Exploring the accessibility of deformed digital heritage models

Antón, Daniel * *danton@us.es*

PhD, MSc, BSc, HNC

(1) Departamento de Expresión Gráfica e Ingeniería en la Edificación, Escuela Técnica Superior de Ingeniería de Edificación, Universidad de Sevilla, Seville 41012, Spain

(2) The Creative and Virtual Technologies Research Lab & Product Innovation Centre, School of Architecture, Design and the Built Environment, Nottingham Trent University, Nottingham NG1 4FQ, United Kingdom

Amaro-Mellado, José -Lázaro

(3) Departamento de Ingeniería Gráfica, Universidad de Sevilla, Seville 41092, Spain

Rico-Delgado, Fernando

(1) Departamento de Expresión Gráfica e Ingeniería en la Edificación, Escuela Técnica Superior de Ingeniería de Edificación, Universidad de Sevilla, Seville 41012, Spain

Díaz-Cañete, Pablo

(1) Departamento de Expresión Gráfica e Ingeniería en la Edificación, Escuela Técnica Superior de Ingeniería de Edificación, Universidad de Sevilla, Seville 41012, Spain

* Corresponding author

Abstract

The concept of accessibility has been examined by the scientific community in various fields such as education, health care, social inclusion, disabilities, transport, and tourism. Regarding heritage, the European Commission's efforts toward accessible cultural heritage are highlighted, along with the use of digitisation and modelling technologies for complex heritage shapes. Thus, this chapter explores relevant scientific research into the accessibility of digital heritage models that represent the assets' real condition, that is, as-is or as-built models produced using advanced digitisation and modelling technologies. The study emphasises the importance of both physical and semantic aspects of heritage conservation and the need for public awareness and cooperation toward the aimed accessibility. The methodology addresses the search for publications in Scopus and Web of Science and their filtering based on inclusion and exclusion criteria to ensure documents related to the accessibility of deformed digital heritage models are considered. The research concludes that creating accessible deformed digital heritage models is crucial for inclusion and participation from the public and stakeholders, and while some studies achieve accurate as-built geometries and accessibility, there is room for improvement.

Keywords: Accessibility; as-is; as-built; remote sensing; modelling; repositories; heritage; immersive; VR; collaboration

1. Introduction

Considering the enormous evolution and availability of advanced digitisation and modelling technologies in recent decades, their application to the field of cultural heritage—the use of accurate reports and data was already established in the Athens Charter (International Council on Monuments and Sites, 2011)—opens up multiple, diverse possibilities such as the in-depth study of these assets, the modelling of their actual geometry for the sake of knowledge generation and preventive conservation, as well as their cataloguing and dissemination through different channels.

As seen in the work by Taher Tolou Del et al. (Taher Tolou Del et al., 2020; Taher Tolou Del & Kamali Tabrizi, 2020), heritage conservation involves physical aspects and semantic aspects. The former are related to the tangible condition of the assets, where advanced technologies may be applied. In contrast, the latter aspects address the assets' heritage values, meanings, messages, and concepts latent in the heritage spaces (Australia ICOMOS, 1999). These semantic aspects fall beyond the scope of this chapter, but can be addressed with digital technologies to include narratives, social history and anthropological mapping (Selim et al., 2022). On the other hand, in addition to experts and institutions, architectural (and archaeological) heritage conservation should involve individuals, communities, in cooperation with those specialists and governments. The physical and semantic aspects of conservation allow for identifying the heritage values and what needs to be conserved, which is mainly to be done by the cited experts. Other important requirements should be raising public awareness of the positive impact of heritage conservation on people's lives, the existence of clear conservation standards from governments, and their cooperation with private companies and other stakeholders (Taher Tolou Del et al., 2020).

Finally, in addition to heritage management for conservation, the accessibility of heritage models becomes crucial in today's increasingly inclusive society, not only for individuals with certain difficulties but also for the general public to experience, explore, and learn from this legacy.

1.1. Accessibility

The word *accessibility* has different acceptations, that is to say, dictionary entries (Cambridge University Press, 2023). They are mainly related to the quality of something of being able to be reached, entered, or obtained with no difficulty and to the ability of a person to reach, approach, enter, or use it. On that basis, the scientific community has addressed *accessibility* in diverse fields. A simple search for this term on two of the primary databases alone, Scopus (Elsevier B.V., 2023) and Web of Science (Clarivate, 2023), yielded 236,200 (only considering the document title, abstract, and keywords) and 132,909 (all search fields) documents, respectively, a number in continuous evolution. The publications found were in the form of journal articles, review articles, books and book chapters, and conference papers, among others. They were more or less focused on the implications of accessibility, dealing with this term as a research topic or keyword. The chronological distribution and growth of indexed documents can be seen in Figure 1 below.

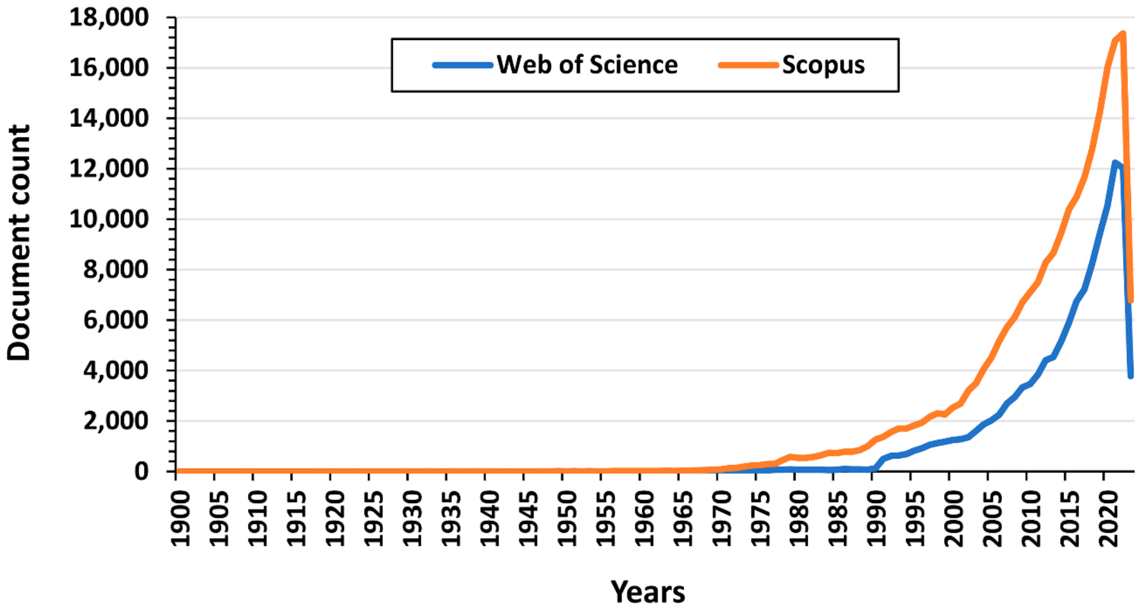

Figure 1. Scopus and Web of Science-indexed documents dealing with accessibility.

Statistical data from the graph above also reveals a substantial increase in research publications on accessibility in recent decades, especially since 2018. Considering periods every five years until 2022 (the latest full year), Table 1 shows the breakdown of the research outputs dealing with the topic:

Database	Statistical descriptor	20 years 2003-2022	15 years 2008-2022	10 years 2013-2022	5 years 2018-2022
Scopus	Mean	9,360.10	10,948.87	12,852.90	15,498.20
	Standard deviation	4,334.00	3,801.48	3,177.80	1,959.72
	Coefficient of variation	0.46	0.35	0.25	0.13
Web of Science	Mean	5,523.35	6,668.07	8,202.30	10,495.00
	Standard deviation	3,405.14	3,173.56	2,771.744	1,711.71
	Coefficient of variation	0.62	0.48	0.34	0.16

Table 1. Quantitative data on the chronological distribution and growth of indexed documents in Scopus and Web of Science from 2003 to 2022.

This active topic has been addressed in different fields such as education (Lambert, 2020), health care (Matin et al., 2021), social inclusion (Sen et al., 2022; Woodgate et al., 2020), disabilities (Kubenz & Kiwan, 2022), transport and micro-mobility (Milakis et al., 2020), tourism (Gillovic & McIntosh, 2020), among many others. Still, there are authors who provided additional meanings of the term *accessibility*, as in the case of the urban fields of transport and land use. Here, particularly focusing on land development from the economic and zoning points of view, Hansen (Hansen, 1959) identified *accessibility* as the potential of opportunities for interaction against the usual definition, which he explained was the intensity of the possibility of interaction. Besides, one of the acceptations described at the beginning of this section includes the word *disability* as an obstacle in those activities. According to the literature review conducted by Mack et al. (Mack et al., 2021), the leading community of focus in research on accessible computing are blind or low-vision persons—it is worth noting the disproportionate frequency of this group in research (43.5%). Motor or physical disabilities and hearing impairment appear in significantly fewer publications (14.2% and 11.3%, respectively). Below 10% of the total of papers, the rest of the communities are cognitive impairments (9.1%), older adults (8.9%), autism (6.1%), other general disabilities or accessibilities (4.10%), and intellectual or developmental disability (2.8%). As a result, accessibility can be studied from different perspectives, depending on the object and the person or group.

1.2. Towards accessible cultural heritage in Europe

In the field of cultural heritage, by means of the Digital Agenda for Europe, the European Commission advocates the need for large-scale digitisation and online accessibility of heritage assets, for which European Union (EU) Member States are invited to increase their digitisation efforts (European Commission, 2011; Santos et al., 2017). At this point, it is worth synthesising the Commission Recommendation of 27 October 2011 on the digitisation and online accessibility of cultural material and digital preservation (2011/711/EU), currently in force.

