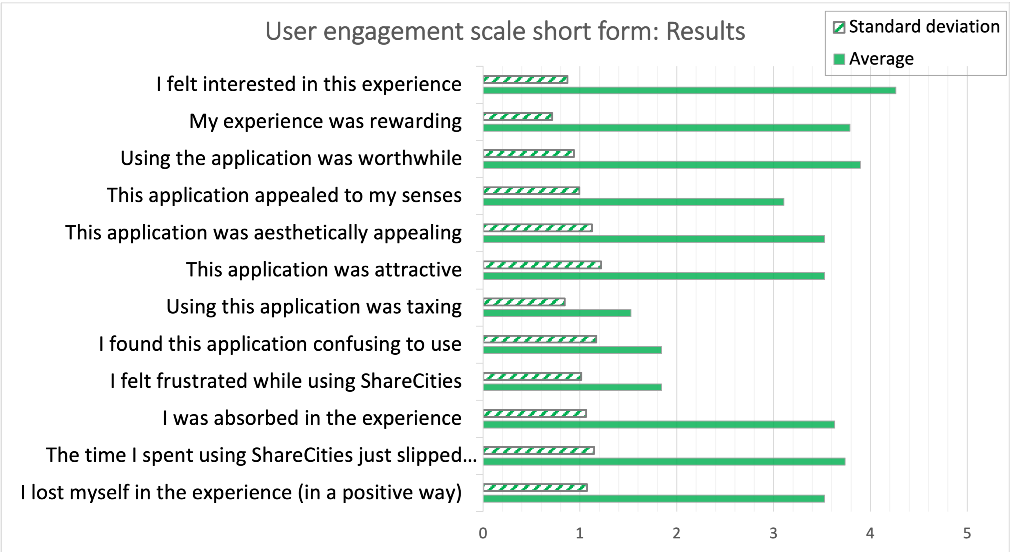

FIGURE 4.5: Obtained data using the UES questions.

Sense of judgment, immersion, and flow.

Then, we considered the participants' answers related to the sense of judgment, immersion, and flow, relevant when investigating VR (section 5. of the questionnaire). An overview is presented in Figure 4.6. Also, in this case, the Figure presents the average (ranging from 1 - Strongly disagree, to 5 - Strongly agree) and the standard deviation values for each item. Interesting to notice that all participants didn't feel uncomfortable using the 360° VR function. This is a relevant result since the app exploits the smartphone's built-in gyroscope sensor to navigate the virtual room; this means that the user needs to move the phone and/or rotate on his/her-self holding the phone to visualize the room's elements. This is not an obvious finding since previous literature emphasized the possibility of feeling uncomfortable using such technologies in public space [17, 188].

Focusing on the immersion dimension, such as the possibility of feeling physically in the virtual environment and fully involved so as to become unaware of things happening around the user, the average values show uncertainty. In fact, the average values of such questions are close to 3, which is the neutral answer considering the five-point Likert scale (neither agree nor disagree). This could be explained by the fact that we explored 360° VR through a smartphone, a technological solution that, for its nature, doesn't allow users to feel completely immersed in a virtual environment.

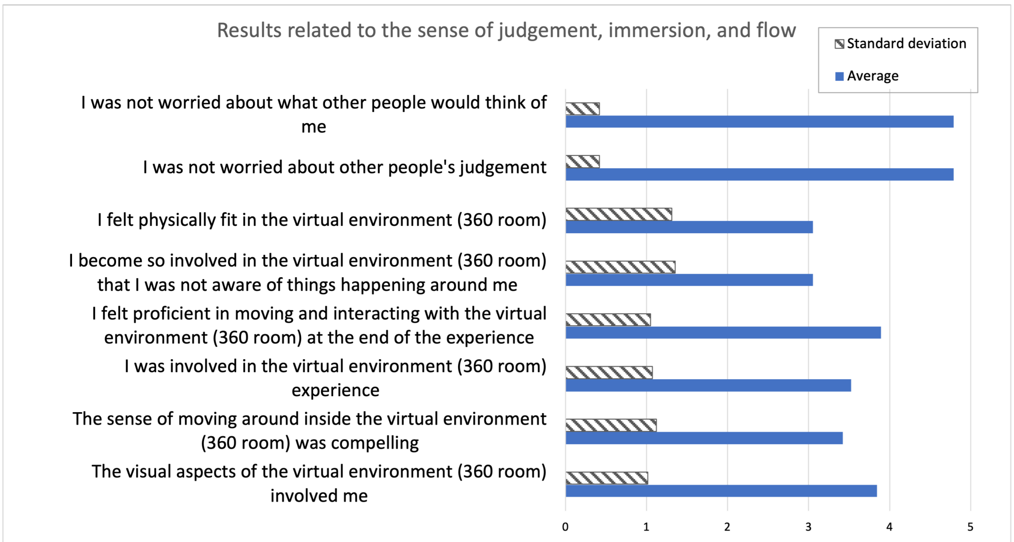

FIGURE 4.6: Obtained data related to the sense of judgment, immersion, and flow.

Host's preferences and information.

Concerning the core issue investigated in this study, we analyzed the answers provided in section 2. We asked participants to write a short description of the three hosts to understand if they were able to grasp some information from the personalized rooms and messages hidden in the room. The provided descriptions, in general, included the main aspects of the host's personality and interests. Some of them were very detailed, such as *Matteo works in the city hall, he likes the historical parts of his town, the architecture and buildings. Has a dog, and probably likes football because has a ball and a club badge. I think he likes some DJ* others very brief, such as *Matteo likes Dogs, Historical Places*. Figure 4.7 presents the word cloud created by analyzing all the descriptions related to Matteo provided by participants. It is possible to see how the more recurrent words are "dog", "historical", "football", and "Tiziano" "Ferro" (an Italian singer).

This is an important result, confirming our intuition to exploit personalized digital rooms to let future tourists know the hosts and, eventually, cultivate a sense of affinity and empathy. Such a positive outcome is confirmed by the data obtained in the true/false questions. All the users (100%) answered in the correct way to such questions, questions in the form of: "Matteo doesn't like playing football" or "Matteo likes to provide historical guided tour".

FIGURE 4.7: The words cloud obtained by analyzing Matteo's descriptions made by the participants.

Sense of empathy.

Figure 4.8 presents an overview of the results obtained investigating the use of 360° VR customized rooms to foster a sense of empathy and affinity. The Figure depicted the average (ranging from 1 - Strongly disagree, to 5 - Strongly agree) and the standard deviation values. We investigated different dimensions, including acquiring knowledge about the host, getting to know the host, a sense of empathy, but also a sense of authenticity regarding the provided content, and acquiring knowledge about Cesena. The outcome is very positive. Most of our investigations got an average value close to 4 (Agree), confirming our intuition to use the personalized room to foster curiosity, empathy, and affinity toward the host. The only question that obtained a lower score (close to 3 - Neutral) was related to the possibility of acquiring knowledge about Cesena. The information provided inside the room was probably mostly perceived as relevant to getting to know the host and her/his personality than the city. Following this line of thought, the question that got the higher average score (4.2 out of 5) concerns the extent to which the user feels that s/he was acquiring knowledge about the host, confirming that the room explicitly presented information about the users.

Moreover, we asked participants to rate (from 1 to 5) the level of affinity with the host. 8 participants out of 19 rated at least one host with the maximum score, and only one person assigned 3 (neutral) to the three hosts. Such an outcome validates our claim that the personalized room can help the tourists create a mental image of the host, fostering connections and a sense of affinity before the actual meeting. Negative rates (1 and 2) are also very intriguing since they reveal that the created mental image of the host seems too distant from the visitor's personality.

Despite the positive findings, it is interesting to enrich the discussion with qualitative data. For example, interesting is the comment of one participant who really liked the idea and the concept behind the app but s/he also claimed: *"I liked the hints it provided, like that a person liked "The Simpsons", or their music style, but I couldn't feel the person's personality. " "The visuals are cool, but it felt like a "stage", not real. Like, it should be a messy room or something, so we can feel the vibe from that person."*

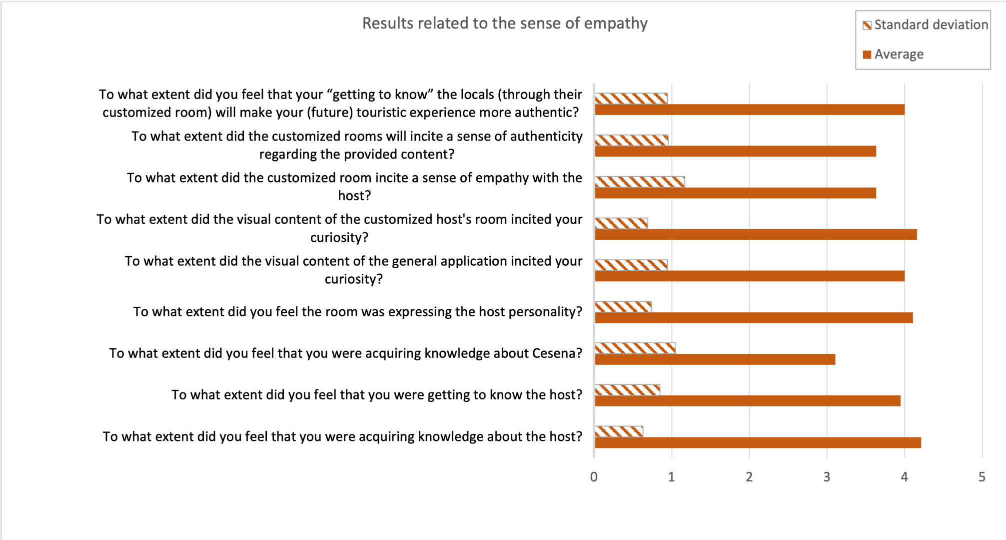

FIGURE 4.8: Obtained data related to the sense of empathy.

4.7 Recommendations to foster authentic experiences

Based on the findings from the previous study, we then started focusing on the investigation of different people-to-people recommendation criteria in order to understand if there is a criterion that best suits our goal: increase the likelihood of positive interaction.

Our investigation started with a preliminary users' study, where we asked users if they would like to have locals-to-tourists recommendation criteria. Then, we implemented the three recommendation criteria in our application, and finally, we performed a specific evaluation engaging more than 100 users.

4.7.1 Preliminary user study

To collect their insights, we performed a preliminary user study engaging 19 future tourists (11 males and 8 females) recruited via the Interactive Technologies Institute (Funchal, Madeira, Portugal) mailing list. Participation was voluntary based on informed consent. The age ranged from 24 to 42. The participants' background was variegated, from computer science and engineering to design, psychology, and management. Regarding nationality, all the participants were Portuguese. We engaged one participant per session. The session was comprised of four different moments: introduction, app interaction, questionnaire, and interview. The experiment mainly focused on understanding the visitor's point of view and, in particular, if the use of 360° VR personalized rooms can facilitate the creation of connections, affinity, and empathy between the tourist and the local. Details about the evaluation methodology, the participant demographic, and the obtained results can be found in the previous Section. In addition to the main objective of the experiment, we included additional questions in the provided questionnaire to perform a preliminary inquiry about the possibility of exploiting recommendation criteria to match locals with tourists and facilitate interaction among them.

In particular, we asked participants: 1. To what extent do you like the possibility of visualizing a proximity rank (i.e., a number, from 1 to 5, inside a heart icon) that compares your profile with the local's one?; 2. To what extent do you find useful the possibility to visualize a proximity rank (i.e., a number - from 1 to 5 - inside a heart icon) that compares your profile with the local's one?; 3. To what extent do you think a recommendation strategy (based on the profile proximity) could benefit your experience?; 4. To what extent would you like to provide personal information to have a more accurate recommendation mechanism? (e.g., preferred color, animal, music); 5. Once in the touristic city, would you prefer to visualize the locals' rooms in order by geographical proximity (the first is the one "physical" closer to you) instead of the "profile" proximity (the first is the more similar to your profile)?.

Considering items 1., 2., and 3. the answers reveal a positive interest (with the majority of people rating 4 out of 5, and none selecting negative values - that are 1 or 2) with no negative answers. Item 4. obtained a more controversial outcome, with two users voting 5 (strongly agree), eight voting four (agree), and eight voting three (neutral), while one voting 1 (disagree). Finally, the strong majority of people (16 out of 19) selected "both profile geographical proximity" to item 5, while the remaining selected "Only profile proximity" (the option we here call profile similarity).

Speculating on the collected results and elaborated insights, we design this study.

