

A Systematic Literature Review to Assist in Defining New Guidelines and Practical Handbooks for the Documentation of Built Heritage

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Review

# A Systematic Literature Review to Assist in Defining New Guidelines and Practical Handbooks for the Documentation of Built Heritage

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## Abstract

The documentation of cultural heritage, particularly built heritage, represents a critical component in ensuring its preservation, sustainable management, and effective transmission to future generations. As the field increasingly undergoes a digital transformation, there is a growing need for structured, standardised approaches that can guide professionals and stakeholders through the complexities of documentation practices. Despite the availability of numerous standards and charters, a clear synthesis of consolidated methodologies and recent technological shifts remains limited. This study addresses this gap by conducting a Systematic Literature Review (SLR) to assess current documentation practices. The research is part of a larger initiative funded by the FSE REACT-EU programme under the Italian PON Ricerca e Innovazione 2014–2020, specifically aiming to support public and private stakeholders in developing practical documentation strategies. Using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, over 266 publications were analysed to reconstruct the state of the art. The findings confirm widely adopted practices among research groups while also highlighting emerging trends driven by technological advancements in geomatics. These insights will contribute to the formulation of practical guidelines to support operators in the field and reinforce the integration of innovative tools in Cultural Heritage documentation workflows.



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**Keywords:** systematic literature review; PRISMA; built heritage documentation; 3D survey; geomatics

## 1. Introduction and Framing of the Research Project

It is widely recognised that research in the field of Cultural Heritage involves engaging with a vast, complex, and multifaceted domain. Therefore, it is essential to establish clear boundaries before delving into the core of the topic addressed in this study.

The presented work is focused on developing geomatic approaches to built heritage documentation at the typical architectural representational scales from the single building (or portion of the building in case of well-preserved structures) to the urban documentation of a small urban centre. The final, ambitious objective is to provide a first set of practical guidelines and directions thanks to the reconstruction of the state of the art via an SLR (Systematic Literature Review).

Considering that the effectiveness of these technologies is often related to the specific characteristics of the heritage object being documented, limiting the domain of

interest is mandatory. It is worth recalling the statements reported in the definition of cultural heritage given in the first article of the UNESCO Convention of 1972 [1]. In this text, heritage, considering only the tangible heritage, is divided into different categories. If we leave outside the natural heritage, the cultural heritage is divided into monuments, groups of buildings, and sites. Each of these categories is then further detailed with more definitions, and the different characteristics of each category are highlighted. For this research project, it was decided to narrow the focus to only the heritage defined as built heritage. This realm embraces multiple disciplines and can be analysed through several reading levels and representation scales. We decided to focus on the building element, being this partially conserved, as in the case of archaeological built heritage, or fully preserved, in the case of buildings that are also still used today. From this selection, archaeological sites that are preserved in the state of ruins were excluded: if only small sections with a limited elevation are present on the site, this was not considered for this research. Likewise, this research did not include all the decorative and monumental elements, e.g., frescoes, statues, stuccos, etc.

These categories of heritage were excluded, not for being less important but because they needed a specific, in-depth investigation, and we needed a particular focus to develop our research. In defining which heritage is considered as such, it was also crucial to define a reference timeframe: we have more or less included built heritage from all the periods, from the so-called archaeological heritage to the modern one. Ultimately, only the contemporary heritage was not included, mainly because the timeframe is often too short to understand the cultural value of the built heritage considered.

All the considerations reported so far must be placed in the reference context of the project from which this research originated, which is linked to the Italian scenario. With its 60 World Heritage Sites, Italy is the country that has the most Cultural sites inscribed on the list of UNESCO. Moreover, it is a country with a rich and capillary presence of heritage sites all over its territory. In this context, documenting, managing, preserving, and promoting this heritage is a complex and multifaceted task. In this complexity of operations and strategies, this research project is focused on the first step of the process: the documentation phase. This phase is crucial and the starting point of the overall knowledge process; more specifically, the focus is on these assets' metric and geometric documentation.

#### *Some Examples from the International Context*

Extensive scholarly attention has been devoted to the significance of documenting cultural heritage, a concern that dates back to the formulation of the earliest International Charters. The documentation process is fundamental for preserving and interpreting the past, ensuring its transmission to future generations, and reinforcing a collective sense of identity and cultural continuity. It serves as a foundation for conservation, research, and public engagement, while also providing valuable records for legal protection and security. Several international societies, like English Heritage<sup>1</sup>, Historic England<sup>2</sup>, ICOMOS<sup>3</sup>, ISPRS<sup>4</sup> and CIPA Heritage Documentation<sup>5</sup> contributed to better defining standards and guidelines for the documentation process of cultural heritage.

It is, of course, challenging to find shared standards and strategies in this domain. Nevertheless, this remains an essential open topic that needs attention.

An initiative worth citing is the RecorDIM project, described by the authors as a "Partnership for Heritage Recording, Documentation and Information Management" [2]. This project was developed thanks to a collaboration between ICOMOS, GCI (Getty Conservation Institute), and CIPA Heritage Documentation.

Despite being focused on the conservation process, this initiative provides a general overview of the documentation process to connect the needs of the people in charge of heritage management and the operators involved in the documentation process. Among other reference texts in this scenario, we cannot omit the Metric Survey Specification for cultural heritage [3]. This text, published by English Heritage, was recently updated with a new edition titled Geospatial Survey Specification for Cultural Heritage [4]. This work covers several topics and provides a series of specifications for surveys conducted in the cultural heritage domain starting from the general conditions that revolve around the work organisation and the relationship between client and operator, the different techniques that can be used, the control over the survey performances and the characteristics of the final products to be produced from the survey data. This document is an important starting point for all the operators involved in the documentation process of cultural heritage, especially the updated version, published a few weeks after the end of the collection of texts for the SLR. The only limitation concerning our research project's aims is that those texts are particularly connected with the English scenario and specifically with the English Heritage.

An ongoing initiative that must be cited for the Italian scenario is the Piano Nazionale di Digitalizzazione (the National Digitisation Plan)<sup>6</sup>. This ongoing initiative aims to facilitate digital transformation in the cultural sector, and it is managed by the Central Institute for the Digitisation of Cultural Heritage—Digital Library. The plan and its documentation are constantly evolving; thus, in the current version, only some general notes on the 3D documentation are reported; a specific focus on this topic is foreseen for the future.

In the European scenario, it is worth reporting the work of the European Commission's Expert Group on Digital Cultural Heritage and Europeana (DCHE)<sup>7</sup>. The work of this group led to the definition of some fundamental principles on tangible heritage documentation. The idea behind the ten principles structured by this initiative is to guide different stakeholders in the documentation process, from the definition of the aims to the long-term preservation and open access dissemination of digitalisation products. The effort of the European Union in supporting heritage safeguarding and protection can also be traced in different EU-funded projects/initiatives over the last years, e.g., Cultural Heritage Cloud (ECCCH)<sup>8</sup>, European Union's REKconstructed content in 3D (EUreka3D)<sup>9</sup>, 3D Digitisation of Icons of European Architectural and Archaeological Heritage (3D-ICONS)<sup>10</sup>, Online Competence Centre in 3D for Cultural Heritage (3D-4CH)<sup>11</sup>.

The technological evolution of geomatics methodology and techniques is often rapid, and it is difficult to maintain the practical guidelines updated. Moreover, new technologies and instruments require a period of study and validation to understand if they meet the requirements of cultural heritage documentation. The SLR is a perfect instrument to highlight the latest technological evolution and how they are affecting the overall documentation process. The creation of new good practices could then start from the previously mentioned works and integrate the latest technological developments identified from the SLR.

## 2. Systematic Literature Review Methodology

Reconstructing the state of the art is a fundamental step in positioning the research topic within a broader disciplinary and methodological context. The central aim of this work is to extract key insights from the existing scientific literature and, based on these findings, formulate preliminary guidelines and highlight new research trends. These are intended to support the various stakeholders engaged in the documentation of cultural heritage and to contribute meaningfully to the ongoing debate within the scientific community.

As it will be extensively described in the following sections, one of the crucial aspects of this research is to highlight the most consolidated and up-to-date technologies for the digital documentation of built heritage. Several methodologies are available to assess the development of a set of technologies designed to complete one or more specific tasks. In our case, it was decided to adopt a consolidated and widespread approach: an SLR (Systematic Literature Review). It is well known that SLR is a tool to independently analyse and assess the contents of the published scientific literature on a specific subject. This set of tools might also help researchers highlight shortcomings and further perspectives on the selected research question. To successfully implement an SLR, it is mandatory to create an ad hoc protocol to reduce the reviewer's subjectivity and limit possible biases.

The research will be performed on the main electronic databases available for the scientific literature, which will be chosen a priori before the start of actual research.

The methodology adopted for the SLR is crucial and needs to be defined before starting the research. We decided to adopt the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement<sup>12</sup> to develop our SLR [5].

Furthermore, to ensure the limitation of possible bias, the two authors of this work independently completed the phase of literature selection; both are experts in the field of geomatics applied to cultural heritage, and have worked separately in the phase of literature screening before merging the results.

The methodology implemented for an SLR developed via the PRISMA statement is well known. However, it might be helpful to recall the main steps that need to be implemented:

Definition of the research question and eligibility criteria  
Identification and selection of the databases/sources for the SLR  
Definition of the search terms  
Checking data and looking for duplicates  
Inclusion or exclusion of the results (via screening by title, abstract, and full-text)  
Review  
Summary of the results

In the following subsections, each of these steps will be further described, and how it was applied in the specific case of this research will be reported.

### 2.1. Search Terms and Eligibility Criteria

Several methodologies can be adopted to formulate the research question. Different schemes have been proposed in other research fields, such as the CIMO scheme [6] for economic science or the SPIDER scheme [7] in the medical field. For the thematic area considered in this research, geomatics techniques applied to the documentation of cultural heritage, there are no existing and consolidated schemes for defining the research question. Nevertheless, it is possible to formulate the research question by considering some constraints:

- It should be clear, simple, and straight to the point. What is the aim of the SLR? What questions should be answered, and what issues should be addressed?
- It must be defined before starting the SLR.

- It should be general enough to yield a broad range of results, yet sufficiently specific to keep the research focused on the topic of interest.

In this stage, it is also essential to define the eligibility criteria for the inclusion or exclusion of the records resulting from the search. The criteria selected are multiple and consider different characteristics of the records: time and geographical limits, quality criteria (e.g., the impact factor of the journal), language, type of review (peer-review, blind, etc.), type of publication (e.g., proceedings, article, report), etc.

