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Review

The Application of Three Dimensional Digital Technologies in Historic Gardens and Related Cultural Heritage: A Scoping Review

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Abstract: This paper presents a comprehensive scoping review of the application of 3D digital technologies in the documentation, conservation, and management of historic gardens and related cultural heritage. By analyzing a curated selection of literature, this study assessed the current state of research, highlighting trends in publications, the geographic distribution of contributors, and the key technologies employed. Using bibliometric methods and visualization tools, followed by a case study review, this review identified significant research hotspots and technical methodologies, particularly focusing on advanced techniques such as mobile laser scanning, UAV photogrammetry, and point cloud processing and their relationships with end users. The findings emphasize the importance of integrating multiple technologies to capture the diverse elements of historic gardens, including architectural features, vegetation, and topography. This review also underscores the significance of dynamic landscapes facing challenges posed by environmental degradation and urban development pressures. Moreover, it discusses the limitations of existing research and outlines future opportunities, such as the development of 4D documentation systems and the incorporation of AI for improving heritage management. This paper concludes by recommending interdisciplinary collaboration and public engagement to enhance the accessibility, understanding, and sustainable management of historic gardens through innovative technological applications.

Keywords: historic gardens; 3D digital technologies; cultural landscapes; cultural heritage; geomatics; point cloud; scoping review

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1. Introduction

Three dimensional (3D) digital technologies enable the creation of highly detailed and accurate digital 3D models with computer-based tools and processes [1], which can be used for a wide range of purposes, from research and conservation to education and public engagement in Cultural Heritage (CH) [2].

This paper conducted a scoping review of literature to explore the application of 3D digital technologies in historic gardens and related heritage objects and then presents the topic in detail through some case studies. It aimed to address the growing acknowledgement of the geomatics field's contribution to this field. This study examined suitable and promising 3D digital technologies for application in Historic Gardens.

1.1. Historic Garden

Currently, historic gardens constitute a distinct and delicate subtype within the domain of CH. Primarily, the garden's structure is inherently fragile; its principal, albeit not exclusive, focal plant elements are susceptible to significant damage even from brief periods of neglect and exhibit a dynamic quality shaped by vegetation growth, climatic fluctuations, and management decisions. Some historical gardens, born as private villa gardens and later transformed into public gardens or parks, have undergone great transformations that, in most cases, fail to preserve their original values and are often now man-aged like a common green public area. Conversely, it is currently acknowledged that gardens, especially in urban areas, serve as a significant element of the landscape and as a pivotal component in shaping the cultural identity of the local populace residing near the gardens [3].

Historic gardens are an essential part of Cultural Heritage, reflecting the artistic, architectural, and horticultural styles of different eras and cultures. The Florence Charter, adopted by the International Council on Monuments and Sites (ICOMOS) in 1982, defines a historic garden as "an architectural and horticultural composition of interest to the public from the historical or artistic point of view" [4]. These gardens are considered living monuments that encompass a wide range of green spaces, from small formal gardens to expansive landscape parks. They combine permanent features, such as layout, topography, structures, and decorative elements, with the dynamic and perishable nature of vegetation [4].

According to the "Italian Charter of Historic Gardens" drafted in 1981, the historic garden, like architecture, can be understood as a palimpsest, a text repeatedly written and rewritten, possessing its own material consistency, with sedimented and stratified signs that cannot be erased [4,5].

Surveying gardens is essential and crucial to supporting documentation, study, analysis, and historical field research. In particular, the survey is indispensable in documenting any remaining evidence of gardens that no longer exist.

As a type of cultural landscape listed in the UNESCO Operational Guidelines (2023) [6], a historic garden could be "an area, perceived by people, whose character is the result of the action and interaction of natural and/or human factors" [7].

Historic gardens face numerous challenges today, such as natural deterioration, inadequate maintenance, and pressure from urban development [8]. Natural and human-induced disasters present substantial threats to these delicate landscapes, highlighting the need for comprehensive disaster risk management and consistent maintenance efforts. To ensure their preservation for future generations, detailed management plans that incorporate maintenance, conservation, restoration, and, in certain instances, reconstruction, are crucial [4,9].

These plans should be grounded in thorough research and documentation, utilizing modern technologies and fostering collaboration among experts from multiple disciplines [4,10]. Furthermore, raising public awareness and promoting the value of historic gardens through education, research, and enhanced accessibility are essential for their long-term conservation [4,11].

1.2. 3D Digital Technologies

The application of 3D digital technologies has become increasingly prevalent in the field of CH, especially the tangible cultural heritage, offering numerous benefits and opportunities ranging from documentary research for preservation to digital applications for public engagement. These cutting-edge tools enable the creation of detailed, accurate, and immersive digital representations of cultural assets, such as artifacts, monuments, and sites, by capturing, modeling and visualizing them in a digital format. The process of creating digital representations involves several steps, including data acquisition [12–14], data processing [15], modeling [16–18], texturing [18,19], and visualization [20–22]. Various for public engagement. These cutting-edge tools enable the creation of detailed, accurate, and immersive digital representations of cultural assets, such as artifacts, monuments, and sites, by capturing, modeling and visualizing them in a digital format. The process of creating digital representations involves several steps, including data acquisition [12–14], data processing [15], modeling [16–18], texturing [18,19], and visualization [20–22]. Various techniques and software tools are employed in each stage to ensure the accuracy, quality, and authenticity of the digital representation (Figure 1).