Europe's Digital Agenda focuses on harnessing the benefits of information technology to boost economic growth, the creation of jobs, and quality of life for European citizens. One of the main areas covered is the digitisation and preservation of European cultural memory, including prints, photographs, museum artifacts, archival documents, audio and audiovisual materials, monuments, and archaeological sites. In this way, the EU has developed a digitisation and preservation strategy for cultural material and heritage assets, building on previous efforts such as the development of Europeana, the European Digital Library Archive and Museum. Digitisation is critical to enabling online access to cultural materials, facilitating their use, and ensuring their preservation for future generations. In turn, this offers vast economic opportunities and is crucial for the development of Europe's cultural and creative capacities and industrial presence in this field. Nonetheless, collaborative action by Member States is required to avoid duplication of digitisation and create a safer environment for companies investing in digitisation technologies. Private funding and partnerships with the public sector can help cover the high costs of digitisation. Likewise, digitisation activities can be co-financed by EU Structural Funds as part of projects that impact the local economy.

Materials in libraries, archives and museums are generally protected by intellectual property rights that inspire creativity. However, the digitisation and preservation of cultural materials must be done with due respect for copyright and related rights. Digitisation of non-commercial works may require legal support for stakeholder-developed licensing solutions. Obtrusive watermarks and other visual protections should be avoided to allow broad access and use of public domain content. Europeana currently provides direct access to over 19 million digitised objects, with a set target of 30 million objects by 2015. Together with scientific publications achieving complex digital heritage models and data, and those achieving the availability of these assets, this is the *accessibility* this chapter addresses.

In order to ensure the survival of digitised materials, it is necessary to develop effective means of digital preservation. In this line, legal submission policies and practices should also be encouraged. Efficient cooperation among EU Member States is necessary to avoid major differences in the policies for the deposit of digital materials.

Overall, this Recommendation aims to promote the digitisation and online accessibility of cultural materials, strengthen long-term preservation strategies for digital materials, and promote cooperation among countries to achieve these goals.

1.3. Digitisation and modelling technologies for complex heritage shapes

Manual measurement instruments and processes have been left far behind with the advent of massive geometric data capture tools (Mallafrè Balsells et al., 2021). Without delving into the principle of operation of these remote sensing technologies here, they allow specialists to obtain hundreds of thousands and millions of data on the shape of objects within the Cartesian coordinate system (XYZ coordinates in space) (Bakker et al., 2009). In this way, complex heritage shapes can be accurately represented in a digital environment, which in turn facilitates the generation of three-dimensional (3D) models. Among others, those technologies include the LiDAR (Light Detection and Ranging)-based Terrestrial Laser Scanning (TLS) and the often handheld Structured-Light Scanning (SLS) for smaller objects, as well as the Structure-from-Motion (SfM) photogrammetric technique. All these techniques are capable of capturing colours to be later mapped onto the resulting 3D point clouds, which are the sets of points defining the objects' volume. In the case of SfM, this also allows for generating textured 3D meshes of the assets' geometry. Point clouds require processing to extract meaningful information from the data; this may include filtering, segmentation, registration, and feature recognition.

Once digitisation and data processing are completed, the 3D modelling stage takes place. Different modelling approaches can be adopted depending on the intended accuracy, level of detail (usually referred to as LoD) or level of development (usually LOD, considering geometry and information), from an abstracted, theoretical models to geometrically complex shapes (*as-built* or *as-is* models). Thus, Computer-Aided Design (CAD) tools or Building Information Modelling (BIM) technology can be used to produce 3D models of heritage assets. However, in order to avoid manual 3D modelling and those approaches that do not fully represent the real condition of the assets, the virtual reconstitution should be based on 3D point cloud data (Logothetis et al., 2015). Regardless of the technology used to capture the geometry, there are algorithms capable of discretising it and calculating 3D meshes that fit the shape of the object, with lower or greater degrees of simplification and smoothening (Antón et al., 2019). One of the most widely used algorithms is Kazhdan and Hoppe's Screened Poisson Surface Reconstruction (Kazhdan & Hoppe, 2013), usually integrated into open-source software as a plug-in. The Historic Building Information Modelling (HBIM) methodology, the application of BIM to heritage or historic buildings (H), can be enriched when importing as-built or as-is geometries (based on TLS or SfM data) to define the complex shapes of assets (Liu et al., 2023).

In view of the above, the European Commission's Expert Group on Digital Cultural Heritage and Europeana (DCHE Expert Group) developed a set of guidelines for 3D digitisation of cultural heritage assets, called the Basic principles and tips for 3D digitisation of cultural heritage (European Commission's Expert Group on Digital Cultural Heritage and Europeana (DCHE Expert Group), 2020). This document gathers a series of benefits of 3D digitisation for heritage, such as aiding conservation, reproduction, research, education, and exploration, creative or tourism-related purposes, safeguarding of at-risk tangible cultural heritage, or avoiding direct handling of assets. However, in words by the Expert Group, it should be noted that, by itself, this process *does not prevent risks to cultural heritage, and it is by no means a replacement of physical* *preservation*. Besides, *3D digitisation by itself does not imply digital preservation in the long term*. Therefore, 3D digitisation must be accompanied by good practices and policies for prevention, management, and restoration. These guidelines also highlight the possibility of virtual access to non-reachable, inaccessible, cultural heritage, especially for visually impaired individuals by enabling tactile experiences.

2. Research aim

This chapter is intended to explore current and recent research on the accessibility of digital heritage models that represent the real condition of the assets. In other words, the focus is on those publications that have achieved deformed models, which include geometrical alterations following as-is or as-built modelling approaches, thus avoiding ideal geometries.

3. Methodology

This exploratory research aims to investigate relevant scientific literature on the accessibility of deformed digital heritage models in the last 5 years (from 2018 to present). Given their extensive use and reputation in providing access to a diverse range of scholarly literature across various disciplines, the Scopus and Web of Science databases were the primary sources for identifying those publications. The methodology adopted was as follows:

a) Keyword selection: Appropriate keywords, or different combinations of them, were used to search a wide range of documents closely aligned with the research topic. Those keywords did not have to be exclusively the keywords used for indexing the publications in the databases, but also terms included in their abstracts: *as-is*, *as-built*, *accessible*, *accessibility*, repository, *TLS*, *scanning*, *photogrammetry*, *point cloud*, 3D *model*, *modelling*, *complex shapes*, *geometry*, *heritage*, *digital*, *virtual*, *virtual reality*, *disabilities*, or *tour*.
b) Database search: The selected keywords were used to search in the Scopus and Web of Science databases, as mentioned above. Additional search using the artificial intelligence (AI)-based Consensus App (Olson et al., 2022) obtained further publications—some of them are already indexed in Scopus and/or Web of Science. To do this, the prompt "accessibility of digital heritage models" was used to search for research on the topic, and the processes below were also conducted for this secondary search.
c) Publication filtering: Once a number of documents were found, a manual filtering process was conducted to assess the relevance and fit of each publication to the research topic. The filtering process involved examining the titles, abstracts, and keywords of the identified publications.
d) Inclusion and exclusion criteria: Specific criteria were applied during the filtering process. Publications that were deemed unrelated or did not sufficiently address the research topic were excluded, while those directly related to the topic or providing valuable insights were included.
e) Data synthesis: Finally, once documents were filtered and selected, data synthesis was carried out to show current and recent perspectives on the accessibility of heritage

models considering this modelling approach, and to what extent published digital models represent the real condition of the assets.

4. Accessibility of deformed digital heritage models

As seen above, this research refers to "deformed" models as those that take into consideration the surface geometrical alterations of heritage assets.

Prior to 3D reconstruction, Grilli and Remondino (Grilli & Remondino, 2019) explained that the heterogeneous remote sensing 3D point clouds need to be segmented and classified to better characterise, describe and interpret the study object, and that those processes can be automated and accelerated with the aid of machine learning. At this stage, the different specialists involved in the conservation process can automatically annotate 2D textures of heritage objects and see them mapped onto 3D geometries for a better understanding.

Having processed the data, 3D reconstruction methods enable mesh-based geometries consisting of triangulated surfaces fitting the point clouds (Antón et al., 2018, 2019; Bassier et al., 2016; Sani et al., 2022). 3D entities can also be produced using NURBS (Non-Uniform Rational Basis-Splines) with a lower or greater degree of simplification or level of detail (LoD) for their integration into HBIM projects (Barazzetti et al., 2015; Murphy et al., 2013; Rodríguez-Martín et al., 2022). In this context, the *scan-to-BIM* workflow is still semi-automatic, despite the great efforts by the scientific community. Recent documents aim to improve the automation of HBIM from point clouds using artificial intelligence, which was recently reviewed by Cotella (Cotella, 2023). Those 3D reconstruction approaches based on TLS, SLS, or SfM data that produce 3D meshes (Figure 2, centre) significantly differ from ideal or simplified 3D modelling in terms of accuracy (Figure 2, left and right, respectively), which, in fact, should have a severe impact on diverse analyses such as structural behaviour assessment and other simulations.

