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Application of digital tools in heritage landscapes: A Systematic Literature Review

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This study provides a systematic literature review of the academic research on the deployment of digital tools and applications in Heritage Landscapes (HL) that are designated by UNESCO. While we frame HL as the sites of historical interaction between man and environment, in this paper we aim to document, analyze, and evaluate the scholarly efforts that illustrate how digital tools were applied within diverse context of HL including world heritage sites (e.g., historic urban areas, nature parks), biosphere reserves, and global geoparks. The study employed a scoping review methodology, starting with the definition of eligibility criteria, followed by the identification of suitable papers through search, screening, and selection. Followingly, a thematic analysis was conducted to systematically categorize and evaluate selected papers covering five key questions: Who (Researchers), What (HL type), Where (HL location), When (UNESCO recognition year), and Which (Digital technologies applied in HL). The results highlight four key critical insights and implications: (1) while non-European researchers focus on the digitization of HL within their own countries, European researchers are more involved in digitalizing HL in non-European contexts, (2) the scale of HL influences the selection and deployment of digital tools, (3) there has been a shift in UNESCO site designations after the 1990s to include non-European HL, (4) certain digital tools and technological advancements are applied across different types of HL.

Keywords:
Heritage landscapes; UNESCO site designations; Digital technologies; Geographic Information System (GIS); 3D modelling; Digital Photogrammetry

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1. INTRODUCTION

In this paper we aim to present an overview of the academic research undertaken on the use of digital technologies in 'heritage landscapes' (HL) designated by UNESCO including World Heritage Sites (e.g., historic urban areas, nature parks, archeological sites), Global Geoparks, and Biosphere Reserves. However, before presenting our research results, it is necessary to define a conceptual framework for the term 'heritage landscape' to clarify the main question, scope, and methodology of our research. In this paper, we use the term 'heritage landscape' to frame heritage sites as an integration of culture and nature. Almost since the 1960s, a critical approach has developed in the academia to reflect on the culture-nature divide (Larsen & Wijesuriya, 2015; Sundseth, 2019; Tamborrino et al., 2022). This criticism has resonated also in the heritage field since the 1970s. Within the culture-nature binary, while the term 'heritage' has usually been associated to culture, 'landscape' has been perceived as related to nature. An emblematic representation of this dichotomy can be found also in the international context; while UNESCO was founded in 1945 to encourage international collaboration

through culture (in addition to education and science), International Union for Conservation of Nature (IUCN), was founded in 1948 to encourage conservation and sustainable management of natural resources and biodiversity. In line with the critical academic approach to reject culture-nature divide, UNESCO and IUCN have been collaborating since UNESCO has adopted the well-known 1972 Convention concerning the Protection of the World Cultural and Natural Heritage. While the Convention was a key moment in developing an international approach to 'cultural heritage', the same approach had a different timeline for the areas of 'nature'. Although the Convention united natural and cultural sites under a single framework, it initially lacked a mechanism to acknowledge sites shaped by the interaction of cultural and natural values, such as landscapes of outstanding universal value. Moreover, UNESCO is continuously developing projects on seeing culture and nature as integral, interlinked and dynamic components of heritage(UNESCO, 2015). This shows that cultural heritage cannot be fully understood or preserved without considering its natural context. As part of this vision, UNESCO site designations such as Biosphere Reserves, World Heritage Sites, and Global Geoparks provide a comprehensive framework that celebrate our heritage, conserves diverse ecosystems, and promotes sustainable development.

Within this international institutional frame for 'heritage' and 'nature', the notion of 'landscape' adds another layer to the interaction between culture and nature (Lowenthal & Olwig, 2013). The concept of landscape has evolved significantly over the course of the twentieth century, transitioning from being seen primarily as a physical territory to being understood as an approach for interpreting the world. In this context, landscape became to be perceived not only as a physical terrain, but as a process of interaction between humans with environment (Council of Europe Landscape Convention, 2000). Following this strong interaction, the degradation of landscape has been discussed in relation to the degradation of society (Settis, 2010). Indeed, both UNESCO and IUCN have recognized the power of landscape not only as a term, but also as new way of thinking that could unite culture and nature that can be adapted for the management of urban historic environments as well (Bandarin et al., 2012). Landscape has been used as a term to define not only natural areas but also the urban areas including their historical stratification and their ongoing changes.

In 1992, the World Heritage Convention became the first international legal framework to formally acknowledge cultural landscapes as a category for protection under the World Heritage List. During the 16th session of the World Heritage Committee in Santa Fe, USA, the Committee updated the operational guidelines for the implementation of the World Heritage Convention to include cultural landscapes. They were classified into three main types of designed landscapes (Deliberately created by humans, such as gardens and parks), organically evolved landscapes (Shaped by social, economic, and cultural factors over time, including continuing landscapes), and associative cultural landscapes (Valued primarily for religious, artistic, or cultural associations).There are other types of HL (e.g., historic urban areas, nature parks, archeological sites) that are not necessarily cultural landscapes but are incorporated under the UNESCO world heritage list. Moreover, the other two UNESCO site designations including Biosphere Reserves and Global Geoparks represents HL.

The main scope of this study is to provide a systematic literature review of the academic studies undertaken on these HL, which are not necessarily inscribed as 'cultural landscape' or as other pre-existing inscription categories, but represent the above-mentioned power of landscape to integrate culture and nature. In this paper, HL refers to sites that are managed with concrete measures such

as natural regulations and binding statuses and/or international recognition with consequences on policy, therefore, we focus on the HL that are designated by UNESCO including biosphere reserves, global geoparks, and world heritage sites inscribed in World Heritage List.

While we frame 'HL' as an integrated realm where human and natural elements are closely connected, the digitization of HL is essential to document, disseminate, preserve, promote and enhance both tangible and intangible cultural heritage values. As argued by the European Commission digital technologies can help overcome the challenges of managing or safeguarding such culturally rich and ecologically diverse areas which can be easily damaged or even destroyed over time (European Commission, 2021). Over the past two decades, concepts like the Virtual Museum have focused on the idea that if visitors cannot physically access a museum, the museum can reach them instead, an innovation made possible by the rapid advancements in digital technology. In the context of HL, a similar concept applies, not only providing remote access to people but also enabling digital technologies to manage, preserve, and promote these areas (Stylianidis et al., 2022). As will be discussed further below, such uses have different finalities within different types of HL, each adapted to a diverse set of objectives ranging from documentation to interpretation, from monitoring of sites for climate risks to historical research, and from education to community engagement.

In this paper, we aim to document, analyze, and evaluate these scholarly efforts that illustrate how digital tools are used in HL, via a global systematic survey of existing literature by scoping review and thematic analysis. The research takes advantage of a Systematic Review Facility (SyRF) platform as a tool to analyze the studies from a geographical and thematic perspective. SyRF is a widely used platform for conducting systematic reviews and helps to streamline the review process, facilitate collaboration among researchers, and ensure the quality of the review.[1]

2. SYSTEMATIC RESEARCH METHODS

The current investigation involved collecting and analyzing the articles on the application of digital technologies in HL. The methodology of this study was carried out in two main phases: a scoping review following the PRISMA methodology to systematically assess the academic efforts, and a thematic analysis to categorize the relevant literature based on five key questions: Who (Researchers), What (HL type), Where (HL location), When (UNESCO recognition year), and Which (Digital technologies applied in HL).

2.1 Phase 1: Scoping review following the PRISMA methodology:

The study employed a scoping review methodology as suggested by Peters, M. D., et al., 2015 (Peters et al., 2015). The review process was implemented into three main phases of (i) planning the review by defining eligibility criteria; (ii) identifying suitable papers through search, screening, and selection; and (iii) carrying out the review and analyzing the findings.

In this regard, a total of 11189 articles were initially retrieved from three major academic databases: Web of Science Core Collection (5010 articles), Scopus (5470 articles), and Science Direct (709 articles).

[1] The SyRF online platform is accessible through https://syrf.org.uk/.

To refine the dataset and eliminate duplicate records, the Automated Systematic Search Deduplication tool (AsySD) (Hair et al., 2023) was used. This process removed 4182 duplicate records automatically, while 23 additional potential duplicates were manually reviewed. Ultimately, 6984 articles remained for further analysis.

Prior to collection, the following criteria were considered for the research; keywords of "digital" coupled with the term "heritage" were included to gather a wide range of literature on heritage contexts and digital technologies. By incorporating these terms, the research aimed to ensure the inclusion of studies that addressed digitization efforts regarding all heritage items, including movable, immovable, tangible, intangible, and so on. After first initial analysis, we deliberately avoided using the terms 'landscape' or 'cultural landscape' along with 'digital' and 'heritage' terms because many relevant articles did not necessarily use these terms, but they corresponded with the above-mentioned framing of HL. For instance, initially, we included the keyword 'landscape' along with 'digital' and 'heritage' keywords and the results returned 476 papers. However, we found that many relevant studies did not use term 'landscape' but still addressed topics related to HL by using some other keywords such as 'site' or 'area'. On the other hand, with the keyword 'cultural landscape', we had 353 results, but it did not include other UNESCO designated sites that are not inscribed as 'cultural landscape' although they represent the above-mentioned characteristics of HL. For this reason, we needed to select manually the papers whose scope corresponded to HL, particularly those listed by UNESCO, even if the term "landscape" was not used in their titles, or abstracts, or keywords. By searching these two keywords ('digital' and 'heritage'), the research aimed to capture a broader range of relevant studies that explored the intersection of digital technologies and HL, without excluding some papers that did not have mainly mentioned the term "landscape."