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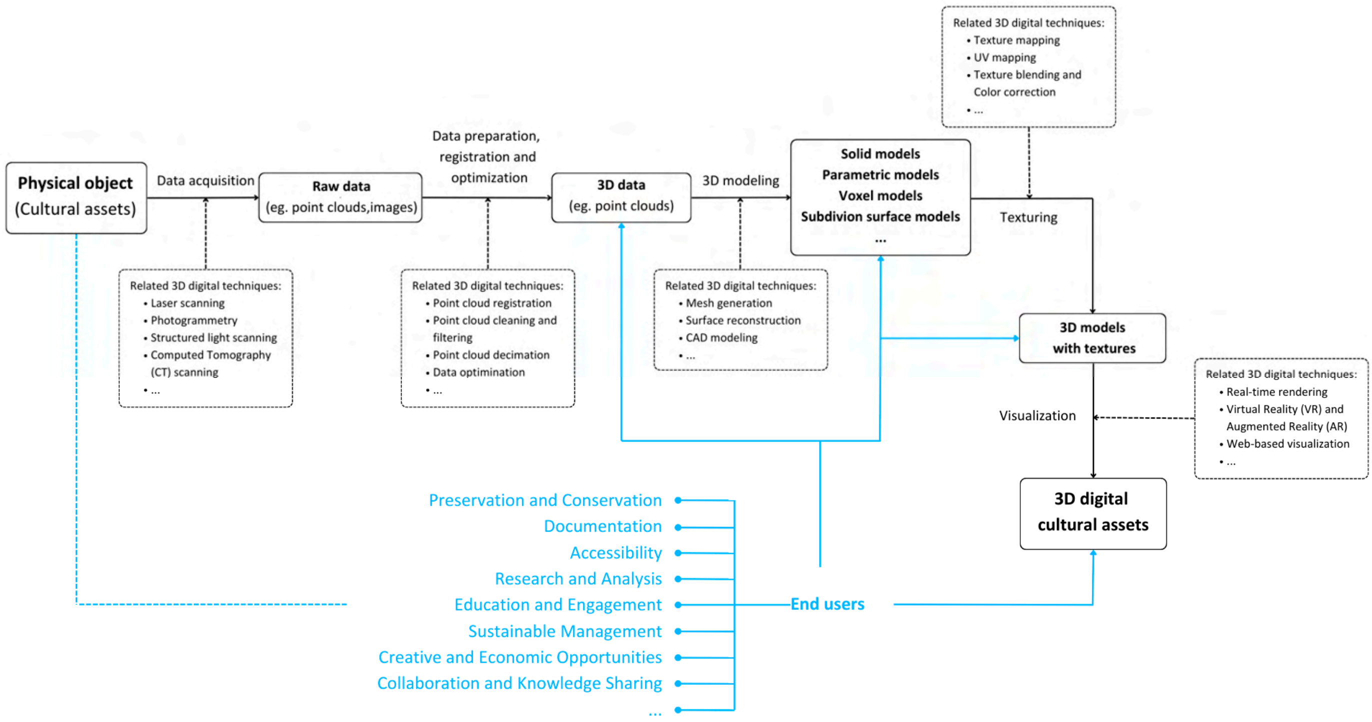

Figure 1. The schematic process of applying 3D digital techniques in Cultural Heritage and the use by end users.

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3D models as the main digital representations of objects or structures could be created from point clouds acquired using surveying techniques such as laser scanning, photogrammetry, or computer-aided design (CAD) technologies. These models accurately capture the geometry, texture, and appearance of the original objects, enabling detailed visualization, analysis, and other applications for end-users [23]. By creating accurate and detailed 3D digital models, the long-term preservation and management of cultural heritage assets can reap benefits, even in the face of potential loss or damage to physical objects and sites [24]. These digital copies provide comprehensive documentation, enabling researchers to conduct in-depth analysis and make informed decisions [25].

Moreover, 3D digital technologies enhance accessibility, allowing Cultural Heritage to be shared and experienced by people worldwide through online platforms and virtual environments [26–28]. They facilitate collaboration among professionals, foster interdisciplinary studies, and create new opportunities for education, creative industries, and sustainable heritage management. Ultimately, by harnessing the power of 3D digital technologies, cultural treasures can be safeguarded, new knowledge can be unlocked, and a deeper appreciation can be inspired for the shared heritage among future generations [29].

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1.3. Current Application for 3D Digital Technology in Historic Gardens

ICOMOS has actively advocated for the purposeful and organized use of digital technologies, including 3D surveying, modeling, and information management, in Cultural Heritage projects [30].

In the field of historic gardens, 3D digital technologies have been making increasingly significant contributions and can become a beneficial tool to support heritage conservation efforts. For instance, Unmanned Aerial Vehicle (UAV) photogrammetry, Airborne Laser Scanning (ALS), Mobile Laser Scanning (MLS), Terrestrial Laser Scanning (TLS) or other

3D surveying techniques have been applied to historic gardens to acquire point cloud data and obtain satisfying and complete 3D geometric information [16,31,32].

By collaborating with other digital techniques including Geographic Information Systems (GIS), Information modeling, VR, AR or other Web-based technologies, 3D models of garden objects can be used for information management, interactive visualization, or stakeholder collaborations of garden heritage [33–35].

Historic gardens or parks are often extensive in scale, with abundant, diverse, and complex heritage elements. The application of 3D digital technologies to historic gardens, compared to other heritage assets like historical buildings and archaeological sites, can be more complicated and require different technologies and skills [36].