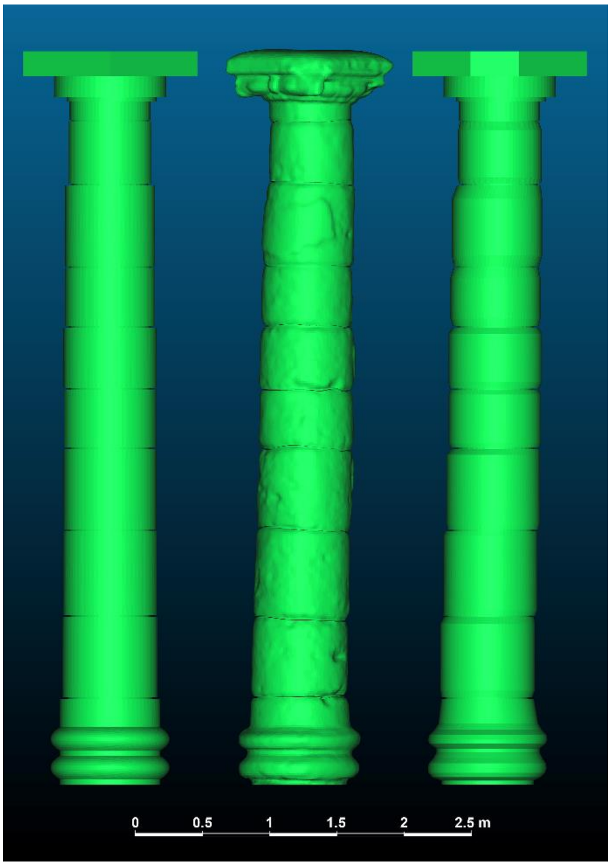

Figure 2. Digital reconstitution of a column in the Archaeological Ensemble of Baelo Claudia, in Tarifa, Cádiz (Spain): (left) ideal model; (centre) as-is model; (right) simplified model. Source: (Antón et al., 2019)

In view of both the research context and the given definitions of the term *accessibility* in section 1, the authors of the present study found the need to explore how accessible deformed 3D models of heritage sites, buildings and assets are.

3D digitisation and restitution, Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR) enable scientific knowledge, digital storytelling, and access (in a more or less immersive experience) to both natural and cultural heritage through a three-dimensional database with relevant information of the asset for the users to understand their history and specifications (Marinos Ioannides et al., 2017; Maietti et al., 2017). In this way, Kidd and Nieto McAvoy (Kidd & Nieto McAvoy, 2019) discussed the increasing interest on immersive experiences for heritage organizations and their funders, driven by challenges and emerging technologies. These authors emphasised the need for better evidence on the role of immersive experiences in achieving goals such as visibility, audience appeal, participation, engagement, and revenue, which benefit not only the heritage assets in question but also the institutions and public involved. Immersive experiences in heritage models and assets have implications for accessibility, requiring consideration of inclusive design and features to accommodate diverse abilities and preferences. Here, the possibilities for physical interaction (one of the definitions of *accessibility* reviewed in this chapter) decrease when using the generally exclusive virtual reality. Not devoid of challenges such as the cost of the equipment and the specialisation needed to develop the immersive content, this technology often requires a separate space to be experienced by the users and is intended for the use of a single person per headset, an individual with the capacity of bear the unpleasant physical symptoms involved. To a certain extent, this diminishes how accessible these immersive technologies are. However, they offer users the opportunity to actively engage with and become part of the heritage site, establish personal connections to it, and acquire knowledge (learn) through the immersive experience (Bekele & Champion, 2019).

Putting aside the immersive technologies, the accessibility of heritage should be manyfold. Not being preliminary related to digital matters, the ease of access (the lack of barriers) starts from the actual physical access to historic buildings. Kose (Kose, 2022) analysed the accessibility challenges in a set of Japanese historic buildings, mainly posed by the strict Japanese regulations on the protection of cultural properties, which hinder the changes needed to comply with accessibility standards in new built buildings. Here, the use of digital technologies could support reform proposals to persuade the governments involved. Similarly, from a university teaching perspective, Vardia et al.'s contribution consisted in developing design proposals to raise awareness of the importance of accessibility of heritage sites (Vardia et al., 2018). Using the heritage site of Jantar Mantar in India as a case study, these authors defended the Universal Design (UD) as a show of sensitivity and compassion for diversity and respect for vulnerable populations, but also as a great opportunity to leverage an economic return from an increase in visitors to a previously inaccessible site.

In that line, Jiménez Martín et al. (Jiménez Martín et al., 2022) posed an interesting question that led to their research on the accessibility of historic city centres: *What is the point of heritage if it cannot be known and visited?* Considering accessibility and UD principles, the authors analysed the urban fabric and pedestrian itineraries as crucial spaces in the search for good accessibility practices and challenges. Being applicable to other historic centres, their research yielded essential aspects to be considered when undertaking actions on pedestrian routes in those urban heritage environments, encompassing mobility, location, orientation, understanding, and more. This research could be supported, again, by as-is digital models as a valuable basis for the study of heritage towards its accessibility.

Having introduced the implications of digital technologies for the accurate representation of heritage buildings and sites and the importance of ensuring access to both the physical and digital assets, the following classification gathers relevant contributions by the scientific community to the topic on the accessibility of deformed digital heritage models.

4.1. Disabilities

This chapter found a review article on the weight of disabilities on accessible computing research. In that field, although majorly focusing on visual impairments, other physical limitations and conditions are also present. The heritage field has also addressed the accessibility of digital heritage models from a disability perspective.

Pérez et al. (Pérez et al., 2020) addressed the barriers faced by people with disabilities, particularly in relation to archaeological heritage buildings and environments. They developed a VR experience specifically designed for individuals in wheelchairs in order to evoke realistic sensations on them while virtually touring archaeological sites. Focusing on the monumental building of Cancho Roano, a significant site in Spanish Protohistory, the VR application aimed to promote social integration by granting access to inaccessible cultural heritage for people with disabilities. The authors adopted two strategies to enhance the experience: TLS-based models to visualise the site accurately, and a novel VR system that integrated motion capture, visualisation, a motion platform with haptic rollers, and a workstation. The application was intended to undergo testing with wheelchair users and general users to evaluate its realism and the perceived value of accessing otherwise inaccessible areas of the site. By seeking to raise awareness about the challenges faced by wheelchair users in such environments, the research endeavoured to provide inclusive and immersive experiences, thus enabling individuals with disabilities to engage with and appreciate cultural heritage.

Marín-Nicolás and Sáez-Pérez (Marín-Nicolás & Sáez-Pérez, 2022) created and deployed a physical accessibility assessment tool tailored to the specific needs of heritage buildings by following BIM methodology. They focused on heritage buildings in collaboration with the Regional Government of Murcia, Spain. Different parameters were considered: types of buildings (religious, military, and civil buildings); area of analysis (access, door, moving walkway and furniture) and the type of disability (list of barriers and levels of accessibility). The tool not only detected barriers but also analysed their impact on user activities in different spaces and elements of the buildings. It assessed accessibility levels based on the main qualities of the building and identified areas to be improved. The tool provided accurate information for specific groups of people with disabilities, allowing for prioritised actions and their planning. It is also worth highlighting the benefits of BIM in analysing and managing barrier removal. The research offered new possibilities for UD while promoting inclusive design in heritage buildings by integrating accessibility considerations into BIM tools.

Regarding visually impaired individuals, Scianna and Filippo (Scianna & Di Filippo, 2019) designed a rapid prototyping approach to improve cultural heritage accessibility. The authors compared the effectiveness of a set of 3D models for guiding blind and visually impaired people in the tactile use of models of monuments. Thus, a sample of disabled people helped define some 3D printing parameters in order to obtain a more fruitful product.

Using a different technology, Lo Valvo et al. (Lo Valvo et al., 2020) explored the potential impact of convolutional networks trained to recognise monuments using smartphones as mediation instruments. This enabled users to access associated content and offered new forms of engagement for visually impaired individuals. Additionally, computer vision can support autonomous mobility by identifying predefined paths in heritage sites, bridging the gap between the digital and real world. The paper presented two key components: improving accessibility for visually impaired and mobility-restricted users, as well as facilitating access to digital content associated with real monuments through smartphone-based virtual navigation. The authors envisioned personalised service instances that catered to specific user needs, such as voice descriptions, simplified content for children, and enlarged targets for the elderly, thereby enhancing the overall tourist experience.

In an effort to enhance accessibility to cultural heritage objects for the visually impaired, Montusiewicz et al. (Montusiewicz et al., 2022) used 3D scanning, modelling, and 3D printing techniques. This addressed the limitations faced by contemporary museums in accommodating this group. The digitisation of cultural artifacts enabled the creation of virtual museums and touch-accessible 3D replicas. As an illustration, the authors presented a case where prototype copies of museum objects from the Silk Road were developed, catering specifically to tactile recognition by blind individuals. These replicas, characterised by their lightweight nature, allowed for the identification of intricate details and the reading of Braille texts. By integrating Braille descriptions onto the surfaces of the objects, a multifunctional approach was established, thus enabling tactile exploration of the objects' shapes and access to accompanying textual content. The effectiveness of the chosen methodology, technology selection, and 3D printing with fused filament fabrication was demonstrated in the production of manipulable and lightweight 3D models. These versatile replicas can be used in various contexts, including museum exhibitions, home printing, conservation training, and archival purposes. This allowed for expanding accessibility and facilitating the sharing of cultural heritage objects.

Zada (Zada, 2021) contributed to the development of innovative cartographic solutions for blind and partially impaired students in Kurdistan, addressing the challenges they face in utilising maps. The study implemented a Geographic Information System (GIS) to create digital interactive tactile maps, also with the possibility of being updated, allowing users to customise data representation through touch displays. The effectiveness of those maps in improving text and space memorisation among visually impaired Kurdish students was examined. The research aimed to fill the gap in providing effective multimodal communication maps for various demographic groups in Kurdistan. It explored the application of interactive tactile maps not only for visually impaired individuals but also for other populations. The authors believed their results were beneficial for blind and low-sighted users in easily accessing geographical information through assistive technologies, and it enhanced the learning experience and exposure to the latest information and technological advancements for students.

Closing the visual impairment disability, Rossetti et al. (Rossetti et al., 2018) deployed low-cost interactive 3D models to enhance the understanding of architectural details in cultural sites. The focus was on designing digital models, printing, and assembling tangible models, in addition to creating an interactive and self-explanatory system. Eight participants with visual disabilities, including four blind and four severely visually impaired individuals, were involved in evaluating the impact of the proposed method. The results revealed positive feelings and perceptions from participants.