For the aim of this work, the research question has been defined as follows: **What are the most up-to-date digital technologies in the field of geomatics for the 3D metric documentation of the built heritage?**

Concerning the research question and for the purposes defined in this work, the following definitions apply (they will also be adopted in the “Definition of the search terms” step):

- Geomatics: “discipline concerned with the collection, distribution, storage, analysis, processing, presentation of geographic data or geographic information” [8];
- Digital technologies: all the instruments and techniques that produce data that are natively digital;
- 3D metric survey: a survey aimed at the 3D documentation of a specific asset that is metrically controlled and validated;
- Built heritage: single or groups of buildings. From well-preserved portions of historical structures to small urban centres (see Section 1 for more details).

In the second step, the eligibility criteria have been defined as follows:

- Geographical frame: no constraints
- Time frame: from 1 January 2014 to 31 December 2024
- Language: English
- Type of publication: Scientific manuscript (research articles, Reviews, Technical notes, Conference Proceedings, Book chapters)
- Type of review: at least single-blind
- Availability of full text for academics: yes

The eligibility criteria were selected based on the research project requirements. The time frame covered 10 years, contemplating the rapid evolution of this kind of technology and the rapid change in instruments and techniques. English was chosen as the accepted language to include the most significant number of products possible and to insert the SLR in the international context. For the same reason, no geographical constraint was added. The texts accepted should be at least single-blind reviewed before publication, and the full text should be available to complete the phase of results screening.

## 2.2. Identification and Selection of Databases

The selection of the databases consulted for the SLR is a crucial step; if correctly performed, it can minimise the selection bias (alterations caused by an individual selection), retrieval bias (alterations caused by wrong or inaccurate database indexing), and finally the publication bias (studies that find null, or unexpected, effects are less likely to be published than those that find significant effects in the expected direction). Based on the authors’ experience and considering the selection criteria just reported, it was decided to use two well-established databases:

- Scopus by Elsevier<sup>13</sup> uniquely combines a comprehensive, expertly curated abstract and citation database with enriched data and linked scholarly literature across various disciplines.

- Web of Science by Clarivate<sup>14</sup> provides access to multiple databases that provide reference and citation data from academic journals, conference proceedings, and other documents in various academic disciplines.

When performing the database choice, there are, of course, some limitations that need to be considered. First of all, despite being accessible to most academic institutions, these databases are not fully available to other stakeholders, limiting their ability to find and consult all the relevant publications retrieved by the SLR. Furthermore, there are some types of results that might not be indexed in this database, such as benchmarking datasets or whitepapers/position papers. This limitation could be considered in a future extension of the research presented in this study.

### 2.3. Definition of Search Terms

The following step to be completed is the definition of the search terms that will be listed in the matrix of terms, which is the backbone for implementing the database search.

To define the search terms, the research question is split into blocks of terms of equal ranking, and as many synonyms and complementary words as possible are identified for each partial term. Since the focus is on the documentation process and the methodologies to complete it, we decided to identify two blocks of terms: geomatics and built heritage. These two domains are the main focuses of our research project. The matrix of terms was then defined as reported in Table 1.

**Table 1.** Matrix of terms defined for the database search.

Terms	Search Terms	
	Block 1 <b>geomatics</b>	Block 2 <b>built heritage</b>
Synonyms and complementary words	<b>geomatic 3d metric survey 3d survey 3d surveying</b>	<b>cultural heritage architectural heritage archaeological heritage heritage</b>

The words in each block of terms are linked with the Boolean operator “OR” while the different blocks are connected with the operator “AND”.

Thus, the following terms will be used to identify the relevant literature:  
geomatic, geomatics, 3D metric survey, 3D survey, 3D surveying (**OR**)

**AND**

built heritage, cultural heritage, architectural heritage, archaeological heritage, heritage (**OR**)

Finally, the selected terms have been searched through specific fields of the databases:

- **Title**
- **Keywords**
- **Abstract**

The queries for the two selected databases (Scopus and Web of Science) have been implemented as reported in Figure 1.



## Advanced search

< Basic Search Advanced [Search tips ?](#)

Enter query string

(TITLE-ABS-KEY ( geomatics OR geomatics OR ("3D Metric Survey" OR "3D Survey" OR "3D Surveying" ) AND TITLE-ABS-KEY ( ("Built Heritage" OR "Cultural Heritage" OR "Architectural Heritage" OR "Archaeological Heritage" OR "Heritage" ) ) AND PUBYEAR > 20140101 AND PUBYEAR < 20231231

[Outline query](#) [Add Author name / Affiliation](#) [Clear form](#) [Search Q](#)

(a)

Clarivate

Web of Science™ Search

< BACK TO BASIC SEARCHES

**Advanced Search Query Builder**

Session Queries

Build a new query based on your searches in this session.

1

((TS=(geomatics OR geomatics OR "3D Metric Survey" OR "3D Survey" OR "3D Surveying")) AND TS=("Built Heritage" OR "Cultural Heritage" OR "Architectural Heritage" OR "Archaeological Heritage" OR "heritage" )) AND DOP=(2014-01-01/2023-12-31)

349

[Add to query](#) [Link](#) [Edit](#) [Alert](#)

(b)

**Figure 1.** Construction of the query strings in the selected databases. Scopus (a) and Web of Science (b).

### 3. Analysis of the SLR Results

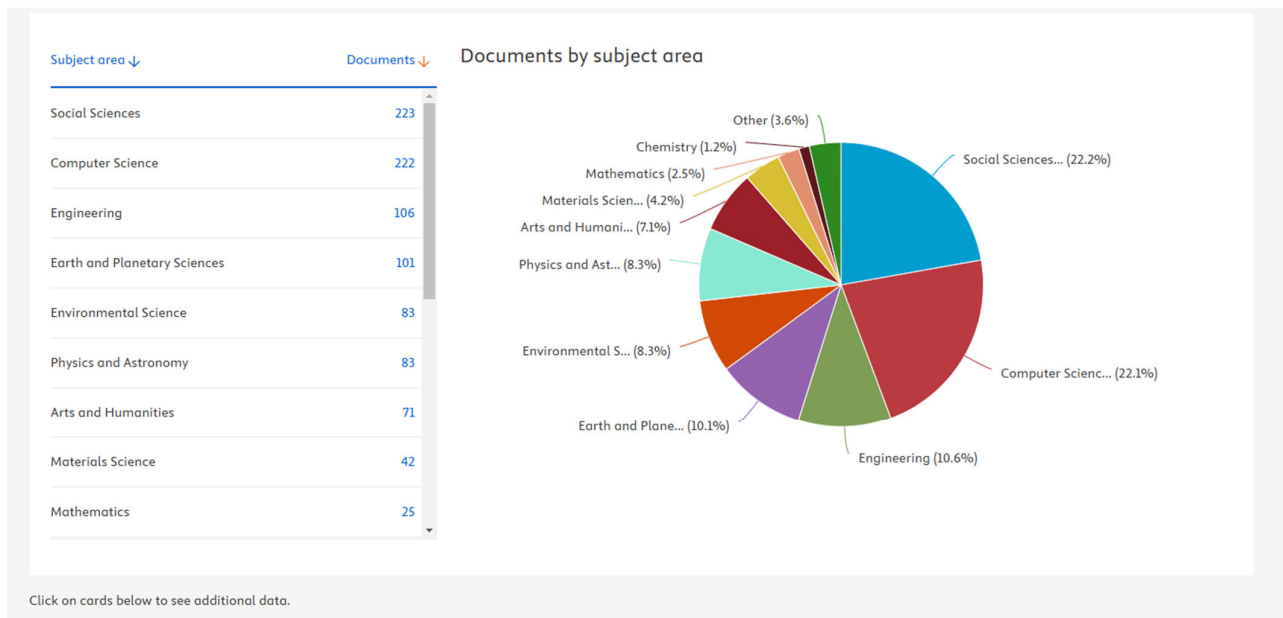
#### 3.1. Formal Analysis

The first step after completing the search on the two databases consisted of merging the results and conducting a formal analysis of the data. The queries of the databases produced 427 results for the Scopus database and 349 for the Web of Science database, leading to a total number of 776 results.

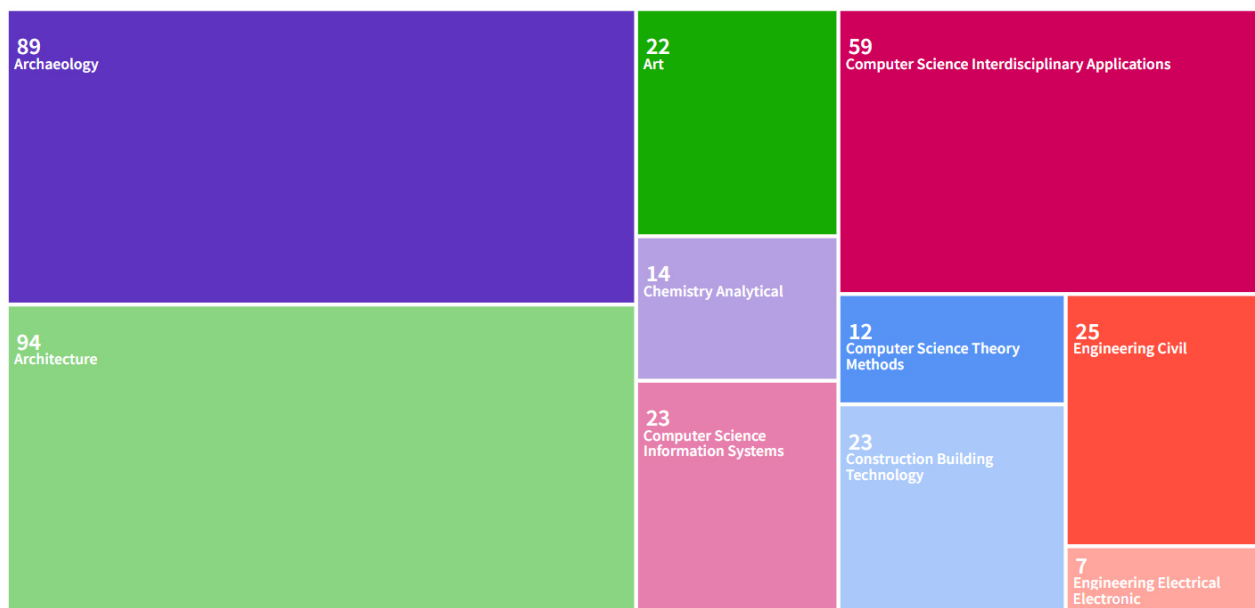
It is possible to follow different strategies and adopt various approaches to manage the results of the database search. Before moving to the actual analyses of the literature, the data needs to be retrieved, structured, organised, and sorted. This operation can also be made following manual approaches and using tools such as Excel; however, to enhance and speed up the process, it is advisable to use dedicated solutions such as EndNote, Zotero, Mendeley, etc.