4.7.2 Recommendation criteria implementation

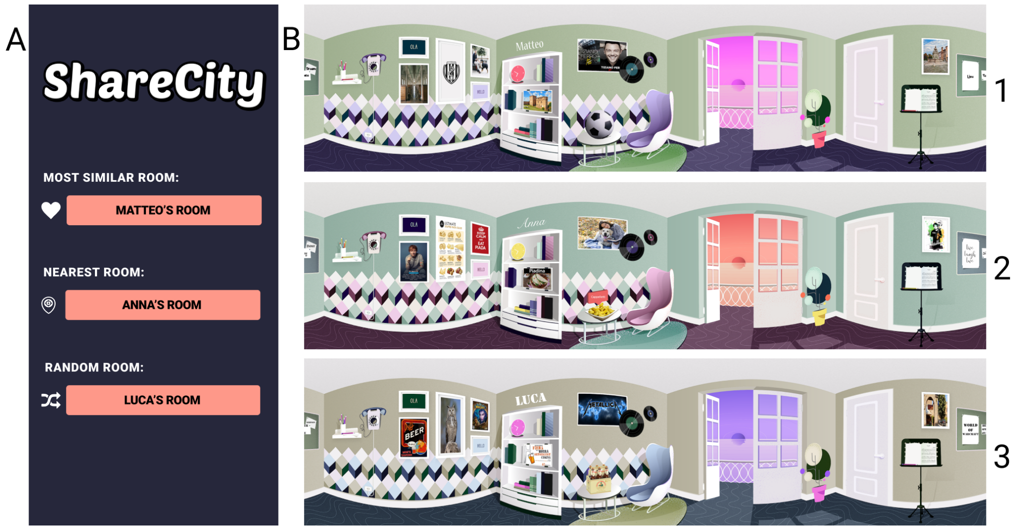

FIGURE 4.9: **(A)** The user interface that proposes to a tourist three different kinds of locals' profiles, in order: (i) the local most similar to the tourist (in terms of interests); (ii) the local nearest to his/her geographical position; and (iii) a random local registered into the system. **(B)** The three rooms of Matteo (1), Anna (2), and Luca (3) with all the paintings customized based on the interests and hobbies of the owner.

Inspired by the resulting insights, we included in ShareCities the possibility for a tourist to visualize locals rooms ordered by three recommendation criteria:

1. profile similarity: how much a tourist is similar to the locals in terms of common interests;
2. geographical proximity: how much a tourist is physically near to locals in terms of geographical position;
3. random exploration: the rooms will be presented in totally random order.

For the purpose of this study, we decide to provide only the best match for each criterion to better investigate the three options.

Profile similarity The first room suggested to the tourist belongs to the most similar local (Figure 4.9). To compute a similarity between the two individuals, we exploited their common interests. In particular, we asked the locals to choose their interests from a checklist during the creation of the room. The checklist was a shortlist of 32 popular and common hobbies in 2021[12]. We made the same request to tourists at the time of registration. After the registration or login, the tourist can choose the city to visit, and then the interests of the tourist and locals are analyzed. As a matter of fact, we computed the similarity between the tourist and each of the locals according to the Jaccard similarity:

$$Jaccard(T, L) = \frac{|T \cap L|}{|T \cup L|} \tag{4.1}$$

where T is the set of interests of the tourist, while L is the set of interests of the locals. Then, as result, we chose the local with the higher Jaccard similarity score. We decided to exploit Jaccard Similarity as it is used to measure similarities between sets when categorical data or keywords are examined [189]. This method allowed tourists to discover people with similar tastes and bring them closer together and, eventually, create empathy between them and live more authentic experiences during their travel. The score for the profile similarity is also visible inside the locals' room. We exploited five hearts icons that are colored based on the score in the left corner of the room. The profile similarity could benefit the tourists' travel both before the actual departure (e.g., they can decide the places to visit after asking for suggestions from the most similar locals) and during the trip (e.g., taking advantage of the services and experiences offered or proposed by the most similar local).

Geographical similarity The second room suggested to the tourist belongs to the nearest local in terms of geographical position (Figure 4.9). This criterion exploited the GPS of the tourist's mobile device in order to get the local nearest to him/her. We asked the locals to also provide an approximate location during the creation of the room. After the registration or login, the tourist can choose the city to visit, and then, if the GPS is on, we computed the distance between the two locations.

[12]https://skillscouter.com/popular-common-hobbies/

We computed the distance between the two geographic points exploiting the *haversine formula*, which calculates the great-circle distance between two coordinates as the shortest distance over the earth's surface, with the following formula:

$$a = sin^2(\frac{\Delta lat}{2}) + cos(lat_1) * cos(lat_2) * sin^2(\frac{\Delta long}{2})$$
$$d = 2 * R * arcsin(\sqrt{a}) \quad (4.2)$$

where lat_1 and lat_2 are the latitudes of the two coordinates, Δlat is the difference between lat_1 and lat_2, $\Delta long$ is the difference between the longitude of the two coordinates, and R is the radius of the earth (=6,371km). In choosing this particular formula, we were inspired by previous works [73, 233].

To provide the actual geographical distance to the tourist, we chose to display the value in kilometers in the bottom-right corner of the room (next to a marker icon and above the hears icons). This similarity could be an appropriate choice, especially to avoid taking transportation or in case the tourist has little time but has the desire to live authentic experiences on site. However, contrary to profile similarity, in order to be effective, it should be used only during the trip and not before as it exploits GPS position.

Random exploration The third and last room suggested to the tourist belongs to a random local registered in our system (Figure 4.9). In this scenario, we proposed to the tourist a randomly chosen local, different from the most similar and the nearest. The random exploration could be a way to discover interesting experiences away from the tourist's usual interests, providing a new approach that had not been thought of to interact with the locals.

4.7.3 User Study evaluation

To evaluate the ShareCities platform, we conducted an online survey (using Google Form[13] and Figma[14]), consisting of two phases: testing the prototype

[13] https://docs.google.com/forms/
[14] https://www.figma.com

and answering a questionnaire. We opted for an online survey due to the COVID restrictions we are still experiencing. Via the provided URL, participants were able to access the survey and read details about the research project and data storage and usage (in accordance with the European General Data Protection Regulation). Then, they needed to give their consent to participate in the study.

Testing the prototype The first phase of the user study was the prototype test of the ShareCities mobile app. To easily perform this task without an additional burden (such as requiring the respondent to install the app), we replicated our working mobile app in Figma. The resulting prototype had the same look and feel as our mobile app.

In order to provide participants with the actual rooms with the best match in terms of profile similarity, geographical proximity, and random exploration, we first asked them to express their interests. We just provided three simple and very general options: cooking, playing football, and gaming. Based on the answer, we provided participants with the appropriate Figma prototype. Basically, we created three Figma prototypes, and we presented the user with only the one created on the basis of the selected interest.

For the user study, we created three personas, each one associated with a specific virtual room to better highlight their personality, interests, and provided services. Our three personas were living in Cesena and were Anna, Matteo, and Luca.

Anna has long-time friends that she cares about and meets often and regularly. She loves to share her knowledge about her culture, in particular culinary culture, coming from Emilia Romagna food is very important to her. She is very careful about details and loves quality ingredients. She loves animals and, in particular, her dog, films, and contemporary art. She practices yoga at home and in the nearby studio. Anna loves the sea, so she takes her dog to run on the beach in the winter and, as soon as the summer starts, she loves to go swimming in the sea.

Matteo is an architect, and he lives with his girlfriend and beloved dog. He is very extroverted and likes to meet new people. He loves his city and knows a lot about its history and, in particular, about its historic buildings. I can walk the street of Cesena and talk about it for hours. He walks with his dog, sometimes stops to talk to tourists, helps them find their way, and gives them tips. Sometimes they end up going to a cafe and having coffee while he explains all about the wonderful Cesena.

Luca is a musician and, to make ends, works at the supermarket as a cashier. But as soon as work is done, he goes home and picks up his guitar. He is composing a new Album. He also plays in a band, and they do covers, play at birthday day parties, and sometimes in pubs as well. He also loves beer, and he is an expert in the best draft beer pubs in town. When he comes home after playing, he plays games online, often with strangers from the other side of the world.

During the prototype test, we asked the participants to look carefully at all three rooms. As a matter of fact, they could see one room as the most similar based on the participant's interests, one as the nearest, and the last as the random one. Participants were free to interact with the Figma prototype for as long as needed.

Questionnaire The questionnaire provided after the interaction with the prototype was aimed to analyze the three dimensions we coined in our research framework: profile similarity, geographical proximity, and random exploration, and it was composed of six steps, as shown in Table 4.4.

Step 1: questions on locals (Q1-Q6). We first asked the participants to answer six closed-ended questions to understand if they explored and looked carefully at the rooms. The questions were related to the personas we created and covered their room, hobbies, and services provided. We decided to include this set of questions to test the participant's attention during the interaction and then apply a quality control check.

Step 2: questions on the proximity similarity and on the recommendation systems (Q7-Q13). In the second step, we asked the participants to answer a 5-point Likert scale (from 1-Strongly disagree to 5-Strongly Agree) and an open question about the usefulness of the proximity similarity in the given context (Q7-Q8). Moreover, to better investigate if the recommendation system influenced the participants' opinions, we also asked 4 5-point Likert scale questions and an open question to analyze their trust in them (Q9-Q13). In this case, we were inspired by [239].

Step 3: questions on the geographical proximity and privacy issues (Q14-Q18). In the third step, we asked the participants to answer a 5-point Likert scale (from 1-Strongly disagree to 5-Strongly Agree) and an open question about the usefulness of the geographical proximity in the given context (Q14-Q15). Moreover, we investigated if the interest in "hyper-local tourism" (intended on a very specific area/community/neighborhood) influenced the previous answers through a 5-point Likert scale (Q16). Finally, we investigated the privacy issue, trying to understand if the participants would have preferred to share with the app the GPS position, their interests, both of them or neither of them through a closed-ended question and an open question (Q17-Q18).

Step 4: questions on the random exploration and serendipity (Q19-Q23). In the fourth step, we asked the participants to answer 2 5-point Likert scales (from 1-Strongly disagree to 5-Strongly Agree) and an open question about the usefulness of the random exploration in the given context (Q19-Q21). Finally, we asked two 5-point Likert scale questions related to serendipity's concept linked to the random local (Q22-Q23) inspired by [54].

Step 5: general comments/preferences on the three dimensions (Q24-Q25). In the fifth step, we asked the participants to answer a closed-ended question and an open question about the preferred criteria for the selection of the local (Q24-Q25).

ID	Question
Q1	In Anna's room, which food was on the table?
Q2	Which is Anna's favorite hobby?
Q3	Matteo doesn't like playing football.
Q4	Matteo likes to provide historical guided tours.
Q5	Luca is a wine sommelier.
Q6	Luca likes metal music.
Q7	I find useful the possibility to visualize the room of the local who most match my interests and personality.
Q8	Please, explain your previous answer.
Q9	I trust recommendation system.
Q10	Please, explain your previous answer.
Q11	I am willing to let the recommendation system help me choose the local who best fit my interests / personality.
Q12	I feel secure about relying on the recommendation system to choose the local who best fit my interests / personality.
Q13	I think the recommendation system knows what I want / what I like.
Q14	I find useful the possibility to visualize the room of the local nearest to me.
Q15	Please, explain your previous answer.
Q16	I think geographical proximity could enhance the possibility to better explore "hyperlocal tourism".
Q17	Are you more willing to share your GPS position or your interests with the app?
Q18	Please, explain your previous answer.
Q19	I find useful the possibility to visualize the room of a random local.
Q20	Please, explain your previous answer.
Q21	I think random exploration could provide me with the possibility to meet diverse people, facilitating unexpected connections among even distant ideas.
Q22	The random local was a pleasant surprise.
Q23	The random local was unexpected.
Q24	What criteria do you think would be most helpful in discovering and experiencing authentic travel experiences?
Q25	Please, explain your previous answer.
Q26-Q35	Ten Item Personality Measure (TIPI) [99]
Q36-Q51	Toronto Empathy Questionnaire (TEQ) [246]
Q52	To which gender identity do you most identify?
Q53	What is your age?

TABLE 4.4: Questions asked during the user study to analyze the three dimensions of profile similarity, geographical proximity, and random exploration.

Step 6: personal questions (Q26-Q53). In the sixth step, we asked the participants to answer the Ten Item Personality Measure (TIPI) questionnaire (Q26-Q35) [99] and the Toronto Empathy Questionnaire (TEQ) (Q36-Q51) [246] to gain insight on their personality and empathy's level, to better investigate if they influenced the previous answers. Moreover, we asked for three personal pieces of information about gender and age (Q52-Q53).

4.7.4 Results

User Sample

126 participants answered our questionnaires. Considering their background, all of them were students enrolled in Computer Science and Engineering degrees (including Bachelor's and Master's degrees). This was due to the methodology exploited to engage them. We invited CS students enrolled in the Web Technologies class (Bachelor's Degree in Computer Science) and Web services class (Master's Degree in Computer Science) using the snowball sampling method. Participation was voluntary based on informed consent. We selected such groups based on the fact that young adults are our main target audience.

However, based on our attention questions (Q1-Q6), we rejected 20 of them, as they answered in the wrong way two or more of them (about 16%). Hence, 106 participants passed the quality control check (P1-P106). Adding more details, on a scale between 1 and 7, our participants had a low average score in extraversion (μ = 3.6, σ = 1.3) and agreeableness (μ = 4.4, σ = 1.0); while they had a high average score on conscientiousness (μ = 5.2, σ = 1.3) and emotional stability (μ = 4.4, σ = 1.2), and an average score on openness to experiences (μ = 5.0, σ = 1.1) (Q26-Q35). The reference values were taken from [245]. Concerning their empathy level, on a scale between 0 and 64, they scored on average low in the TEQ questionnaire (μ = 43.1, σ = 7.5) (Q36-Q51). The reference values were taken from [246]. Finally, our participants were 83 males and 17 females (Q52) aged between 18 and 54 years old (Q53).