Digitizing historic gardens can mean a range from cartographic scale to high-detail objects. For instance, historic gardens possess a lot of different spatial features and patterns of dynamic change. Many technologies are needed to capture and record their topography, architectural structures, and vegetation, providing a reliable data foundation for subsequent stages (investigate, preserve, manage, etc.).

The optimal application of the digitizing process to historic gardens can actively contribute to their maintenance and conservation, provide valid metric support, and serve as a starting point for any other management tools (CAD, GIS, WEB, etc.).

1.4. Objectives

This article sought to explore and illuminate the current state of advanced 3D digital technologies in historic gardens and related heritage objects. It thoughtfully examined the diverse techniques and tools employed in this realm and aspired to uncover opportunities and areas for further exploration within this field of research.

1.5. Scope

A scoping review presents an overview of a broad topic from a potentially large and diverse body of literature, sharing a rigorous and transparent method for comprehensive identification and analysis [37].

The scope of this review was defined based on the three conceptual constructs to explore the application of 3D digital technologies in historic gardens and related cultural heritage. A comprehensive list of key terms for the literature search was developed (Table 1).

Table 1. Key search terms.

Adjectives for Heritage Construct	Garden Construct	3D Digital Technologies Construct
Historic	Garden	Point cloud
Historical	Park	3D survey
Heritage		3D modeling
Archeological		3D visualization

To comprehensively obtain literature related to this topic, the concept of "historic garden" was divided into two conceptual constructs. In the "Adjectives for Heritage Construct", similar adjectives such as "Historic", "Historical", "Heritage", and "Archaeological" were used to present the historical values of objects. According to the definition and scope of the historic garden [4], in the "Garden Construct", in addition to the common key term "Garden", "Park" was included to represent gardens and related objects. Regarding 3D digital technologies, this article focused on 3D data acquisition, processing, modeling and visualization of heritage objects, and the point cloud as a fundamental component. Therefore, "Point Cloud", "3D Survey", "3D Modeling" and "3D Visualization" were selected as key terms in this conceptual construct to explore the applications of 3D digital technologies.

1.6. Structure of Scoping Review

This article critically selects and reviews current international research papers on the application of 3D digital technologies in historic gardens and related fields. The structure of a scoping review covers five parts [37]:

1. Identifying research question(s);
2. Searching for literature;
3. Selecting studies;
4. Extracting and mapping data;
5. Synthesizing and reporting the results.

Based on the research objectives, three review questions are posed in this article:

- What is the current state in this research field?
- How are 3D digital technologies applied to historic gardens and related heritage objects?
- What could be the current gaps, and which 3D digital techniques and tools could be more suitable or promising for this research field?

To answer these questions, this paper continued the review by identifying relevant articles using key search terms and predefined inclusion/exclusion criteria. The selected articles were then subjected to data extraction and analysis. Based on the synthesized results, this paper discussed current gaps in literature and proposed potential directions for future research within this field of study.

2. Materials and Methods

This scoping review followed the PRISMA-ScR guidelines [38]. This section details the eligibility criteria, information sources, search strategy, and the process for selecting evidence sources based on inclusion and exclusion criteria. It also includes the key search terms used, the data charting process, the specific data items collected, and the methods for critically analyzing and synthesizing the results.

2.1. Eligibility Criteria

The final review papers were selected based on the following inclusion and exclusion criteria:

- Articles published in English or in other languages with available English translations were included.
- Books or conference proceedings were excluded.
- Articles not related to heritage, gardens and 3D digital technologies were excluded.
- Only articles with full text access were included.

2.2. Search Process

To identify relevant studies for the research topic, two comprehensive database searches were conducted based on key search terms, and the literature search process concluded with the final queries executed during January 2025:

- In Scopus, the search query employed a combination of keywords that were found in the article's title, abstract or author keywords, specifically: TITLE-ABS-KEY (("Historic" OR "Historical" OR "Heritage" OR "Archaeological") AND ("Garden" OR "Park") AND ("Point cloud" OR "3D Survey" OR "3D Modeling" OR "3D Visualization")). This initial search yielded a total of 158 records.

- In Web of Science, records where the search terms appeared in any part of the database record were retrieved. In detail: ALL = ((“Historic” OR “Historical” OR “Heritage” OR “Archaeological”) AND (“Garden” OR “Park”) AND (“Point cloud” OR “3D Survey” OR “3D Modeling” OR “3D Visualization”)). The preliminary search query resulted in the retrieval of 103 records.

Finally, a total of 261 studies were identified (Table 2).

Table 2. Search results (8 January 2025).

Adjectives for Heritage Construct (AND)	Garden Construct (AND)	3D Digital Technologies Construct (AND)	Number of Studies
Historic OR Historical OR Heritage OR Archeological	Garden OR Park	Point cloud OR 3D survey OR 3D modeling OR 3D visualization	158 in Scopus
			103 in Web of Science

2.3. Screening

The screening process involved systematically evaluating the eligibility of each article by reading the titles, keywords and abstracts of all records and applying the inclusion/exclusion criteria initially. If an article was deemed to meet the criteria, the full text would be accessed online and selected if available. The full text of the records was reevaluated against the eligibility criteria to obtain final review articles. Figure 2 illustrates the screening process, and the inclusion stage resulted in the selection of 58 studies from 2001 to 2024 for the literature review.