Additionally, the publication timeframe was set between 2015 and 2025 to align with key global heritage and digitization milestones. The year 2015 marked an important moment when heritage was increasingly recognized as an element of human-environment interaction, reinforced by the adoption of the UN 2030 Agenda for Sustainable Development (Goal 11, Target 4), which emphasized the protection of cultural heritage(Xiao et al., 2018). Furthermore, UNESCO's 2015 Recommendation on the Preservation and Access to Documentary Heritage in Digital Form underscored the importance of digitization in safeguarding cultural heritage. Extending the search period to 2025 ensured that the study captured the latest advancements in digital heritage research.

Following the methodology proposed by Li et al. (2018), this study considered only empirical articles published in peer-reviewed journals, excluding non-empirical sources such as books, reports, and internet materials (Li et al., 2018). For each article, important attributes, such as title, abstract, publication year, keywords, and language were recorded. The main concern of the study was about excluding articles in other languages since many researchers publish authoritative articles in domestic journals. Thus, a comprehensive systematic review might not be possible to achieve. However, the study's purpose was to assess the trend of previous research on a global scale, so the non-English articles could not be considered for a general assessment. Table 1 demonstrates a summary of parameters, eligibility criteria, and the reason for defining each criterion adapting the methods established by (Aliakbari, 2023; Li et al., 2018; Shafiee et al., 2019).

Table 1. Paper selection criteria

Parameters	Eligibility Criteria	Reason
Data Source	Scopus, Science Direct, Web of Science Core Collection	To access peer-reviewed literature.
Searching period	2015 to 2025	2015 aligns with the adoption of the 2030 Agenda (Goal 11, Target 4) focusing on cultural heritage. It also coincides with UNESCO's recommendation on preserving documentary heritage in digital form. The research period was extended to 2025 to record the latest research on digitization of HL.
Searching keywords	"digital" AND "heritage"	To gather a wide range of literature on HL context and digitization efforts.
Document types	"Journal articles"	To investigate the peer reviewed studies.
Language	"English"	To ensure a global overview of the topic.

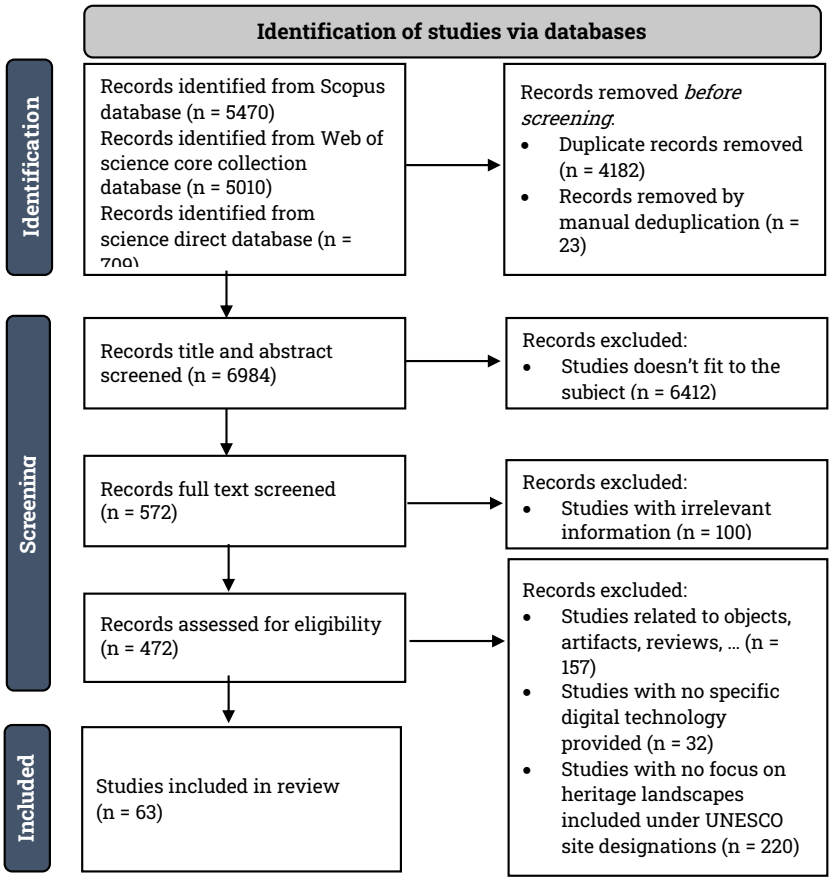


Figure 1. PRISMA flow diagram for the scoping review process

After the definition of selection criteria, the PRISMA method (Fig. 1) was used to choose and include records in a methodical, transparent, and objective manner (Page et al., 2021). During the screening process, the SyRF platform was used to screen, annotate and extract information from the selected studies. For this, a new project in SyRF was created and the remaining data after the deduplication process (6948 studies) were stored in a CSV format and uploaded to the project. Then, the inclusion and exclusion criteria for the screening process were defined to ensure that the studies selected for the review met certain standards of quality and relevance. A key aspect of the review was on studies that used digital tools and applications in those landscapes designated by UNESCO. In this route, the studies using digital tools in the HL such as (Lercari et al., 2018; Martínez-Graña et al., 2018, 2022; Zhenrao et al., 2021)were selected for analysis. The studies with keywords related to various technologies such as Augmented Reality, Laser scanning, Building Information Modelling, Storytelling, 3D reconstruction, Geographic Information Systems, and Digital twin were included during the first screening process. While the studies such as (Beel et al., 2015; Gomes et al., 2018; Grifoni et al., 2022; Hansson & Dahlgren, 2022; Khan et al., 1 C.E.a, 1 C.E.b; Pierdicca et al., 2018; Van Nguyen et al., 2022; Wu et al., 2015) related to digitization of museum artifacts, archives, collections, images, objects, sculptures, review papers; and studies with no specific tool provided; studies with no focus on HL designated by UNESCO were excluded. Finally, a number of 63 papers remained for data extraction, analysis, and synthesis.

2.2 Phase 2: Thematic analysis

The thematic analysis of the current review was formulated to analyze the selected papers (63) based on five key questions: *Who* (Researchers), *What* (HL type), *Where* (HL location), *When* (UNESCO recognition year), and *Which* (Digital technologies applied in HL) (Fig. 2).

Q1. WHO	• *Who are the researchers and their country of the affiliation?*
Q2. WHAT	• *What type of HL does each study focus on?*
Q3. WHERE	• *Where is the country of HL where located?*
Q4. WHEN	• *When is the recognition year of HL by UNESCO?*
Q5. WHICH	• *Which digital technology applied in HL?*

Figure 2. An overview of thematic analysis framework

The first question, ***Q1***, focused on the authors and country of the affiliation of authors in order to investigate the dynamics of academic research in this topic. The second question, ***Q2,*** seek to identify the specific type of HL addressed in the studies. This includes UNESCO-designated sites, such as World Heritage sites (e.g., historic urban areas, nature parks, archaeological sites, cultural landscapes, and gardens), together with other two site designations like Global Geoparks and Biosphere Reserves. ***Q3,*** concentrated on the recognition year of HL by UNESCO. The fourth question, ***Q4,*** investigated the location of HL and the country where HL located. The last question, ***Q5,*** identified the specific digital tools and applications deployed in HL. This included data acquisition

techniques (e.g., digital photogrammetry, drones, laser scanning, and remote sensing), mixed reality tools (e.g., augmented reality, virtual reality), presentation and communication technologies (e.g., multimedia), design and construction technologies (e.g., Building Information Modeling), data analysis and visualization technologies (e.g., Geographic Information Systems), and design and presentation technologies (e.g., 3D modeling and visualization tools). It also covered data processing tools (e.g., digital elevation models, and digital terrain models), software applications (e.g., mobile applications, platforms), communication tools (e.g., social media), interactive tools (e.g., serious games).

3. RESULTS: PUBLICATION TRENDS AND THEMATIC ANALYSIS OUTCOMES

In line with the research questions developed in the previous section, a total of 63 studies were thoroughly reviewed to assess the application of digital tools across different types of heritage landscapes. A clear trend is observed in the publication record: academic interest in this field has grown steadily over the past decade. As shown in Fig. 3, only a single paper was published in 2015, while by 2025 the number had increased to six. This therefore illustrate not only a quantitative rise but also a qualitative signal of growing academic engagement with digitization in heritage landscapes. Peaks are observed around 2020 and again in 2022, when publications reached their highest annual output, indicating periods of intensified scholarly focus on this topic.