Finally, regarding the enhancement of disability rights, particularly for individuals with motor disabilities, Kocaman et al. (Kocaman & Ozdemir, 2020) proposed a comprehensive framework by using advancements in geographic information science (GIScience). This framework integrated GIS, Volunteered Geographic Information (VGI), and citizen science to address location-based challenges faced by individuals with motor disabilities. They also explored the relationship between law and geography, emphasising the structural injustices caused by geographies and the efforts by the United Nations to promote the cited disability rights. The authors noted that establishing a disability-oriented Spatial Data Infrastructure (SDI) is crucial to ensure compatibility at both national and international levels. By implementing this framework, factors enabling or disabling motor disabilities in specific geographic contexts were identified, which led to innovative solutions and evidence-based policy making.

4.2. Multidisciplinary collaboration (collaborative platforms, GIS, and HBIM)

Pinto Puerto (Pinto Puerto, 2018) considered digital resources as rule breakers in relation to how data are understood, accessed, and used to build knowledge and support management and dissemination processes. In this way, the researcher and his team focused their efforts on enabling an interoperable database infrastructure that would allow various disciplines to operationalise the data and visualise phenomena from a spatio-temporal point of view. Their proposal involved using BIM and GIS, digital systems that have evolved the way architecture and land data are read, organised, selected, and analysed.

López et al. (López et al., 2018) reviewed the implementation of HBIM in the cultural heritage sector for modelling and managing architectural elements. The work highlighted the importance of digital 3D models for remote planning and conservation projects. Combining BIM and GIS tools, along with auxiliary software, enables the semi-automatic modelling of graphical and semantic data. The authors also described that HBIM libraries facilitate interdisciplinary collaboration and knowledge exchange, although challenges such as the lack of international libraries and shape recognition algorithms remain. By the time the research was conducted, there was a need to advance BIM platforms and create a universal HBIM library accessible to various experts in the field. The latter has been partly achieved as seen in the multidisciplinary collaborations in HBIM projects.

Regarding digital preservation, Champion and Rahaman (Champion & Rahaman, 2019) highlighted the limited visibility and sustainability of 3D digital heritage models despite their potential to convey the importance of preserving cultural artifacts and intangible heritage. Through an examination of digital heritage papers, they revealed a lack of active promotion and preservation of these models as scholarly resources, hindering the evolution of the discipline and impeding public engagement in heritage preservation. The problem stems from inadequate infrastructure and the absence of integrated links to 3D assets in academic publication and dissemination systems. To address these issues, the authors proposed recognising 3D models as scholarly resources and establishing guidelines for creating and maintaining a robust infrastructure. They emphasised the need to incorporate the dynamic and environmental aspects of built heritage into digital models to effectively communicate the principles of research and sustainability. By adopting an evolving scholarly digital ecosystem approach, the authors believed that both the scholarly publication system and digital heritage projects can better fulfil their goals of knowledge dissemination, preservation, and sustainability.

Nishanbaev (Nishanbaev, 2020) drew attention to the progress made in 3D surveying and web technologies for the digital preservation and sharing of cultural heritage. The author introduced a methodology and web repository that integrated maps, 3D models, and geospatial data for long-term archiving and visualisation on the web. According to the researcher, the use of free and open-source content management systems enhanced flexibility and reusability. Remaining challenges were also addressed, including metadata and semantic interoperability, as well as interlinking 3D models with relevant knowledge bases. Overall, this research contributed to the development of web repositories for 3D cultural heritage models.

Croce et al. (Croce et al., 2020) referred to the growing trend in Cultural Heritage research towards digital information systems that combine geometric representations of artifacts with meaningful tags. This process, known as semantic annotation, enhances digital architectural heritage models by linking geometric representations to knowledge-related information. The study compared traditional 2D mapping methods with more recent approaches, e.g., HBIM techniques and collaborative reality-based platforms. The advantages of semantic annotations over 2D mapping were explored, and ongoing research focused on constructing a formalised knowledge base, transferring annotations between representation systems, and automating the annotation process. These advancements aimed to reduce human involvement, improve the detection and labelling of architectural elements in 3D models, streamline annotation procedures, and facilitate the exchange and dissemination of research results in the field of heritage architectural assets.

Messaoudi et al. (Messaoudi et al., 2018) focused on addressing the challenge of integrating diverse data and creating a unified information model for the conservation and restoration of historical monuments. They developed a correlation pipeline that combines semantic, spatial, and morphological dimensions of built heritage using an ontological model. By spatially representing and semantically classifying information about material, alteration phenomena, and conservation state, they provided conservation experts with a practical means to explore and record scientific observations. The pipeline was successfully tested on a church in France, demonstrating its ability to correlate and retrieve various types of information. The proposed domain ontology model enabled the annotation and monitoring of stone degradation phenomena, facilitating decision-making for heritage experts. Further advancements include in-situ data acquisition and correlation using mobile devices to provide real-time results. The integration of components and the concept of an "informative continuum" contribute to the interconnected representation of spatialised and semantically enriched photographs, enriching the knowledge base on heritage building degradation.

Pepe et al. (Pepe et al., 2021) implemented a novel Scan-to-BIM method in the cultural heritage field, specifically focusing on a rock church in Grottaglie, Italy. Through an integrated survey using TLS and SfM, they constructed a 3D GIS model of the structure, enabling architectural and historical analysis. They developed a procedure in Rhinoceros software to accurately model the objects from the point cloud, resulting in a high-quality BIM project. Importing this BIM into a 3D GIS environment allowed for the connection of multi-information to each identified element. This method overcome limitations in BIM software and facilitated the parameterisation and management of objects, even those with complex and irregular surfaces. The use of unique codes for each layer within the structure enhanced the relational database and enabled the association of multiple information to each element.

In the field of archaeology, Pietroni et al. (Pietroni et al., 2023) participated in the e-Archeo project, which aimed to enhance knowledge of Italian archaeological sites by using digital technologies (GIS, Digital Elevation Models (DEM), and 3D surveys) to restore their three-dimensionality, highlight cultural convergence, and promote accessibility. It fostered collaboration between public entities, research bodies, and private industries, resulting in the development of multimedia solutions and applications. The project had a positive impact, leading to increased cultural offerings, educational programs, and the integration of project narratives into civic education initiatives and virtual reality experiences. Its goal was to raise awareness and foster a greater appreciation for Italy's cultural heritage.

Malinverni et al. (Malinverni et al., 2019) conducted a multidisciplinary study at the Umm ar-Rasas archaeological site in Jordan, focusing on enhancing knowledge of the polychrome mosaic floor in the Church of Saint Stephen. They collected a vast amount of data, including archaeological investigations and geomatic surveys, and organised it in a geo-database for information exchange. Through the use of GIS and multimedia applications, they created virtual experiences and disseminated information to experts and visitors, including those with disabilities. This innovative approach improved accessibility, provided immersive cultural experiences, and facilitated the sharing of knowledge across different platforms.

Finally, the scientific community has also used BIM, a well-known methodology of the Architecture, Engineering, and Construction (AEC) sector, for documentation and data sharing purposes in archaeology. Among other achievements, Cortés-Sánchez et al. (Cortés-Sánchez et al., 2018) documented and characterised cave surfaces using TLS and SLS techniques, and stone engravings by means of SfM and SLS at a millimetric scale. Data accessibility allowed the different specialists of that multidisciplinary team to consult and manage the as-is models of the cave sectors in BIM for diverse studies in the research. Similarly, Moyano et al. (Moyano et al., 2020) worked on the A-BIM (Archaeological Building Information Model) of La Pastora tholos in Valencina de la Concepción, Seville (Spain), a funerary megalithic monument of the Copper Age. The A-BIM of the tholos granted access to the data by the different specialists, including the archaeologist and the BIM operator. On the other hand, by adopting the Scan-to-BIM approach, these authors carried out the parametric modelling of archaeological elements using TLS data and Kazhdan and Hoppe's 3D reconstruction algorithm. This produced 3D meshes defining the original shapes and were later converted into BIM *morph* elements so that Boolean operations trimmed the thickness excess in the created BIM wall. However, the model failed to achieve the full as-is condition, since the wall geometry in both the corridor and the chamber was clearly affected by the modelling method followed. The upward extrusion Boolean operation, with the morph mesh as the splitting object, resulted in a loss of relief on the wall. For their part, Marini et al. (Marini et al., 2022) 3D surveyed and reconstructed a complex-shaped archaeological site, the San Giorgio Cave in Usini (Italy), for documentation purposes. However, the authors did not explicitly describe how they achieved the desired "public archaeology", as no link to the 3D model was provided to facilitate accessibility. This suggests that there is a potential benefit to accessibility, as it should be inherent in the production of digital models of heritage assets. Furthermore, the authors recommended that accessibility of the data to archaeologists should occur through the point cloud rather than the 3D model. This is nothing but missing the opportunity to generate knowledge from actual geometry.

4.3. Open access, repositories, and virtual museums

According to Benchekroun and Ullah (Benchekroun & Ullah, 2021), sharing access to 3D heritage scanning data is an important obstacle to the creation of a complete pipeline for this sort of material. In their work, these authors developed a flexible and accessible approach for the creation, processing, and web hosting of digital heritage materials, which was exemplified through a case study conducted in partnership with the La Mesa Historical Society (LMHS). By showcasing different 3D scanning pipelines, they demonstrated that even inexperienced practitioners can successfully produce high-quality 3D data using their methods. The authors also created an interactive online Web3D platform to share the captured data, allowing individuals who cannot physically visit the site to experience it virtually. Furthermore, they aimed to empower local stakeholders, including the LMHS, by enabling them to conduct their own scans using the accessible 3D digital recording pipelines. In their research, the authors compared the output of their pipelines with professional quality 3D scanning tools, aiming to bridge the accessibility gap in equipment. The authors believed that their methodologies would not only benefit fields such as digital archaeology and heritage conservation in practical terms, but would also broaden access, control and action over the creation and dissemination of digital heritage assets. Moreover, the authors predicted increased public engagement in the documentation and visualization of cultural heritage, ultimately generating more interest and care for humanity's valuable heritage.