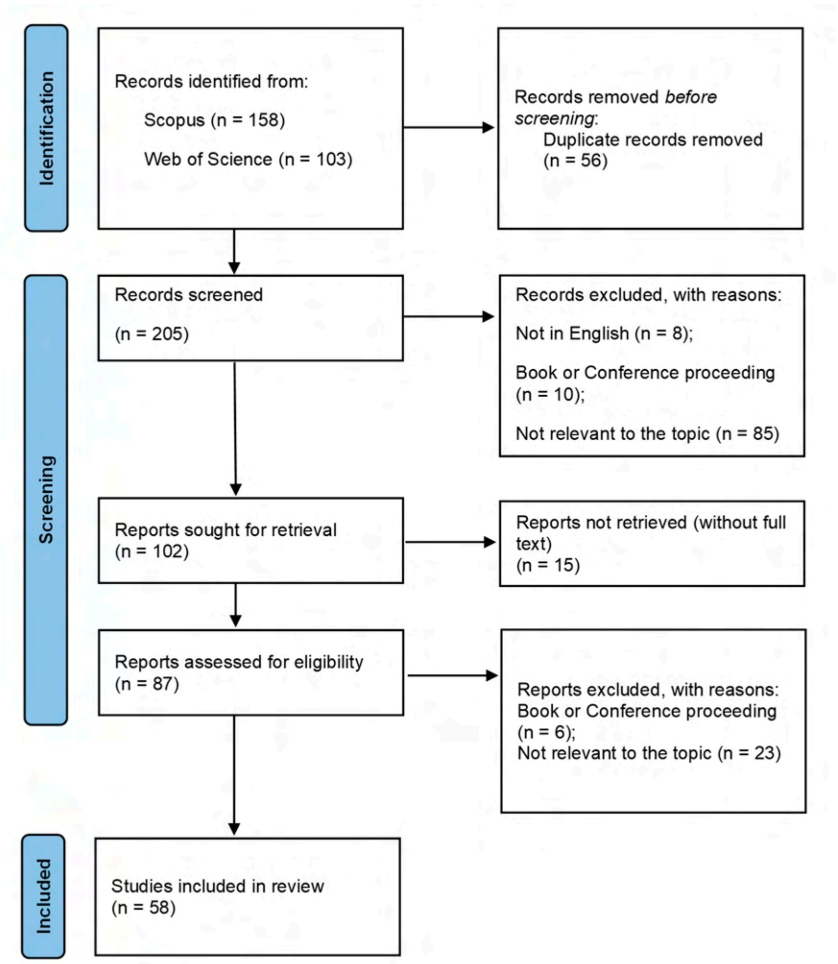

Figure 2. The flow diagram for the literature search and evaluation for inclusion.

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2.4. Data Charting

Data from the included articles were extracted and entered into a custom-designed data sheet addressing the three review questions and review objectives. The extracted data categories included:

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1. Reference: Author(s)/Date of publication;
2. Source: Publishers/Journals or organizations contributing to academic work;
3. Country (for studies with authors from different countries, the affiliations were grouped under "International cooperation" or "European cooperation");
4. Types of heritage studied;
5. Location of heritage;
6. 3D digital techniques and tools applied;
7. Objectives and results.

For Reference, Source and Country data, information was gathered after retrieving the relevant articles. Other data were extracted from the abstracts or full texts. These data were subsequently analyzed and synthesized to address the research questions and objectives.

2.5. Analysis and Synthesis

Two primary methods were employed for the analysis and synthesis of the extracted data and papers included. Firstly, bibliometric methods and statistical functions were applied to analyze the Reference, Source, and Country data, with the aim of evaluating the impact, performance, and characteristics of the research outputs within this specific field of study [39]. This analysis provided insights into influential publications, key authors, and the geographical distribution of research activities.

Subsequently, the data extracted from abstracts or full texts were organized into keyword groupings and analyzed using the same bibliometric approach. This categorization facilitated the identification of prevalent technical methods and tools, as well as the research focus concerning various heritage objects and their respective locations. Through synthesis, the relationships and interconnectedness among the papers were explored, revealing potential patterns and trends within the discipline.

Finally, building upon these analyses, a case study review method was employed to conduct an in-depth examination of selected cases from the reviewed papers, thereby enhancing the understanding of the practice of 3D digital technologies in historic gardens and related elements.

3. Results

This section presents a comprehensive analysis and synthesis of the findings from the included studies. The first part employed bibliometric techniques and data visualization to provide an overview of the literature. The second part provided a detailed examination of the methods employed in the selected studies and their implications through case study review. These findings contribute to a deeper understanding of the current state of knowledge in this specific research field and are further discussed in the following section.

3.1. Overview of the Included Studies

3.1.1. Interannual Distribution of Paper

Since 2001, the application of 3D digital technologies has become increasingly prominent in this research field as evidenced by the growing volume of publications on this topic (Figure 3).