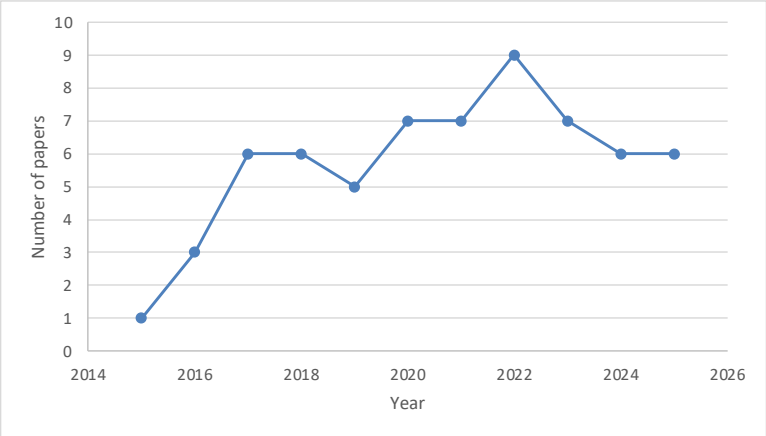


Figure 3. Distribution of publications over time

As mentioned above, we developed out thematic analysis according to five key questions: WHO, WHAT, WHERE, WHEN, and WHICH (Table 2).

Table 2. Classification of articles according to the thematic analysis. Abbreviations: AR: Augmented Reality, AS: Archaeological Site, BIM: Building Information Modeling, BR: Biosphere Reserve, CL: Cultural Landscape, DEM: Digital Elevation Model, DPh: Digital photogrammetry, DTM: Digital Terrain Model, G: Garden, GIS: Geographic Information System, HU: Historic Urban area, MA: Mobile Apps, MM: Multimedia, MU: Multi type N: None of the above technologies, NP: Nature Parks (National, natural, regional), O: Other (Technologies that do not fit into the above categories), P: Platform, RS: Remote Sensing, SG: Serious Games, SM: Social Media, TLS: Terrestrial Laser Scanning, GGP: Global Geopark, UAV: Unmanned Aerial Vehicle, VR: Virtual Reality, 3D: 3D Modeling.

REFERENCE	Q1. WHO	Q2. WHAT	Q3. WHERE	Q4. WHEN	Q4. WHICH
(Apollonio et al., 2017)	Italy	HU	Italy	2000	3D
(Rossato et al., 2021)	Italy	HU	India	2017	3D
(Parrinello et al., 2017)	Italy	AS	Israel	2001	3D
(Bennoui-Ladraa & Chennaoui, 2018)	Algeria	AS	Algeria	1982	3D, DPh
(Buscemi & Figuera, 2019)	Italy	AS	Italy	2005	3D, DEM/DTM
(Deng et al., 2017)	China	HU	China	1987	3D, UAV
(Liang et al., 2018)	China	G	China	1997	3D, UAV, TLS
(Walters & Hajna, 2020)	Slovenia, UK	NP	Slovenia	1986	3D, TLS, DPh
(Liang et al., 2020)	China	G	China	1997	3D, TLS, DPh
(Armstrong et al., 2018)	Australia Africa	AS	Africa	1999	3D, TLS, DPh
(Nevola et al., 2022)	UK	HU	Italy	1982	AR
(Bouzekraoui et al., 2018)	Morocco	GGP	Morocco	2015	DEM/DTM, GIS, N
(Martínez-Graña et al., 2022)	Spain	NP	Spain	2002	AR, VR
(Savaşkan & Özener, 2023)	Turkey	HU	turkey	2014	BIM
(Demetrescu et al., 2020)	Italy	AS	Romania	1999	3D, BIM, DPh
(van Lanen et al., 2022)	Netherlands	AS	Netherlands	1995	GIS
(Quarterly, n.d.)	Italy, Germany, USA, France	AS	Egypt	1979	GIS
(Nishanbaev et al., 2021)	Australia	NP	Australia	1987	GIS
(Rysaeva et al., 2019)	Russia	AS	Russia	2014	GIS
(Fiorini et al., 2022)	Italy	HU	Italy	1987	3D, GIS
(Dhonju et al., 2018)	Nepal, UK	HU	Nepal	1979	3D, GIS
(Tache & Sandu, 2018)	Romania	AS	Romania	1991	3D, GIS, UAV, DPh
(Jorayev et al., 2016)	Usa, Spain, UK	AS	Tanzania	1979	UAV, DPh, DEM
(Filocamo et al., 2020)	Italy	BR	Italy	1977	MA
(Thekkum Kara, 2021)	India	MU	India	-	P
(Mubaideen et al., 2022)	UK	MU	Jordan	-	P
(Fassoulas et al., 2022)	Greece	GGP	Greece	2015	P
(Picchio & De Marco, 2019)	Italy	HU	Palestine	2012	P
(Kuna et al., 2022)	Poland	HU	Poland	2017	P, GIS
(Martínez-Graña et al., 2017)	Spain	HU	Spain	1988	3D, P
(Myers et al., 2016)	USA	HU	Syria	1986	3D, P
(Pérez González & Gallego Revilla, 2020)	Spain, France	HU	Bolivia	2000	3D, RS, UAV
(Pepe, 2023)	Italy	AS	Italy	1997	3D, RS
(Ginzarly & Teller, 2021)	Lebanon, Belgium	HU	Lebanon	2023	SM
(Zhao et al., 2021)	Australia India	HU	India	2017	TLS, UAV, BIM
(Pagano et al., 2020)	Italy	AS	Italy	1998	VR
(Sylaiou et al., 2022)	Greece	MU	Greece	-	VR
(Luigini et al., 2020)	Italy, Chile	NP	Italy	2009	VR, SG

(Abdelmonem et al., 2017)	UK, Saudi Arabia	HU	Egypt	1979	VR, P
(Lercari et al., 2018)	USA	AS	Türkiye	2012	VR, P
(Domínguez-Jiménez et al., 2021)	Spain	HU	Spain	1984	VR, 3D, DPh, RS
(Martínez-Graña et al., 2018)	Spain	NP	Spain	2002	VR, 3D,
(Zhenrao et al., 2021)	China	NP	China	1996	VR, TLS, P
(Buill et al., 2015)	Spain	AS	Spain	2000	3D, DPh
(Beni et al., 2023)	Italy	AS	Saudi Arabia	2008	3D, TLS, UAV
(Parmeggiani et al., 2023)	Italy	HU	Italy	2018	P, GIS
(Gonçalves et al., 2023)	Portugal	NP	Portugal	2001	3D, DPh, DEM/DTM
(Hollesen et al., 2023)	Denmark	AS	Denmark	2017	TLS, UAV
(Dabanlı et al., 2023)	Turkey	CL	Turkey	2014	3D
(Leopoldo Repola, 2023)	Italy	AS	Turkey	1986	3D, TLS, UAV, DPh
(SCIRES-IT & 2023, 2023)	Italy	AS	Italy	2019	VR
(Hidalgo-Sánchez et al., 2024)	Spain	HU	Spain	-	MA, P, GIS
(Terrone et al., 2024)	Italy	HU	Italy	2006	3D
(Dieb et al., 2024)	Syrian Arab Republic	HU	Syria	1980	VR, P
(Tribhuvan & Binnaser, 2024)	India	AS	India	1983	3D, VR, DPh
(Pukanská et al., 2024)	Slovakia	NP	Slovakia	1995	3D, DPh, TLS
(Federici & Omenetto, 2024)	Italy	CL	Kosovo	2004	3D
(Pappalardo et al., 2025)	Italy	AS	Italy	1997	3D, AR, VR, UAV, RS, GIS
(Leipold et al., 2025)	Austria	AS	Austria	2011	3D, MA
(Abdelalim & Abdelalim, 2025)	Saudi Arabia	HU	Egypt	1979	3D, TLS, BIM
(Hagmann, 2025)	Austria	AS	Austria	2021	VR, GIS
(Novák et al., 2025)	Prague	HU	Prague	1992	P
(Gaffney et al., 2025)	UK	HU	Africa	2006	3D, VR, MA

As shown in Table 2, most of the studies focused on historic urban areas (37%), archaeological sites (33%), nature parks (14%), gardens (5%), global geoparks (5%), and biosphere reserves (2%). A small number of studies (4%) explored multiple landscape types. Various digital tools were employed across these landscapes in different regions. The most common tool was 3D modeling, used in 46% of studies to create detailed digital representations, particularly for historic urban areas and archaeological sites in countries such as Italy, China, and Greece. This supports findings from a previous study showing 3D modeling as the most widely used tool in cultural heritage preservation and documentation (Mendoza et al., 2023). Virtual reality was utilized in 21% of the studies, mostly in nature parks to provide immersive experiences. Other tools like digital photogrammetry and unmanned aerial vehicles (UAVs) were used in 21% and 10% of studies, respectively, particularly in archaeological sites. Geographic Information Systems (GIS) were applied in 23% of studies for mapping and analyzing spatial data, especially in nature parks, historic urban areas, global geoparks, and archaeological sites. Building Information Modeling (BIM), used for reconstructing-built environments, was employed in 5% of studies, primarily for historic urban areas and archaeological sites. The countries with the most frequent use of digital tools in heritage sites were Italy (21%), Spain (10%), and China (10%), with a focus on historic urban areas, nature parks, and archaeological sites. In these countries, 3D modeling and virtual reality were commonly applied.