While most of her ideas are still valid today, Keene (Keene, 2008) highlighted the evolving expectations for museums. They are urged to be more responsive to public wishes and make better use of their collections. She revealed that expert reports advocate for a shift towards excellence, inclusivity, and approaches that focus on the users. It is also emphasised that museums have the opportunity to be innovative and creative in reinventing their services, particularly by engaging people directly with collections. Overcoming barriers to innovation, such as economic factors and cultural conservatism, is crucial. The sector should prioritise community intelligence, build alliances, and tailor services to local needs. In addition, the fact that only a small number of artefacts in the collecting institutions are accessible to the public indicates the need to improve the accessibility to information about cultural heritage in line with modern requirements. By embracing these changes, museums can shape a future that offers meaningful experiences and challenges the perception of collections as elitist, ultimately fostering greater public engagement and interest.

In that sense, García-Bustos et al. (García-Bustos et al., 2022) developed a virtual museum to make Palaeolithic art more accessible to public, since this sort of heritage is usually prioritised for conservation and research rather than for touristic purposes. To do this, the authors digitised sectors in caves and open-air stations with valuable features using SfM to obtain textured 3D meshes. Following a simplification process to ease data handling, they designed the digital exhibition environment to store the digitised content and made it accessible online in the Sketchfab platform to 1) democratise this (in the words by the authors) important cultural manifestation for understanding human history, and 2) inspire the creation of more digital resources related to this art form.

Foo et al. (Foo et al., 2023) explored the use of digital documentation methods, including 3D scanning and photogrammetry, to create 3D models of a heritage shophouse. They evaluated each method for its strengths and weaknesses in producing accurate models and photorealistic images. The study emphasised the importance of comprehensive documentation for conservation and highlighted the potential of 3D models for initial assessment and data-sharing with stakeholders. The authors suggested that a combination of methods may be necessary to capture intricate architectural features in an effective manner. The implementation of 3D digital documentation offers advantages, but challenges remain, including the need for expertise in both digital documentation and heritage conservation. The authors proposed a multi-disciplinary approach and the creation of a searchable central repository for historical architectural elements to enhance conservation efforts and information sharing. They claimed that more research is needed in this field to improve and expand the use of 3D digital documentation for cultural heritage preservation.

Albertini et al. (Albertini et al., 2022) developed PROTEUS, a VR tool integrated with an online repository for 3D models (both 3D reconstructed and handcrafted), metadata, and chemical analyses in digital humanities. According to the authors of this research, PROTEUS enables seamless transition between macroscopic and microscopic worlds, offering user-friendly and immersive experiences for researchers to manipulate objects, test hypotheses, and visualise metadata interactively. It fosters collaboration, knowledge sharing, and multidisciplinarity, bridging chemistry and cultural heritage. They believed that software's flexibility, compatibility, and future expansion plans, such as temporal analysis and multi-user sessions, should enhance its utility for scholars. Thus, PROTEUS would represent a significant step towards democratising science through VR.

Delving into 3D repositories, Gothandaraman and Muthuswamy (Gothandaraman & Muthuswamy, 2021) developed a symmetry detection and analysis methodology for a more effective search of similar 3D complex objects of cultural heritage.

Halabi et al. (Halabi et al., 2022) coordinated archaeological exercises, data management, digital object representation, and spatial analysis. They proposed a framework that allowed intuitive exploration of 3D reconstructed artifacts and provided detailed information on specific points of interest within a 3D-GIS repository. This pioneering work in Qatar focused on archiving and recording all archaeological data from the Murwab site, shedding light on the social and monetary relations within the ancient community. The implementation of HTML5, Cesium, and WebGL allowed large-scale web-based 3D geospatial visualisation without requiring browser plug-ins or additional applications. The potential applications of this concept ranged from attracting tourists to museums through 3D archaeological data access to 3D printing of artifacts for a tactile experience and creating a cloud-based map with a simulation of the surrounding environment.

Antlej (Antlej, 2022) proposed the creation of a CAD repository for modelled elements and 3D scanned features of the K67 Kiosk, a sample of modernist modular architecture by the Slovenian architect and designer Saša J. Mächtig. This research enabled systematic documentation of the heritage asset and audience engagement through VR, MR and AR, 3D printing, and serious games. Another author (Nishanbaev, 2020) developed a methodology and a web repository to integrate maps, 3D models, and geospatial data, enabling long-term Web archiving and visualisation of geo-located 3D digital cultural heritage models, thus fostering interest and tourism. Nishanbaev addressed challenges in data integration, interoperability, and visualisation, while acknowledging the expansion potential of this methodology to other domains. In addition, the author discussed two major technical challenges, focusing on metadata and semantic interoperability, and the interconnection of 3D model parts with relevant information. Despite remaining challenges, the author's work contributed to enhancing 3D digital cultural heritage preservation and engagement on the Web.Following the 3D digitisation and reconstruction of the Inquisition Prisons and Archaeological Excavation Area of the Palazzo Chiaramonte-Steri monumental complex, Scianna et al. (Scianna et al., 2023) developed a web app to create a single digital platform for the enhancement, use, and management of that case study.

Finally, Zheliazkova et al. (Zheliazkova et al., 2015) focused their research on non-specialist users who do not necessarily have access to expensive equipment. The aim was to bring as-built BIM for heritage (HBIM) to a wider audience. The authors presented a parametric-assisted method for reconstructing and creating BIM projects of built heritage using low-cost technologies and open-source software. They focused on the 3D reconstruction of the ceiling of the Albergo

Diurno "Venezia" in Milan (Italy), an architecturally significant heritage site. The research highlighted the development of custom algorithms to automatically rebuild the complex geometry from 3D meshes into a NURBS-based 3D model. The proposed methodology streamlined data elaboration, improved accuracy depending on the quality of the input dataset and allowed for different BIM levels of detail.

4.4. Immersive experiences

The scientific community has explored visually appealing and immersive settings for different purposes. Examples of those are the work by Kang et al. (Kang et al., 2022), who presented a physics-based simulation of the deformation of soft-bodies using a low-cost RGB-D (Red, Green, Blue-Depth) sensor. With the potential to be applied to different interactive AR and VR environments, the authors' realistic outputs were useful for topological deformations. Other authors (Halder & Afsari, 2022) designed an inspector assistant robot to conduct real-time construction verifications in an immersive environment.

In a way to communicate built cultural heritage, HBIM and other 3D reconstruction methods allow for producing immersive experiences to ensure accessibility to users, experts, and institutions. An example of this is the work by Argiolas et al. (Argiolas et al., 2022), who emphasised the widespread use of HBIM methodology in managing architectural heritage, particularly the Scan-to-BIM process using laser scanning and photogrammetry. They also highlighted the integration of HBIM models into game engines for immersive virtual tours and interactive experiences. The paper focused on developing a virtual tour of the Jesuitical Complex of Santa Croce in Cagliari, adopting HBIM methodology and game engines to enhance understanding and communication of historic architecture. The advantages of informative models directly transposable to development software and the ability to expand user interactions are evident.

Kowalski et al. (Kowalski et al., 2023) developed methodological protocols for enhancing and preserving built heritage through digital reconstruction, particularly using VR-based models. They focused on a 19th-century case study, the coastal battery in the Gdańsk port area. Using TLS, SfM, and GIS, together with historical research, the process involved 3D digitisation, comparison of historical records and maps to the present state, and 3D reconstruction of the lost heritage. This enabled an immersive and accurate experience of historical changes through VR. The contribution of this methodology is twofold: it aids in preserving incomplete or altered heritage sites and opens possibilities for interactive heritage education and engagement through modern technologies, e.g., VR, thus offering fresh insights into the past.Giovannini and Bono (Giovannini & Bono, 2023) developed a methodological workflow to create virtual environments of replicated physical spaces. These immersive and virtual experiences enabled social interaction and augmented content exploration. The authors focused on the temporary 'Phygital Exhibition' at the Sordevolo Passion Museum in the Church of Santa Marta, Italy. The digitisation was performed via SfM using an unmanned aerial vehicle (UAV), and the resulting 3D model was stored in SketchFab to ensure user accessibility. The study showcased that methodology involving the creation of a digital twin to highlight the transformation of scenography over time. The authors demonstrated how virtual scenes can be generated, personalised, and shared on the web. This approach should enhance visitor experience, provide content customisation, encourage collaboration, and offer cost-effective alternatives to traditional exhibitions, ultimately broadening audience reach and offering diverse content experiences.

Jouan et al. (Jouan et al., 2022) proposed a virtual environment prototype in order to create a built-heritage immersive experience of the Collegiate Church of Saint-Jean in Belgium. The technologies they used included 3D laser scanning, photogrammetry and 3D models, and employed the 3D Unity game engine. The result facilitated not only the tasks of the experts dealing with the difference stages of the conservation project but also the views of the non-expert stakeholders in the maintenance issues and previous states of existence.

Benardou and Droumpouki (Benardou & Droumpouki, 2022) brought together multiple works on immersive experiences related to built heritage. Topics addressed included digital immersion to analyse built heritage as an enabler of equity in urban sites, experiences in a concentration camp, or unearthing the Rosewood massacre.

Other authors (Spallone et al., 2023) pursued accessibility to built heritage via 3D reconstruction and AR-VR interactive visualisation. The case study was Piffetti's Library in Villa Della Regina Museum in Turin, Italy. The interdisciplinary team comprised experts from art history, digital surveying, 3D modelling, and digital cultural heritage solutions, who combined 3D laser scanning and photogrammetry to recreate the library's original structure on an accurate basis. The AR application allowed visitors to experience the library's original location, while a detailed VR model provided a comprehensive online experience. This project aimed to engage users, making history accessible through immersive technologies. Being ongoing, the project strives to offer interactive elements and connections between Villa della Regina and Quirinale, enhancing the understanding of historical artifacts and their significance. The project's approach integrates historical, architectural, and technological aspects to bridge the gap between cultural heritage and modern accessibility.