ID question	Strongly Disagree	Disagree	Neither agree or disagree	Agree	Strongly Agree
Q9	1.9%	2.8%	38.7%	**41.5%**	15.1%
Q11	3.8%	2.8%	27.4%	**46.2%**	19.8%
Q12	4.7%	10.4%	**36.8%**	34%	14.2%
Q13	4.7%	15.1%	**35.8%**	**35.8%**	8.5%
Q16	1.9%	8.5%	22.6%	**50.9%**	16.0%
Q21	0.9%	12.3%	18.9%	**39.6%**	28.3%
Q22	6.6%	14.2%	**34.9%**	27.4%	17.0%
Q23	4.7%	16.0%	**36.8%**	34.0%	8.5%

TABLE 4.5: Percentage for each group for the 5-point Likert scale questions.

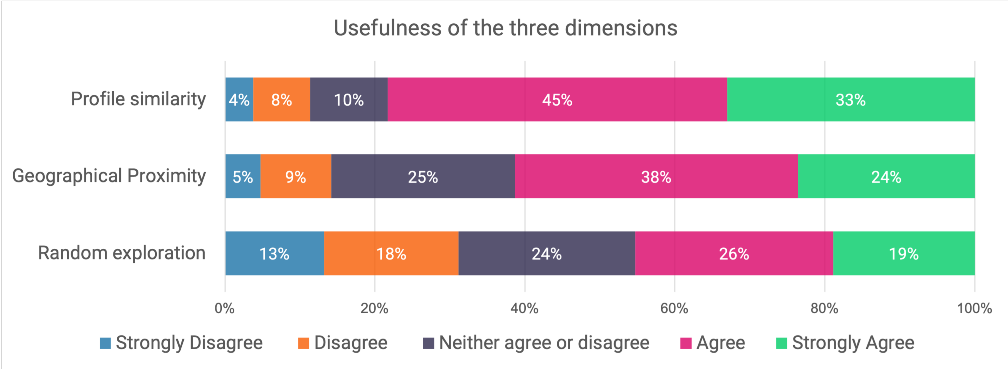

FIGURE 4.10: The results for the usefulness of the three criteria: profile similarity (Q7), geographical proximity (Q14), and random exploration (Q19).

Profile Similarity

Concerning the profile similarity, when we asked our participants if they found useful the possibility to visualize the room of the local who best matches their interests and personality through a 5-point Likert scale from 1 to 5, the answers were generally positive (M = 4.0, Mdn = 4.0, SD = 1.3) (Q7), as shown in Figure 4.10. This positive approach to profile similarity was also demonstrated by the answers to the open question Q8. For example, P103 stated: "It is important because, if I have to visit a city, I'd like to be guided by a person who gives me similar vibes to mine.", and P98: "It is useful to have suggestions that match the user's tastes, which will increase the odds of a successful experience for both parties.". As a matter of fact, many participants highlighted the advantages of this criteria in finding a local. In particular, it could be useful to find new friends (P3: "Basic interests are important in categorizing users, and is the faster mode for finding friends."), to engage in interesting conversations and discussions (P48: "Usually those with similar interests can provide advice and an interesting debate can arise."), it can be more engaging, easier, and quick (P101: "When you visit a new town, and you don't have much time, it is better to be matched as soon as possible with a similar profile to better interact with common interests."), and can provide new knowledge (P27: "I think that is very useful so you can learn new things about your favorite interest.".). However, some participants (12 out of 106) considered this similarity a bit limited, hence not fully useful (e.g., P105 stated: "Not really, because I would also like to explore new points of view.", and P42: "It may be a nice concept, but at the same time I like to meet people with totally different interests.").

Considering the trust in the recommendation systems, the participants had on average a neutral/slightly positive opinion about them (M = 3.7, Mdn = 4.0, SD = 0.8) (Q9), as shown in Table 4.5. 44 of the participants recognized the general usefulness (Q10), as reinforced by P14 in the comment "nowadays we are surrounded by these systems". For example, P95 stated that "Because in a world full of possible choices (e.g., which movie to watch, which product to buy, ...) recommendation systems are needed and useful" and P33 wrote that "It makes my life easier". However, 24 participants acknowledged that the usefulness depends on the system's algorithm and implementation. As a matter of fact, P53 stated that: "Maybe I trust some recommendation systems and I don't trust some others.", or P58: "I don't fully trust them because they may be subject to bias and/or not consider all relevant parameters to correctly suggest and recommend.". Moreover, 9 of them perceived a privacy issue when using this type of system, which affected their evaluation of their trust. For example, P40 stated: "I think profilation is good if helps you have a better experience of the product. Despite that, I think too many companies are using it to sell too many targeted ads, and sometimes it can appear scary too.", and P7: "they are usually pretty good there is a privacy issue though.". Finally, 9 of them would trust these systems more if they can also personalize the inputs and the results or have some kind of control on the algorithm. In this scenario, P2 stated: "although a recommendation system can give you good results a user should be able to personalize it's behavior in the application.", and P44: "I trust them in what they are doing, but I often like to choose a different option.". Another problem arose with the recommendation systems was that "In my opinion recommendation systems tend to recommend always the same things, I am a person who likes to explore many different topics" (P38), so their usefulness can decrease with time.

We tested the correlation between these answers and the ones from Q7 with Spearman correlation. The results showed a very weak correlation between the two variables (r = 0.19, p = 0.049). Hence, trust in this type of system doesn't affect the opinion on the usefulness of the profile similarity.

Considering the willingness to let the recommendation systems help in decision-making for finding a local, the participants had, on average, a neutral/slightly positive opinion about them (M = 3.8, Mdn = 4.0, SD = 0.9) (Q11), as shown in Table 4.5. We tested the correlation between these answers and the ones from Q7 with Spearman correlation. The results showed a positive moderate correlation between the two variables (r = 0.46, $p < 0.001$). Hence, the willingness to let this type of system help choose a local moderate affects the opinion on the usefulness of the profile similarity.

Considering the feeling of security about relying on the recommendation system to choose the local, the participants had, on average, a neutral opinion about them (M = 3.4, Mdn = 3.0, SD = 1.0) (Q12), as shown in Table 4.5. We tested the correlation between these answers and the ones from Q7 with Spearman correlation. The results showed a positive weak correlation between the two variables (r = 0.39, $p < 0.001$). Hence, the feeling of security weakly affects the opinion on the usefulness of the profile similarity.

Finally, considering the thought that recommendation systems know what the user wants/likes, the participants had, on average, a neutral opinion about it (M = 3.3, Mdn = 3.0, SD = 1.0) (Q13), as shown in Table 4.5. We tested the correlation between these answers and the ones from Q7 with Spearman correlation. The results showed a positive weak correlation between the two variables (r = 0.33, $p < 0.001$). Hence, the fact that recommendation systems know what someone wants/like weakly affects the opinion on the usefulness of the profile similarity.

Moreover, we tested the correlation between Q9 and Q13 with Spearman correlation, and, as we expected, there was a positive moderate correlation between the two questions (r = 0.47, $p < 0.001$).

Summing up, the opinions that our participants had on the usefulness of the profile similarity were weakly or moderately affected by what they thought about the recommendation system that created that similarity.

Geographical Proximity

Concerning geographical proximity, when we asked our participants if they found useful the possibility of visualizing the room of the local nearest to their GPS position through a 5-point Likert scale from 1 to 5, the answers were generally neutral or weakly positive (M = 3.7, Mdn = 4.0, SD = 1.1) (Q14), as shown in Figure 4.10. The major flaws found by the participants on this dimension were the fact that "the match with a person is made without looking at common interests." (P55 on Q15) and "the closer you stay, the higher are the chances of getting a place you already know well." (P62). However, 13 participants mentioned that proximity could be a different way to meet new people and find new friends. For example, P101 wrote that "it could be a new way to break the ice in meeting people" and P77 mentioned that "it can introduce you to new interests and make immediate connections and outings, shifting your focus less to your interests and more to your city". The focus on the city and the surroundings appeared in 3 comments. In fact, P100 stated that "It may make me want to explore that area of the city." and P96: "It could be helpful to encourage exploration of nearby". Moreover, staying in the surroundings may avoid the risk of getting lost (P98: "Geographical proximity is important when visiting a new place, as it might reduce the probability of the user getting lost and ending up somewhere else.") and could be quicker and more comfortable, without having to take public transport (P95: "it could be useful to evaluate people who are closer and possibly more comfortable to reach."). Finally, the proximity could be used for 4 participants as a decision parameter when choosing a local. As a matter of fact, P66 stated that "I believe that the proximity of the room can be on many occasions the discriminating factor between two locals.", and P80 mentioned that: "can be helpful to take better decisions.".

Considering the thought that geographical proximity could enhance the possibility of better exploring "hyperlocal tourism" (tourism based on a very specific area/community/neighborhood), the participants had, on average, a positive opinion about it (M = 3.7, Mdn = 4.0, SD = 0.9) (Q16), as shown in Table 4.5. We tested the correlation between these answers and the ones from Q14 with Spearman correlation. The results showed a positive moderate correlation between the two variables (r = 0.55, $p < 0.001$). Hence, the possibility to better explore "hyperlocal tourism" affected the opinion on the usefulness of geographical proximity.

Considering the privacy issue of the data shared with the application, 44 participants (41.5%) preferred to share only their interests, 10 participants (9.4%) were willing to share only the GPS position, 36 (34.0%) both GPS and interests, while the remaining 16 (15.1%) none of them (Q17). This data demonstrated that our participants were aware of the privacy issue behind mobile applications. However, two participants consider their interests more sensitive information, as mentioned by P66 on Q18: "sometimes sharing interests is too invasive.". The participants who were more in favor of sharing their interests stated that "I would have no problem in sharing my interests with the app, but I would be more reticent in sharing my GPS position due to privacy concerns." (P34) or "I don't trust to share my position. You never know in the hands of who will end up with that data." (P48). The participants who were willing to share both interests and GPS recognized that these permissions were necessary to have a better experience while using the app. As a matter of fact, P5 mentioned that "sharing both of them would let the app give me all that it has to offer.", and P45 stated that: "I think that with GPS position and Interests combo it's possible to have more accurate results.". Finally, the participants (12 out of 106) who weren't willing to share any data usually explained that "data can be stolen" (P31) or "I don't like sharing any kind of personal information" (P32).

Random Exploration

Concerning the random exploration, when we asked our participants if they found useful the possibility to visualize a random room of a local registered into the app through a 5-point Likert scale from 1 to 5, the answers were generally neutral or weakly positive (M = 3.2, Mdn = 3.0, SD = 1.3) (Q19), as shown in Figure 4.10. This outcome on random exploration was also braced by the answers to the open question Q20. Some participants (33 out of 106) would not use this functionality because they didn't find it useful (as P87 said on Q20: "it is fancy but not so useful" or P80: "It's important to visualize what is interesting to me in a specific place, not a random local."), and created a feeling of disorientation (P62: "the fact that I know nothing about the match make me feel a little bit bewildered".). However, seven of them believed that this was a funny strategy to visualize new information as it was a "fun "mini-game" to do" (P56), and other four thought that "It might add an element of surprise, which I personally like" (P42). The majority of the positive comments (26) were about the opportunity it could create. As a matter of fact, "It could be a way to explore new and different interests, maybe finding something interesting, in a serendipity way" (P99), "Even if a random local probably does not match my interests very much, checking his/her room can still offer an interesting perspective on the area and the people who live there." (P100), and "Sometimes we could feel the desire to escape from our comfort zone" (P101).

Considering the thought that random exploration could provide the possibility to meet diverse people, facilitating unexpected connections among even distant ideas, the participants had, on average, a positive opinion about it (M = 3.8, Mdn = 4.0, SD = 1.0) (Q21), as shown in Table 4.5. We tested the correlation between these answers and the ones from Q19 with Spearman correlation. The results showed a positive strong correlation between the two variables (r = 0.62, $p < 0.001$). Hence, the possibility of meeting diverse people affects the opinion on the usefulness of random exploration.

Considering the thought that the random local was a pleasant surprise, the participants had, on average, a neutral opinion (M = 3.3, Mdn = 3.0, SD = 1.1) (Q22), as shown in Table 4.5. We tested the correlation between these answers and the ones from Q19 with Spearman correlation. The results showed a positive strong correlation between the two variables (r = 0.61, $p < 0.001$). Hence, the fact that the random local was a pleasant surprise affected the opinion on the usefulness of the random exploration.

Finally, considering the thought that the random local was unexpected, the participants had, on average, a neutral opinion (M = 3.3, Mdn = 3.0, SD = 1.0) (Q23), as shown in Table 4.5. We tested the correlation between these answers and the ones from Q19 with Spearman correlation. The results showed a weak correlation between the two variables (r = 0.21, p = 0.028). Hence, the fact that the random local was unexpected slightly affected the opinion on the usefulness of the random exploration.