4. CRITICAL INSIGHTS AND IMPLICATIONS

As a result of the inquiries into the dataset presented in Table 2, we interlinked its attributes to four critical insights that are mainly (i) international engagement, (ii) scale as a determinant, (iii) temporal shifts in UNESCO recognition patters (iv) and other critical insights.

4.1 Research geographies and cross-border engagement

We interlinked the profiles of researchers (WHO) with the geographical location of HL (WHERE). The analysis showed a global academic commitment to celebrating heritage landscapes and the increasing importance of cross-cultural collaborations in digitization efforts. From this perspective, two distinct approaches can be identified. In the first approach, which encompasses the majority of the studies, authors work on heritage landscapes located in the same country as their institutional affiliation. The second approach, by contrast, is largely characterized by Europe-based researchers working in non-European contexts.

The first category of articles indicates a localized commitment to enhancing national heritage. For example, researchers with an affiliation to Italy-based institutions have extensively studied HL in Italy, such as historic urban areas and archaeological sites (Apollonio et al., 2017; Buscemi & Figuera, 2019; Fiorini et al., 2022; Pepe, 2023). Similarly, authors with China-based affiliations have worked on HL in China, including historic urban areas and classical gardens (Deng et al., 2017; Liang et al., 2018, 2020). This localized focus reflects the accessibility of these sites and a deeper cultural and historical connection of authors to their HL.

The second category is predominantly dominated by researchers affiliated with European institutions. For instance, UK authors have contributed to studies of HL in Jordan (Mubaideen et al., 2022) and Italian researchers focused on HL in India (Rossato et al., 2021). As observed in the analysis, these cross-border research efforts are more prevalent among European researchers who tend to focus on non-European HL. For instance, studies conducted on non-European HL by European researchers, such as (Armstrong et al., 2018; Gaffney et al., 2025; Parrinello et al., 2017; Pérez González & Gallego Revilla, 2020; Picchio & De Marco, 2019; Quarterly, n.d.), indicate that European researchers are often engaged with HL located outside Europe, such as in Tanzania, Egypt, and other non-European contexts. This reflects a Eurocentric approach, where European scholars research and analyze HL in other regions, indicating a broader geographical scope in their research. Conversely, non-European researchers mostly focus on non-European HL, within their own regions or neighboring areas. For example, studies conducted by (Abdelalim & Abdelalim, 2025; Bennoui-Ladraa & Chennaoui, 2018; Bouzekraoui et al., 2018; Deng et al., 2017; Dieb et al., n.d.; Liang et al., 2018; Mubaideen et al., 2022; Rysaeva et al., 2019; Savaşkan & Özener, 2023; Tache & Sandu, 2018; Tribhuvan & Binnaser, 2024; Zhenrao et al., 2021)focused on HL located in their own countries. These studies tend to prioritize HL that reflects local, cultural, historical, and geographical significance, demonstrating a more localized research focus. Unlike their European counterparts, these researchers generally do not engage significantly with European HL. There are some studies, like Studies (Abdelmonem et al., 2017; Armstrong et al., 2018), where the HL is located in a non-EU country, and there is a collaboration between EU researchers and non-EU researchers. However, even in these cases, the focus remains on HL located in non-EU countries, not on European HL. This shows a

consistent pattern where European researchers, even when collaborating with non-European authors, tend to focus on non-European context rather than European one.

4.2 Scale as a determinant of digital tool selection

Our investigation showed that the relationship between the type of HL (WHAT) and the digital tools deployed in each HL (WHICH) is mainly determined by the scale of the HL. We identify three scales to demonstrate how the scale influences the selection of digital tools: namely, (i) small-scale HL, (ii) medium-scale HL, and (iii) large-scale HL. Each type of HL required specific technology to ensure accurate data collection and modeling.

(i) Small-scale HL relates to the building/architectural scale, such as archaeological remains, that were located in archaeological sites. In this scale, utilized data acquisition techniques like digital photogrammetry for their high capacity in capturing detailed spatial information about archaeological sites as observed in the studies conducted by (Armstrong et al., 2018; Bennoui-Ladraa & Chennaoui, 2018; Demetrescu et al., 2020; Jorayev et al., 2016; Pepe, 2023; Tache & Sandu, 2018). The study presented by some scholars introduced a new method for creating digital replicas of the archeological site of Sarmizegetusa in Romania (Demetrescu et al., 2020). The authors used digital photogrammetry to collect data and created immersive digital replicas of archeological structures. Moreover, GIS was widely used in these types of HL because of its versatility in data analysis, visualization, and interpretation as found in the studies conducted by (Dhonju et al., 2018; Hagmann, 2025; Lercari et al., 2018; Nishanbaev et al., 2021; Pappalardo et al., 2025; Rysaeva et al., 2019). 3D modelling was also used in archeological sites as seen in the studies conducted by (Armstrong et al., 2018; Bennoui-Ladraa & Chennaoui, 2018; Buscemi & Figuera, 2019; Demetrescu et al., 2020; Parrinello et al., 2017; Pepe, 2023; Tache & Sandu, 2018)The research implemented by (Armstrong et al., 2018) combined digital photogrammetry, laser scanning, and 3D modeling to record highly accurate fossil and 3D site contexts in a remote location in Africa. (Pérez González & Gallego Revilla, 2020) concentrated on modelling and locating of many unknown archaeological remains of an ancient city using unmanned aerial vehicle and remote sensing technologies. Building information modelling was also found in research by (Savaşkan & Özener, 2023) to document the traditional construction techniques of a small historical site.

(ii) Medium-scale HL relates to the district scale, including historic urban areas. In the medium scale, the digitization approach 3D modeling and GIS appear as the most used digital tools as an accurate representation of the built environment as observed from the studies conducted by (Apollonio et al., 2017; Deng et al., 2017; Dhonju et al., 2018; Domínguez-Jiménez et al., 2021; Fiorini et al., 2022; Pérez González & Gallego Revilla, 2020; Rossato et al., 2021). Some scholars utilized 3D modeling to visualize and interpret historical data (Apollonio et al., 2017). They investigated a historical site, Piazza delle Erbe in the city of Verona, Italy, where these techniques provided new opportunities for understanding the rich historical context of the area. The study implemented by (Deng et al., 2017) explored the cooperation between unmanned aerial vehicle for acquisition of the data and 3D modeling to reconstruct a historic urban site located in China. (Martínez-Graña et al., 2017; Myers et al., 2016) investigated platforms alongside 3D modeling to develop a geoportal for two historic cities. (Fiorini et al., 2022) utilized 3D modeling and GIS to create a historical city model of the temporary architecture built for Napoleon's visit to Venice. Recent work on digital twins, such as the Virtual

Bradford project (Gaffney et al., 2025)and the preservation of Historic Cairo (Abdelalim & Abdelalim, 2025), demonstrates how medium-scale applications are increasingly tied to global agendas of sustainability, resilience, and smart-city integration. Here, digitization is not only about documenting the past but also about planning for the future, embedding heritage in broader urban development frameworks.

(iii) Large-scale HL relates to the territorial scale including nature parks, which are large, complex, and ecologically diverse areas. The digitization approach for the large-scale HL is influenced by the need to capture landscapes requiring advanced data acquisition technologies like laser scanning. For example, the study conducted by (Walters & Hajna, 2020) utilized laser scanning to capture the high-resolution data and to create a 3D model of a large natural area. Moreover, virtual reality emerged as an immersive tool that were used more in this type of HL. This was showed in the study done by (Martínez-Graña et al., 2022) that explored the implementation of this immersive tool to develop a virtual geological route through the natural park of Arribes del Duero. Another study focused on the application of virtual reality alongside 3D modeling to facilitate immersive experiences and simulations in a natural landscape in Spain (Martínez-Graña et al., 2018).

4.3 Temporal shifts in UNESCO recognition patterns

Based on our findings, there has been a shift in UNESCO site designations after the 1990s to include non-European HL. Most of the HL (WHAT) involved in the studies have been recognized by UNESCO (WHEN) during the late 20th century, with frequent recognitions in the 1970s, 1980s, and 1990s. Early UNESCO HL recognitions were mostly Eurocentric, with a focus on historic urban areas and archaeological sites in countries like Italy, and Spain (Domínguez-Jiménez et al., 2021; Fiorini et al., 2022; Martínez-Graña et al., 2017; Nevola et al., 2022; Pagano et al., 2020; Pepe, 2023). Non-EU countries, like and archeological site in Tanzania (1979) (Jorayev et al., 2016) and a nature park in Australia (1987) (Nishanbaev et al., 2021), saw fewer early designations, showing a slower inclusion of non-European sites. From the 1990s onward, UNESCO included large-scale landscapes like biosphere reserves and global geoparks, as seen in Morocco (2015) (Bouzekraoui et al., 2018). This shift marked also an increase in non-EU UNESCO site designations, such as historic urban areas in India (2017) (Rossato et al., 2021) and Palestine (2012) (Picchio & De Marco, 2019), showing a more inclusive recognition of cultural diversity. Europe continued to lead in designations, balancing both cultural and natural heritage, while non-EU countries were often recognized for their unique natural landscapes.