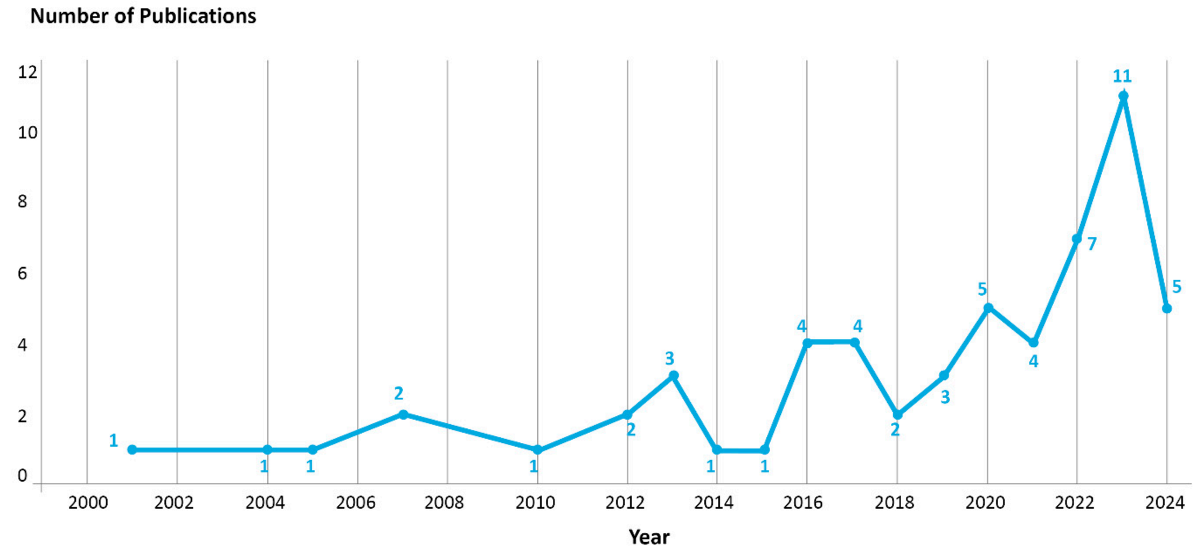


Figure 3. Number and trend of publications that met the selection criteria set.

It is noteworthy that, after 2016, there has been a consistent upward trend in the number of publications, culminating in a peak in 2023. This trend indicates a growing interest and heightened research activity in the area.

The rise in publications may suggest potential breakthroughs or significant advancements in the application of 3D digital technologies to historic gardens and related cultural heritage contexts during this period. Contributing factors to this increase may include technological advancements, improved accessibility to tools and software, and a rise in research funding and collaborative efforts. While there have been intermittent declines in the number of published papers since 2017, this may reflect the substantial time investment required for research projects focusing on this subject, particularly in areas such as data collection, analysis, and interpretation, which can significantly extend the research lifecycle.

3.1.2. Distribution of the Affiliations of Researcher by Country

Italy emerges as the leading country, with its researchers and institutions contributing the highest number of publications in this research area (Figure 4). This highlights that Italy has a robust and active research community dedicated to exploring the applications of 3D digital technologies in historic gardens and associated fields [40]. The country's rich Cultural Heritage, numerous historical sites, and strong emphasis on preservation and conservation may have contributed to this significant research output. China follows Italy as the country with the second-highest number of publications, indicating a substantial research interest and expertise in this domain. The presence of several historic gardens and a vibrant research community in China may have fueled this notable contribution to the field. Except for national cooperation, international cooperation and European cooperation indicate that collaborative initiatives and research inputs from diverse global regions are influencing the application of 3D digital technologies in historic gardens.

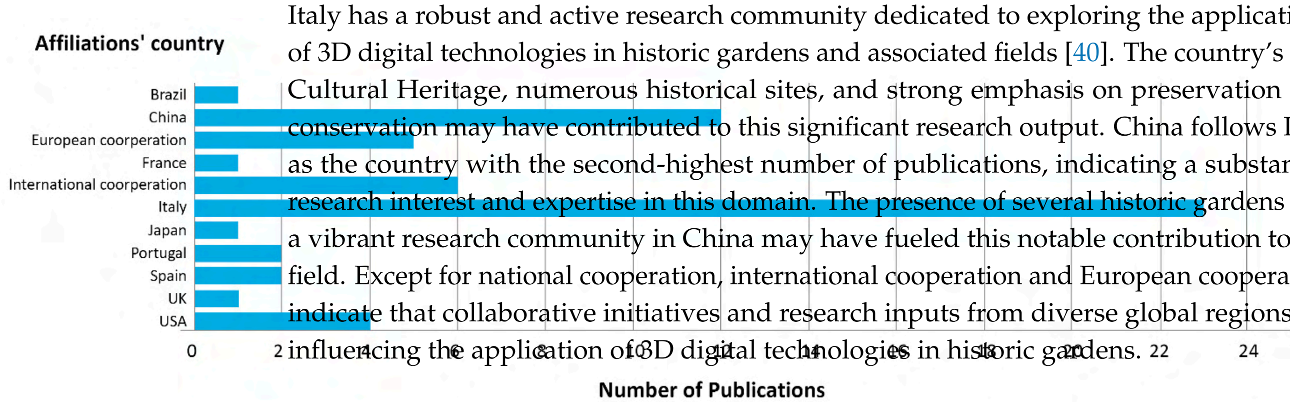
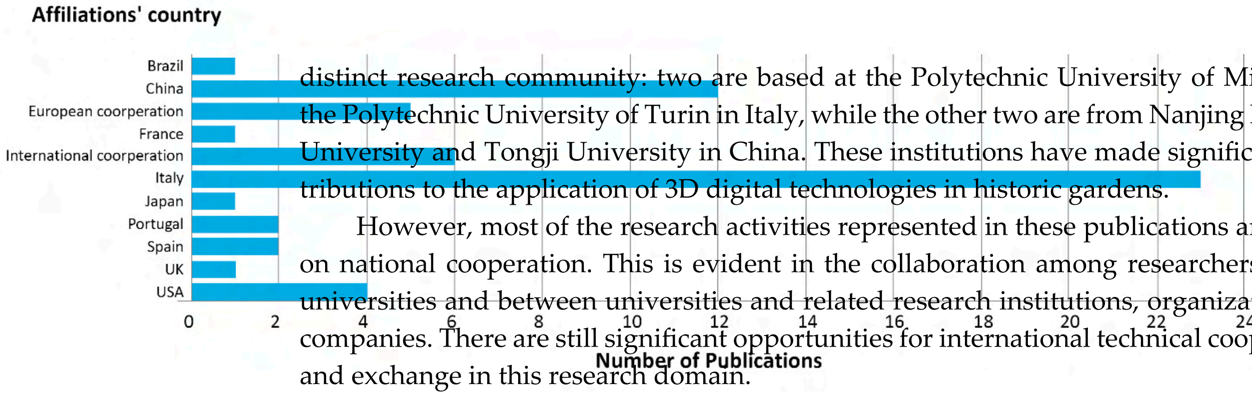