Preference on the recommendation criteria

Concerning Q24, there was no clear preference for the best criteria, as shown in Figure 4.11. As a matter of fact, 34 of our participants (32%) preferred the profile similarity, 18 of them (17%) the random exploration, and 12 of them (11%) the geographical proximity. However, 18 of them (17%) would like to have all three dimensions, 22 of them (21%) thought that the best dimension depends on the situation, and 2 of them (2%) didn't like any of the dimensions. To better investigate the different choices, we analyzed the answers to Q25. Regarding the choice of the *profile similarity*, P20 stated that "it is easier to try to interact with people who have tastes and personalities similar to ours", while P67 recognized the utility of a local guide: "It helps to enjoy a new place based on the things that you like, guided by a point of view of a local.". The same concept was also expressed by P69: "A local with the same tastes as yours can guide you to places that you are interested in.". Regarding the choice of the *geographical proximity*, two major topics came up: convenience and budget. P6 stated that

"Geographical proximity is more convenient to use." and P66 added that "Geographical proximity limited the movement around". However, P5 affirmed that "For economic reasons, maybe, geographical proximity is the best choice", and the same concept was expressed by P23: "The major target is young people, so I think the Geographical proximity could interest most of them cause their limited budget". Regarding the choice of *random exploration*, the motivation found was related to the travel experience. As a matter of fact, P62 stated that: "travel is about experiencing new things, geographical proximity and profile similarity would have the opposite effect in general", and P84: "I believe that when you travel one of the main objectives is to discover cultures and people and get out of the comfort zone. The criterion that comes closest to this is Random exploration". The idea of discovery was also present in the comment of P71: "In my opinion, during our choices, we consider our interests too much and this is right, but sometimes getting carried away by a random choice can help us find new interests that we would have underestimated.". Regarding the participants who didn't like any of the criteria, the explanation was the following: "I think travel is an experience that is planned only to the extent of *Where do I land, where do I sleep* the rest must not be pre-written." (P38). Regarding the choice of all three criteria, 18 participants thought a combination of all three criteria could be an advantage while exploring the rooms. In fact, P97 affirmed that: "Random exploration has its importance in making new experiences, but I believe there should be a little bit of familiarity (i.e. profile similarity) in order to make the experience not too random. Also, it could be interesting getting to know the local hidden gems that not many people know about.", and P78 stated that: "the authentic travel experiences must have all three previous characteristics for be like a real experience.". Finally, regarding the last participants who have chosen the option "It depends", the motivations were linked to the usefulness of all three criteria that can be used in different situations and by different people. For example, P13 stated: "I think it changes for each individual and how they relate with new people and places", P35 added: "It depends on what kind of experience I want to do when the time comes", and P98: "The importance of the criteria depends on the nature of the travel experience.".

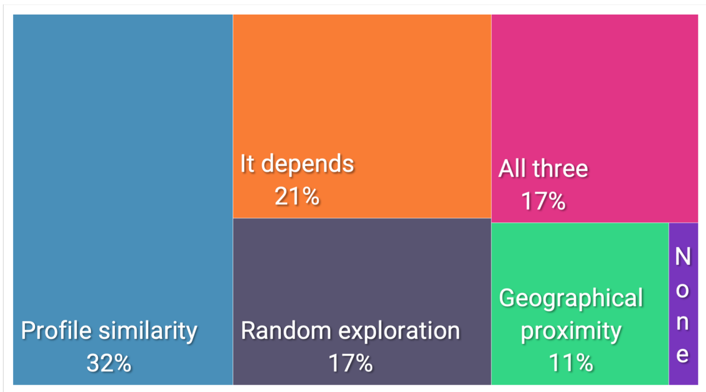

FIGURE 4.11: The dimensions preferred by our participants. As demonstrated by the percentage, there wasn't a clear preference in their choice (Q24).

To gain more insight into the study, we decided to investigate the possible relationship between the dimension chosen (profile similarity, geographical proximity, and random exploration) and the participants' profiles. In particular, as shown in Figure 4.12, we analyzed the TEQ scores divided by the dimension chosen. From the boxplot, we noticed that the participants who chose the geographical proximity had, on average, the lowest score in the TEQ. Hence, Kruskal-Wallis Test was conducted to examine the differences in the TEQ score according to the dimension chosen: profile similarity, geographical proximity, and random exploration (Q24). The results indicated there was a significant difference ($H(2) = 6.031$, $p = 0.049$) between the three dimensions, with a mean rank TEQ score of 35.31 for the profile similarity, 20.63 for the geographical proximity, and 35.11 for the random exploration.

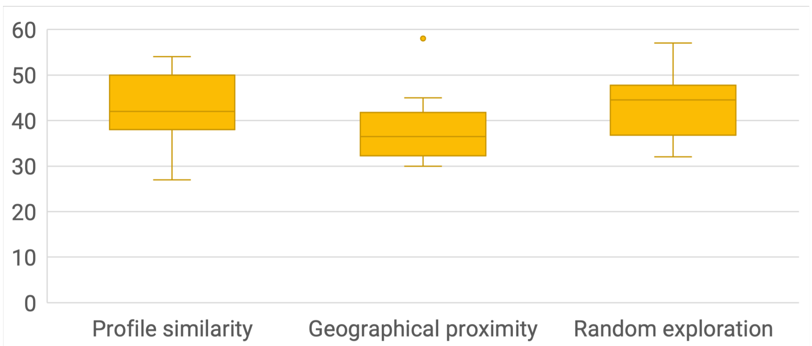

FIGURE 4.12: The TEQ scores for the participants divided by the dimension preferred (Q24). The participants who chose geographical proximity had on average the lowest score in the TEQ.

Moreover, as shown in Figure 4.13, we analyzed the TIPI scores for each of the five traits (extroversion, agreeableness, consciousness, emotional stability, and openness to experience) divided by the dimension chosen. We did not notice any particular difference between the three groups from the boxplot. Hence, we conducted the Kruskal-Wallis Test to examine the differences in the Big-Five personality traits from the TIPI with the dimension chosen. Regarding the extraversion, the results indicated there was no statistically significant difference ($H(2) = 1.22$, $p = 0.54$) between the three dimensions. Regarding agreeableness, the results indicated there was no statistically significant difference ($H(2)$ = 0.006, p = 0.997) between the three dimensions. Regarding conscientiousness, the results indicated that there was no statistically significant difference ($H(2)$ = 5.87, p = 0.053) between the three dimensions. Regarding emotional stability, the results indicated there was no statistically significant difference ($H(2)$ = 2.89, p = 0.24) between the three dimensions. Regarding openness to experiences, the results indicated there was no statistically significant difference ($H(2)$ = 0.08, p = 0.96) between the three dimensions.

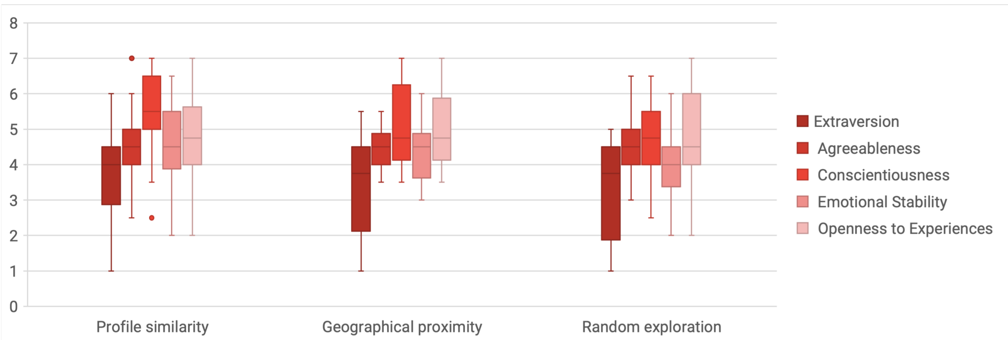

FIGURE 4.13: The TIPI score for each trait (extroversion, agreeableness, consciousness, emotional stability, and openness to experience) for the participants divided by the dimension preferred.

4.7.5 Discussion

After interacting with the prototype of the ShareCities mobile app, our participants were exposed to three different recommendation criteria. The aim was to find out the best criteria to implement in the tourist context to foster the interaction between tourists and locals and to have more probability of living an authentic experience. However, our user study didn't highlight a preferable criterion; as presented in Figure 4.11, a clear majority doesn't emerge. Our participants generally liked the profile similarity, but their trust in the algorithm influenced their opinion on the usefulness of this criterion. At the same time, a privacy issue emerged in their comments. As a matter of fact, existing literature highlights privacy as one of the main factors that could affect mobile recommendation systems [204, 249]. The privacy concern was also a major flaw of the geographical proximity criterion. Nevertheless, it could be seen as more convenient, in terms of time and money, and a way of experiencing "hyper-local" tourism. Interestingly, this recommendation could also be seen as a way to interact and make new friendships with locals even distant from their interests. For this aspect, it was similar to random exploration. The participants highlighted both advantages and disadvantages of this criterion. As a negative aspect, the random local could create a feeling of disorientation in some participants. However, for others could be a way of stepping outside their comfort zone and discovering new interests.

This variety of opinions emerged also when analyzing the user's profile in relation to her/his peculiar point of view. Accordingly, some of the findings and comments from our participants could suggest a link between the personality and the preferred criterion, but, as demonstrated, there was no statistically significant relationship between the criterion and the Big-Five personality traits from the TIPI questionnaire. However, a statistically significant relationship was found between the criterion and the participants' empathy level, analyzed through the TEQ score.

Finally, the analysis demonstrated that all three criteria could be a good choice in the tourism context, both used alone and in combination, due to the specific scenario and nature of the travel. Moreover, this finding highlighted the necessity of having some kind of personalization strategy to have a better experience within the app and during the actual travel. Indeed, in line with [122], the personalization strategy in the Smart Tourism Technology can affect the touristic experience, but its effect could be moderated by the perceived security/privacy issues.

As a final remark, it is worth noting that, although we provided participants with only three local room options (one for each recommendation criterion), we are confident that such a decision didn't influence our results. We recall that the main objective of this study was to investigate the concept behind the three types of recommendation (named profile similarity, geographical proximity, and random exploration) in terms of the target users' preferences. Accordingly, in the evaluation study, we asked general questions based on the three concepts that did not concern satisfaction with the single rooms provided. Hence, we can assume that the results are not influenced by the number of rooms we provided.

Limitations

The main limitation of this study is the experiment sample in terms of (i) size, (ii) background, and (iii) nationality.

Size: we were able to engage 126 participants, which clearly does not represent a statistically significant sample size if considering the whole population of young adults as the main target of our system. Future studies should include larger sample sizes to achieve more accurate findings. Nonetheless, analyzing in detail the obtained results, we can affirm that data provide valuable information given the research hypothesis framed in this study, and such insights can be useful for developing cumulative knowledge [161].

Background: the uniform background of the users might produce bias. All the engaged users were enrolled in the Computer Science bachelor's and master's degrees. We are aware that the underline condition could have affected our results, in particular when discussing technological issues, such as privacy, trust, and data protection. Despite that, several studies investigated young-adult users' perceptions when using the smartphone, enforcing the fact that it is an actual issue that people are aware of [95, 21].

Nationality: all the participants were Italian. Also, in this case, we are confident in thinking that this condition did not strongly affect our study due to the nature of the application. However, to validate our assumptions, a future experiment with a larger number of young adults of different nationalities should be performed.

4.8 Discussion and conclusion

In this Chapter, our approach is presented in order to promote the creation of authentic experiences between locals and tourists as a way of fostering more sustainable tourism. We wanted to give tourists the opportunity to live authentic experiences and make meaningful connections with locals. In particular, our case study was based on the ShareCities platform.

To investigate the dimensions presented in Section 4.3, we designed, developed, and evaluated the platform engaging potential future tourists. The results are here summarized and discussed.

Effects of an immersive 360° VR visualization. We report on the design and study of a hospitality application driven by the following assumptions: *"In the visitor experience of the ShareCities hospitality service, an immersive 360° VR visualization contrast with a 2D visualization"; and "The design of playful information sharing hospitality platforms has some implications that we can draw from the study conducted on the visitor experience of ShareCities"*. As a case study, we designed and implemented ShareCities, a mobile application that extends on a previous effort [44] exploiting 360° mobile VR as a playful immersive tool to connect and engage visitors and locals alike, through the navigation of a virtual room. Engaging 15 digital natives, we performed a within-subject design experiment to investigate the tourists' perspective, exploiting two mobile versions of ShareCities to navigate the virtual room: one presenting 2D scroll-based images of the room, and the other exploiting 360° VR gyroscope-based navigation. The collected data allow us to positively confirm that the 360° VR version was perceived as more involving, engaging, motivating, real, mobile, and with an easier interface to acquire information than the 2D one. Data shows that the 360° VR feature can be playful due to the high user engagement and involvement it provoked. Moreover, curiosity about the host and its VR personalized environment was generated in the users, who asked for real-time interactions with the objects in the room and also the possibility to move across rooms by simply opening the door. Ultimately, the desire to establish a dialogue between tourists and locals emerged in the words of one user that expressed the desire to have a direct channel to talk with the host. Following these encouraging results, we are planning to continue investigating mobile 360° VR technologies focusing on supporting dialogue among locals and tourists (considering the locals' perspective) in emerging hospitality services. Moreover, we would like to investigate whether the role of the urban public space, as a space to facilitate social interactions, can play a relevant role in fostering such a dialogue.