These temporal shifts can be situated within broader critiques of UNESCO, particularly in the field of critical heritage studies. On the one hand, Lynn Meskell in *A Future in Ruins* argues that UNESCO has been criticized for becoming an expert-led, technical heritage body, increasingly distanced from its foundational ideals of using heritage to foster international collaboration and sustain world peace (Meskell, 2018). From this perspective, the recognitions identified in our study can be discussed in relation to UNESCO's stated commitments to international cooperation and representativeness. On the other hand, the predominance of European inscriptions on the UNESCO World Heritage List has long been criticized in international debates. For example, Brumann and Gfeller (Brumann & Gfeller, 2022), drawing on African nominations, argue that even though heritage definitions expanded in the 1990s, many non-European sites have continued to face significant challenges in gaining UNESCO

recognition. In fact, UNESCO acknowledged concerns about geographic and typological imbalance as early as 1994 by launching the "Global Strategy" for a representative and internationally balanced World Heritage List, which explicitly noted the over-representation of developed regions, particularly Europe (UNESCO World Heritage Centre - Global Strategy, 1994). However, the political and ethical implications of the World Heritage List remain the subject of ongoing debate (Meskell et al., 2015). Accordingly, the pattern identified in our study can be framed as part of UNESCO's continuing effort to move toward a more representative and inclusive World Heritage List.

4.4 Other critical insights

Some other critical insights emerged from the review concerning the transversal application of certain digital tools across different types of HL (WHAT), regardless of their scale or size. In particular, platforms and mobile applications appear consistently across multiple HL categories, supporting documentation, visualisation, tourism development, and community engagement.

For example, scholars presented a web- GIS based platform to visualize a 3D digital model of Uluru–Kata Tjuta National Park (Nishanbaev et al., 2021). Fassoulas and colleagues developed a user-friendly platform to visualize the cultural heritage assets of a global geopark and engage local people to interact with the platform (Fassoulas et al., 2022). Others launched a website for the historical city center of Bethlehem (Picchio & De Marco, 2019), and produced an interactive GIS platform for a hisoric urban area in Poland (Kuna et al., 2022). Some researchers designed a virtual reality mobile application to digitalize specific historical periods and historical places which were part of the Greek history and its cultural heritage (Sylaiou et al., 2022). In a biosphere reserve in Italy, a mobile application was invented to provide a diversified geotourism information combining geosites and geologic itineraries (Filocamo et al., 2020). (Zhenrao et al., 2021) integrated techniques to create a cultural heritage tourism platform in a natural park. (Mubaideen et al., 2022) generated an online platform as an engagement tool for the local community in Jordan. Moreover, (Thekkum Kara, 2021) designed an Indian cultural heritage information system where several HL were documented, managed, preserved and integrated with a searchable user interface mechanism. (Lercari et al., 2018)developed a platform, and a virtual reality tool to analyze archaeological data in a realistic and highly interactive virtual environment. However, although laser scanning and virtual reality was mostly utilized in some specific HL type like nature parks, it also found significant applications in other types of HL of such as historic urban areas, and archeological sites.

Furthermore, it should be noted that in recent years, increasingly sophisticated and innovative digital techniques have been developed for heritage documentation and representation, including digital twin environments (Spanò et al., 2023), LiDAR-based terrestrial laser scanning systems (e.g., FARO TLS) (Patrucco et al., 2021; Pueschel, 2013; Windham et al., 2019), rapid 3D data acquisition techniques such as portable and wearable Simultaneous Localization and Mapping (SLAM)-based systems as efficient tools(Bonora & Colapietro, 2026) and advanced GIS-based integrative platforms(Author et al., 2025; Pandey & Karnatak, 2024) for documentation of historic built heritage assets. These technologies have significantly enhanced metric precision, enabled real-time data integration, and facilitated multi-scalar interoperability, thereby expanding the analytical and representational capacities of heritage landscape modelling and monitoring. The FARO system, for example, integrates multiple sensing technologies to generate highly precise and visually detailed

3D models (Windham et al., 2019). This shows that the field is evolving rapidly and new tools are continuously being developed, tested, and refined, and their benefits and drawbacks are progressively identified by both researchers and practitioners operating on the ground. However, our focus lies in identifying how current landscape-oriented studies deploy digital tools, and where further critical, scale-sensitive technological evaluation remains necessary. On this matter, the present study highlights two observations regading this. First, it aligns with research employed by (Patrucco et al., 2021), demonstrating that the quality of digital heritage documentation depends not only on the selected technology but also on acquisition geometry and survey strategy. Comparative investigations employing FARO terrestrial laser scanners alongside UAV-based photogrammetry have shown that distance, incidence angle, scanner positioning, and environmental conditions directly influence point cloud density, surface roughness detection, and metric reliability. Elevating a TLS device using telescopic supports may increase density and reduce angular distortion, yet it can introduce vibration-related topological errors. Conversely, UAV photogrammetry provides broader spatial coverage and improved radiometric documentation but often generates smoother surfaces with reduced surface characterization compared to TLS (Patrucco et al., 2021). These findings confirm that hardware configuration, acquisition design, and contextual constraints fundamentally shape the level of geometric and material detail achievable in heritage documentation. Second it highlights that advanced technological analyses remain more extensively developed at the building scale and within built heritage contexts. Studies focusing on digitizing HL tend to emphasize implementation and application rather than critically examining the technological configurations, acquisition parameters, and comparative performance of different digital systems. In landscape-scale studies, digital tools are frequently employed as operational instruments for documentation and visualization, whereas fewer contributions critically interrogate how acquisition parameters, sensor configuration, or processing strategies affect representation quality across extended territorial systems. This distinction highlights an ongoing methodological gap and reinforces the need for more scale-sensitive, technologically explicit evaluations within heritage landscape research.

5. CONCLUSION

The study presented here is a systematic literature review of the latest research focusing on the application of digital tools in the context of Heritage Landscapes (HL). The research addresses the main question of how various digital technologies were applied within diverse HL types (e.g., historic urban areas, nature parks, gardens, archeological sites) in order to preserve and promote these areas. This research provides key contributions for academic purposes because (i) it employs a thematic framework to classify and organize current trends in digital applications within diverse context of HL, (ii) it uses thematic outcomes to identify the most and least utilized digital tools across different HL types, and (iii) it presents key critical insights and implications based on the findings from existing literature. The systematic literature review identified 63 articles which present and discuss the application of digital tools in HL context. Results of the review highlight the importance of cross-cultural collaborations in digitization efforts. It is significant that the selection and application of digital tools in HL is influenced by the scale and complexity of the sites to ensure accurate data collection and modeling. However, certain tools are transversal across different types of HL. This paper focused on UNESCO-designated sites, yet many lesser-known heritage landscapes worldwide

with unique artistic value remain unexplored. Similar research frameworks could be applied to these sites. Furthermore, although this study concentrated on academic research efforts, numerous digital initiatives could have been undertaken by practitioner communities. Therefore, future research could build on the developed thematic framework and move from theory to practices by examining how digital tools are effectively applied by practitioners across diverse HL contexts. This could evaluate the specific benefits and drawbacks of each tool according to its application and scale, thereby providing clearer guidance for practitioners in selecting appropriate digital solutions.

6. AUTHORS' CONTRIBUTION

Farzaneh Aliakbari: Conceptualization, Methodology, Software, Validation, Formal Analysis, Investigation, Resources, Data curation, Writing- Original draft preparation, Writing- Reviewing and Editing, Visualization, Supervision. Mesut Dinler: Conceptualization, Resources, Writing- Reviewing and Editing, Visualization.

7. REFERENCES

Abdelalim, M., and M. Abdelalim. 2025. "Heritage Preservation Using Laser Scanning: Architectural Digital Twins Using Al-Mu'izz Street as a Case Study." Buildings 15 (9). https://doi.org/10.3390/BUILDINGS15091480

Abdelmonem, M. G., G. Selim, S. Mushatat, and A. Almogren. 2017. "Virtual Platforms for Heritage Preservation in the Middle East: The Case of Medieval Cairo." Archnet-IJAR: International Journal of Architectural Research 11 (3): 28–41. https://doi.org/10.26687/ARCHNET-IJAR.V11I3.1404

Aliakbari, F. 2023. "Cyberspace Serves Culture: Experiences from Iran During the COVID-19 Crisis." Studies in Digital Heritage 7 (1): 47–67. https://doi.org/10.14434/SDH.V7I1.35527

Apollonio, F. I., M. Gaiani, F. Fallavollita, E. C. Giovannini, and R. Foschi. 2017. "Un viaggio nel quattordicesimo secolo. Una ricostruzione digitale di piazza delle Erbe a Verona." Diségno 2017 (1): 035–044. https://doi.org/10.26375/DISEGNO.1.2017.6

Armstrong, B. J., A. F. Blackwood, P. Penzo-Kajewski, C. G. Menter, and A. I. R. Herries. 2018. "Terrestrial Laser Scanning and Photogrammetry Techniques for Documenting Fossil-Bearing Palaeokarst with an Example from the Drimolen Palaeocave System, South Africa." Archaeological Prospection 25 (1): 45–58. https://doi.org/10.1002/ARP.1580

Author, L., P. Cynthia, E. Oyokunyi, and E. Abubakar Rahmat Salihu. 2025. "Applications of Advanced GIS Technologies: A Focus on Spatial Modeling, Remote Sensing Integration, 3D GIS, and Cloud-Based GIS Platforms." Technology Research 13 (4): 375–385. https://doi.org/10.5281/zenodo.17907369

Bandarin, Francesco, and Ron Van Oers. 2012. The Historic Urban Landscape: Managing Heritage in an Urban Century. Oxford: Wiley-Blackwell.

