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. |

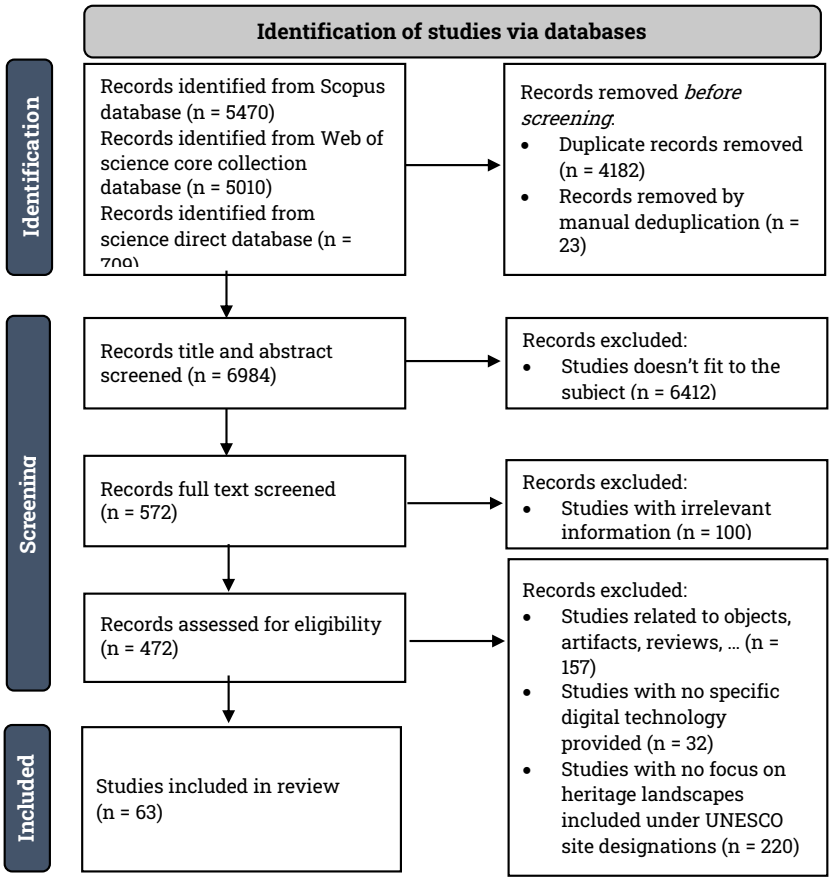


*Figure 1. PRISMA flow diagram for the scoping review process*

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.

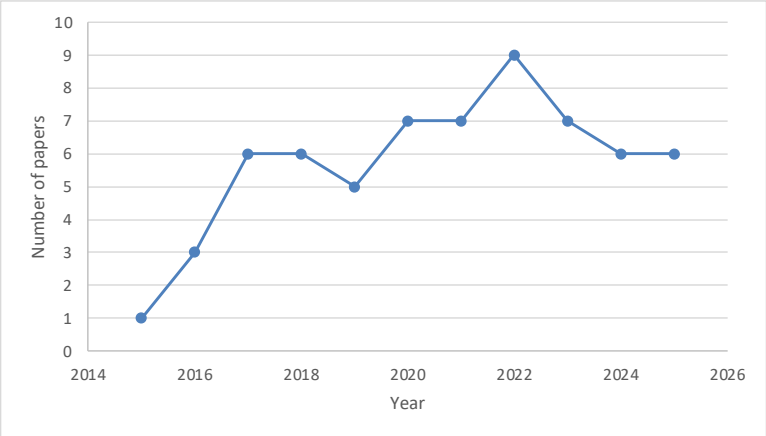


*Figure 3. Distribution of publications over time*

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.

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