Effects of personalized 360° rooms. We investigated the potential to exploit 360° VR and customization, particularly customized rooms representing the hosts' personality and interests, to foster personal connections, a sense of affinity, and, eventually, empathy. In doing that, we performed an experiment engaging 19 "future" tourists. The findings are very positive and pushed us to better investigate issues related to the tourists' and locals' profiles in terms of recommendation mechanisms and algorithms to further facilitate connections.

Recommendations to foster authentic experiences We presented an extended analysis on the opportunity to use people-to-people recommendation criteria based on two people's (i.e., a local and a tourist) proximity in terms of profile similarity (investigated both considering the closest profiles and two random ones) and geographical proximity. We hence defined three criteria (that correspond to the three dimensions of interest for our analysis: i) profile similarity, ii) geographical proximity, and iii) random exploration. Through an online questionnaire, we collect answers from 126 young-adults students. Results highlight a general positive interest in using all three proximity-based recommendation criteria while outlining some concerns in terms of privacy and trust (when considering profile similarity), privacy (when considering geographical proximity), and disorientation (when considering random exploration). The findings from the study represented our attempt to answer RQ2, as presented in Section 1.2, and proved to us the effectiveness of the ShareCities platform in connecting tourists and locals.

Chapter 5

Case study: Industry

As mentioned in Chapter 1, one of the main targets of SDG8 is decent work for all and social protection, which takes into consideration the work environment. This chapter presents the work done to promote awareness related to sustainability in the industry context, in particular, we wanted to increase awareness regarding sustainability efforts made by the companies and how they are perceived by former and current employees.

Internal sustainability efforts (ISE) refer to a wide range of internal corporate policies focused on employees. They promote, for example, work-life balance, gender equality, and a harassment-free working environment. At times, however, companies fail to keep their promises by not publicizing truthful reports on these practices, or by overlooking employees' voices on how these practices are implemented. To partly fix that, we developed a deep-learning framework that scored four-fifths of the S&P 500 companies in terms of six ISEs, and a web-based system that engages users in a learning and reflection process about these ISEs. We finally evaluated the system in two crowdsourced studies.

The rest of this Chapter is organized as follows. Section 5.1 introduces the importance of sustainability and SDGs, and, in particular, Internal Sustainability efforts. Section 5.2 presents the main related works about ML4VIS. Section 5.3 illustrates the main assumption behind our system in relation to the main research questions of this thesis. Sections 5.4, 5.5, 5.6 describe the design, and the implementation of the whole system, while Section 5.7 presents the user study and the evaluation involving users. Finally, Section 5.8 summarizes the work and the main findings.

5.1 Introduction

Internal sustainability efforts (ISEs) describe a broad range of corporate policies focused on employees, including, for example, work-life balance, gender equality and diversity, and a harassment-free working environment. These ISEs not only can decrease staff turnover but also enhance a company's competitiveness. It comes as no surprise that companies, at times, obfuscate information about how ISEs are actually implemented in their public reports[1], contributing to a gap between what companies publicize and what they actually do. Also, a study showed that investor reports and annual corporate reports (the gold standard for business assessment) are more of a corporate PR exercise than objective assessments[2], especially for emerging concepts such as sustainability. Therefore, as the same study also argued, accountability and verification of corporate claims are very much needed.

To partly close that gap, we developed a DL-driven visualization (available at `http://social-dynamics.net/sustainability/`) for surfacing ISEs in big companies and engaging the general public in a debate about them. In so doing, we made three sets of contributions: (1) we collected public employee reviews from a company reviewing site, and, using a DL Natural Language Processing (NLP) tool, we scored fourth-fifths of the S&P 500 companies in terms of their ISEs [236]; (2) using these scores, we developed a web-based visualization tool for raising ISEs awareness; (3) we evaluated the tool in two crowdsourced studies with 421 participants and compared our treemap visualization with a baseline textual representation. We found that treemap increased by up to 7% our participants' opinion change about ISEs, demonstrating its potential as an alternative representation in ML-driven visualizations.

[1]https://www.forbes.com/sites/forbesnonprofitcouncil/2021/03/23/businesses-should-be-held-accountable-for-their-esg-claims/

[2]https://hbr.org/2019/06/business-as-usual-will-not-save-the-planet

5.2 Background and Related Work

ML4VIS is a new branch of research, which uses ML techniques to develop, design, and evaluate visualizations [270]. Cunningham-Nelson *et al.* [70] used a Latent Dirichlet Allocation algorithm to analyze free-text students' comments obtained from satisfaction surveys, which, in turn, powered a visualization that allowed educators to understand students' concerns about teaching. Corporate sustainability efforts have gained traction within academic circles. For example, a theoretical framework divides companies into ones that report on their own efforts only to manage their brands (symbolic) and to those that genuinely report on actual changes (substantial) [87]. To add transparency in this area, Sneha *et al.*[243] developed interactive visualizations for comparing companies' sustainability efforts. Similarly, the OECD's Life Index[3] provides a web-based visualization for comparing sustainability efforts (e.g., health, environment), but it does so at the country level rather than company level.

To summarize, previous works focused on public reports, often overlooking employees' opinions on the practical implementation of ISEs. Additionally, ML-driven visualizations often use static, default types of graphs, and exploration techniques (e.g., bar charts) [270]. The unmet design challenge is, therefore, how to provide users with dynamic, ML-driven visualizations using a new combination of data engagement mechanisms.

5.3 Research questions

Considering the background analyzed in the previous Section, we aimed to answer the two research questions, presented in Section 1.2, in the context of sustainability inside the corporate context.

In particular, concerning **RQ1**, we were interested in understanding how to promote awareness of the effort made by the companies in relation to sustainability

[3] `http://do.minik.us/blog/oecd_bli`

practices. That said, a workplace observant of SDGs can achieve the target of "decent work and social protection for all".

In relation to **RQ2**, we wanted to evaluate the systems engaging users to gain insight into the most effective features. In this case study, we defined effectiveness as the system's capability to increase awareness of sustainability efforts and practices inside well-known companies.

5.4 Methods

We collected a dataset of 358,527 reviews published on a popular company reviewing site. On that site, former or current employees share their experiences of their companies as free-form textual reviews, in addition to ratings about different aspects like management and culture. We selected 104 US-based companies with at least 1000 reviews between 2008 and 2020, and with a (physical) presence in more than 10 US states. 81% of these companies were in the S&P 500.

he reviewing site ensures quality reviews by performing both automatic and manual content moderation (e.g., registered users and those who wrote at least one review have full content access, and a maximum of one review per employee per year is allowed[4]). However, while data could be biased, it is systematically so across companies, making companies and their scores comparable. Therefore, several studies have explored corporate culture at scale using data from the site [72, 153]. The site explicitly divides reviews into pros (positive) and cons (negative). As sustainability has a positive valence, we opted for using pros. By manually inspecting a random sample of 500 pros and cons, we found that, on average, 89% of pros mentioned ISEs (and did so with positive valence) compared to 63% of cons (with mixed valence). To then operationalize ISEs, we adopted a three-step mixed-method approach:

[4] https://www.glassdoor.com/research/app/uploads/sites/2/2017/10/Glassdoor_GiveToGet_Oct2017-1.pdf

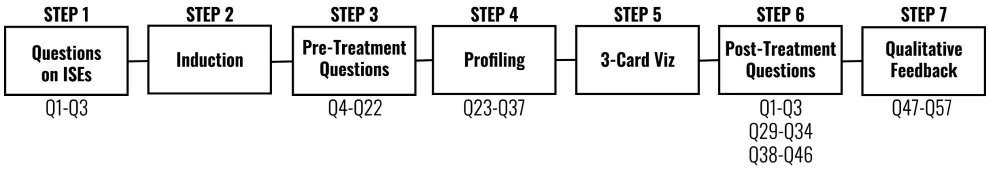

FIGURE 5.1: Our user study procedure consists of seven steps.

Step 1: Pre-selection. Three annotators assessed the UN's Sustainable Development Goals (SDGs) definitions[5] [236].

Given their broad scope, not all 17 goals might be relevant to internal corporate practices. The annotators unanimously decided to discard four: 'life below water', 'life on land', 'sustainable cities', and 'partnerships for goals'. The former three focus on water bodies, land, and cities, which are unlikely to appear in employees' reviews outside of highly specialized companies. 'Partnership on goals' was explicitly designed to foster countries' collaboration, and, as we focused on US-based companies, that goal was also excluded.

Step 2: Unsupervised discovery. To find the similarity between reviews and goal definitions, we employed the state-of-the-art DL method called SBERT [224]. Using SBERT, we scored each employee's review against the 13 previously retained goals [236]. For each goal, the three annotators assessed the relevance of the top five most relevant reviews identified by the framework. On average, they reached an agreement as high as Fleiss K equal to 0.83. To take a conservative approach and ascertain which goals were less accurately identified by the framework, we identified which goals had less than 4 (of the top 5) reviews to be marked as relevant by the majority of the annotators. As a result, we dropped 5 goals, which had to do with environmental sustainability (e.g., "clean water", "climate change") rather than corporate internal sustainability, leaving us with 8 goals.

[5]https://sdgs.un.org/goals

Step 3: Consolidation. The refined goals were assessed for semantic relatedness, and strongly related goals were merged together, ultimately leaving us with 6 goals. Sustainability goals are not mutually exclusive and a certain degree of overlap might be expected (e.g., work-life balance facilitates both health and gender equality). However, there might be cases where two goals are so strongly related to one another that cannot be discerned. To systematically tackle this issue, we plotted the content overlap O for each pair of goals by computing the proportion of sentences that two goals j and k have in common. The only overlap higher than 0.5 occurred for the pair 'food (no hunger)' vs 'health'. These have indeed strong conceptual relatedness, thus subsuming 'no hunger' under 'health'. Note that two other goals' pairs exhibited semantic relatedness close to 0.5: these were 'supportive environment' vs 'supporting infrastructure', and 'diversity' vs 'gender equality'. To decide whether to combine them, the annotators assessed the top five reviews for each goal, and found that 'supportive environment' and 'supporting infrastructure' covered related yet different concerns; however, they discovered that the 'diversity' goal (reducing inequality) was mostly expressed through mentions of 'gender discrimination'. Consequently, we merged these two goals together.

Scoring companies. After identifying these six goals, the framework computed each company's score $s(c,i)$ of the i^{th} ISE for company c as the fraction of c's reviews that mentioned i:

$$s(c,i) = \frac{\sum_{r \in R(c)} sim_t(v_r, v_i)}{|R(c)|} \tag{5.1}$$

where $R(c)$ is the set of c's reviews, v_i is the SBERT vector of ISE i (Figure 5.2a – definitions of the six ISEs), and $sim_t(v_r, v_i)$ is the *thresholded* SBERT similarity score [224] between the SBERT vector of review r and the SBERT vector of ISE i. More precisely, $sim_t(v_r, v_i)$ is defined as:

$$sim_t(v_r, v_i) = \begin{cases} sim(v_r, v_i), & \text{if } sim(v_r, v_i) > 0.31 \\ & \text{ AND} \\ & sim(v_r, v_i) > 95\%(i); \\ 0, & \text{otherwise.} \end{cases} \tag{5.2}$$

where $sim(v_r, v_i)$ is the cosine similarity between v_r and v_i. We chose the threshold of 0.31 by computing the mean SBERT similarity for the goals. We then paired the fixed generalized threshold of 0.31 with an ISE dimension-specific threshold. Based on our experiments, we chose a $95\%(i)$ threshold value, which is the 95% percentile of the ISE's distribution.

To support a seamless visualization experience, for each company c, we computed its company vector (v_c) *offline* (i.e., the computation was not repeated for every user but was performed only once):

$$v_c = [s'(c,1), s'(c,2), ..., s'(c,6), sg(c)], \tag{5.3}$$

where $s'(c,i)$ is the i^{th} ISE scaled score for c ($s'(c,i)$ is the value of $s(c,i)$ scaled between 0 and 100), and $sg(c)$ is c's internal sustainability gap computed as per Eq. (5.4). As the sum of the scaled scores of a company ($\sum_{i=1}^{6} s'(c,i)$) may not reach the maximum value of 600 (each ISE can take a maximum of 100), we wanted to reflect that information in the company card and, as such, introduced the concept of *internal sustainability gap* (sg) for company c:

$$sg(c) = max - \sum_{i=1}^{6} s'(c,i), \tag{5.4}$$

6 is the number of ISEs, and max is 600, which is the maximum score for the sum of the ISEs.