Beel, D., C. Wallace, G. Webster, and H. Nguyen. 2015. "The Geographies of Community History Digital Archives in Rural Scotland." Scottish Geographical Journal 131 (3–4): 201–211. https://doi.org/10.1080/14702541.2014.980839

Beni, T., L. Nava, G. Gigli, W. Frodella, F. Catani, N. Casagli, J. I. Gallego, C. Margottini, and D.

Spizzichino. 2023. "Classification of Rock Slope Cavernous Weathering on UAV Photogrammetric Point Clouds: The Example of Hegra (UNESCO World Heritage Site, Kingdom of Saudi Arabia)." Engineering Geology 325: 107286. https://doi.org/10.1016/J.ENGGEO.2023.107286

Bennoui-Ladraa, B., and Y. Chennaoui. 2018. "Use of Photogrammetry for Digital Surveying, Documentation and Communication of the Cultural Heritage: Example Regarding Virtual Reconstruction of the Access Doors for the Nameless Temple of Tipasa (Algeria)." Studies in Digital Heritage 2 (2): 121–137. https://doi.org/10.14434/SDH.V2I2.24496

Bonora, V., and M. Colapietro. 2026. "Performance Assessment of Portable SLAM-Based Systems for 3D Documentation of Historic Built Heritage." Sensors 26 (2): 657. https://doi.org/10.3390/S26020657

Bouzekraoui, H., A. Barakat, A. Mouaddine, M. El Youssi, F. Touhami, and A. Hafid. 2018. "Mapping Geoheritage for Geotourism Management, a Case Study of Aït Bou Oulli Valley in Central High-Atlas (Morocco)." Environmental Earth Sciences 77 (11): 413. https://doi.org/10.1007/s12665-018-7589-x

Brumann, C., and A. É. Gfeller. 2022. "Cultural Landscapes and the UNESCO World Heritage List: Perpetuating European Dominance." International Journal of Heritage Studies 28 (2): 147–162. https://doi.org/10.1080/13527258.2021.1941197

Buill, F., M. A. Núñez-Andrés, J. M. Puche, and J. M. Macias. 2015. "Geometric Analysis of the Original Stands of Roman Amphitheater in Tarragona: Method and Results." Journal of Cultural Heritage 16 (5): 640–647. https://doi.org/10.1016/J.CULHER.2014.12.007

Buscemi, Francesca, and Marianna Figuera. 2019. "The Contribution of Digital Data to the Understanding of Ritual Landscapes: The Case of Calicantone (Sicily)." Open Archaeology 5 (1): 468–483. https://doi.org/10.1515/opar-2019-0029

Council of Europe. 2000. European Landscape Convention. European Treaty Series No. 176. Strasbourg: Council of Europe.

Dabanlı, Ö., and M. Şimşek. 2023. "Ancient Witnesses of the Silk Road: The Cultural Tourism Potential of Historical Caravanserais in Anatolia." Scientific Culture 9 (1): 89–106. https://doi.org/10.5281/zenodo.7459996

Demetrescu, E., E. d'Annibale, D. Ferdani, and B. Fanini. 2020. "Digital Replica of Cultural Landscapes: An Experimental Reality-Based Workflow to Create Realistic, Interactive Open World Experiences." Journal of Cultural Heritage 41: 125–141. https://doi.org/10.1016/J.CULHER.2019.07.018

Deng, F., X. Zhu, X. Li, and M. Li. 2017. "3D Digitisation of Large-Scale Unstructured Great Wall Heritage Sites by a Small Unmanned Helicopter." Remote Sensing 9 (5): 423. https://doi.org/10.3390/RS9050423

Dhonju, H. K., W. Xiao, J. P. Mills, and V. Sarhosis. 2018. "Share Our Cultural Heritage (SOCH): Worldwide 3D Heritage Reconstruction and Visualization via Web and Mobile GIS." ISPRS International Journal of Geo-Information 7 (9): 360. https://doi.org/10.3390/IJGI7090360

Dieb, R., A. Alsalloum, and N. Webb. 2024. "Interactive 360° Media for the Dissemination of Endangered World Heritage Sites: The Ancient City of Palmyra in Syria." Built Heritage 8 (1). https://doi.org/10.1186/s43238-024-00126-3

Domínguez-Jiménez, J. L., B. Castilla-Agredano, M. González-Nieto, M. Moreno-Alcaide, and A. Monterroso-Checa. 2021. "Preparing Rural Heritage for Another Kind of Covid Pandemic:

Heritage Digitalization Strategies in the Alto Guadiato Valley and Subbetica of Cordoba, Spain." SCIRES-IT – SCIentific RESearch and Information Technology 11 (1): 195–208. https://doi.org/10.2423/I22394303V11N1P194

European Commission. 2021. "How Digital Technologies Can Play a Vital Role for the Preservation of Europe's Cultural Heritage." https://cordis.europa.eu/article/id/413473-how-digital-technologies-can-play-a-vital-role-for-the-preservation-of-cultural-heritage

Fassoulas, C., E. Nikolakakis, and S. Staridas. 2022. "Digital Tools to Serve Geotourism and Sustainable Development at Psiloritis UNESCO Global Geopark in COVID Times and Beyond." Geosciences 12 (2): 78. https://doi.org/10.3390/GEOSCIENCES12020078

Federici, A., and S. Omenetto. 2024. "Digital Reconstructions of Wounded Memories in Kosovo: A Methodological Proposal." Fieldwork in Religion 19 (1): 68–89. https://doi.org/10.1558/firn.29311

Filocamo, F., G. Di Paola, L. Mastrobuono, and C. M. Rosskopf. 2020. "MoGeo, a Mobile Application to Promote Geotourism in Molise Region (Southern Italy)." Resources 9 (3): 31. https://doi.org/10.3390/RESOURCES9030031

Fiorini, G., I. Friso, and C. Balletti. 2022. "A Geomatic Approach to the Preservation and 3D Communication of Urban Cultural Heritage for the History of the City: The Journey of Napoleon in Venice." Remote Sensing 14 (14): 3242. https://doi.org/10.3390/RS14143242

Gaffney, C., K. Croucher, C. R. Bates, O. Booker, R. Dunn, A. Evans, E. B. Ichumbaki, et al. 2025. "Digital Twins at the City and Town Scale: Europe and Beyond." Internet Archaeology 70. https://doi.org/10.11141/IA.70.5

Ginzarly, Manal, and Jacques Teller. 2020. "Online Communities and Their Contribution to Local Heritage Knowledge." Journal of Cultural Heritage Management and Sustainable Development 11 (4): 361–80. https://doi.org/10.1108/JCHMSD-02-2020-0023

Gomes, L., L. Silva, and O. R. P. Bellon. 2018. "Exploring RGB-D Cameras for 3D Reconstruction of Cultural Heritage." Journal on Computing and Cultural Heritage 11 (4). https://doi.org/10.1145/3230674

Gonçalves, G. V., D. B. Pereira, M. Gómez-Ullate, and A. da S. Mano. 2023. "Water Heritage in the Rural Hinterland Landscapes of the UNESCO Alto Douro Wine Region, Portugal: A Digital Humanities Approach." Heritage 6 (4): 3706–3721. https://doi.org/10.3390/HERITAGE6040196

Grifoni, Emanuela, Letizia Bonizzoni, Marco Gargano, et al. 2022. "Hyper-Dimensional Visualization of Cultural Heritage: A Novel Multi-Analytical Approach on 3D Pomological Models in the Collection of the University of Milan." Journal on Computing and Cultural Heritage 15 (2). https://doi.org/10.1145/3477398

Hagmann, D. 2025. "I Walk an Ancient Road: A Straightforward Methodology for Analyzing Intra- and Inter-Regional Connectivity Systems along Roman Frontier Zones (c. 1st–5th Century AD)." Journal of Archaeological Science 176: 106151. https://doi.org/10.1016/J.JAS.2024.106151

Hair, Kaitlyn, Zsanett Bahor, Malcolm Macleod, Jing Liao, and Emily S. Sena. 2023. "The Automated Systematic Search Deduplicator (ASySD): A Rapid, Open-Source, Interoperable Tool to Remove Duplicate Citations in Biomedical Systematic Reviews." BMC Biology 21 (1): 189. https://doi.org/10.1186/s12915-023-01686-z

Hansson, Karin, and Anna Näslund Dahlgren. 2022. "Choice, Negotiation, and Pluralism: A Conceptual Framework for Participatory Technologies in Museum Collections." Computer Supported Cooperative Work (CSCW) 31 (4): 603–31. https://doi.org/10.1007/s10606-022-09441-8

Hidalgo-Sánchez, F. M., R. Merino-Del-Río, E. J. Mascort-Albea, I. Ruiz-Moreno, M. Linares-Gómezdelpulgar, and A. Tejedor-Cabrera. 2024. "Digital Reactivation of Territories through Geospatial Cultural Itineraries: The VIDA-HTL Web Application." Heritage Science 12: 56. https://doi.org/10.1186/s40494-024-01173-w