Ad hoc software exists to aid researchers in performing SLR, and they are facing rapid growth, especially thanks to the development of AI (Artificial Intelligence) tools. Nevertheless, these approaches need careful methodological validation, especially for the use of AI, and thus, they have not been considered for this research. In our case, we decided to use Zotero<sup>15</sup>. We choose to use Zotero instead of other available solutions for different reasons: it is open source, it has a good tagging system to manage an SLR and allows easy collaboration and sharing of data between multiple users.

It is worth reporting that some research databases have been implementing analytics tools for the analysis of the search results. These tools are present both in Scopus and Web of Science databases (Figure 2). Since the data retrieved from the two databases are different, we followed a different strategy to analyse and visualise the data from our SLR.



(a)



(b)

**Figure 2.** An example of one of the analyses (subject area of the results) available inside Scopus (a) and Web of Science (b).

To assist us in this analysis, we also used software solutions like VOSviewer (v. 1.6.20)<sup>16</sup>. This free software is developed by Leiden University's Centre for Science and Technology Studies and can assist researchers in visualising results from bibliometric analyses. The visualisation of the results is not a mere graphical aspect, but allows for identifying clusters and key themes, as well as relationships between researchers.

After the queries of the two databases, results were exported using the ris. file format and imported into Zotero (v. 7.0.15). The first operation that was completed was the identification and removal of duplicates. This operation reduced the number of results from 776 to 509.

### 3.2. Application of Eligibility Criteria

The next step is the application of inclusion and exclusion criteria previously defined to select the search results that will be further analysed in the SLR. This process has been completed using the Zotero software (v. 7.0.15).

For the application of these criteria title, abstract, and keywords are generally sufficient; in case of uncertainty, it is possible to consult the whole article/text. Using Zotero, it is possible to add a “tag” field to each record; the tag field was used to specify the inclusion or exclusion of the results and was later used to filter and analyse the results. Moreover, another tag indicating the motivation for the exclusion was added. To guarantee the transparency of the selection process, the number of included/excluded works needs to be reported: for this purpose, the PRISMA flow diagram was used (as reported in Figure 3).

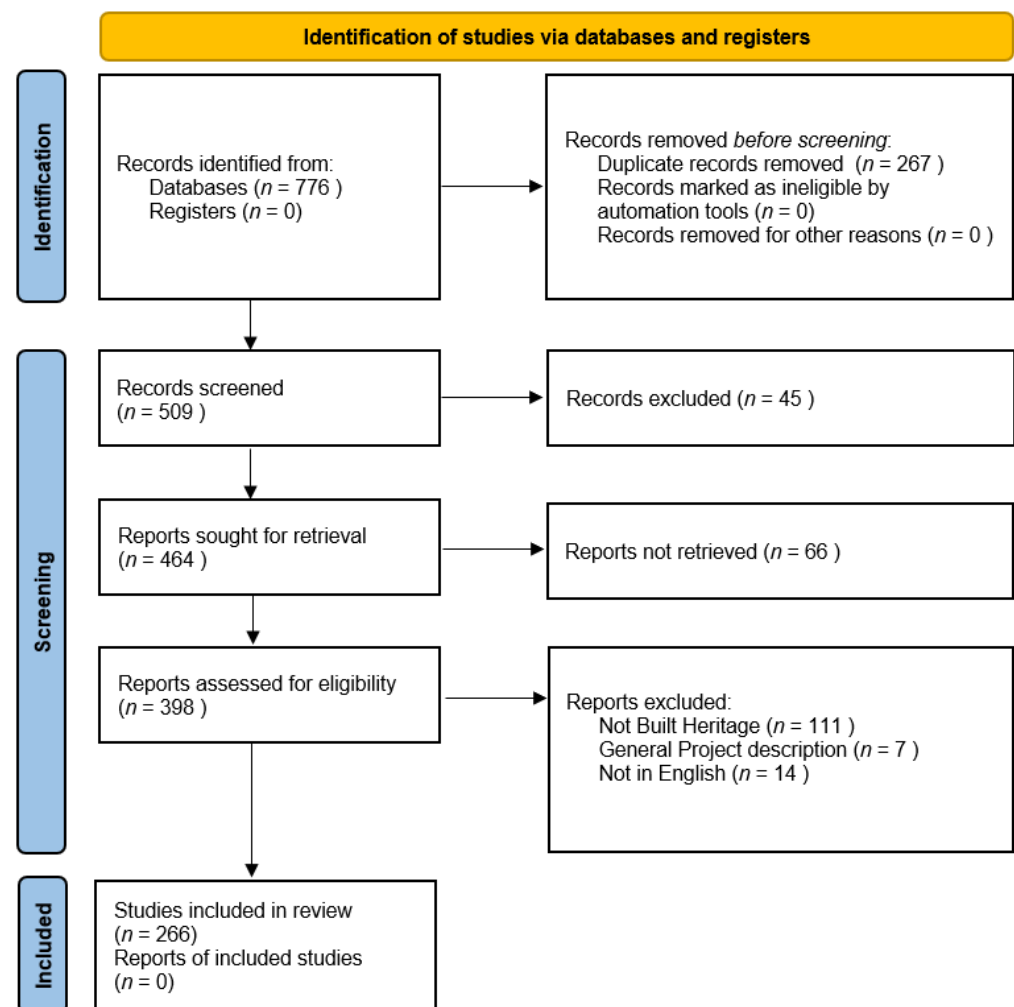


Figure 3. PRISMA flow diagram with the results of our SLR.

As shown in the flow diagram, in the identification phase, the results from Scopus and Web of Science were merged and compared. This formal phase led to the selection of the 509 reports that were screened in the second phase of the SLR process. The screening phase foresaw the review of titles, keywords, and abstracts and led to the exclusion of 45 results:



the full sequence of words was selected, differences in typing were corrected (e.g., H-BIM and HBIM), etc.

Finally, before creating the VOSviewer analysis, the more general keywords were deselected, i.e., cultural heritage, geomatics, archaeology, digital archaeology, architectural heritage, heritage, and cultural heritage documentation. This decision was made to highlight the technological solutions available and the different approaches to the documentation process.

Just looking at the co-occurrence network, it is possible to start addressing some considerations. First of all, some keywords are the centre for the clustering of other terms. This role is particularly evident for the words related to the instruments, techniques, and approaches that are the basis of the documentation process, such as photogrammetry, 3D survey, LiDAR, UAV, etc.

The second aspect is connected with the use that could be made of the survey products: here, we can find all the procedures for data analysis and interpretation, such as HBIM, GIS, 3D modelling, Digital Twin, etc.

It is then possible to connect the publication dates to see emerging technologies and trends. In the last five years, the growing topics seem to be related to data acquisition from one side (especially with the growth of UAV technologies) and data processing and interpretation on the other side: with a digital twin, HBIM, and in general, the testing and implementation of AI-based solutions for data interpretation and analysis.

### 3.4. Summary of the Results: Co-Authorship

The second analysis performed using VOSviewer was a co-authorship analysis (Figure 5).

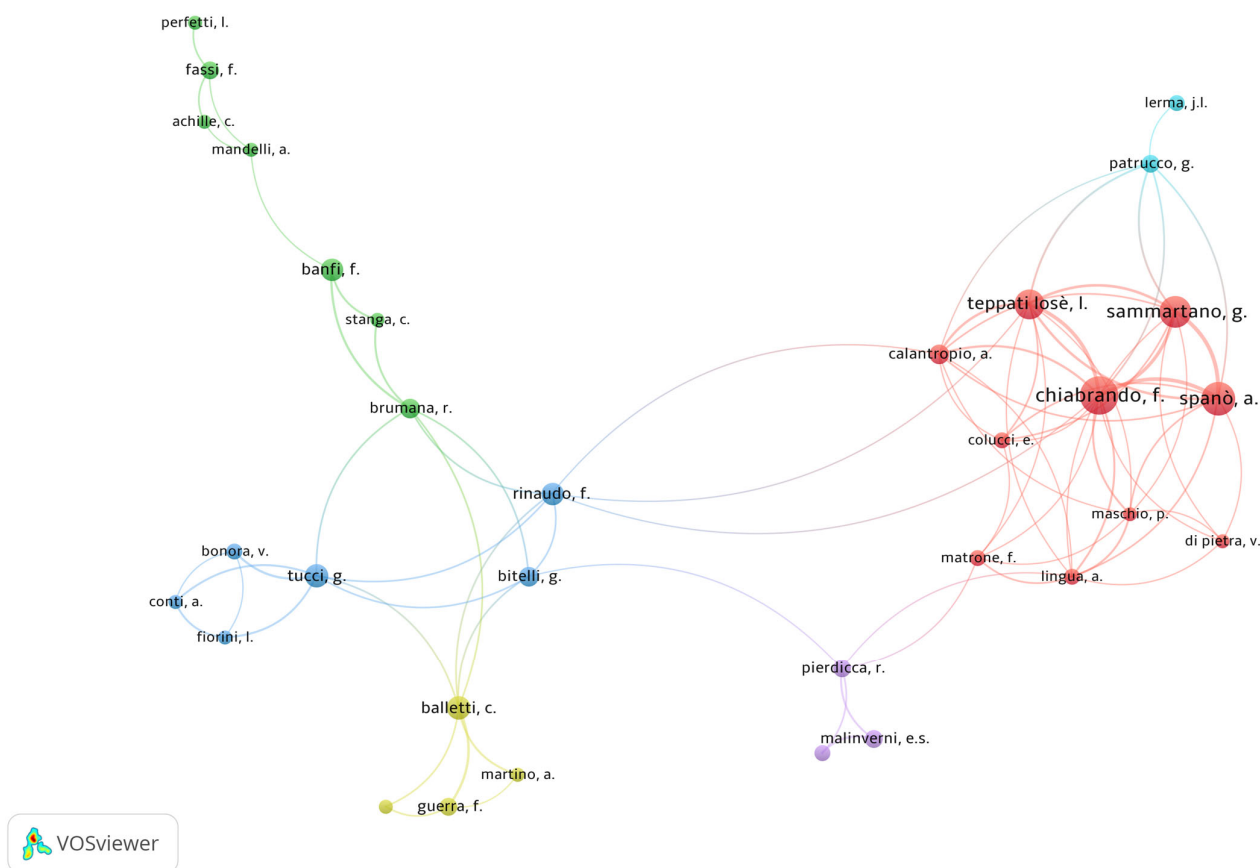
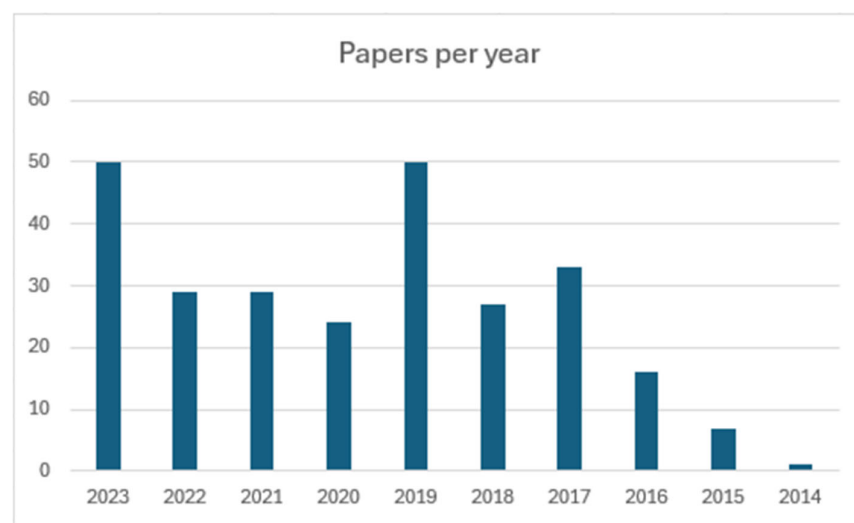


Figure 5. Co-authorship network generated using VOSviewer.