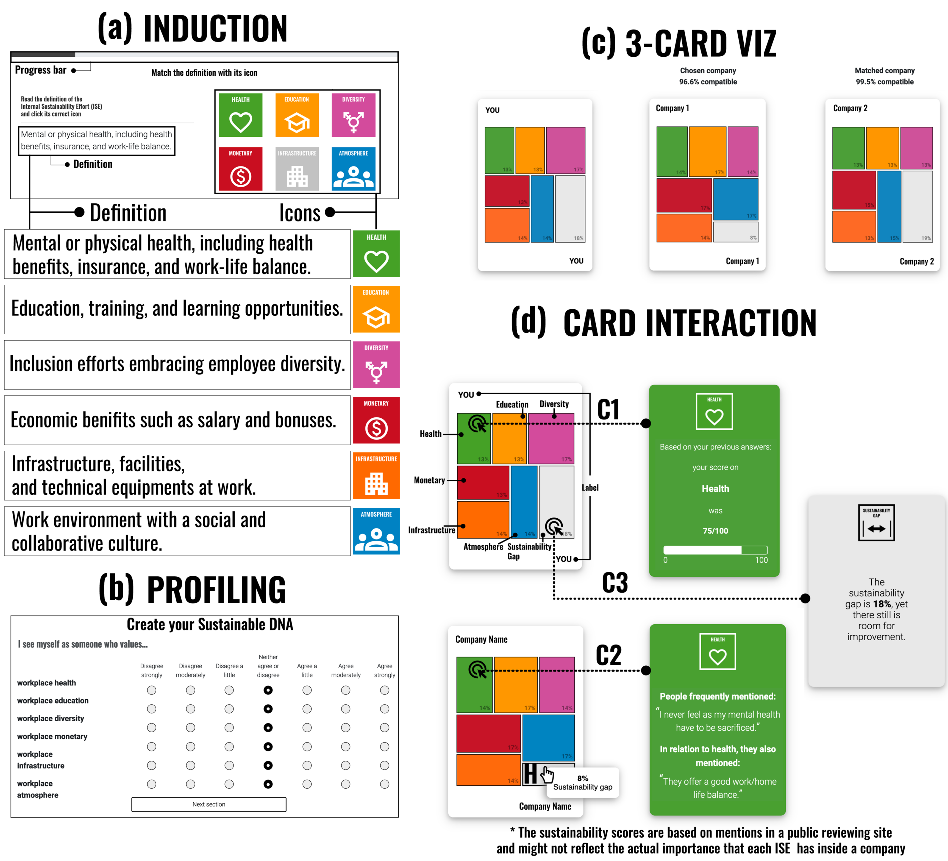

FIGURE 5.2: **(a)** User interface for step 2 (induction) consisting of: a progress bar at the top, a definition of one of the six ISEs to be matched on the left; and the six icons to be matched (if the match done by the user is correct, the corresponding icon is disabled and turned gray, as the infrastructure icon is in this picture). **(b)** User interface for step 4 (profiling) consisting of a statement/question the user needs to answer, typically on a 1-7 Likert scale. All the answers at this step were used to create the user vector v_u. **(c)** The 3-card viz (step 5) consisting of three cards (user card, chosen company card, and recommended company card). **(d)** Interactions with a card included: clicking on a colored rectangle to flip the clicked user (C1, C3) or company (C2) card; and hovering on a rectangle to display the tooltip showing the name of ISE and its relative percentage score (H).

5.5 Scoring the user

In our visualization tool, we had two types of cards: company card and user card. The company card is the graphic representation of the company's vector previously collated as per expression (5.3). The user card is the graphic representation of the user's vector. During our user study (Figure 5.1), our participants go through seven steps, some of which consist of answering questions. To collate the user's vector, we relied on the user's answers to the two sets of questions (Q23-Q34), asked before exposing the user to the visualization

(Figure 5.2b). The first set Q23-Q28 consists of six questions (one for each ISE) asking the user whether (s)he values a given ISE with a statement: "I see myself as someone who values workplace *[X]*". The second set Q29-Q34 consists of six questions asking the user whether (s)he chose an employer based on a given ISE with a statement: "In the past, I chose one employer because it valued workplace *[X]*". To then quantify the extent to which u cared about the i^{th} ISE, we used the two sets of questions. For example, to quantify the extent to which u cared about internal efforts related to *health*, we took u's score for Q23 (his/her disposition to value health) plus u's score for Q29 (whether (s)he decided to work for an employer because it valued health). In other words, for internal efforts related to *health* ($i = 1$), u's score $s(u, 1)$ is: $score(u, Q23_t) + score(u, Q29_t)$, where t is the time before exposing u to the visualization. This procedure was then repeated for all the six ISEs by computing each user u's score $s(u, i)$ for the i^{th} ISE as:

$$\begin{aligned} s(u,i) = score(u, Q(k+i)_t) + \\ score(u, Q(k+6+i)_t) \end{aligned} \tag{5.5}$$

where $i \in [1, 6]$, k is 22, t is the time before exposing u to the visualization, $score(u, Q(k + i)_t)$ is user u's score to question $Q(k + i)$ at time t, which goes through the set Q23-Q28, while $score(u, Q(k + 6 + i)_t$ goes through the set Q29-Q34.

Hence, we computed six $s(u, i)$, scored between 2 and 14. Finally, to compare users with companies, we linearly mapped these scores from the range of [2,14] to [0,100], obtaining $s'(u, i)$, and collated these values in u's vector:

$$v_u = [s'(u,1), s'(u,2), ..., s'(u,6), sg(u)], \tag{5.6}$$

where $s'(u, i)$ is the i^{th} ISE scaled score for u, and $sg(u)$ is u's internal sustainability gap computed in a way similar to Eq. (5.4) as $sg(u) = 600 - \sum_{i=1}^{6} s'(u, i)$, where 600 is the maximum score of the six ISEs' sum.

Recommended company. After obtaining the user vector v_u, we knew u's preferences concerning ISEs. We then matched these preferences with the extent to which a company matched the preferences, and did so by computing v_u's cosine similarity values with all companies v_c's, and, as a result, found the company most similar to u, which we call u's recommended company.

5.6 3-card viz: awareness and reflection

Our visualization consisted of a "card game" with three cards: one visualizing the user's vector, and the other two visualizing the vectors of two companies: one company was the *recommended company*, while the other was provided by the user, which we call *chosen company* (Figure 5.2c–C2).

We chose only one card for the *recommended company* due to the limited screen size. If more cards were to be displayed, alternative interaction techniques would have been used (e.g., scrolling through the card deck [81, 16], or stacking cards into multiple groups). However, such an implementation would have increased complexity in comparing cards. Therefore, a card of any of those three types was designed with two main characteristics concerning its display and its interactions.

Card display. We relied on the metaphor of DNA. DNA is a structure made of molecules that encode individuals' biological information and, therefore, it can uniquely identify them. Similarly, sustainable behavior can be seen as a structure where the molecules are represented by the six ISEs, and the unique combination of the six ISEs scores can uniquely identify the user's predispositions or a company's internal initiatives. Despite being an oversimplification, the DNA metaphor likely reflects the popular understanding of dynamic and adaptable patterns.

The card was designed as a treemap wherein six rectangles showed the six ISEs and one gray rectangle showed the internal sustainability gap (Figure 5.2c). We chose treemaps because they: i) allow for visualizing fractional values that must be interpreted in a comparative fashion rather than at face value, and ii) have considerable engagement qualities over alternatives (e.g., lists) for the task at hand [89].

Moreover, SDGs are typically visualized in grids[6], representing each goal as a square. We did the same but with rectangles of different dimensions obtained from the "*squarify*" treemap algorithm. This algorithm - as many other treemap algorithms - creates rectangles approximated to squares that are easier to compare and select regardless of screen size [36]. The total treemap's dimension $area$ depended on the screen size of the device. Since the rectangles inside the card graphically represented a user/company's vector, we computed each rectangle's dimension $d(e, area)$ based on the vector being displayed in the card (either v_u or v_c):

$$d(e, area) = \frac{v_x(e) * area}{\sum_{j=1}^{7} v_x(j)}, \tag{5.7}$$

where x is either company c or user u, e is a counter for user/company vector v_x, $v_x(e)$ is the e^{th} values of v_x (e.g., $v_x(1)$ is about health, $v_x(7)$ is the internal sustainability gap sg), 7 is the length of v_x (6 ISEs+sg), and $area$ is the total area of the treemap.

Card interactions.

Interactions with card-based visualizations are generally inspired by physical cards use [272], being based on hovering, swiping, stacking, and shuffling [81, 16]. In our design, we opted for the minimal set of interactions that balance: *i)* fitting the limited screen space, *ii)* showing extracted patterns, and *iii)* providing example reviews. As a result, we opted for two interactions - *card flipping* and *hovering on a rectangle*. On the front of both the user's card and the company's card, the user can view his/her vector and the companies' vectors in

[6] `https://sdgs.un.org/goals`

the form of seven colored rectangles. Flipping allows for interacting with both sides of a card - a modality the general public is likely familiar with (e.g., from memory-matching games). The card flips when the user clicks on a rectangle corresponding to a specific ISE: if the card is a user card, then the back shows the user's score for that ISE (Figure 5.2d–C1 and C3); if it is a recommended/-chosen company's card, the back instead shows two reviews of that company related to that ISE (Figure 5.2d–C2). These two reviews come from a clustering process. For each ISE, we indeed clustered reviews based on semantic similarity and took one review from the most frequent cluster, and another review from the second most frequent cluster. The back of the card shows these two reviews under ("*Employees frequently mentioned*") and ("*they also mentioned*"), respectively. In addition to flipping, a user can interact with the front of a card by 'hovering on a rectangle' (on an ISE) and being shown a tooltip with the corresponding ISE's name and score (Figure 5.2d–H).

5.7 User study

We evaluated our tool in an online crowdsourcing study on Amazon MTurk (AMT) wherein our participants followed a 7-step study procedure (Figure 5.1), with a completion time of 15 minutes and compensation of $0.50. To ensure quality responses, we applied quality controls in the form of two attention questions in steps 3 and 6. To then ensure a comprehensive assessment, the questions focused on whether our visualization contributed to: user learning; user opinion change; and increasing transparency between a company and the public.

Step 1: Questions concerning ISEs (Q1-Q3). Before being exposed to the visualization, the user answered three questions (Figure 5.3-Q1-Q3), reflecting what (s)he knew about ISEs. We also asked the very same questions after exposing the user to the visualization (step 6). The differences in the before/after answers then reflected whether the user learned anything new about ISEs as a

ID	Question		Step
Q1	With which statement do you agree the most? Internal sustainability initiatives at the workplace translate into: 1) multiple ecological and environmental benefits for employees 2) multiple monetary benefits for employees 3) multiple benefits for employees beyond ecological and monetary benefits		STEP 1, STEP 6
Q2	Is internal corporate sustainability more than the natural environment?		STEP 1, STEP 6
Q3	Did people mention ISEs in company's reviews?		STEP 1, STEP 6

ID	Question	Step
Q4 – Q13	Ten Item Personality Measure (TIPI)	STEP 3
Q14	What is your first name or nickname?	STEP 3
Q15	To which gender identity do you most identify?	STEP 3
Q16	What is your age?	STEP 3
Q17	Without speculating on possible advances in science, how likely are you to live to 500 years old?	STEP 3
Q18	What is the highest degree or level of school you have completed?	STEP 3
Q19	In which country do you currently live?	STEP 3
Q20	In which USA state do you currently live?	STEP 3
Q21	In which country were you born?	STEP 3
Q22	In which USA state were you born?	STEP 3

ID	Question		Step
Q23	I see myself as someone who values workplace...	health	STEP 4
Q24		education	STEP 4
Q25		diversity	STEP 4
Q26		monetary	STEP 4
Q27		infrastructure	STEP 4
Q28		atmosphere	STEP 4
Q29	In the past (future), I chose (will choose) at least one employer because it valued workplace...	health	STEP 4, STEP 6
Q30		education	STEP 4, STEP 6
Q31		diversity	STEP 4, STEP 6
Q32		monetary	STEP 4, STEP 6
Q33		infrastructure	STEP 4, STEP 6
Q34		atmosphere	STEP 4, STEP 6
Q35	What is your area of work?		STEP 4
Q36	What is your area of interest?		STEP 4
Q37	Choose a company of your interest		STEP 4

ID	Question	Step
Q38	Did the visualization help you understand whether your chosen company cared about ISEs?	STEP 6
Q39	Did your chosen company care about ISEs as you expected?	STEP 6
Q40	Do you feel your recommended company is a good match?	STEP 6
Q41	Which action did you find the most engaging?	STEP 6
Q42	Did the percentage displayed next to the colored box help you explore the data?	STEP 6
Q43	Did your card make you more aware of your values?	STEP 6
Q44	Based on what you've learned, the best definition for monetary benefits at the workplace is: 1) Mental or physical health, including health benefits, insurance, and work/life balance. 2) Infrastructure, facilities, and technical equipments at work. 3) Economic benefits such as salary and bonuses. 4) Inclusion efforts embracing employee diversity.	STEP 6
Q45	Did you know something about ISEs before?	STEP 6
Q46	Did the visualization help you reflect on ISEs?	STEP 6

ID	Question	Step
Q47	Why the visualization help (or not) you understand whether your chosen company cared about ISEs?	STEP 7
Q48	Did the comparison between the two companies' cards help you better quantify their ISEs?	STEP 7
Q49	Why do you feel your recommended company is (or isn't) a good match?	STEP 7
Q50	Why did you select action [X] as the most engaging?	STEP 7
Q51	Why the percentage displayed next to the colored box help (or not) you explore the data?	STEP 7
Q52	Why your card make you more aware (or not) of your values?	STEP 7
Q53	Which part of the visualization was the most helpful? Why?	STEP 7
Q54	Which part of the visualization was the least helpful? Why?	STEP 7
Q55	What was the most surprising thing you learned about ISEs at the workplace?	STEP 7
Q56	Is there any way you can make other people aware of ISEs?	STEP 7
Q57	Please share any comment you might have on the project.	STEP 7

FIGURE 5.3: The set of questions/statements presented to the user during the user study sketched in Figure 5.1. The evaluation questions tested our visualization's contribution to: user learning (questions in orange asked pre- and post-treatment); user opinion change (questions in yellow asked pre- and post-treatment); and increasing transparency between companies and the general public (post-treatment questions in light blue).

consequence of interacting with our visualization.