Pavelka jr. et al. (Pavelka jr. et al., 2023) achieved a comprehensive SfM 3D reconstruction of the church of St. Panteleimon, near Skopje (North Macedonia). However, in relation to the development of the VR experience from the case study, the authors missed the opportunity to reach as-is geometries as they focused on the simplified (ideal) HBIM of the temple.

Additionally, it is worth including freely accessible examples of immersive content based on as-is or as-built 3D reconstructions from remote sensing data. Although they are not indexed in scientific databases, the following contributions were made within the framework of nationally and internationally funded research and development (R&D) projects (UK, and the EU), other international collaborations, or contracts with private institutions. Given that they are available online on YouTube, the accessibility to the general public, experts, institutions, and businesses is ensured.

Another interesting contribution is that by Odyssey Visual Media (Odyssey Visual Media, 2019) video on YouTube an impressive and realistic panoramic virtual tour of the as-is model of some Pyramids of Egypt.

Funded by the National Lottery Heritage Fund, a TLS survey of St Barnabas Catholic Cathedral in Nottingham, UK, enabled a simplified structural as-is model to support future analysis and restoration of the building (Antón, 2020). In this line, the European Regional Development Fund

(ERDF) part-funded project entitled ‘Live Experiential and Digital Diversification – Nottingham’ (LEADD:NG) made it possible to survey and create simplified as-is models of important landmarks in that city. Firstly, the Anglican St John the Baptist Beeston Parish Church was selected as a case study of the application of remote sensing and modelling digital technologies to deformed heritage buildings, thus enabling fully rendered 2D (Antón, 2022b) and 360° (spherical, panoramic) (Antón, 2022a) virtual tours to explore and disseminate the temple. Secondly, Ye Olde Trip to Jerusalem, claimed to be the oldest pub in England (1189 AD), shows numerous deformations due to the course of time. A game engine-based immersive experience was created, for which a virtual tour showing its exploration was made available to the public (Antón, 2022c).

More recently, a team of researchers from Universidad de Sevilla (Spain) applied non-destructive techniques (NDT) from the architectural field to a different heritage typology in order to study it and make it accessible to the public and the institution involved. Thus, they carried out the SfM digitisation and virtual exploration of the virgin Nuestra Señora del Socorro’s procession cape, of the Hermandad del Amor in Seville (Antón, 2023). Here, the as-is 3D reconstruction enabled the analysis, digital preservation, and dissemination of this embroidery textile asset, a religious heritage piece of a great value.

5. Conclusions

Cultural heritage is a source of knowledge and enjoyment for all people, including those with visual disabilities. However, these sites are usually not accessible or do not offer adapted resources for exploration. One way to improve the inclusion and participation of blind or visually impaired individuals in the cultural field is through the use of 3D models that reproduce architectural or artistic elements of interest. These models, based on precise geometries and representative of the current conservation status of heritage assets, allow for detailed study, restoration actions, preventive conservation, and exploration for dissemination purposes. Thus, it is essential to make this legacy accessible so that all people, regardless of their physical or mental condition, can enjoy it.

This research has identified a number of relevant studies that achieve as-built geometries and make those models accessible. However, other publications do not demonstrate achieving that level of accuracy completely. Nevertheless, there is a great effort by the scientific literature to create and/or apply collaborative platforms in which stakeholders can share information.

The main limitation of this research is the overview (exploration) of the existing literature, which, while ensuring reasonable coverage of relevant publications, does not constitute a fully comprehensive and extensive literature review as such. Therefore, a more thorough search for publications in these and other databases, considering additional criteria, will be undertaken in future research.

Acknowledgements

This research has been supported by funding for a post-doctoral researcher contract from the VI Plan Propio de Investigación y Transferencia of Universidad de Sevilla (reference VIPPIT-2020-II.5), Spain.

Artificial intelligence disclosure

During the preparation of this work, the author(s) used (1) Consensus App and (2) ChatGPT to (1) locate publications that may have been overlooked, or those not indexed in Scopus or WoS, and (2) edit text to improve readability and language of the work, and not to analyse or draw insights from data or publications' content. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

References

Albertini, N., Baldini, J., Dal Pino, A., Lazzari, F., Legnaioli, S., & Barone, V. (2022). PROTEUS: an immersive tool for exploring the world of cultural heritage across space and time scales. *Heritage Science*, *10*(1), 71. https://doi.org/10.1186/s40494-022-00708-3

Antlej, K. (2022). Digital Heritage Interpretation of Modernist Modular Architecture: The K67 Kiosk. In C. Bartolomei, A. Ippolito, & S. H. T. Vizioli (Eds.), *Digital Modernism Heritage Lexicon* (pp. 523–552). Springer. https://doi.org/10.1007/978-3-030-76239-1_23

Antón, D. (2020). *St Barnabas Cathedral, Nottingham, UK - 3D model virtual tour (flythrough and walkaround animation)*. YouTube. https://irep.ntu.ac.uk/id/eprint/43139

Antón, D. (2022a). *360/VR mobile devices - Beeston Parish Church (Nottingham) - rendered 3D model and 360 video tour*. YouTube. http://irep.ntu.ac.uk/id/eprint/45980/

Antón, D. (2022b). *Beeston Parish Church (Nottingham) - rendered 3D model and video tour*. YouTube. http://irep.ntu.ac.uk/id/eprint/45979/

Antón, D. (2022c). *Ye Olde Trip to Jerusalem, England's oldest pub (fly-through of VR immersive experience)*. YouTube. http://irep.ntu.ac.uk/id/eprint/47661/

Antón, D. (2023). *Manto de Salida de Nuestra Señora del Socorro - Fotogrametría y exploración virtual realista*. YouTube. http://irep.ntu.ac.uk/id/eprint/48368/

Antón, D., Medjdoub, B., Shrahily, R., & Moyano, J. (2018). Accuracy evaluation of the semi-automatic 3D modeling for historical building information models. *International Journal of Architectural Heritage*, *12*(5), 790–805. https://doi.org/10.1080/15583058.2017.1415391

Antón, D., Pineda, P., Medjdoub, B., & Iranzo, A. (2019). As-Built 3D Heritage City Modelling to Support Numerical Structural Analysis: Application to the Assessment of an Archaeological Remain. *Remote Sensing*, *11*(11), 1276. https://doi.org/10.3390/rs11111276

Argiolas, R., Bagnolo, V., Cera, S., & Cuccu, S. (2022). Virtual Environments to Communicate Built Cultural Heritage: A HBIM Based Virtual Tour. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVI-5/W1-*, 21–29. https://doi.org/10.5194/isprs-archives-XLVI-5-W1-2022-21-2022

Australia ICOMOS. (1999). *The Burra Charter: the Australia ICOMOS Charter for Places of Cultural Significance*. Australia ICOMOS Incorporated 2000. https://australia.icomos.org/wp-content/uploads/BURRA_CHARTER.pdf

Bakker, W. H., Feringa, W., Gieske, A. S. M., Gorte, B. G. H., Grabmaier, K. A., Hecker, C. A., Horn, J. A., Huurneman, G. C., Janssen, L. L. F., Kerle, N., van der Meer, F. D., Parodi, G. N., Pohl, C., Reeves, C. V, van Ruitenbeek, F. J., Schetselaar, E. M., Tempfli, K., Weir, M. J. C., Westinga, E., & Woldai, T. (2009). *Principles of Remote Sensing* (K. Tempfli, N. Kerle, G. C. Huurneman, & L. L. F. Janssen (eds.); 4th ed.). The International Institute for Geo-Information Science and Earth Observation (ITC). https://webapps.itc.utwente.nl/librarywww/papers_2009/general/principlesremotesensing.pdf

Barazzetti, L., Banfi, F., Brumana, R., Gusmeroli, G., Previtali, M., & Schiantarelli, G. (2015). Cloud-to-BIM-to-FEM: Structural simulation with accurate historic BIM from laser scans. *Simulation Modelling Practice and Theory*, *57*, 71–87. https://doi.org/10.1016/j.simpat.2015.06.004

Bassier, M., Hadjidemetriou, G., Vergauwen, M., Van Roy, N., & Verstrynge, E. (2016). Implementation of Scan-to-BIM and FEM for the Documentation and Analysis of Heritage Timber Roof Structures. In M Ioannides, E. Fink, A. Moropoulou, M. Hagedorn-Saupe, A. Fresa, G. Liestøl, & P. Grussenmeyer (Eds.), *Digital Heritage. Progress in Cultural Heritage: Documentation, Preservation, and Protection: 6th International Conference, EuroMed 2016* (pp. 79–90). Springer International Publishing. https://doi.org/10.1007/978-3-319-48496-9_7

Bekele, M. K., & Champion, E. (2019). A Comparison of Immersive Realities and Interaction Methods: Cultural Learning in Virtual Heritage. *Frontiers in Robotics and AI*, *6*. https://doi.org/10.3389/frobt.2019.00091

Benardou, A., & Droumpouki, A. M. (2022). *Difficult Heritage and Immersive Experiences*. Routledge. https://doi.org/10.4324/9781003200659

Benchekroun, S., & Ullah, I. I. T. (2021). Preserving the Past for an Uncertain Future. *The 26th International Conference on 3D Web Technology*, 1–9. https://doi.org/10.1145/3485444.3507684

Cambridge University Press. (2023). *Accessibility*. Cambridge Dictionary. https://dictionary.cambridge.org/dictionary/english/accessibility

Champion, E., & Rahaman, H. (2019). 3D Digital Heritage Models as Sustainable Scholarly Resources. *Sustainability*, *11*(8), 2425. https://doi.org/10.3390/su11082425