This visualisation highlighted some of the aspects confirmed also by the analysis that will be reported in the following sections. It is possible to see the clustering of the different authors depending on the institution of affiliation. In this panorama, the contribution of the different Italian institutions and their researchers is clear, as well as the connection between the research groups of each institution.

#### 4. Other Quantitative Analysis

The first analyses completed were related to the statistical distribution of the search results, considering different factors. The first element considered was the year of publication. As it is possible to see in Figure 6 there seems not to be a specific trend to highlight. The number of publications per year is generally consistent aside from the year 2014 (where only one publication is present) and for the years 2019 and 2023, where there is an increase in publications. The trend also seems not to be affected by the COVID-19 circumstances in terms of the number of articles published during the pandemic.



**Figure 6.** Number of papers per year.

If we look at the type of publication reported in Figure 7, we can notice that two-thirds of the scientific works were published in conference proceedings, and all the others, except for one book chapter, were published in scientific journals as articles. Considering that, generally speaking, publications in journals are more expensive and require more time and work from researchers, this is also a quite consolidated trend.

Finally, it is also possible to look at the number of papers per source as reported in Figure 8. We decided to report only the sources with more than two occurrences. In this case, it is possible to notice the importance of ISPRS (International Society for Photogrammetry and Remote Sensing) in disseminating knowledge in this field of research and the participation of the society members in several of the events organised by the society. Among the 173 Conference proceedings retrieved in this SLR, 121 (93 ISPRS Archives and 21 ISPRS Annals) are published by this society. The journals with the highest number of results are MDPI Heritage (11 results), MDPI Remote Sensing (9 results), and Springer Applied Geomatics (9). These three journals cover up to one-third of the works published in the form of articles.

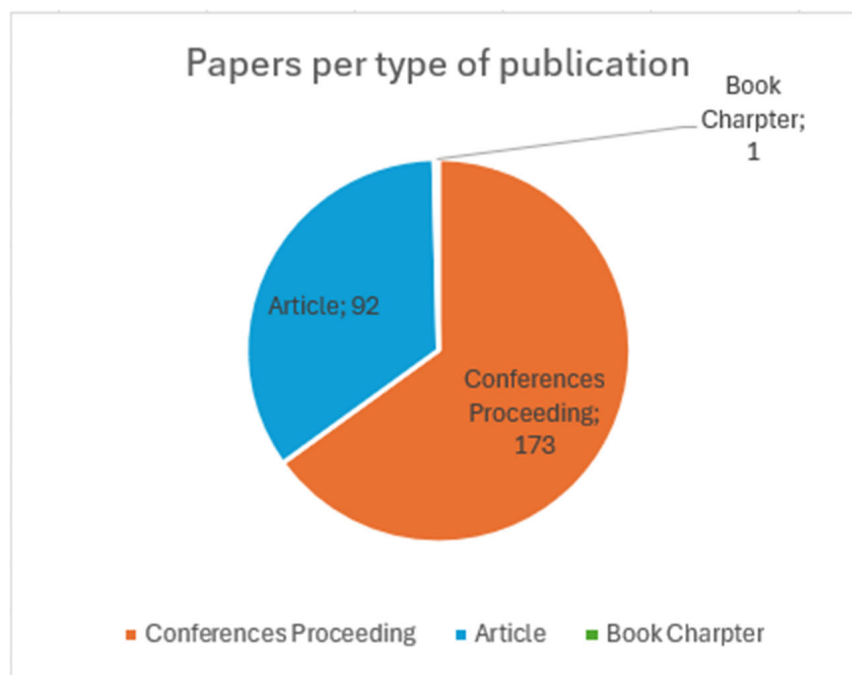


Figure 7. Number of papers per type of publication.

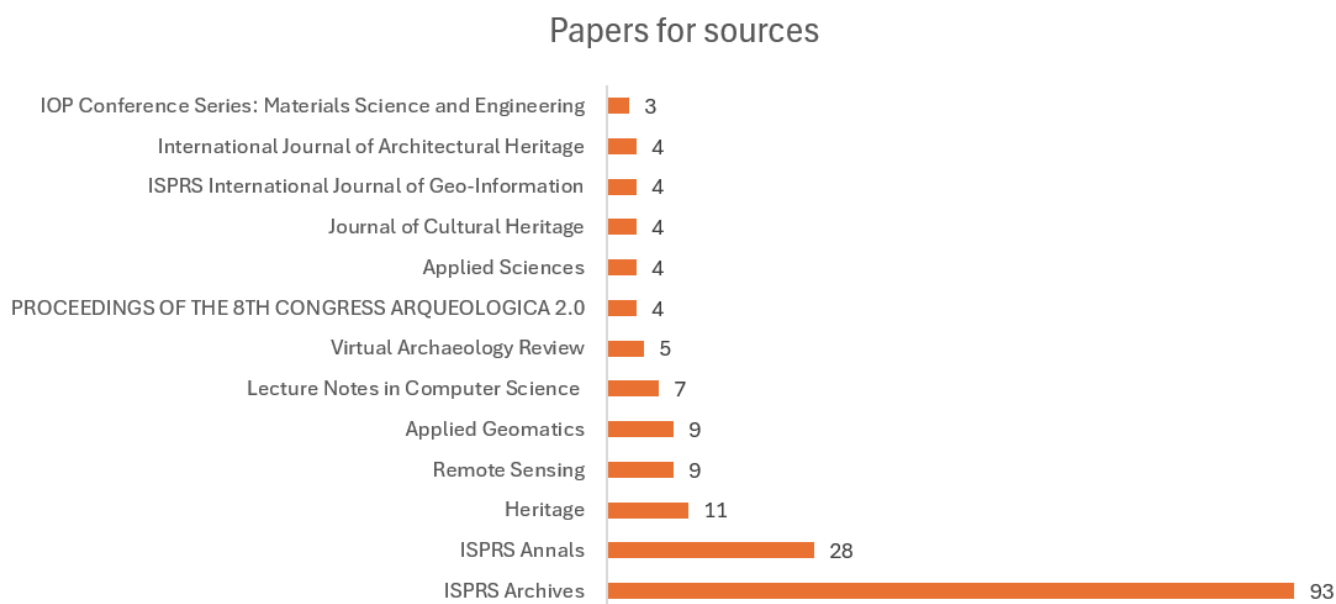
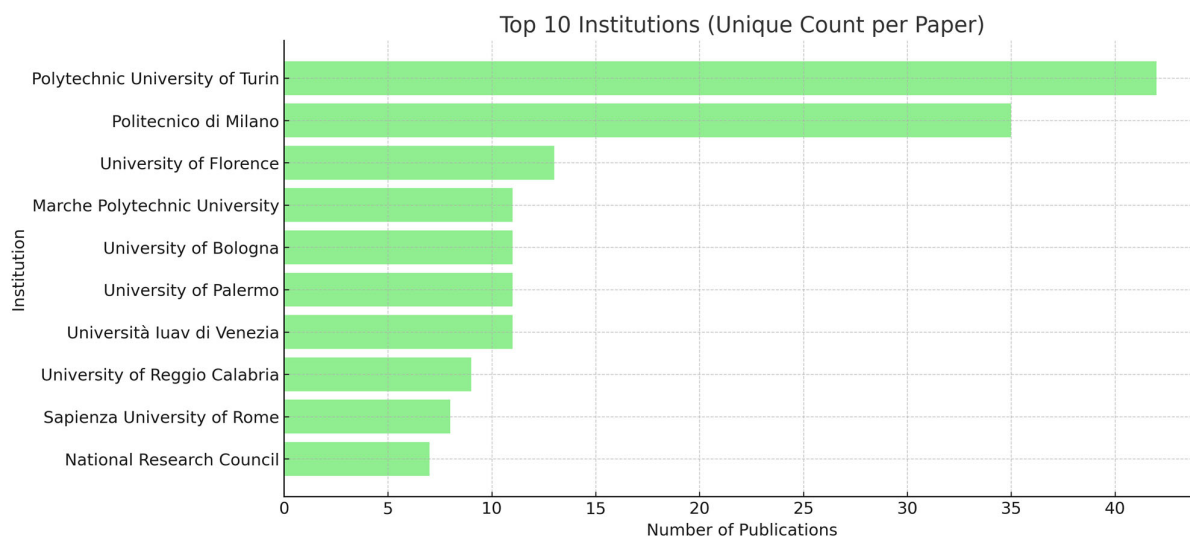


Figure 8. Number of papers per source with more than one occurrence.

To conclude, the analysis reported in Figure 9 confirmed what had already emerged from the co-authorship analysis previously presented. If we count the number of occurrences of institutions on the overall SLR, the predominance of Italian institutions is clear. To simplify the analysis of these data, only the affiliation of the first author was counted. This trend is confirmed by other results of the SLR, e.g., the scoping review reported in [10] and the wide bibliometric investigation presented in [11].



**Figure 9.** Top institution per search results. Unique count for paper: only the first author was counted for this analysis.

## 5. Results of the SLR to Define Practical Handbooks

The final and most important part of the SLR is the reading and analysis of the texts. As already reported, this was completed by the two authors independently and using a concept matrix as support (see Supplementary Materials Table S1). Based on the first screening of the SLR results, the concept matrix was organised into 17 different topics/concepts to highlight the main theme addressed by the SLR search results.