Figure 4. The number of publications categorized by the country affiliations of researchers.

3.1.3. Distribution of Authors

Approximately 200 researchers contributed to the selected literature. To analyze co-authorship patterns, authors with more than two publications in this review were selected to explore their relationships with other researchers in the field. Ultimately, six authors were identified, forming four co-authorship clusters (Figure 5). Each cluster represents a distinct research community: two are based at the Polytechnic University of Milan and the Polytechnic University of Turin in Italy, while the other two are from lows Italy as the country with the second-highest number of publications, indicating a substantial research interest and expertise in this domain. The presence of several historic gardens and a vibrant research community in China may have fueled this notable contribution to the field. Except for national cooperation, international cooperation and European cooperation indicate that collaborative initiatives and research inputs from diverse global regions are influencing the application of 3D digital technologies in historic gardens.

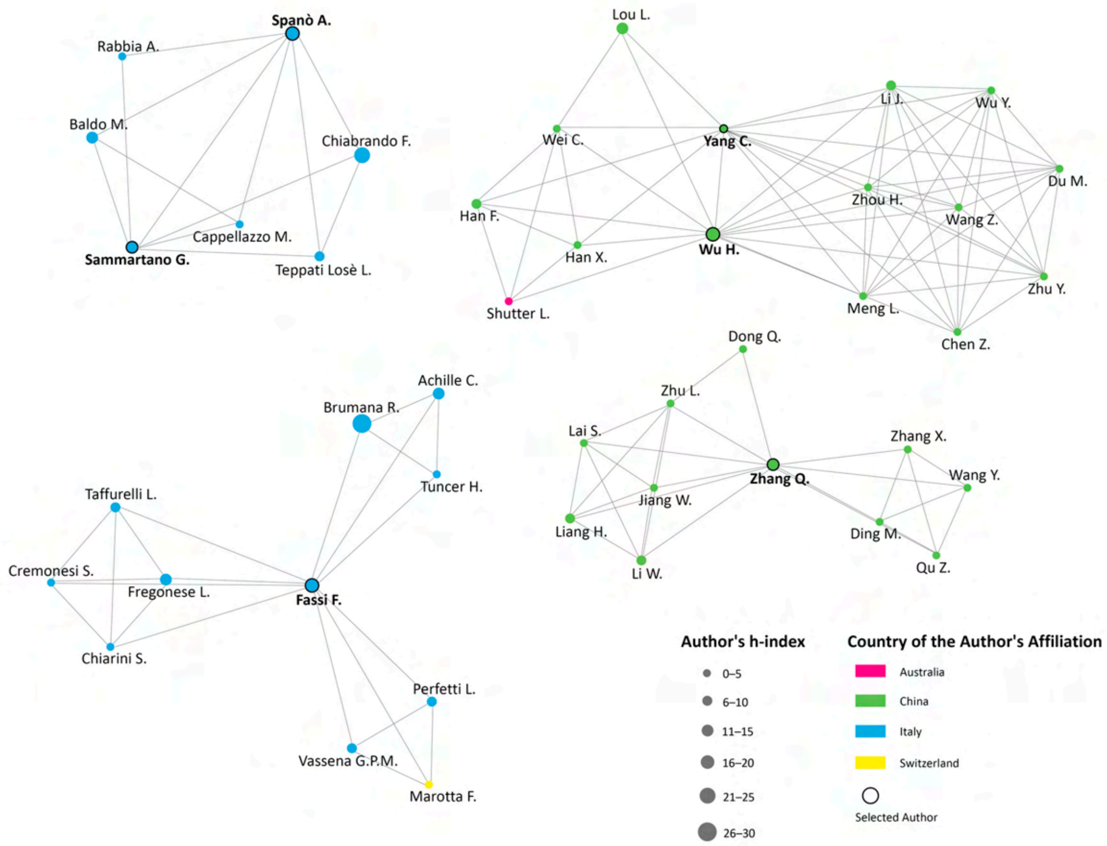
Nanjing Forestry University and Tongji University in China. These institutions have made significant contributions to the application of 3D digital technologies in historic gardens.



distinct research community: two are based at the Polytechnic University of Milan and the Polytechnic University of Turin in Italy, while the other two are from Nanjing Forestry University and Tongji University in China. These institutions have made significant contributions to the application of 3D digital technologies in historic gardens.