Hollesen, Jørgen, Malte S. Jepsen, and Hans Harmsen. 2023. "The Application of RGB, Multispectral, and Thermal Imagery to Document and Monitor Archaeological Sites in the Arctic: A Case Study from South Greenland." Drones 7 (2): 115. https://doi.org/10.3390/drones7020115

Jorayev, G., K. Wehr, A. Benito-Calvo, J. Njau, and I. de la Torre. 2016. "Imaging and Photogrammetry Models of Olduvai Gorge (Tanzania) by Unmanned Aerial Vehicles: A High-Resolution Digital Database for Research and Conservation of Early Stone Age Sites." Journal of Archaeological Science 75: 40–56. https://doi.org/10.1016/J.JAS.2016.08.002

Khan, N. A., S. M. Shafi, and H. Ahangar. 2018. "Digitization of Cultural Heritage: Global Initiatives, Opportunities and Challenges." Journal of Cases on Information Technology 20 (4): 1–16. https://doi.org/10.4018/JCIT.2018100101

Kuna, J., J. Jeremicz, D. Kociuba, R. Niedźwiadek, K. Janus, and J. Chachaj. 2022. "Interactive HGIS Platform Union of Lublin (1569): A Geomatic Solution for Discovering the Jagiellonian Heritage of the City." Journal of Cultural Heritage 53: 47–71. https://doi.org/10.1016/J.CULHER.2021.11.001

Larsen, P. B., and G. Wijesuriya. 2015. "Nature-Culture Interlinkages in World Heritage: Bridging the Gap." World Heritage Review 75: 4–15.

Leipold, F., H. S. da Fonseca, C. Dworsky, and R. Weßling. 2025. "Surfaced—The Digital Pile Dwellings." Heritage 8 (5). https://doi.org/10.3390/HERITAGE8050145

Lercari, N., E. Shiferaw, M. Forte, and R. Kopper. 2018. "Immersive Visualization and Curation of Archaeological Heritage Data: Çatalhöyük and the Dig@IT App." Journal of Archaeological Method and Theory 25 (2): 368–392. https://doi.org/10.1007/S10816-017-9340-4

Li, J., L. Xu, L. Tang, S. Wang, and L. Li. 2018. "Big Data in Tourism Research: A Literature Review." Tourism Management 68: 301–323. https://doi.org/10.1016/J.TOURMAN.2018.03.009

Liang, Huilin, Weizheng Li, Siqi Lai, Wenli Jiang, Lingxi Zhu, and Qingping Zhang. 2020. "How to Survey, Model, and Measure Rockeries in a Chinese Classical Garden: A Case Study for Huanxiu Shanzhuang, Suzhou, China." Landscape Research 45 (3): 377–91. https://doi.org/10.1080/01426397.2019.1632276

Liang, Huilin, Weizheng Li, Siqi Lai, Lingxi Zhu, Wenli Jiang, and Qingping Zhang. 2018. "The Integration of Terrestrial Laser Scanning and Terrestrial and Unmanned Aerial Vehicle Digital Photogrammetry for the Documentation of Chinese Classical Gardens: A Case Study of Huanxiu Shanzhuang, Suzhou, China." Journal of Cultural Heritage 33: 222–230. https://doi.org/10.1016/j.culher.2018.03.004

Lowenthal, D., and K. Olwig. 2013. The Nature of Cultural Heritage, and the Culture of Natural Heritage. Abingdon: Routledge

Luigini, A., M. A. Parricchi, A. Basso, and D. Basso. 2020. "Immersive and Participatory Serious Games for Heritage Education, Applied to the Cultural Heritage of South Tyrol." Interaction Design and Architecture(s) 43: 42–67. https://bia.unibz.it/esploro/outputs/journalArticle/Immersive-and-participatory-serious-games-for-heritage-education-applied-to-the-cultural-heritage-of-South-Tyrol/991005772911101241

Martínez-Graña, Antonio M., Teresa Díez, José Á. González-Delgado, Juan C. Gonzalo-Corral, and

Leticia Merchán. 2022. "Geological Heritage in the 'Arribes Del Duero' Natural Park (Western, Spain): A Case Study of Introducing Educational Information via Augmented Reality and 3D Virtual Itineraries." Land 11 (11): 1916. https://doi.org/10.3390/land11111916

Martínez-Graña, A. M., J. L. Goy, J. Á. González-Delgado, R. Cruz, J. Sanz, C. Cimarra, and I. de Bustamante. 2019. "3D Virtual Itinerary in the Geological Heritage from Natural Areas in Salamanca-Ávila-Cáceres, Spain." Sustainability 11 (1): 144. https://doi.org/10.3390/SU11010144

Martínez-Graña, A. M., L. Serrano, J. A. González-Delgado, C. J. Dabrio, and P. Legoinha. 2017. "Sustainable Geotourism Using Digital Technologies along a Rural Georoute in Monsagro (Salamanca, Spain)." International Journal of Digital Earth 10 (2): 121–138. https://doi.org/10.1080/17538947.2016.1209582

Meskell, Lynn. 2018. A Future in Ruins: UNESCO, World Heritage, and the Dream of Peace. Oxford: Oxford University Press.

Meskell, L., C. Liuzza, and N. Brown. 2015. "World Heritage Regionalism: UNESCO from Europe to Asia." International Journal of Cultural Property 22 (4): 437–470. https://doi.org/10.1017/S0940739115000247

Mubaideen, S., P. Flohr, J. Smithies, F. Bala'awi, C. Palmer, S. Idwan, and A. Esposito. 2022. "Assessing the MaDiH CKAN Catalogue as an Engagement Tool for the Jordanian Cultural Heritage Community." Levant 54 (2): 277–284. https://doi.org/10.1080/00758914.2022.2070233

Myers, David, Alison Dalgity, and Ioannis Avramides. 2016. "The Arches Heritage Inventory and Management System: A Platform for the Heritage Field." Journal of Cultural Heritage Management and Sustainable Development 6 (2): 213–24. https://doi.org/10.1108/JCHMSD-02-2016-0010

Nevola, F., T. Coles, and C. Mosconi. 2022. "Hidden Florence Revealed? Critical Insights from the Operation of an Augmented Reality App in a World Heritage City." Journal of Heritage Tourism 17 (4): 371–390. https://doi.org/10.1080/1743873X.2022.2036165

Nishanbaev, I., E. Champion, and D. A. McMeekin. 2021. "A Web GIS-Based Integration of 3D Digital Models with Linked Open Data for Cultural Heritage Exploration." ISPRS International Journal of Geo-Information 10 (10): 684. https://doi.org/10.3390/IJGI10100684

Novák, D., V. Staňková, V. Rýpar, J. Podliska, and J. Hasil. 2025. "Managing the Urban Archaeological Heritage of Prague: The Benefits of Collaboration." Internet Archaeology 70. https://doi.org/10.11141/ia.70.3

Pagano, A., A. Palombini, G. Bozzelli, M. De Nino, I. Cerato, and S. Ricciardi. 2020. "ArkaeVision VR Game: User Experience Research between Real and Virtual Paestum." Applied Sciences 10 (9): 3182. https://doi.org/10.3390/APP10093182

Page, M. J., J. E. McKenzie, P. M. Bossuyt, I. Boutron, T. C. Hoffmann, C. D. Mulrow, L. Shamseer, et al. 2021. "The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews." BMJ 372. https://doi.org/10.1136/BMJ.N71

Pandey, K., and H. Karnatak. 2024. "Geographic Information Systems." In Advances in Geospatial Technologies for Natural Resource Management, 41–63. https://doi.org/10.1201/9781003035404-3

Pappalardo, G., S. Mineo, D. Caliò, et al. 2025. "A Multi-Sensor Surveying Approach Supporting Landslide and Rock Cliff Evolution Analyses at the Temple of Juno, UNESCO Valle Dei Templi Site (Italy)." Bulletin of Engineering Geology and the Environment 84 (7): 376. https://doi.org/10.1007/s10064-025-04401-0

Parmeggiani, G., A. d'Atri, L. Perotti, and A. Borghi. 2023. "Geo-Heritage Tour Across the Ornamental Stone of the Historic Centre of Ivrea, UNESCO World Heritage Site (Piedmont Region, NW Italy)." Geoheritage 15 (2): 1–16. https://doi.org/10.1007/S12371-023-00836-7

Parrinello, S., M. Bercigli, and D. Bursich. 2017. "From Survey to 3D Model and from 3D Model to 'Videogame': The Virtual Reconstruction of a Roman Camp in Masada, Israel." Disegnarecon 10 (19): 11.1–11.19. https://disegnarecon.univaq.it/ojs/index.php/disegnarecon/article/view/295

Patrucco, G., S. Perri, and A. Spanò. 2021. "TLS and Image-Based Acquisition Geometry for Evaluating Surface Characterization." https://doi.org/10.4995/ARQUEOLOGICA9.2021.12143

Pepe, M. 2023. "Survey by Airborne Laser Scanner of Open Large Structure: A Case Study of Pompeii Amphitheatre." Journal of Engineering and Applied Sciences 12 (21): 6172–6182. https://ricerca.unich.it/handle/11564/802518