The 17 concepts are the following:

1. Teaching and capacity building. This includes results that report activities related to university teachings or capacity-building initiatives connected to the documentation of built heritage. Summer schools, workshops, training experiences, and international exchange programmes are part of this topic.
2. Topography/metric control (e.g., GCPs—Ground Control Points, CPs—Check Points). This concept includes all the search results where at least some minimal strategy for metric control and accuracy evaluation is considered. Generally speaking, this is achieved using traditional topographic techniques, but other strategies can be adopted as well.
3. TLS (Terrestrial Laser Scanner). This concept is applied to all the results where the use of this technology is foreseen.
4. Mobile Mapping Systems (MMS)/HMLS (Handheld Mobile Laser Scanner). This concept is applied to all the results where mobile mapping systems are used; more specifically, if the instruments are carried by the operators, these systems are referred to as HMLS.
5. Terrestrial photogrammetry. This concept is for all the results where the use of this technique is foreseen.
6. Aerial acquisitions (e.g., photogrammetry/LiDAR). For this concept, all the data acquired from the sky have been considered. These acquisitions are, in most cases, performed via UAV (Uncrewed Aerial Vehicles), but, for the architectural scale, they could also be performed by traditional aircraft.
7. 2D drawings. This concept has been counted if the documentation process also led to the creation of traditional 2D representations.

8. Other analyses (e.g., decay, cracks, FEM-Finite Elements Modelling, GPR—Ground Penetrating Radar). This voice was used to count all the sources that used the data acquired in the documentation process for performing several types of analyses.
9. 3D model/HBIM (Historical Building Modelling). If the 3D data acquired in the documentation process led to the generation of 3D models in different forms (also HBIM), sources have been counted under this category.
10. 360 (images or photogrammetry). This concept was used to count all the sources that reported the use of 360 data in terms of video, images, or photogrammetric approaches.
11. VR (Virtual Reality)/AR (Augmented Reality)/ER (Extended Reality)/Virtual Tour. If one of the products of the documentation process falls into these categories, more related to the immersive dissemination of heritage, it has been counted in this voice.
12. Risk assessment/management/post-event. If the experiences described in the results deal with some of the phases of risk assessment and management, they have been counted in this concept.
13. Online viewer. This concept was used to report the sources where online viewers were created to disseminate the results of the documentation process.
14. Other sensors (multi and hyperspectral/thermal). If other less commonly used sensors were adopted in the search results, they were counted here.
15. Heritage management. If one of the declared aims of the work reported in the search results is the facilitation of the processes of heritage management, they were counted under this category.
16. Point Cloud/Raster segmentation and classification. If AI (Artificial Intelligence) tools were used to segment and/or classify the data from the documentation process, sources were counted here.
17. GIS (Geographical Information System). If the data of the documentation process is managed or analysed via GIS software, sources are counted under this category.

#### 5.1. Topography/Metric Control (e.g., GCPs, CPs)

The first aspect that needs to be highlighted is related to the metric control over the survey process and the products derived from it. In the analysis of the results retrieved from the SLR, it is clear that this topic is present in the overall documentation process. As previously described, all the sources that foresaw some sort of metric control over the documentation process have been counted under this voice: 196 out of 266 records include some procedures for the metric control over the documentation process. In most cases, this function is fulfilled using traditional topographic techniques. The implementation of first and second-order control networks is the basis for all the subsequent survey activities. Traditional topographic techniques, such as total station or GNSS (Global Navigation Satellite Systems), are used to create the main reference system of the survey and/or acquire control points. These control points are then used as GCPs or CPs in the data processing and might serve for the georeferencing of the data in a unique coordinate system, as well as for evaluation of the accuracy of the processing and the data generated.

In most of the research works retrieved by the SLR, the use of topography and metric control strategies is given as a well-established procedure and is briefly described. Furthermore, it will not be of any use to report here the contents of all the 195 works that adopt these approaches. Nevertheless, some of the work that describes in detail these approaches will be briefly cited as a reference, as well as some of the research products that adopt more peculiar strategies to assess the accuracy of the collected and processed data.

Among the results of the SLR, the research described in [12] is focused on analysing and describing the impact and importance of first and second-order control networks

for architectural surveys. In [13] the first and second-order control networks are briefly described, and it is particularly clear how these networks were designed to encompass the building included in the survey. The description of a complex topographic network measured with different techniques is reported in [14] where it also served the purpose of ensuring a common reference system for a long-term project on 20th-century buildings. The importance of topography and first and second-order control networks in the survey of cultural heritage is described in [15] together with an overview of the connection between cultural heritage and the documentation process.

In the case of complex environments, the first- and second-order control networks need to be carefully designed and measured with traditional topographic techniques: this is the case reported in [16–23]. For extensive areas, it would be possible to adopt rapid approaches, mainly based on GNSS differential positioning for the survey of the second-order control network [24,25]. The work presented in [26] discusses different strategies for measuring the second-order control network (GCPs) in post-disaster scenarios using different instruments and evaluating the final accuracy of the generated products.

In case of small and/or isolated buildings, the setup of the first and second-order control network is a crucial step, as described in the experience [27–30].

A particular approach is reported in [31,32] where the instrument used might work both as a total station and laser scanner; thus, the TLS acquisitions were registered using a topographic approach by a traverse method, where the scanner also measures the other scan positions and uses this information for the registration.

When a site needs to be monitored over time, the contribution of traditional topographic techniques is crucial, and specific strategies need to be adopted; this is the case described in [33,34].

## 5.2. Acquisition Techniques

In the following subsections, the different acquisition techniques that emerged from the SLR have been reported and briefly discussed.

### 5.2.1. Terrestrial Laser Scanner

Terrestrial laser scanners have been around for more than 10 years now, and since the early diffusion of these systems, the technique has gained popularity in the heritage documentation domain. For this technique, the literature is vast and varied, and the SLR is no exception: 200 out of 266 results recall or discuss the use of TLS in the built heritage domain. Among the different texts, it is worth recalling some experiences where the TLS acquisition and processing are described in more detail: [16–18,35–49].

For TLS, the research focus has been on the overall enhancement of the associated procedures, from data acquisition to data processing and interpretation. In particular, new TLS systems allow the possibility of starting the registration process of the different scans directly in the field using different strategies and leaving the office work for its fine-tuning [31,32,50,51]. To deal with the quality of the RGB information associated with the TLS data, which does not always satisfy the resolution needed for CH documentation, some researchers tested different strategies to integrate photogrammetric data with the range-based information [52–55].

### 5.2.2. Photogrammetry

Photogrammetry has been a game changer in the process of documenting cultural heritage: its flexibility, versatility, performance, and low costs have been precious elements for its implementation in this field. It is thus not strange to find 143 results out of 266 in our SLR (only considering the terrestrial photogrammetry).

An overview of how photogrammetry, and the integration of computer vision techniques, can be used in the documentation of cultural heritage is reported in the SLR results in [56]. Photogrammetry, in general, is nowadays considered a consolidated technique; thus, the procedures and the overall pipeline are often just briefly cited in the results of the SLR. There are, however, some exceptions: in [18] the importance of lighting in indoor environments is discussed, and the adopted strategy to achieve the best possible results is described; in [57,58] low-cost and COTS (Commercial Off-The-Shelf) solutions are discussed in the context of rapid mapping surveys or in comparison with more consolidated techniques [59]; in [60,61] the researchers tested different software for the photogrammetric processing of the acquired data; applications on built heritage are described in [62,63].

A peculiar approach is adopted in [64,65] to process historical footage using modern photogrammetric techniques, or in [66] where is used to integrate the 3D model of a building design's wooden maquette with the actual real-world configuration. A similar approach is reported in [67] where photogrammetry is used in combination with historical images to reconstruct a lost architectural heritage.

In some of the SLR results, the possibilities offered by photogrammetry are pushed to their limits: in [68] a multi-lens system is used to document archaeological heritage in Egypt; in [69] a fisheye multicamera solution is presented for the survey of complex environments; in [70] the process of generating a Gigapixel Orthophoto is described as supporting the maintenance of a complex building. In terms of photogrammetric applications, it is interesting to report an example of testing the performance of low-cost and commercial systems in [58]: images and videos acquired from a steady camera are used within a standard photogrammetric approach and compared with the 3D and 2D reconstructions achieved with more consolidated techniques.

### 5.2.3. UAV

The growing use and diffusion of UAV (Uncrewed Aerial Vehicle) is a phenomenon that encompasses several sectors, and the domain of built heritage documentation is no exception. Among the 266 results of the SLR, 138 research papers involved the use of UAVs and exploited the possibilities offered by the different available payloads nowadays, aside from RGB cameras, e.g., LiDAR sensor [71].

UAVs proved to be particularly efficient in the management of emergency contexts due to their flexibility, rapidity, and ease of deployment and use. This topic is described in several research papers: [26,72–78].

In the general context of built heritage documentation, it is well-known that these platforms allow a different point of view on the documented objects and permit the complete documentation of these contexts in areas that are inaccessible from the ground [21,28,35,42,61,79–89].

Of course, one of the main advantages of the deployment of these platforms is the possibility of covering wide extensions of the territory in a reasonable time, allowing the documentation of urban areas or big sites: [24,90–94].

An interesting experience with the use of these systems for the documentation of industrial-built heritage is reported in [22] and describes the results achieved by the benchmark organised by the Italian Society of Photogrammetry and Topography (SIFET).

Several topics have been researched in connection with the use of UAVs for built heritage documentation and in the definition of the best strategies for their use, but they will not be reported in this research. There is plenty of literature that can be consulted on this topic, and we encourage the readers to refer to these articles for more specific aspects. Nevertheless, it is important to stress that one of the latest researched topics is connected with the exploitation of direct georeferencing approaches using UAVs, an approach that

can further speed up the acquisition and processing steps, making these systems even more attractive for built heritage documentation [95,96].

#### 5.2.4. Mobile Mapping Systems/Handheld Mobile Laser Scanner

An emerging technology of the last years in the field of built heritage documentation is the one connected with the use of MMS (Mobile Mapping Systems). This is especially related to the development of HMLS (Handheld Mobile Laser Scanner), many of which are based on SLAM (Simultaneous Localization And Mapping) algorithms. These systems are generally less precise than TLS and provide a lower level of detail in terms of the geometrical description of the surveyed objects. Nevertheless, this reduction in terms of precision and level of detail is compensated by a more agile and faster acquisition procedure. Moreover, this technology is rapidly evolving, and these systems are bridging the gap with more consolidated TLS systems. In our SLR, MMS is reported 38 times out of 266.

Due to the growing popularity and diffusion of HMLS systems, several research works are focused on the assessment of their performance and often in comparing them with more consolidated techniques such as TLS. In [97], HMLS are used to survey an architectural complex that was previously documented with other techniques, and the performances of the tested HMLS are discussed together with some analysis of different data processing strategies; the same approach is tested and validated in [98]. In [79], the integration of HMLS with other techniques (TLS, GNSS, and UAV photogrammetry) for a comprehensive survey of an isolated building is described and commented. A similar approach is described in [99], where different techniques are used to achieve the complete documentation of a multifaceted architectural complex, and also in [100]. In [101], an HMLS system is deeply tested and reviewed for the survey of different historical architectures, and different acquisition and processing strategies are highlighted and evaluated together with the ability of the system to cover the traditional architectural scales of representation. In this series of research, it is possible to find a detailed and complete overview of the use of HMLS fully integrated into the documentation process [102].