However, most of the research activities represented in these publications are based on national cooperation. This is evident in the collaboration among researchers within universities and between universities and related research institutions, organizations, or companies. There are still significant opportunities for international technical cooperation and exchange in this research domain.

Figure 4. The number of publications categorized by the country affiliations of researchers.



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3.1.4. Distribution of Sources

The selected papers are distributed across 34 journals and other academic contributions. The top ten journals, conferences, and proceedings account for a significant proportion of the published papers, with high influence, as shown in Table 3.

The papers published in these journals or other sources collectively cover the multidisciplinary and multi-scale characteristics of digital technologies in the preservation and study of historic gardens and related areas. They reflect a convergence of fields including Digital Humanities, Cultural Heritage, Remote Sensing, Geomatics, Urban Development and Computer Science, demonstrating the breadth and depth of ongoing research. These publications explore various aspects, including the use of multiple data sources, the integration of different technologies, key technological advancements, and innovative applications, which highlight the growing trend of technological collaboration and interdisciplinary integration in this domain.

Table 3. Representative journals or conferences and proceedings [42].

Source Title	Type	Covering the Categories	h-Index	Publisher	Number of Selected
International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences—ISPRS Archives	Conferences and Proceedings	Geography; Planning and Development; Information Systems	87	International Society for Photogrammetry and Remote Sensing	15
ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences	Conferences and Proceedings	Earth and Planetary Sciences; Environmental Science; Instrumentation	53	Copernicus GmbH	3
Heritage Science	Journals	Archeology (Q1); Archeology (arts and humanities) (Q1); Conservation (Q1); Chemistry (miscellaneous) (Q2); Computer Science Applications (Q2); Materials Science (miscellaneous) (Q2); Spectroscopy (Q2)	35	Springer Science + Business Media	3
Urban Forestry & Urban Greening	Journals	Ecology (Q1); Forestry (Q1); Soil Science (Q1)	117	Elsevier GmbH	2
Journal of Cultural Heritage	Journals	Anthropology (Q1); Archeology (arts and humanities) (Q1); Conservation (Q1); Economics, Econometrics and Finance (miscellaneous) (Q1); History (Q1); Chemistry (miscellaneous) (Q2); Computer Science Applications (Q2); Materials Science (miscellaneous) (Q2); Spectroscopy (Q2)	84	Elsevier Masson s.r.l.	2
Virtual Archaeology Review	Journals	Archeology (Q1); Archeology (arts and humanities) (Q1); Conservation (Q1); Computer Science Applications (Q3)	17	Universitat Politecnica de Valencia	2
PLoS ONE	Journals	Multidisciplinary (Q1)	435	Public Library of Science	1
AUTOMATION IN CONSTRUCTION	Journals	Building and Construction (Q1); Civil and Structural Engineering (Q1); Control and Systems Engineering (Q1)	176	Elsevier B.V.	1
Sustainability (Switzerland)	Journals	Geography, Planning and Development (Q1); Computer Networks and Communications (Q2); Energy Engineering and Power Technology (Q2); Environmental Science (miscellaneous) (Q2); Hardware and Architecture (Q2); Management, Monitoring, Policy and Law (Q2); Renewable Energy, Sustainability and the Environment (Q2)	169	Multidisciplinary Digital Publishing Institute (MDPI)	1
Landslides	Journals	Geotechnical Engineering and Engineering Geology (Q1)	113	Springer Verlag	1

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3.1.5. Types of Cultural Heritage Studied

The types and location of heritage objects were extracted from the selected papers to demonstrate the diverse research focus on historic gardens and related heritage objects across different countries (Figure 6).