Pérez González, M. E., and J. I. Gallego Revilla. 2020. "A New Environmental and Spatial Approach to the Tiwanaku World Heritage Site (Bolivia) Using Remote Sensing (UAV and Satellite Images)." Geoarchaeology 35 (3): 416–429. https://doi.org/10.1002/GEA.21778

Peters, M. D. J., C. M. Godfrey, H. Khalil, P. McInerney, D. Parker, and C. B. Soares. 2015. "Guidance for Conducting Systematic Scoping Reviews." International Journal of Evidence-Based Healthcare 13 (3): 141–146. https://doi.org/10.1097/XEB.0000000000000050

Picchio, F., and R. De Marco. 2019. "Landscape Analysis and Urban Description of Bethlehem Historical Center: A Methodological Approach for Digital Documentation." Heritage 2 (1): 507–518. https://doi.org/10.3390/HERITAGE2010034

Pierdicca, R., M. Paolanti, S. Naspetti, S. Mandolesi, R. Zanoli, and E. Frontoni. 2018. "User-Centered Predictive Model for Improving Cultural Heritage Augmented Reality Applications: An HMM-Based Approach for Eye-Tracking Data." Journal of Imaging 4 (8): 101. https://doi.org/10.3390/JIMAGING4080101

Pueschel, P. 2013. "The Influence of Scanner Parameters on the Extraction of Tree Metrics from FARO Photon 120 Terrestrial Laser Scans." ISPRS Journal of Photogrammetry and Remote Sensing 78: 58–68. https://doi.org/10.1016/J.ISPRSJPRS.2013.01.005

Pukanská, K., K. Bartoš, J. Gašinec, R. Pašteka, P. Zahorec, J. Papčo, P. Bella, et al. 2024. "Methodological Approaches to Survey Complex Ice Cave Environments: The Case of Dobšiná (Slovakia)." Frontiers in Environmental Science 12. https://doi.org/10.3389/fenvs.2024.1484169

Repola, Leopoldo. 2023. "Extraction of Constructive Geometries from Numerical Models: The City Walls in the Hattusa Gorge." Disegnarecon 30. https://doi.org/10.20365/disegnarecon.30.2023.10

Rossato, L., P. Massai, F. Maietti, and M. Balzani. 2021. "Digital Tools for Documentation and Analysis of Vernacular Cultural Heritage in Indian City Centers." International Journal of Architectural Heritage 15 (6): 931–941. https://doi.org/10.1080/15583058.2019.1683778

Rysaeva, I. A., F. Z. Rafikova, and N. S. Gladnev. 2019. "Application of GIS Technologies to Display of Archaeological Heritage in the Republic of Tatarstan." Revista San Gregorio 1 (32): 51–56. https://doi.org/10.36097/rsan.v1i32.996

Salvoldi, Daniele. 2017. "A Historical Geographic Information System (HGIS) of Nubia Based on the William J. Bankes Archive (1815–1822)." DHQ: Digital Humanities Quarterly 11 (2): 13–23.

Savaşkan, M. O., and O. Ö. Özener. 2023. "H-BIM Applications for Vernacular Architecture: A Historic Rural House Case Study in Bursa, Turkey." Engineering, Construction and Architectural Management 30 (9): 3997–4017. https://doi.org/10.1108/ECAM-01-2022-0017

Settis, S. 2010. Paesaggio costituzione cemento: La battaglia per l'ambiente contro il degrado civile. Torino: Einaudi.
Shafiee, S., A. Rajabzadeh Ghatari, A. Hasanzadeh, and S. Jahanyan. 2019. "Developing a Model for Sustainable Smart Tourism Destinations: A Systematic Review." Tourism Management Perspectives 31: 287–300. https://doi.org/10.1016/J.TMP.2019.06.002
Spanò, A., G. Patrucco, G. Sammartano, S. Perri, M. Avena, E. Fillia, and S. Milan. 2023. "Digital Twinning for 20th Century Concrete Heritage: HBIM Cognitive Model for Torino Esposizioni Halls." Sensors 23 (10). https://doi.org/10.3390/S23104791
Stylianidis, E., K. Evangelidis, R. Vital, P. Dafiotis, and S. Sylaiou. 2022. "3D Documentation and Visualization of Cultural Heritage Buildings through the Application of Geospatial Technologies." Heritage 5 (4): 2818–2832. https://doi.org/10.3390/HERITAGE5040146
Sundseth, Kerstin. 2019. Natural and Cultural Heritage in Europe: Working Together within the Natura 2000 Network. Luxembourg: Publications Office of the European Union.
Sylaiou, S., G. Pavlidis, C. Fidas, A. Kargas, G. Loumos, I. Mamakou, and D. Varoutas. 2022. "Digital Routes in Greek History's Paths." Heritage 5 (2): 742–755. https://doi.org/10.3390/HERITAGE5020041
Tache, A., and I. Sandu. 2018. "UAV Solutions for the Protection and Management of Cultural Heritage: Case Study: Halmyris Archaeological Site." International Journal of Conservation Science 9 (4).
Tamborrino, R., M. Dinler, E. Patti, A. Aliberti, M. Orlando, C. De Luca, S. Tondelli, Z. Amirzada, and I. Pavlova. 2022. "Engaging Users in Resource Ecosystem Building for Local Heritage-Led Knowledge." Sustainability 14 (8): 4575. https://doi.org/10.3390/SU14084575
Terrone, M., A. Mandarino, P. Piana, and F. Faccini. 2024. "Identification, Computation, and Mapping of Anthropogenic Landforms in Urban Areas: Case Studies in the Historical Centre of Genoa, Italy (UNESCO World Heritage)." Progress in Physical Geography: Earth and Environment 48 (5–6): 801–819. https://doi.org/10.1177/03091333241276507
Thekkum Kara, G. K. 2021. "Developing a Sustainable Cultural Heritage Information System." Library Hi Tech News 38 (6): 17–20. https://doi.org/10.1108/LHTN-08-2021-0053
Tribhuvan, A. P., and A. A. Binnaser. 2024. "Exploring the Digital Heritage of Ajanta Caves through VR Technology." Digital Applications in Archaeology and Cultural Heritage 35: e00381. https://doi.org/10.1016/J.DAACH.2024.E00381
UNESCO. 1994. "Global Strategy for a Balanced, Representative and Credible World Heritage List." World Heritage Centre. https://whc.unesco.org/en/globalstrategy/
UNESCO. 2015. "World Heritage." World Heritage Centre. https://whc.unesco.org/en/review/75/
van Lanen, R. J., R. van Beek, and M. C. Kosian. 2022. "A Different View on (World) Heritage: The Need for Multi-Perspective Data Analyses in Historical Landscape Studies: The Example of Schokland (NL)." Journal of Cultural Heritage 53: 190–205. https://doi.org/10.1016/J.CULHER.2021.11.011
Van Nguyen, S., S. T. Le, M. K. Tran, and H. M. Tran. 2022. "Reconstruction of 3D Digital Heritage Objects for VR and AR Applications." Journal of Information and Telecommunication 6 (3): 254–269. https://doi.org/10.1080/24751839.2021.2008133
Walters, R., and N. Z. Hajna. 2020. "3D Laser Scanning of the Natural Caves: Example of Škocjanske Jame." Geodetski Vestnik 64 (1): 89–103. https://doi.org/10.15292/GEODETSKI-

VESTNIK.2020.01.89-103
Windham, Josh, James Elder, John Bobbitt, and Travis Hubbard. 2019. “Creating 3D Models With The Faro Scanner.” Report Number: INIS-US--21-WM-P14 (Research Org.: WM Symposia, Inc., PO Box 27646, 85285-7646 Tempe, AZ (United States)). https://www.osti.gov/biblio/23005490
Wu, T. C., Y. C. Lin, and M. F. Hsu. 2015. "A Study of 3D Modeling for Conservation Work of Large-Scale Industrial Heritage Structures: Using the South Chimney of Taiwan Tile Corporation's Takao Factory as a Case Study." Journal of Asian Architecture and Building Engineering 14 (1): 153–158. https://doi.org/10.3130/JAABE.14.153
Xiao, W., J. Mills, G. Guidi, P. Rodríguez-Gonzálvez, S. Gonizzi Barsanti, and D. González-Aguilera. 2018. "Geoinformatics for the Conservation and Promotion of Cultural Heritage in Support of the UN Sustainable Development Goals." ISPRS Journal of Photogrammetry and Remote Sensing 142: 389–406. https://doi.org/10.1016/J.ISPRSJPRS.2018.01.001
Zhao, X., K. Marnane, and K. Greenop. 2021. "The Role of Digital Technologies in Recording Values of Human Settlements: Testing a Practical Historic Urban Landscape Approach in China and India." Digital Creativity 32 (4): 253–274. https://doi.org/10.1080/14626268.2021.2001538
Zhenrao, C., F. Chaoyang, Z. Qian, and C. Fulong. 2021. "Joint Development of Cultural Heritage Protection and Tourism: The Case of Mount Lushan Cultural Landscape Heritage Site." Heritage Science 9 (1). https://doi.org/10.1186/S40494-021-00558-5

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