A peculiar field of application where HMLS were tested is the documentation of the underground built heritage, as reported in [103–106]. In these challenging environments, these systems have proven to be reliable, efficient, and also competitive compared to other more consolidated techniques.

One of the most interesting features of HMLS systems is the possibility of acquiring wide areas in a short period. This possibility is well-tested and described in [107] for different areas of Venice, acquiring data both from the ground and from the water. A similar approach was adopted in [108] to document several kilometres of historical porticoes. In this research, MMS was flanked by several other geomatics techniques. Another experience where HMLS systems are used to survey wide portions of urban areas is reported in [109]. A complex scenario is also the one described in [110] where HMLS systems play a crucial role in the documentation of the Valley of the Kings in Egypt. Another archaeological heritage complex where HMLS systems have been successfully used is presented in [111].

Similarly to other techniques, HMLS have also been tested in Scan to BIM applications as the base for the modelling process; this topic is presented in [112–114]. In a similar scenario, HMLS have been used in connection with GIS (Geographical Information Systems) for the survey of historical mills in integration with other techniques [115].

In more recent works like [116], the integration of these systems within the consolidated pipeline for data acquisition with several instruments and techniques is reported as completed and fully functioning.

The growing popularity of these systems is also witnessed by the fact that they are starting to be integrated into teaching activities and training curricula of university formation, as in [91] and in [117,118], where some first tests of using this technology in this scenario are presented.

One of the latest solutions that can be used to easily and quickly acquire data in the field is directly embedded in last-generation personal devices like iOS-based smartphones. For a few years, SSL (Solid State LiDAR) has been integrated into Apple smartphones, and the possibilities offered by these solutions in the field of built heritage documentation have been exploited and researched by different authors [119–121].

#### 5.2.5. 360° Images

A technique that has gained popularity again in the last few years is spherical photogrammetry. This approach was developed at the end of the first decade of the 20th century, especially thanks to the work of Gabriele Fangi [122]. In recent years, thanks to the release on the market of new low-cost 360° cameras, research in this field gained a second boost. One of the main characteristics of this type of data is its versatility; spherical images and video can serve different purposes, from the photogrammetric approach to virtual tours (as will be described in Section 5.3.7). An example of the versatility of these data is reported in [123] where panoramic images are used to create semantic annotations that are later reprojected on the 3D data.

These instruments have started to evolve recently, and the metric components have been integrated into web-based platforms, together with the possibility of incorporating different data sources. An example of one of these platforms is reported in [124], and it is used as a tool for rapid mapping and 3D survey in cases where other techniques could not be deployed. In [18], spherical photogrammetry is compared with more traditional approaches like terrestrial photogrammetry and TLS, and the acquired 360° images are also used for the creation of a virtual tour. In [107], spherical photogrammetry is compared with the results achieved using the latest generation MMS. In another research [125], the results of spherical photogrammetry are compared to traditional frame photogrammetry and TLS.

The integration of spherical images into consolidated workflows is researched in [126], where a 360° camera is mounted on a UAV platform and spherical images are integrated with frame images to achieve a complete 3D reconstruction of different scenarios, including the built heritage, and in [127] where data from 360° cameras are used together with TLS and UAV photogrammetry. A series of geomatics techniques are deployed in [108] and the pros and cons of using spherical images for a big documentation project are discussed. In [128], spherical images are used to flank and assist the traditional survey pipeline, providing additional semantic information that can integrate the informative content of 3D data, similar to the research presented in [90] that deals with the documentation of underground built heritage and the one presented in [129]. In [130], panoramic images are integrated into the GIS platform to assist rapid mapping approaches in post-emergency scenarios.

The case study reported in [131] is peculiar, where spherical photogrammetry is used to digitally reconstruct the Roman Theatre of Palmyra after it was destroyed by the war. This approach was already proposed in [132] again for the Syrian lost heritage, thanks to the work of Prof. Fangi. Nevertheless, Spherical Photogrammetry might be tricky and requires more expertise from the operators in data acquisition and processing; it is not suitable in all scenarios as reported, for example, in [133], where it was not possible to achieve a 3D photogrammetric reconstruction using spherical images.

### 5.2.6. Other Sensors: Multispectral, Hyperspectral, and Thermal

Despite being a specific field of research that requires dedicated approaches and trained operators, it is worth reporting the presence in the results of the SLR of techniques and sensors that work on the entire electromagnetic spectrum and not only in the visible.

Multispectral data are used in [134] to assess the state of conservation of built heritage and apply this non-destructive technique to highlight pathologies that could not be visible otherwise. Similarly, thermal images can be used to evaluate the state of conservation of some parts of the building, as highlighted in [135]. A thermal camera is used [136] in conjunction with other 3D data to highlight hidden cracks in the studied architecture or to better understand some details of the building [137].

In a wider context, UAV or airborne-acquired multispectral and thermal data can be used to study the natural context where the built heritage is inserted [138,139].

These techniques can support the design of the restoration process, and also in the case of specific materials, as showcased in [140], thermography is used together with other non-destructive techniques to assess the state of conservation of a wooden ceiling. Multispectral and thermal images are used concurrently in [141,142] to support built heritage conservation and are integrated inside an HBIM model. Similarly to multispectral and thermal data, hyperspectral data can also be used to highlight and analyse different pathologies [39].

### 5.3. Use of the Acquired Data

Something that needs to be highlighted, which also emerged from the SLR, is the fact that, in the majority of the cases related to the documentation of built heritage, the use of geomatics techniques is always connected to the overall knowledge process. Aside from specific research, where the focus is on testing and validating the performance of new sensors, the documentation process and the techniques employed are deeply linked to the study of the heritage itself. From the performed SLR, several applications emerged concerning the use of geomatics data acquired during the documentation process. The different specific applications and approaches will be briefly described in the following sections. Nevertheless, it is possible to highlight two main macro categories that are also linked together: heritage management and risk management/assessment and post-event management for built heritage. This topic is clearly of central importance and thus is also at the centre of the formation of the new professional figures that will work in this sector [117]. It is also important not to forget the possibility of implementing multitemporal monitoring when needed, thanks to the evolution of instruments and techniques that allow the adoption of these approaches more easily [33,143]. In [10], a scoping review is implemented to highlight the perspective of decision-makers on the possibilities offered by digital documentation techniques in the management of built heritage.

As will be reported afterwards, HBIM is often one of the main tools used for heritage management: [35,50,51,112,144–157]. On the other hand, the other most selected approach is GIS: [81,115,158–163]

Finally, several approaches are focused on exploiting geomatics techniques for the phases of risk assessment and management, as well as the post-event management of built heritage: [13,14,17,21,26,34,72–78,83,90,121,130,158,164–184].

#### 5.3.1. 2D Drawings

First of all, it is interesting to notice that the creation of traditional 2D drawings still plays a crucial role in these processes. Especially because the drawing phase is part of the interpretative process, and other disciplines more related to humanistic sciences are deeply connected to this kind of representation. Since modern geomatics techniques can

acquire and/or generate large amounts of 3D data, the research topic in these cases is often shifted to the interpretation of these data to retrieve the 2D products. The presence of 2D drawings or the investigation of approaches to retrieve this information is reported in 81 out of 266 results. Among these, it is worth citing some experiences. An overview of the importance of the generation of 2D drawing and their connection with historical surveys is described in [184] using an Abbey in Italy as a case study.

In [72], it is clear how these added value products generated from the 3D metric survey were allowed to connect the experts of different disciplines involved in the management and restoration of the built heritages after the 2012 earthquake in Emilia Romagna-Lombardia. The same experience is also described in [167]; while the consequences of the same seismic events are described in [173] where once again, a similar approach to the documentation of the damaged heritage is applied to support its restoration. In a previous seismic event, the one of L'Aquila in 2009, geomatics techniques and 2D drawing served as crucial support in the reconstruction process [176]. In [128], the data from different techniques were used together to achieve a complete and detailed 2D representation of valuable heritage in Venice and to support further analysis from other disciplines. In [185], 2D and 3D representations retrieved from the metric survey are combined to study and reconstruct the functioning of two 19th-century furnaces. Similarly, a reverse modelling approach is adopted in [186] starting from the traditional approach of extracting section profiles from the 3D data and mathematically modelling the façade of an 18th-century church.

The work presented in [84] highlights clearly that, in a context where architecture and archaeology meet, as the one described, 2D representations are crucial in defining a common language and how they can be retrieved from the 3D data following specific procedures. In other archaeological scenarios, the potential of these techniques is highlighted: in [16], it is showcased how a TLS survey allowed for reaching a high level of detail in the 2D representations. The same results are described in another archaeological palimpsest in [187] using TLS and other geomatics techniques.

In [188], the history and evolution of a medieval castle in the Calabria region are reconstructed thanks to a series of studies and analyses completed on the 2D drawing and other metric products generated after the 3D metric survey. A similar approach is presented in [189] where it is also integrated with archaeometric analyses.

Another medieval castle is the case study of [42], where multiple geomatics techniques were integrated to overcome the environmental constraints posed by the topography of the site; the final products of the documentation process were yet again the traditional 2D representations.

The possibility of working with 3D data to generate 2D drawings can also be useful for complex architectures; an example is reported in [190]. In this research, the 3D models generated via metric survey were used to develop the surface of a cylindrical tower into an unrolled surface.

### 5.3.2. Other Analysis/Applications

Among the 266 results, some research paper deals with specific applications. It is interesting to report the integration of historical images in the photogrammetric processing as described in [27]. For the project CHT2 (Cultural Heritage Through Time) [191–193], several techniques were used to record the remains of lost heritage and reconstruct its original appearance and structure.

In [194] the 2D products are used for decay analysis and pathologies identification, but also for statistical analysis of the brick dimensions. In [195], geomatics techniques are used to analyse the vaults of a Gothic cathedral from a formal point of view and better understand the construction history of the site. In the domain of archaeological built heritage, the

products derived from the documentation process could serve to support the stratigraphical analysis of the different construction phases of the building [139,188,189,196,197]; in [198], they are also combined with mortar analyses.

In [78], the seismic vulnerability of the S. Agostino Church in Amatrice is assessed combining historical data with the 3D metric survey completed after the different earthquakes that affected the structure. Another interesting approach is described in [37,199], where data from mineralogical-petrographic analysis are combined with the geomatics data from the 3D survey. In [162], 3D data are converted into 2D products, and a GIS solution is used to propose a complete workflow for the lithological mapping and analysis of different buildings. In [200,201], the documentation process is also fully integrated with the historical reconstruction made by experts from other disciplines.