Clarivate. (2023). *Web of Science*. https://www.webofknowledge.com/

Cortés-Sánchez, M., Riquelme-Cantal, J. A., Simón-Vallejo, M. D., Parrilla Giráldez, R., Odriozola, C. P., Calle Román, L., Carrión, J. S., Monge Gómez, G., Rodríguez Vidal, J., Moyano Campos, J. J., Rico Delgado, F., Nieto Julián, J. E., Antón García, D., Martínez-Aguirre, M. A., Jiménez Barredo, F., & Cantero-Chinchilla, F. N. (2018). Pre-Solutrean rock art in southernmost Europe: Evidence from Las Ventanas Cave (Andalusia, Spain). *PLOS ONE*, *13*(10), e0204651. https://doi.org/10.1371/journal.pone.0204651

Cotella, V. A. (2023). From 3D point clouds to HBIM: Application of Artificial Intelligence in Cultural Heritage. *Automation in Construction*, *152*, 104936. https://doi.org/10.1016/j.autcon.2023.104936

Croce, V., Caroti, G., De Luca, L., Piemonte, A., & Véron, P. (2020). Semantic annotations on heritage models: 2D/3D approaches and future research challenges. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLIII-B2-2*, 829–836. https://doi.org/10.5194/isprs-archives-XLIII-B2-2020-829-2020

Elsevier B.V. (2023). *Scopus*. https://www.scopus.com/

European Commission's Expert Group on Digital Cultural Heritage and Europeana (DCHE Expert Group). (2020). Basic principles and tips for 3D digitisation of cultural heritage. In *Shaping Europe's digital future*. https://digital-strategy.ec.europa.eu/en/library/basic-principles-and-tips-3d-digitisation-cultural-heritage

European Commission. (2011). Commission recommendation of 27 October 2011 on the digitisation and online accessibility of cultural material and digital preservation. In *Official Journal of the European Union: Vol. 2011/711/E* (Issue L283). https://eur-lex.europa.eu/eli/reco/2011/711/oj

Foo, C. P., Wong, C. W., Ng, Y. H., & Jacosalem, R. (2023). Exploring digital documentation for shophouses in Singapore. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVIII-M–2*, 579–586. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-579-2023

García-Bustos, M., Rivero, O., García Bustos, P., & Mateo-Pellitero, A. M. (2022). From the cave to the virtual museum: accessibility and democratisation of Franco-Cantabrian Palaeolithic art. *Virtual Archaeology Review*, *14*(28), 54–64. https://doi.org/10.4995/var.2023.17684

Gillovic, B., & McIntosh, A. (2020). Accessibility and Inclusive Tourism Development: Current State and Future Agenda. *Sustainability*, *12*(22), 9722. https://doi.org/10.3390/su12229722

Giovannini, E. C., & Bono, J. (2023). Creating Virtual Reality Using a Social Virtual Environment: Phygital Exhibition at the Museum Passion in Sordevolo. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVIII-M–2*, 669–676. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-669-2023

Gothandaraman, R., & Muthuswamy, S. (2021). Virtual models in 3D digital reconstruction: detection and analysis of symmetry. *Journal of Real-Time Image Processing*, *18*(6), 2301–2318. https://doi.org/10.1007/s11554-021-01115-w

Grilli, E., & Remondino, F. (2019). Classification of 3D Digital Heritage. *Remote Sensing*, *11*(7), 847. https://doi.org/10.3390/rs11070847

Halabi, O., Al-Maadeed, S., Puthern, M., Balakrishnan, P., & El-Menshawy, S. (2022). 3D GIS Interactive Visualization of the Archaeological Sites in Qatar for Research and Learning. *International Journal of Emerging Technologies in Learning (IJET)*, *17*(01), 160–178. https://doi.org/10.3991/ijet.v17i01.25933

Halder, S., & Afsari, K. (2022). Real-time Construction Inspection in an Immersive Environment with an Inspector Assistant Robot. In T. Leathem, W. Collins, & A. J. Perrenoud (Eds.), *ASC2022. 58th Annual Associated Schools of Construction International Conference* (pp. 389–379). The Associated Schools of Construction. https://doi.org/10.29007/ck81

Hansen, W. G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners*, *25*(2), 73–76. https://doi.org/10.1080/01944365908978307

International Council on Monuments and Sites. (2011). *The Athens Charter for the Restoration* *of Historic Monuments - 1931*. https://www.icomos.org/en/167-the-athens-charter-for-the-restoration-of-historic-monuments

Ioannides, Marinos, Magnenat-Thalmann, N., & Papagiannakis, G. (2017). *Mixed Reality and Gamification for Cultural Heritage* (Marinos Ioannides, N. Magnenat-Thalmann, & G. Papagiannakis (eds.); 1st ed.). Springer International Publishing. https://doi.org/10.1007/978-3-319-49607-8

Jiménez Martín, D., Ramírez Saiz, A., & Ajuriaguerra Escudero, M. A. (2022). Urban Accessibility in World Heritage Cities. Accessibility Considerations in Pedestrian Routes in Historic City Centres. In *Transforming our World through Universal Design for Human Development*. IOS Press. https://doi.org/10.3233/SHTI220879

Jouan, P., Moray, L., & Hallot, P. (2022). Built Heritage Visualizations in Immersive Environments to Support Significance Assessments by Multiple Stakeholders. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVI-2/W1-*, 267–274. https://doi.org/10.5194/isprs-archives-XLVI-2-W1-2022-267-2022

Kang, D., Moon, J., Yang, S., Kwon, T., & Kim, Y. (2022). Physics-Based Simulation of Soft-Body Deformation Using RGB-D Data. *Sensors*, *22*(19), 7225. https://doi.org/10.3390/s22197225

Kazhdan, M., & Hoppe, H. (2013). Screened poisson surface reconstruction. *ACM Transactions on Graphics*, *32*(3), 1–13. https://doi.org/10.1145/2487228.2487237

Keene, S. (2008). *Collections for People. Museums' stored Collections as a Public Resource* (S. Keene (ed.)). UCL Institute of Archaeology. https://discovery.ucl.ac.uk/id/eprint/13886/1/13886.pdf

Kidd, J., & Nieto McAvoy, E. (2019). *Immersive experiences in museums, galleries and heritage sites: a review of research findings and issues*. Creative Industries' Policy and Evidence Centre (PEC). https://orca.cardiff.ac.uk/id/eprint/128879

Kocaman, S., & Ozdemir, N. (2020). Improvement of Disability Rights via Geographic Information Science. *Sustainability*, *12*(14), 5807. https://doi.org/10.3390/su12145807

Kose, S. (2022). How Can We Ensure Accessibility of Cultural Heritage? Toward Better Utilization of Existing Assets in Japanese Context. In I. Garofolo, G. Bencini, & A. Arenghi (Eds.), *Transforming our World through Universal Design for Human Development* (pp. 435–442). IOS Press. https://doi.org/10.3233/SHTI220871

Kowalski, S., La Placa, S., & Pettineo, A. (2023). From Archives Sources to Virtual 3D Reconstruction of Military Heritage – The Case Study of Port Battery, Gdańsk. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVIII-M–2*, 885–893. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-885-2023

Kubenz, V., & Kiwan, D. (2022). "Vulnerable" or Systematically Excluded? The Impact of Covid-19 on Disabled People in Low- and Middle-Income Countries. *Social Inclusion*, *11*(1). https://doi.org/10.17645/si.v11i1.5671

Lambert, S. R. (2020). Do MOOCs contribute to student equity and social inclusion? A systematic review 2014–18. *Computers & Education*, *145*, 103693. https://doi.org/10.1016/J.COMPEDU.2019.103693

Liu, J., Azhar, S., Willkens, D., & Li, B. (2023). Static Terrestrial Laser Scanning (TLS) for Heritage

Building Information Modeling (HBIM): A Systematic Review. *Virtual Worlds*, *2*(2), 90–114. https://doi.org/10.3390/virtualworlds2020006

Lo Valvo, A., Garlisi, D., Giarr´e, L., Croce, D., Giuliano, F., & Tinnirello, I. (2020). A Cultural Heritage Experience for Visually Impaired People. *IOP Conference Series: Materials Science and Engineering*, *949*(1), 012034. https://doi.org/10.1088/1757-899X/949/1/012034

Logothetis, S., Delinasiou, A., & Stylianidis, E. (2015). Building Information Modelling for Cultural Heritage: A review. *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *II-5/W3*, 177–183. https://doi.org/10.5194/isprsannals-II-5-W3-177-2015

López, F., Lerones, P., Llamas, J., Gómez-García-Bermejo, J., & Zalama, E. (2018). A Review of Heritage Building Information Modeling (H-BIM). *Multimodal Technologies and Interaction*, *2*(2), 21. https://doi.org/10.3390/mti2020021

Mack, K., McDonnell, E., Jain, D., Lu Wang, L., E. Froehlich, J., & Findlater, L. (2021). What Do We Mean by “Accessibility Research”? *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 1–18. https://doi.org/10.1145/3411764.3445412

Maietti, F., Di Giulio, R., Balzani, M., Piaia, E., Medici, M., & Ferrari, F. (2017). Digital Memory and Integrated Data Capturing: Innovations for an Inclusive Cultural Heritage in Europe Through 3D Semantic Modelling. In G. Ioannides, M., Magnenat-Thalmann, N., Papagiannakis (Ed.), *Mixed Reality and Gamification for Cultural Heritage* (pp. 225–244). Springer International Publishing. https://doi.org/10.1007/978-3-319-49607-8_8

Malinverni, E. S., Pierdicca, R., Di Stefano, F., Gabrielli, R., & Albiero, A. (2019). Virtual museum enriched by GIS data to share science and culture. Church of Saint Stephen in Umm Ar-Rasas (Jordan). *Virtual Archaeology Review*, *10*(21), 31. https://doi.org/10.4995/var.2019.11919