Step 2: Induction.

After answering those questions, in the form of an induction game, the user had to match a definition of an unnamed ISE with the correct ISE icon (Figure 5.2a). For example, the definition of health ISE should be matched with the heart icon. Every time the answer was correct, the right icon got disabled, and the user was able to proceed with the next match. In the case of a wrong answer, the user was encouraged to try again, learning in a trial-and-error fashion. Note that we designed the six icons to be easily matched with an ISE's meaning, and be distinguishable from each other.

Step 3: Pre-Treatment questions (Q4-Q22). The user completed the Ten Item Personality Measure questionnaire [99] (Q4-Q13), which measures the Big-Five personality dimensions through ten sentences, rated on a 7-point Likert scale (1: strongly disagree; 7: strongly agree). The user provided personal information in Q14-Q16 and Q18-Q22 (i.e., age, gender, education, country of origin, and residence). In between these questions, the user answered a first attention question, which took the form of "Without speculating on possible advances in science, how likely are you to live to 500 years old?", and used as a quality control check (Q17).

Step 4: Profiling (Q23-Q37). The user then answered 15 profiling questions (Figure 5.2b). The first 12 questions were used to build the user's vector v_u (Q23-Q34) and asked whether the user valued the six ISEs (Q23-Q28) and whether (s)he chose to work for an employer because it valued the ISEs (Q29-Q34). The three other questions (Q35-Q37) asked for: *(1)* the industry sector in which the user worked, *(2)* the industry sector the user would like to explore, and *(3)* the name of the company the user would like to explore (the so-called chosen company).

Step 5: 3-Card viz. The user was then shown the three cards (Figure 5.2c): one reflecting his/her ISE vector, and the other two reflecting the vectors of the chosen and recommended companies. This allowed the user to compare his/her own card with those of the two companies.

Step 6: Post-Treatment questions (Q38-Q46 + repeated Q1-Q3 and Q29-Q34). The user answered 18 questions (9 new plus 9 repeated) to evaluate the visualization's contribution to: user *learning* (Q1-Q3 were asked again to test whether the user learned additional information about ISEs after interacting with the visualization); user *opinion change* (Q29-Q34 were asked again to test whether the user changed his/her views on whether (s)he would select an employer based on its commitments to ISEs); and increasing *transparency* between companies and the general public (Q38-Q39 asked whether the user thought that, based on what (s)he learned through our visualization, the two companies effectively communicated their internal efforts). Finally, we asked six questions to test our algorithmic and interaction choices. We asked whether the recommended company could be a good match (Q40), whether the user preferred a specific type of interaction, whether (s)he found the percentage displayed on the card helpful (Q41-Q42), whether the visualization made him/her more aware of what ISEs entailed (Q43) compared to what (s)he knew before (Q45), and whether the visualization helped him/her reflect on ISEs (Q46). In-between this group of questions, the user answered a second attention question (Q44): 'what best defines economic benefits', among options describing mental health, inclusion, infrastructure, and salaries and bonuses.

Step 7: Qualitative feedback (Q47-Q57). Finally, the user provided feedback about the visualization through 11 open-ended questions.

5.7.1 Metrics

To analyze the Likert-scale questions, in line with previous work [199], we divided our participants in three groups based on their answers' polarity: Negatively Polarized (NP) participants who answered "disagree strongly" (-3), or "disagree moderately" (-2); Neutral/Weakly Polarized (NWP) participants who answered "disagree a little" (-1), "neither agree or disagree" (0), or "agree a little" (+1); or Positively Polarized (PP) participants who answered "agree moderately" (+2), or "agree strongly" (+3).

For Likert-scale questions and those asked twice (Q2-Q3 and Q29-Q34), before and after the visualization, we evaluated our participants' opinion change as the percentage growth rate between each of the answers' groups (NP, NWP, PP). In particular, starting from the negative polarized, we calculated the delta between the percentage of NP after experiencing the visualization ($NP_{(t+1)}$) and before experiencing it (NP_t): $\Delta NP = NP_{(t+1)} - NP_t$. The same procedure was repeated for the other two groups: $\Delta NWP = NWP_{(t+1)} - NWP_t$; and, $\Delta PP = PP_{(t+1)} - PP_t$.

We computed an *aggregated opinion change score* $o(u)$ to determine the extent to which our participants changed their opinions after interacting with the 3-card viz. The questions that were repeated before/after the viz were nine: Q1 was a multiple choice question, while those in the set (Q2, Q3, Q29-Q34) were on a Likert scale.

By aggregating the 8 Likert-scale questions, we computed the opinion change score:

$$o(u) = \sum_{k \in \{2,3,29-34\}} |score(u, Qk_{(t+1)} + \\ -score(u, Qk_t)| \tag{5.8}$$

where t is the time before exposing u to the visualization, $(t+1)$ is the time after being exposed, and $score(u, Qk_t)$ is user u's score to question Qk at time t.

Dimensions			ID	Statement			NP	NWP	PP
Profiling user values	PRE-TREATMENT	STEP 4	Q23	S1	I see myself as someone who values workplace...	health	2%	21%	**77%**
			Q24			education	3%	22%	**74%**
			Q25			diversity	4%	30%	**65%**
			Q26			monetary	0%	19%	**81%**
			Q27			infrastructure	1%	31%	**68%**
			Q28			atmosphere	1%	18%	**81%**
Profiling user opinion change	PRE-TREATMENT	STEP 4	Q29	S2	In the past, I chose one employer because it valued workplace...	health	15%	33%	**52%**
			Q30			education	12%	39%	**48%**
			Q31			diversity	17%	40%	**43%**
			Q32			monetary	3%	26%	**71%**
			Q33			infrastructure	12%	**44%**	**44%**
			Q34			atmosphere	6%	26%	**66%**
	POST-TREATMENT	STEP 6	Q29	S3	In the future, I will choose one employer because it values workplace...	health	4%	33%	**63%**
			Q30			education	5%	33%	**62%**
			Q31			diversity	9%	33%	**58%**
			Q32			monetary	0%	25%	**74%**
			Q33			infrastructure	4%	34%	**62%**
			Q34			atmosphere	3%	18%	**79%**
Increasing transparency between company and public	POST-TREATMENT	STEP 6	Q38	S4	Did the visualization help you understand whether your chosen company cared about ISEs?		8%	43%	**49%**
			Q39	S5	Did your chosen company care about ISEs as you expected?		15%	**54%**	31%

FIGURE 5.4: The percentages of participants who were negatively polarized (NP), neutrally/weakly polarized (NWP), and positively polarized (PP) on: the importance of a given ISE (S1); having chosen a past employer based on it valuing a given ISE (S2); choosing a future employer based on it valuing a given ISE (S3); and the effectiveness of our visualization in increasing transparency between a company and the general public (S4-S5). For each question, the group with the highest percentage of participants is marked in bold.

5.7.2 Quantitative Results

User sample (pre-treatment Q4-Q22 asking personal information). We had 244 participants. They scored, on average, on a scale from 1 to 7 (Q4-Q13): high in Agreeableness ($\mu = 5.3$, $\sigma = 1.7$), high in Conscientiousness ($\mu = 5.7$, $\sigma = 1.3$), high in Emotional Stability ($\mu = 5.0$, $\sigma = 1.3$), high in Openness ($\mu = 5.0$, $\sigma = 1.5$), and low in Extraversion ($\mu = 3.8$, $\sigma = 1.3$). The distributions of these traits were aligned with the normative personality values drawn from a large U.S. population sample [245]. 133 of the participants were female (Q15), all aged between 18 and 75 years old, with a median age of 40 (Q16). They were well educated (66% held a BSc), and were mostly U.S. citizens (97%), with only 3% being immigrants but residing in the U.S. (Q20-22). In between these questions, participants answered the first attention question (Q17), which led us to filter out the contributions of 29% of the initial participants.

User learning (pre- and post-treatment Q1-Q3). Initially, participants thought that sustainability efforts revolve around ecological and environmental benefits for employees (47%) along with monetary (12%) ($Q1_t$). After interacting with the visualization, 58% of them agreed that sustainability efforts can go beyond ecological and monetary benefits ($Q1_{(t+1)}$). Most of them (73%) were aware that sustainability encompassed more than the natural environment ($Q2_t$); however, only 27% of them had any knowledge of how sustainability efforts could be introduced in the workplace. After interacting with the visualization, 77% of participants recognized that sustainability has many facets ($Q2_{(t+1)}$). Finally, before being exposed to the visualization, 12% of participants knew that employees could mention sustainability in companies' reviews ($Q3_t$); after the visualization, that percentage peaked at 38% ($Q3_{(t+1)}$).

Initial user views on ISEs (pre-treatment Q23-Q28). Before interacting with the visualization ($Q29_t$-$Q34_t$), the ISE most valued for the employer choice was the monetary one (71% PP), followed by atmosphere (66% PP), health (52%

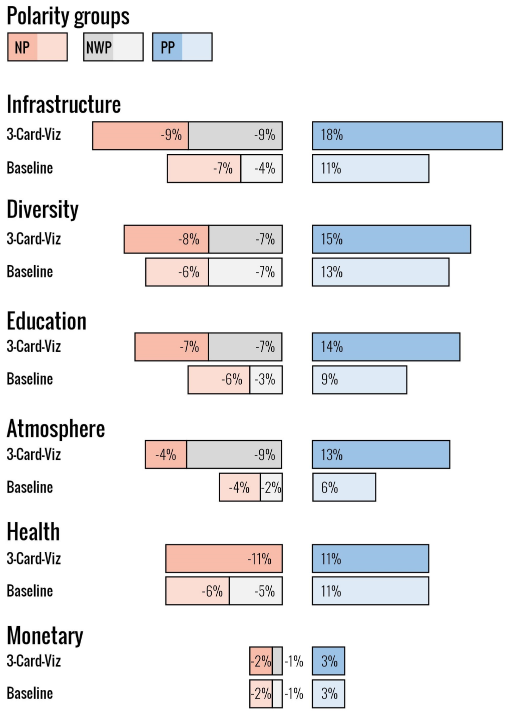

FIGURE 5.5: Percentage growth rates of three groups—negatively polarized (NP), neutrally/weakly polarized (NWP), positively polarized (PP)—toward each ISE answered before the 3-card viz and the baseline ($Q29_t$-$Q34_t$) and after them ($Q29_{(t+1)}$-$Q34_{(t+1)}$).

PP), education (48% PP), infrastructure (44% PP), and diversity (43% PP) (Figure 5.4). To ensure that our participants' answers after interacting with the visualization were not confounded by any previously held opinions, we plotted the distribution of the participants' employer choices before interacting with the visualization. We observed, to a great extent, a normal distribution for the six ISEs (health - ; education - ; diversity - ; monetary - ; infrastructure - ; atmosphere -), suggesting a lack of systematic bias at population level.

User opinion change (pre- and post-treatment Q2-Q3 and Q29-Q34). After interacting with our visualization ($Q29_{(t+1)}$-$Q34_{(t+1)}$), the positive polarized grew in all of the six ISEs (PP in Figure 5.5), suggesting that the 3-card viz persuaded our participants of the importance of all ISEs. Based on the participants who became positively polarized, the opinion change was most remarkable for infrastructure and diversity, and least for monetary (which was already high in the first place). By then computing the Spearman's rank correlation between the

Big-Five personality traits (derived from Q4-Q14) and $o(u)$, we found that opinion change did not correlate with any specific personality trait, suggesting that our participants changed their views mainly because of what they reevaluated about a specific ISE because of their interaction with the visualization rather than who they were (their personality traits). Exceptions to this rule were found in weak correlations of $o(u)$ with: Agreeableness ($r = -0.11, p < 0.1$), Conscientiousness ($r = -0.17, p < 0.01$), and Emotional Stability ($r = -0.14, p < 0.05$). These results suggest that people who changed their views tended, only to a limited extent, to be less organized and goal-oriented, to put their interests above those of others, and to be less emotionally stable.