### 5.3.3. Decay Analysis and Identification

A use of the survey data that is often proposed in the work retrieved by the SLR, and it is connected with decay analyses and identification. In [202], data from the 3D survey are converted into 2D drawings and used to achieve a complete mapping of the pathologies affecting modernist architecture, supporting the future restoration of the building. In [203], the same analysis on the identification of pathologies was achieved using a specific strategy and exploiting the intensity values acquired by a TLS. In [123], decay information is mapped on 2D panoramic images and then back-projected on 3D data. Similar to the previous two contributions, the work presented in [81] proposed a multi and interdisciplinary approach to use survey data in identifying and managing the pathologies affecting a famous historical palace in Florence (Palazzo Pitti).

Concerning built archaeological heritage, the work reported in [149,163] describes the use of 2D representations to map and monitor both materials and pathologies of historical structures. In [147,148,150,152,204–208], both 2D and 3D data are used to map pathologies and evaluate the behaviour of the building under different conditions. A similar approach is described in [209] but aided by AI tools. Geomatics techniques can also support the restoration project, as described in [210], where they are applied in the restoration project after a natural disaster or in [144] to integrate all the available data and information of a single building. The experience described in [160,161] developed a mobile application to let the citizens send notifications about the state of decay or pathologies observed on historical buildings to engage them in the preservation of built heritage.

### 5.3.4. FEM and Structural Analysis

Together with decay, the assessment of the structural integrity of a heritage building is an approach well documented in the literature. The implementation of FEM (Finite Element Method) analysis is within this domain.

In [13], 2D drawings are used to support the in situ analysis of the built heritage object of the research and the further evaluation of its structural stability, as well as the characterisation of the different masonry types and building techniques; a similar approach is discussed in [211].

The work presented in [154] shows how geomatics techniques can support the structural analysis of archaeological built heritage and design interventions to deal with these problems. A similar approach to a comparable heritage building is described in [212]. Several studies stress the implication of moving from detailed 3D models to models suitable for FEM analyses: [14,21,23,72,83,85,166,178,179,181,213–216]. A comprehensive review of how geomatics techniques can support in the assessment of seismic vulnerability on historical masonry buildings is reported in [164]. Examples of semi-automatic procedure are proposed in [17,168,171].

### 5.3.5. GPR and Geophysics

The connection between geophysical approaches such as GPR (Ground Penetrating Radar) and ERT (Electrical Resistivity Tomography) and geomatics techniques emerged quite clearly in this SLR.

In [169], GPR analyses were connected to the 2D representations of the buildings to deepen the knowledge of the building itself and to plan future restoration interventions. In [217] GPR and ERT are deployed in connection with geomatics techniques for the study of historical underground wine cellars.

The connection between geomatics and geophysics is particularly consolidated in the built archaeological heritage domain, where the techniques from the two disciplines are used together to deepen the knowledge of the studied site: [25,218]

### 5.3.6. HBIM/3D Models

The first and primary output of a 3D metric survey is generally a point cloud; nevertheless, it is quite common to further process and interpret this data in 3D. A topic that has been on the cutting edge of several communities of research is the Digital Twin. The development of this approach also affected the field of built heritage documentation and the geomatics community. Geomatics techniques might indeed contribute to the geometric and metric component of the Digital Twin, and researchers have spent their effort on approaches that allow moving from the point cloud to a more structured 3D model. In this field, BIM (Building Information Modelling) and, more specifically, HBIM (Heritage Building Information Modelling) emerged as precious tools. Among the 266 results of the SLR, 112 foresaw some 3D modelling steps and, quite often, the generation of HBIM models.

HBIM is used in [72] to connect all the relevant information on the conservation state of the building and assist in the consolidation and restoration process; the same approach is reported in [144,176]. Examples of experiences of thematic mapping for materials, degradations, or state of conservation on the HBIM models are reported in [112,141,147,148,150,152,196,206,207].

Several sources among the ones retrieved in the SLR are focused on deepening the topic of moving from point clouds to HBIM, the so-called Scan-to-BIM approach: [17,19,32,35,39,50,146,148,155,219–228]. The implementation of this approach is not always straightforward, especially in the context of built heritage and several strategies have been proposed and discussed to reach a balance between the simplification of the 3D data and the preservation of a sufficient level of details, especially addressing the automation of the process [229,230]. To solve these issues, some researchers also investigated semi or fully automatic approaches based on Deep or Machine Learning tools for the generation of the HBIM models from the 3D survey data [114,231].

Several researchers also focused on verifying the deviations between the achieved HBIM model and the original point cloud [118,149,232].

The representational scales in which HBIM can work are quite wide and can also reach the urban scale: an example is reported in [73] where it is used to map the damages that affected the built heritage of the city of Norcia (Italy) after the 2016 earthquake, or in [109].

Furthermore, HBIM applications might be used to assist the preservation and dissemination of built heritage in conjunction with the support that these instruments provide for its maintenance [51,156].

### 5.3.7. VR/AR/XR/Virtual Tour

A specific use of the data acquired in the documentation process is one aimed at developing digital content available for the users. These contents can be created in various forms: VR (Virtual Reality), AR (Augmented Reality), XR (eXtended Reality), and more

traditional virtual tours using 360° or panoramic images. Among the 266 results of the SLR, these topics are addressed in 48 texts.

As already reported for HBIM, one of the criticalities in this scenario is the simplification that the data from the 3D survey needs to undergo to be used inside gaming engines and be fully enjoyable for the final users. Moreover, 3D data are not sufficient to provide attractive products. Thus, other information needs to be connected with the models, together with the creation of storytelling for the users. An example of this complete approach is described in [92,139,233–239]. Some researchers tested the possibility of deriving this immersive solution for data sharing directly from the HBIM model: [51,113,220,234,240–243]

Simple solutions like traditional virtual tours created with spherical or panoramic images might be useful in different ways. They can assist the documentation process by providing more thematic information to the 3D data, and on the other side, they represent a fast and economical tool to share information in an immersive way with various stakeholders [18,43,127,128,135,158,211,244–247].

The development of these tools is also related to the availability of new wearable platforms for immersive experiences [80,248,249] and the increase in the computational capabilities of personal devices [223,250–252].

#### 5.3.8. Online Viewer

The direct advantage of these tools is the possibility of developing web-based platforms and solutions to easily share data. An example is reported in [53,160,253–256]. These platforms can be created in a cooperative scenario with the different stakeholders involved in heritage conservation and management [75,124,151,161,208] or to enhance heritage promotion and knowledge dissemination via these interactive tools [108,110,139,238,239,246,257].

#### 5.3.9. GIS

Another tool that is widely used in the documentation process of built heritage is GIS (Geographical Information System), especially, but not limited to, the analysis of heritage insisting in wider areas of territory. GIS software has faced significant development in recent years and is today capable of collecting, managing, and analysing several types of data sources, including 3D data from the metric surveys. These also led to the possibility of representing entire territories or buildings in 3D, as reported in some of the SLR results: [105,258–261]. GIS is used in [25] to connect all the different data on a wide archaeological site or 20th-century architecture in [158]; in [130,159,180] to manage several damaged buildings and to allow citizens to access all the heritage sites of the territory in [161]. Finally, to map a specific built heritage on a territory [115,262].

Another trending topic of research is the interoperability between HBIM and GIS, which poses a series of threats; some considerations and tests are reported in [240], put to the test on an urban scale in [73]; while the differences between the two approaches are discussed in [263].

Sometimes GIS is used for spatial and thematic analysis on vertical surfaces of the built heritage, like the examples described in [81,163]. Often, GIS is used in the retrieval of historical data and cartography and connects it with the data of actual 3D surveys [99,192,264].

#### 5.3.10. Teaching and Capacity Building

It is also important to recall the importance of transmitting the set of skills and the knowledge derived from the research developed in the above-mentioned field, both to the new generations of professionals and outside the academic field. This topic is cited in 15 of the search results of the SLR. Initiatives of capacity building are reported in [124] for the support that geomatics techniques can provide to the reconstruction of the campus of the Somali National University of Mogadishu, thanks to the remote training of local operators

due to the COVID-19 pandemic. Another capacity-building initiative is described in [265] where a process of knowledge transfer is developed between Italian and Cuban institutions. International exchanges and cooperation experiences between students are also reported in [266–269], exploiting the possibilities offered by ERASMUS programmes.

Other ad hoc training programmes, as registered in [270], are developed under the guidance of international societies like CIPA or ICOMOS. In this case, the summer school aimed to teach the participants how to use the latest geomatics techniques to reconnect with the territory and activate processes of conservation of built heritage in rural areas. Similarly, the importance of implementing learning-by-doing approaches is reported in [91]; in this contribution, students faced the challenges of integrating different geomatics techniques to support the valorisation of archaeological built heritage and its surrounding context. A similar experience is described in [99] where a group of students with their academic tutors combined three disciplines (geomatics, geophysics, and restoration) for the documentation and study of different historical buildings.

The importance of teaching this approach to documentation in the academic curricula is mentioned in [117] where the significance of the training programmes, including and connecting geomatics and HBIM, is underlined in the Italian scenario. Similarly, in [82], the approach used in a Master's Degree course in Architecture for the documentation of a stratified historical building is described. In the latter, the focus is also on the possibilities offered by COTS solutions in supporting other disciplines involved in the knowledge process. Similarly, the work [271] presents the results of the activities of a group of Master's Degree students in combining the use of geomatics techniques and HBIM for the documentation of a World Heritage Site.

Often, the efforts in the teaching activities also lead to the development of student thesis work, like in [211]. Finally, the interactions between the academic world and industries are analysed in [272].

#### 5.4. Use of AI

As for almost every domain of research in recent years, a new paradigm has started to emerge: the use of AI (Artificial Intelligence). The documentation process of built heritage and geomatics, in general, is starting to be affected by these new approaches in different ways; this aspect is also emerging from the results of the SLR, where 18 out of 266 results address this topic.

AI tools are often used to classify the acquired data semantically, and several methodologies have been tested to achieve this goal. These tools have started to be integrated into 3rd party software, like the experience reported in [24]. The segmentation is applied, for example, directly on the 3D model for architectural elements classification [73,114,219,229,231,241] used to speed up the Scan-to-BIM processes. Similar approaches have also been tested on different types of data: an example of point cloud classification on HMLS systems is reported in [104].

In [116], the results of different classification strategies are reported, discussing both the pros and cons of the tested approaches. The work presented in [273] discusses the approaches for the 3D semantic segmentation of point clouds in the heritage field using deep learning approaches, while the research reported in [274] test a specific approach to label the data on 2D images and then transfer these labels to the 3D data. On the other hand, approaches for 3D segmentation have also been tested, also exploiting machine learning approaches [249].

The application of AI approaches is, of course, possible in 2D environments: in [170] these approaches were tested to automatically detect the damages on a historical building roof. In [209] an approach to the automatic detection of a specific pathology of a built

heritage is presented and discussed. In this research, 2D and 3D data are used together to support this approach.