Mallafrè Balsells, C., López Besora, J. M., Costa Jover, A., & Coll Pla, S. (2021). Register of Dry Stone Domes. Simplified Method for Point Clouds. *Nexus Network Journal*, *23*(2), 493–506. https://doi.org/10.1007/s00004-020-00533-w

Marín-Nicolás, J., & Sáez-Pérez, M. P. (2022). An Evaluation Tool for Physical Accessibility of Cultural Heritage Buildings. *Sustainability*, *14*(22), 15251. https://doi.org/10.3390/su142215251

Marini, I., Caradonna, C., Melis, M. G., & Nardinocchi, C. (2022). Terrestrial laser scanning for 3D archaeological documentation. The prehistoric Cave of Sa Miniera de Santu Josi (Sardinia, Italy). *Journal of Physics: Conference Series*, *2204*(1), 012030. https://doi.org/10.1088/1742-6596/2204/1/012030

Matin, B. K., Williamson, H. J., Karyani, A. K., Rezaei, S., Soofi, M., & Soltani, S. (2021). Barriers in access to healthcare for women with disabilities: a systematic review in qualitative studies. *BMC Women’s Health*, *21*(1), 1–23. https://doi.org/10.1186/S12905-021-01189-5/TABLES/3

Messaoudi, T., Véron, P., Halin, G., & De Luca, L. (2018). An ontological model for the reality-based 3D annotation of heritage building conservation state. *Journal of Cultural Heritage*, *29*, 100–112. https://doi.org/10.1016/j.culher.2017.05.017

Milakis, D., Gebhardt, L., Ehebrecht, D., & Lenz, B. (2020). Is micro-mobility sustainable? An overview of implications for accessibility, air pollution, safety, physical activity and subjective wellbeing. In *Handbook of Sustainable Transport* (pp. 180–189). Edward Elgar Publishing. https://doi.org/10.4337/9781789900477.00030

Montusiewicz, J., Barszcz, M., & Korga, S. (2022). Preparation of 3D Models of Cultural Heritage Objects to Be Recognised by Touch by the Blind—Case Studies. *Applied Sciences*, *12*(23), 11910. https://doi.org/10.3390/app122311910

Moyano, J., Odriozola, C. P., Nieto-Julián, J. E., Vargas, J. M., Barrera, J. A., & León, J. (2020). Bringing BIM to archaeological heritage: Interdisciplinary method/strategy and accuracy applied to a megalithic monument of the Copper Age. *Journal of Cultural Heritage*, *45*, 303–314. https://doi.org/10.1016/j.culher.2020.03.010

Murphy, M., McGovern, E., & Pavia, S. (2013). Historic Building Information Modelling – Adding intelligence to laser and image based surveys of European classical architecture. *ISPRS Journal of Photogrammetry and Remote Sensing*, *76*, 89–102. https://doi.org/10.1016/j.isprsjprs.2012.11.006

Nishanbaev, I. (2020). A web repository for geo-located 3D digital cultural heritage models. *Digital Applications in Archaeology and Cultural Heritage*, *16*, e00139. https://doi.org/10.1016/j.daach.2020.e00139

Odyssey Visual Media. (2019). *Pyramids of Egypt Virtual Tour | VR 360° Travel Experience*. YouTube. https://www.youtube.com/watch?v=mOuvAJRknXk

Olson, E., Salem, C., Farid, A., Van Welie, M., & Nebeker, B. (2022). *Consensus*. https://consensus.app/#

Pavelka jr., K., Kuzmanov, P., Pavelka, K., & Rapuca, A. (2023). Different Data Joining as a Basic Model for HBIM – A Case Project St. Pataleimon in Skopje. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVIII-5/W*, 85–91. https://doi.org/10.5194/isprs-archives-XLVIII-5-W2-2023-85-2023

Pepe, M., Costantino, D., Alfio, V. S., Restuccia, A. G., & Papalino, N. M. (2021). Scan to BIM for the digital management and representation in 3D GIS environment of cultural heritage site. *Journal of Cultural Heritage*, *50*, 115–125. https://doi.org/10.1016/j.culher.2021.05.006

Pérez, E., Merchán, P., Merchán, M. J., & Salamanca, S. (2020). Virtual Reality to Foster Social Integration by Allowing Wheelchair Users to Tour Complex Archaeological Sites Realistically. *Remote Sensing*, *12*(3), 419. https://doi.org/10.3390/rs12030419

Pietroni, E., Menconero, S., Botti, C., & Ghedini, F. (2023). e-Archeo: A Pilot National Project to Valorize Italian Archaeological Parks through Digital and Virtual Reality Technologies. *Applied System Innovation*, *6*(2), 38. https://doi.org/10.3390/asi6020038

Pinto Puerto, F. S. (2018). La tutela sostenible del patrimonio cultural a través de modelos digitales BIM y SIG como contribución al conocimiento e innovación social. *Revista PH*, *93*, 27–29. https://doi.org/10.33349/2018.0.4125

Rodríguez-Martín, M., Sánchez-Aparicio, L. J., Maté-González, M. Á., Muñoz-Nieto, Á. L., & Gonzalez-Aguilera, D. (2022). Comprehensive Generation of Historical Construction CAD Models from Data Provided by a Wearable Mobile Mapping System: A Case Study of the Church of Adanero (Ávila, Spain). *Sensors*, *22*(8), 2922. https://doi.org/10.3390/s22082922

Rossetti, V., Furfari, F., Leporini, B., Pelagatti, S., & Quarta, A. (2018). Enabling Access to Cultural Heritage for the visually impaired: an Interactive 3D model of a Cultural Site.

Procedia Computer Science, *130*, 383–391. https://doi.org/10.1016/j.procs.2018.04.057

Sani, N. H., Tahar, K. N., Maharjan, G. R., Matos, J. C., & Muhammad, M. (2022). 3D Reconstruction of Building Model Using UAV Point Clouds. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLIII-B2-2*, 455–460. https://doi.org/10.5194/isprs-archives-XLIII-B2-2022-455-2022

Santos, P., Ritz, M., Fuhrmann, C., Monroy, R., Schmedt, H., Tausch, R., Domajnko, M., Knuth, M., & Fellner, D. (2017). Acceleration of 3D Mass Digitization Processes: Recent Advances and Challenges. In M. Ioannides, N. Magnenat-Thalmann, & G. Papagiannakis (Eds.), *Mixed Reality and Gamification for Cultural Heritage* (pp. 99–128). Springer International Publishing. https://doi.org/10.1007/978-3-319-49607-8_4

Scianna, A., & Di Filippo, G. (2019). Rapid prototyping for the extension of the accessibility to cultural heritage for blind people. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLII-2/W15*, 1077–1082. https://doi.org/10.5194/isprs-archives-XLII-2-W15-1077-2019

Scianna, A., Gaglio, G. F., & La Guardia, M. (2023). Augmented Virtual Accessibility of Ch: The Web Navigation Model of Inquisition Prisons. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVIII-M–2*, 1443–1447. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-1443-2023

Selim, G., Jamhawi, M., Abdelmonem, M. G., Ma'bdeh, S., & Holland, A. (2022). The Virtual Living Museum: Integrating the Multi-Layered Histories and Cultural Practices of Gadara's Archaeology in Umm Qais, Jordan. *Sustainability*, *14*(11), 6721. https://doi.org/10.3390/su14116721

Sen, K., Prybutok, G., & Prybutok, V. (2022). The use of digital technology for social wellbeing reduces social isolation in older adults: A systematic review. *SSM - Population Health*, *17*, 101020. https://doi.org/10.1016/j.ssmph.2021.101020

Spallone, R., Russo, M., Teolato, C., Vitali, M., Palma, V., & Pupi, E. (2023). Reconstructive 3D Modelling and Interactive Visualization for Accessibility of Piffetti's Library in The Villa Della Regina Museum (Turin). *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *XLVIII-M–2*, 1485–1492. https://doi.org/10.5194/isprs-archives-XLVIII-M-2-2023-1485-2023

Taher Tolou Del, M. S., & Kamali Tabrizi, S. (2020). A methodological assessment of the importance of physical values in architectural conservation using Shannon entropy method. *Journal of Cultural Heritage*, *44*, 135–151. https://doi.org/10.1016/j.culher.2019.12.012

Taher Tolou Del, M. S., Saleh Sedghpour, B., & Kamali Tabrizi, S. (2020). The semantic conservation of architectural heritage: the missing values. *Heritage Science*, *8*(1), 70. https://doi.org/10.1186/s40494-020-00416-w

Vardia, S., Khare, A., & Khare, R. (2018). Universal access in heritage site: A case study on Jantar mantar, Jaipur, India. In G. Craddock, C. Doran, L. McNutt, & D. Rice (Eds.), *Studies in Health Technology and Informatics* (Vol. 256, pp. 67–77). IOS Press. https://doi.org/10.3233/978-1-61499-923-2-67

Woodgate, R. L., Gonzalez, M., Demczuk, L., Snow, W. M., Barriage, S., & Kirk, S. (2020). How do peers promote social inclusion of children with disabilities? A mixed-methods systematic review. *Disability and Rehabilitation*, *42*(18), 2553–2579. https://doi.org/10.1080/09638288.2018.1561955

Zada, A. A. K. (2021). Novel Cartographical Designs for Blind and Partially Impaired Students in Kurdistan. *Proceedings of the ICA*, *4*, 1–3. https://doi.org/10.5194/ica-proc-4-56-2021

Zheliazkova, M., Naboni, R., & Paoletti, I. (2015). A parametric-assisted method for 3D generation of as-built BIM models for the built heritage. In C. A. Brebbia & S. Hernández (Eds.), *WIT Transactions on The Built Environment, vol. 153: Structural Studies, Repairs and Maintenance of Heritage Architecture XIV* (pp. 693–704). WIT Press. https://doi.org/10.2495/STR150581