To understand whether the differences in polarization values were due to our design choices or by the content itself (scores plus reviews), we conducted a second experiment to compare our treemap visualization to a plain text baseline. The baseline displayed the scores and the reviews in a textual list. We recruited a new set of 177 participants (95 females, median age of 40) from AMT while ensuring the same participants' characteristics, study duration, and compensation. All participants were well educated (63% held a BSc), and, mostly, U.S. citizens (97%), with only 3% being immigrants but residing in the U.S.

By analyzing this new set of participants' opinion change of the six ISEs when interacting with the two visualizations, we found that, comparatively speaking, the treemap outperformed the baseline (Figure 5.5). The treemap increased the opinion of positively polarized participants in four out of six ISEs compared to the baseline. In particular, we found a 7% increase for infrastructure and atmosphere, 5% for education, and 2% for diversity, whereas we registered no change for monetary benefits and for health. As we shall see from the qualitative analysis, this was explained by the fact that monetary and health are familiar concepts, whereas concepts such as infrastructure or atmosphere were less relatable.

Increasing transparency between a company and the public (post-treatment

Q38-Q39). Almost half of the participants (49%) declared that our visualization helped them understand whether their chosen company cared about sustainability (Figure 5.4-Q38). The visualization introduced a sense of surprise: 31% of them were not aware of how much the chosen company cared about ISEs (Figure 5.4-Q39).

Testing our algorithmic and interaction choices (post-treatment Q40-Q46). Most of our participants found the matched company to fit their own views on ISEs (Q40), adding external validity to our vector-based matching technique. No interaction strategy was preferred (Q41): 30% of participants preferred flipping the cards to get more details, 26% expressed a preference for hovering the colored box to see percentages, 24% preferred comparing their own card with the chosen company card, and 19% with the recommended company card. Showing percentages on cards helped 47% of participants to explore the data (Q42), while 32% of them became more aware of their own values (Q43) and 61% of them had little prior knowledge about ISEs (Q45). After interacting with our visualization though, half of them became more aware of ISEs (as much as 49% were positive polarized to Q46). In between these questions, participants answered the second quality control question (Q44), which led us to filter out the contributions of an additional 19% of our participants.

5.7.3 Qualitative Results

The answers to the open-ended questions (Figure 5.1-Step 7) were broken down into self-contained statements and labeled with concept categories (open coding), and then these concepts were grouped into themes (axial coding) [32]. After the two coding steps, three themes emerged.

Theme 1: Communicating ISEs.

Participants suggested entering into a dialogue with companies for raising ISEs awareness, both internally and externally. By internally, they meant *fostering* *communication between employees and employer* (P58). The discussion could be initiated at the recruitment stage, during team meetings, or through official communication channels. By externally, they meant communicating ISEs to the general public. Participants mentioned several channels on which such a promotion could take place (e.g., social media, and companies' websites). Yet, such communication should pay attention to the so-called "crisis of buzzwords". Participants generally observed that current corporate communication tends to obfuscate internal efforts through *"lip service, lame ads, and email campaigns"* (P81). The challenge would be to convey a genuine tone as people *need actions rather than just words* (P135). Participants also noted that such methodologies could engage *other sustainability actors* (e.g., *"public institutions, hackerspaces"*) in ISEs debate.

Theme 2: Making sense of ISEs. Two orthogonal sense-making strategies emerged—"soft" (emotion-driven) and "hard" (number-based).

In the "soft" strategy, participants framed their data experiences as feelings, e.g. P84: *"I feel like this company is like me"*, P171: *'"I got a better understanding of the company"*, P149: *"I feel that the company engages in environmental practices"*, P186: *"[...] the company believed in sustainability"*. Flipping one's card was strongly connected with *"feeling the data"*. Participants indicated *joy* while *"gaining information"* (P146), *empathy* (P25: *"reading real people's quotes gives a better feel of the company"*), *suspense* (P195: *"It is exciting to turn over a card without knowing what it'd reveal"*), *curiosity* (P30: *"[...] interested in what data was coming next"*), and finally *control* (P231: *"I like I was in control"*).

In the "hard" strategy, participants framed their data experiences as visual comparisons, e.g. P101: *"numbers are clear and unambiguous"*, P218: *"[...] numbers explain things"*. Displaying percentages facilitated *"seeing the data to believe it"*. P97 mentioned that she *"wanted to be sure the color blocks were based on correct numbers."*. Other participants found the scoring method reassuring (P206: *"I'd never put a physical number to my values"*). Others were familiar with certain ISEs (e.g., monetary), e.g., P83: *"I care about monetary value"*, while some participants, using the card visualization, reflected on emerging concepts (e.g., atmosphere), e.g., P107: *"Before this experience, I wouldn't have realized that I valued atmosphere so much."*).

Theme 3: Evaluating companies against ISEs. Two participants mentioned that their personal values did not necessarily need to align with those of their company (P103: *"My values and my job are not the same thing [...] my job is a means to make money"*; P54: *"Disingenuous virtue signaling and mindless corporate pandering are not part of my values"*).

Other participants used the tool to re-evaluate known companies (e.g., P76 was surprised *"how low [Brand X] rated"*). P204 mentioned: *"it makes me want to start looking into companies that I have been loyal to for a long time*). P50 noticed that *"there are top brands which are committed to sustainable ways of doing business"*.

Interaction with the *chosen company* card helped some participants *reinforce* their opinions (P187: *"Interesting to see how a company I would like to work for matched with my values."*) or *question* a company's image (P220: *"Comparing my card to my selected company shows me how different we are in many ways."*).

5.8 Discussion and conclusion

After interacting with the visualization, 58% of our participants learned that sustainability is not a monolithic concept only tied to environmental resources but could rather be seen as a multi-faceted concept (e.g., infrastructure support, workplace atmosphere, and well-being).

From a design perspective, our contribution is threefold. First, our DL-driven visualization created familiar and playful interactions (e.g., card games) through a treemap representation.

Second, our methodology demonstrates the integration of four ML4VIS processes [270]: *i)* "data processing4VIS": extracting mentions of ISEs from reviews;

ii) "data-VIS mapping": automatically updating the cards whenever new reviews are processed; *iii)* "style imitation": generating dynamic cards with similar layouts to SDGs; and *iv)* "user profiling": analyzing user's quiz answers and providing his/her best matching company.

Third, we partly tackled the common distrust for black-box ML models by validating the effectiveness of interactions based on physical gestures (e.g., card flipping allowing for more content to be displayed), and by designing a user-model interaction that is blended (i.e., participants could not generally distinguish where their interactions with the model ended, and where their interactions with the visualization started).

The work done in this case study gave us insights on how to promote sustainability efforts while proving the effectiveness of an interactive visualization using common objects as the cards and a common interaction and the flip of the card in a card game.

Our work has two limitations. First, our DL algorithm processed reviews from US-based companies and, as such, our findings may not generalize to wider populations or other organization types; the proposed method could be replicated to analyze other types of reviews and sustainability actors. Second, more research in the emerging field of ML4VIS should go into: *i)* supporting the two orthogonal ways individuals typically use to make sense of data: "hard" (number-based [199]) and "soft" (emotion-driven [126]; *ii)* increasing people's trust in ML tools (e.g., making algorithms more transparent [52]); and *ii)* how to avoid reinforcing incorrect views users may invariably hold because of their confirmation bias [100] (i.e., the tendency to believe only the information that confirms one's prior beliefs).

Chapter 6

Conclusion

This thesis was inspired by the need to make people aware of the sustainability issue, which is a complex phenomenon, as highlighted by the approval of the 2030 Agenda for Sustainable Development by the general assembly of the United Nations. As a matter of fact, it includes not only the environmental dimension, as stated by the 17 SDGs. In particular, the research described in this thesis focuses on SDG 8 which aims to promote lasting, inclusive, and sustainable economic growth, full and productive employment, and decent work for all, and its target named: green economy, sustainable tourism, and employment, decent work for all and social protection.

To create awareness about these targets, we exploited HCI methodologies and Data Visualization techniques. In particular, we analyzed four different case studies: the first two about the green economy, the third related to sustainable tourism, and the fourth and last one related to decent work.

These needs motivated and framed the research questions and the studies described in this thesis.

6.1 Summary of Contributions

To answer our two research questions, we exploited four different case studies to better analyze and gain insight into interactive data visualization tools able to increase awareness of SDG8 and its targets.

In particular, in our first case study, we investigated the Human-Building Interaction field to increase awareness about the green economy and promote energy and resource efficiency and a more sustainable and efficient use of spaces inside a Smart Campus by exploiting Data Visualization and HCI methodologies. As a final result, we highlighted the necessity of creating different visualization depending on the target users and we extrapolated a series of recommendations to design a map-based interface. The outcomes of these contributions are published in [217, 49, 50, 48].

The second case study focused on the efforts made by the University of Bologna in relation to the reduction and waste of papers and aims to foster awareness about the green economy in terms of dematerialization. We created two different infographics and our findings highlighted that differences exist in the way groups with different characteristics perceived them. Hence a personalization of the infographic for each group could be helpful. The outcome of the contribution is published in [213].

The third case study analyzed sustainable tourism and, in particular, the possibility to create authentic experiences while creating meaningful connections between locals and tourists. Our findings showed that the 360° VR version of a local's room was perceived as more involving, engaging, motivating, real, mobile, and with an easier interface to acquire information, than the 2D one. Moreover, we found that people-to-people recommendation criteria in the relationship between locals and tourists gained a general positive interest while outlining some concerns in terms of privacy, trust, and disorientation. The outcomes of the contributions are published in [218, 212, 51].

Finally, we explored sustainability policies and practices inside the corporate context through a DL-driven visualization. Our findings highlighted the potential of using ML4VIS and interactions based on physical gestures for increasing awareness about sustainability, which is not a monolithic concept only tied to environmental resources but could rather be seen as a multi-faceted concept. The outcome of the contribution is published in [47].

As mentioned in Section 1.2, this thesis follows the "research through design" approach as it aims to apply well-known HCI and data visualization methods to a series of different domains and case studies. In each case study, we exploited different technologies tied to the specific domains. In the HBI case study, designed and implemented two different systems. The first one was a web-based visualization enjoyable through a public monitor, while the second one was a web-based visualization for desktop devices, as the ones presented in the dematerialization case study. In the sustainable tourism case study, we took advantage of mobile devices and VR, which are the main technologies used in the tourism domain. Finally, in the industry case study, we exploited a responsive web-based visualization. Despite these technological differences, summarizing our findings, two main research contributions emerged from this thesis: one more interface-centered on *what to visualize* and one more data-centered on *how to visualize it*.

On one hand, concerning *what* to visualize in interactive data visualization tools to foster awareness about sustainability issues, we highlighted the importance of the personalization and customization of the interface. Adding more details, this personalization can involve both the visual design and the content visualized.

The customization of the visual design, as shown in the HBI case study, was tied to different types of users that have different needs in relation to the system, and then should visualize different graphs. Moreover, as shown in the dematerialization case study, the personalization should also be tied to the different characteristics of the target audience that can perceive infographics and visualization in several ways, as in line with [148, 234]. Finally, also in the industry case study, we showed how the choices and personalities of the users should shape the visualization, creating a mirror of the users themselves, instead of showing general data unrelated to them.

The customization of the content is not tied to how the target users perceive the interface, but it is focused on the user profile in terms of personality and choices. For example, in the sustainable tourism case study, we highlighted the benefits of providing different recommendation criteria to the tourists, offering them the opportunity to find the one that best suits their personality and needs. Moreover, in the industry case study, we highlighted the benefits of providing real-time recommendations based not only on users' preferences but also on their previous choices.

On the other hand, we focused on the data itself and *how* to visualize them. In particular, we investigated how to communicate the data in a way that could foster reflection and awareness. To do so, we transformed data about dematerialization into trees, data about sustainability practices inside companies into colored cards, and users' personalities and interests into colored rooms and images. This is in line with the recent concept of Data Humanism, seen as an evolution of the first wave of Data Visualization [155, 154]. The underlying idea here is to make data and visualization more personal and to imagine new methods that exploit data to make people feel more empathic, so they can easily connect with themselves and others.

6.2 Future works and research vision

This thesis wanted to answer the two research questions presented in Section 1.2 with the final aim to extrapolate some guidelines concerning the design of effective interactive data visualization tools to foster awareness about SDG8.

Starting from these guidelines, future works will be devoted to investigating the opportunity to exploit them to: i) create awareness of the other little-known SDGs and their targets and ii) better test their effectiveness.

Finally, we plan to investigate the capability of these interactive tools to produce a change in the daily behavior of the target users by changing their habits. As a matter of fact, previous works showed how data visualization can elicit considerations on sustainable habits and behavioral change, in order to enable and encourage more conscious daily actions [30, 227]. However, a study of this kind raises new research questions such as: "*how can this change be measured?*" and "*how long can this change last?*".

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