Finally, a comprehensive review of 3D semantic segmentation of point clouds in the heritage field is reported in [275].

## 6. Discussion and Conclusions

The analysis of the results of the SLR allowed us to highlight and confirm the consolidated approaches followed by several research groups, and also stress the latest changes in these approaches driven by the technological evolution of geomatics techniques and research.

The systematic review of 266 search results retrieved from the SLR allowed us to identify 17 concepts that can be summarised in six approaches to answer six needs of the documentation process:

1. Designing for objectives
2. Data for supporting analyses
3. Techniques for products
4. Topography for accuracy and metric control
5. Strategies for data processing and product generation
6. Data for dissemination and management

As reported at the beginning of the work, the aim is to look at the documentation process in a more practical way, leaving to other texts the theoretical and methodological discussion on the principles that drive the built heritage documentation and highlighting some basic principles to follow when tackling built heritage documentation. For a wider point of view on the methodological aspects, it is interesting to report from the SLR the work described in [11] that presents a bibliometric analysis of the topic of digital heritage. The idea is to focus on the actual state of the art, thanks to the SLR, and to create a starting point on which to build together with all the research communities involved in the documentation process, fostering a deeper discussion on the practical aspects of the process.

1. The design for objectives is the first phase of the process and starts with the definition of the objectives of the documentation process and the needs of the commissioner of the documentation. In this phase, preliminary research on already available materials on the object of documentation needs to be completed together with an in-depth reflection with the commissioner to try to understand the needs of the project. This is also the phase where the products that will be generated need to be defined, and also how these products will be used. The following phases of the documentation activities are linked to what is defined in this step. Preliminary knowledge of the site to be documented and the available preexisting materials is also crucial to designing the documentation process; an on-site visit is also advised.

The design of the process will thus collect all the information retrieved in this phase and start setting up the necessary next steps. In the field of built heritage, it is also necessary to consider the conventional accuracy requested by the national or international entities in terms of traditional nominal scales of the products. In Italy, for example, the graphic error is by convention set to 0.2 mm (the minimum size of a line plottable and recognisable by the human eye), and to simplify, this value is used to define the accuracy and tolerance acceptable at the different representational scales. Usually, this value is multiplied by the scale factor to obtain the accuracy of our products and doubled to obtain the tolerance. To recap, after defining the survey objectives, we defined the needed products and the relevant representational scale to adopt, and finally, we selected the appropriate techniques to meet the accuracy and tolerance defined using the graphic error.

2. Data for supporting analyses is the next principle to be considered in the development of the documentation process. As clearly noticeable in the SLR, the documentation phase is always targeted at contributing to the knowledge process of the built heritage considered. In the search results, data are used in multiple ways to complete different types of analyses and support other research domains. Depending on the focus targeted by the knowledge process, it is necessary to adjust the documentation process. The examples reported in the previous sections are multiple: if the target is the decay or materials analysis, more effort in the documentation process must be placed on the radiometric information, which is crucial for this type of study. On the other hand, if structural analyses need to be performed, e.g., using FEM methodology, attention should be on the geometrical information. We have also seen that information coming from other sensors could be available, e.g., thermal or multispectral data, and these should be integrated into the documentation process as well. The coordination and cooperation with all the experts and the disciplines involved in the management and study of the documented built heritage is central and mandatory. Nevertheless, this is something that affects the overall strategy to be adopted in the documentation process and that needs to be considered in the design phase of the documentation activities. This phase is also connected to the final products, and thus, it influences the overall process, becoming the starting point of the process.
3. The techniques for products step are where all the information gathered in the first phases is used to determine which approaches to use in the field to achieve the expected results. Several factors need to be considered in this phase. First of all, the final products to be delivered at the end of the process highly impact the choice of the techniques. The products have an impact in terms of level of detail, type of information, accuracy, etc. As described in the two previous steps, products need to be defined with the commissioner and all the other experts involved in the study of the heritage considered.

What is clear in the SLR results is the fact that one single technique is hardly ever enough to satisfy all the needs of the documentation process. The solutions that are deployed are always based on multi-sensor and multi-scale approaches. This approach also led to a reflection on how to perform data fusion and integration, and the need to have operators that can deploy and manage complex processes. This is an aspect that needs to be considered as well when designing the documentation process and both the field and laboratory activities. The results of the SLR cover almost all the available geomatics techniques that could be deployed for built heritage documentation. TLS is a consolidated approach that is also often used as a ground reference for testing and validating new technologies. Photogrammetry still plays a central role and is still one of the preferred techniques thanks to its versatility, low cost, and automation level. The latter is deployed in the SLR both from the ground and using UAV systems. The aerial platforms have become more and more popular in recent years and are nowadays a consolidated approach in the field of built heritage documentation. In the realm of photogrammetry, spherical data faced a new growth in popularity, and despite being less consolidated in terms of data acquisition and processing, their use is rapidly growing, as reported by the number of results in the SLR. More recently, thanks to the evolution of portable devices and the sensors embedded in our smartphones, the use of personal devices is also gaining popularity. As described by the research present in the SLR, this technology is still evolving, and its use in the built heritage domain is still at an experimental stage, waiting to be evaluated and validated. Nevertheless, preliminary results are promising.

Finally, HMLS are the newest topic in terms of data acquisition in recent years. These

solutions have been deeply tested in the field of built heritage documentation and have proved to be a valid alternative in contexts where other techniques are less efficient, time is a crucial aspect, and some level of detail and accuracy can be sacrificed.

4. Topography for accuracy and metric control emerged as a central theme in the SLR. Despite the technological evolution of the techniques available for the metric survey of built heritage, traditional topography is still a core expertise that needs to be deployed in the field. The documentation process and its products need to be metrically validated both during the data processing and within the final report delivered to the commissioner. Moreover, the generated products need to meet the expected accuracy defined at the beginning of the documentation process. To comply with this need, first and second-order control networks need to be implemented. Depending on several factors, GNSS or Total Station might be used alone or integrated. The choice of which techniques to use is related, for example, to the extension of the site, the need to work indoors or outdoors, the final accuracy expected from the products, the techniques chosen, etc.

It is clear and well-known that first and second-order control networks should be carefully designed and documented, considering all the requirements described in the previous sections. Approaches of direct georeferencing have been developed and tested in the last few years, especially for photogrammetry in the UAV scenario; nevertheless, at this stage of development, they often still need to be supported by traditional topography.

5. Strategies for data processing and product generation is the phase where data needs to be processed and interpreted after fieldwork. An aspect that emerged from the SLR is the fact that we assisted in the automation and speed-up of the fieldwork phases. Nowadays, considering the same level of operators' expertise, it is easier to collect more data in less time; however, the discretization of data has been moved from the field to the office. The need for new strategies to manage and interpret the huge amount of data acquired in the field is clear in most of the SLR results. Aside from the optimisation of the standard processing pipeline, which is still a topic of research, attention has also been focused on the availability of new tools to enhance this phase. The use of AI is also reaching the geomatics field, with an approach that is sometimes referred to as GeoAI. These new tools might assist the researchers in managing the huge amount of data collected in the field and speed up the steps of data processing and interpretation. As emerged from the SLR, this field of research is strongly emerging, but it is in the early stage of development, and potentialities and limits need to be fully explored. In the SLR, the multifaceted nature of the products derived from the documentation process also emerged clearly. Excluding the need for traditional 2D drawings, which is still very often required, the attention in recent years has moved to more complex systems to manage 2D and 3D data. In particular, in the field of built heritage, HBIM and GIS have become a point of attention for researchers, driving a lot of the SLR results in deepening the use of these approaches and testing their potential.
6. Data for dissemination and management is the last step of the documentation process. It is again clear in the SLR that several research groups invested their effort in designing strategies to share and disseminate the results of the documentation process. This dissemination can be performed at different levels and to different stakeholders. On the one side, it is a tool for the operators and the entities that are in charge of managing the considered heritage as well as performing important tasks like risk assessment, management, and post-disaster intervention. On the other side, it is a way to promote this heritage among citizens and local communities. The collected and processed data

must be available via online platforms and tools to assist the processes of managing, protecting, and safeguarding heritage.

To conclude, the findings of this SLR have enabled the identification of six principal approaches corresponding to six key technical and practical requirements for the documentation of built heritage. These requirements are addressed through 17 core concepts distilled from the analysis of the literature retrieved from the SLR. These concepts are operationalised through several geomatics methods, tools, and techniques identified throughout the research. The outcomes of this study provide a valuable foundation for further reflection on current documentation practices and may serve as a basis for the development of more comprehensive and technical guidelines to support the stakeholders involved in built heritage documentation.

**Supplementary Materials:** The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/heritage8070249/s1>, Table S1: Concept matrix for the SLR results.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

## Notes

<sup>1</sup> <https://www.english-heritage.org.uk/> (accessed on 11 March 2025).

<sup>2</sup> <https://historicengland.org.uk/> (accessed on 11 March 2025).

<sup>3</sup> <https://www.icomos.org/> (accessed on 11 March 2025).

<sup>4</sup> <https://www.isprs.org/> (accessed on 11 March 2025).

<sup>5</sup> <https://www.cipaheritagedocumentation.org/> (accessed on 11 March 2025).

<sup>6</sup> <https://digitallibrary.cultura.gov.it/> (accessed on 11 March 2025).

<sup>7</sup> <https://digital-strategy.ec.europa.eu/en/library/basic-principles-and-tips-3d-digitisation-cultural-heritage> (accessed on 11 March 2025).

<sup>8</sup> [https://research-and-innovation.ec.europa.eu/research-area/social-sciences-and-humanities/cultural-heritage-and-cultural-and-creative-industries-ccis/cultural-heritage-cloud\\_en](https://research-and-innovation.ec.europa.eu/research-area/social-sciences-and-humanities/cultural-heritage-and-cultural-and-creative-industries-ccis/cultural-heritage-cloud_en) (accessed on 11 March 2025).

<sup>9</sup> <https://eureka3d.eu/> (accessed on 11 March 2025).

<sup>10</sup> <http://3dicons-project.eu/> (accessed on 11 March 2025).

<sup>11</sup> <https://www.3d4ch-competencecentre.eu/home> (accessed on 11 March 2025).

<sup>12</sup> <https://www.prisma-statement.org/> (accessed on 11 March 2025).

<sup>13</sup> <https://www.elsevier.com/products/scopus> (accessed on 11 March 2025).

<sup>14</sup> <https://clarivate.com/academia-government/scientific-and-academic-research/research-discovery-and-referencing/web-of-science/> (accessed on 11 March 2025).

<sup>15</sup> <https://www.zotero.org/> (accessed on 11 March 2025).

<sup>16</sup> <https://www.vosviewer.com/> (accessed on 11 March 2025).

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