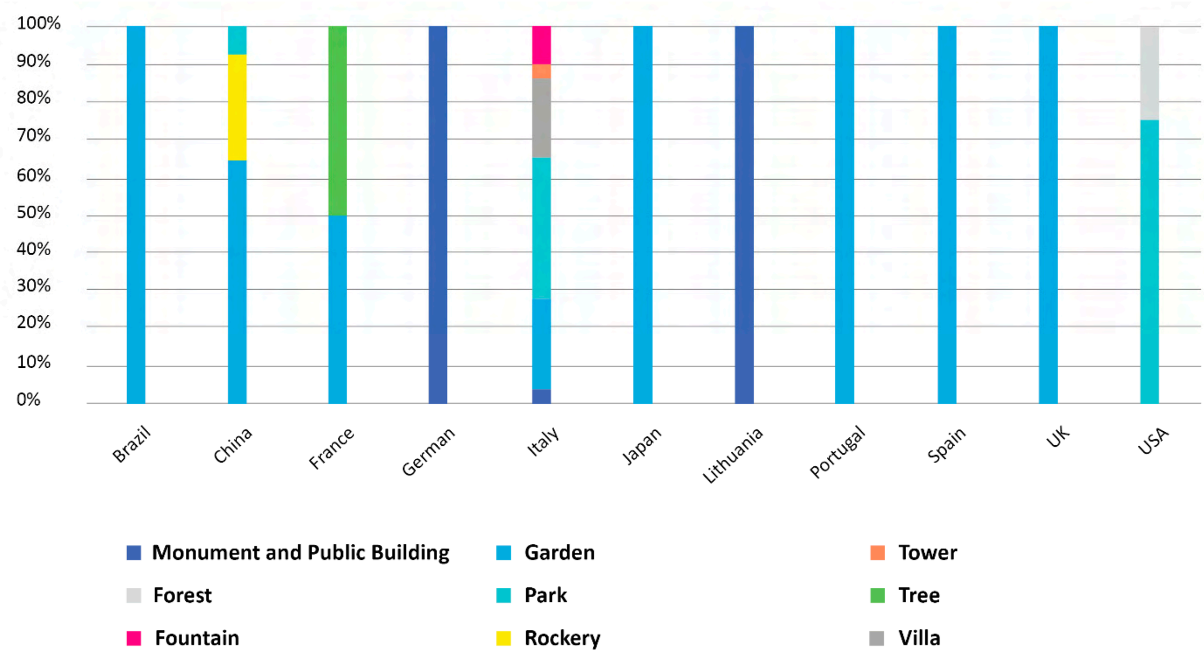

Figure 6. The type and location of heritage objects studied.

The research objects can be divided into two categories: studies that focus on historic gardens as an object, investigating the application of 3D digital technologies to historic gardens and parks; and studies that consider historic gardens as an area, examining the heritage objects contained within or associated with them, such as monuments and public buildings, forests, historical fountains, rockeries, towers, trees, and villas. The research emphasis on different types of historic garden heritage varied among countries, depending on the location and context of the heritage sites. For example, studies in Italy were probably the most inclusive, involving monuments and public buildings, trees, fountains, and villas, while those in China focused more on rockeries. This variation in research focus is influenced by the unique cultural, historical, and environmental factors that shape the characteristics of historic gardens in each country. Moreover, the choice and application of digital technologies in these studies are determined by the scale and features of the research objects. The diverse range of heritage objects within historic gardens, from individual elements like trees and fountains to larger structures such as towers and villas, requires tailored technological approaches.

Figure 6. The type and location of heritage objects studied.

3.1.6. 3D Digital Techniques for Data Acquisition in Historic Gardens and Related Fields

The application of 3D digital technologies for data acquisition in historic gardens and related heritage objects is driven by the pursuit of accuracy, non-invasiveness, non-destructiveness, efficiency, and cost-effectiveness. These key factors influence the choice of data acquisition techniques in this domain. Data acquisition is the primary and crucial step in applying 3D digital technologies, and as Figure 7 illustrates, various technologies have spread rapidly in the historic garden field. The acquisition technologies include photogrammetry and laser scanning, terrestrial and airborne methods, and static and dynamic mobile scanning, allowing for adaptation from a single object to a large area.

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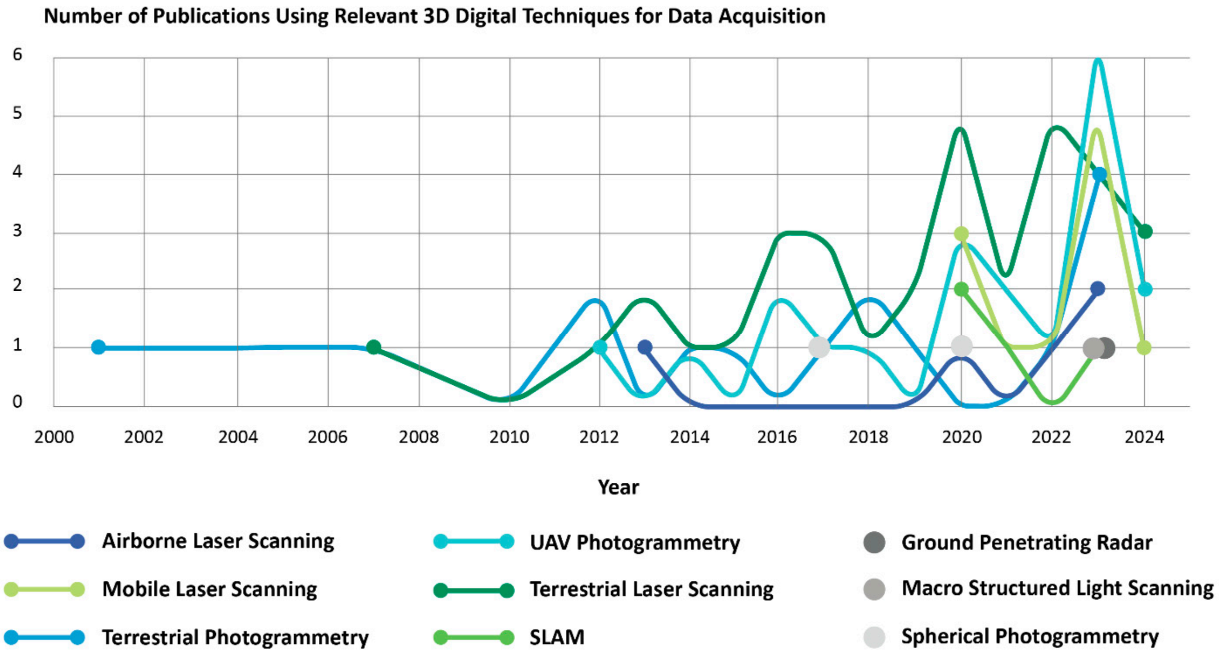

Figure 7. 3D digital techniques for data acquisition in selected publications and their annual variations.

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3.1.7. 3D Digital Technologies in Historic Gardens and Their Use by End Users

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Following the extraction and analysis of keywords from the selected literature, this synthesis developed a comprehensive framework for understanding the complex interactions between various 3D digital techniques, heritage objects, and their end users within the context of historic gardens (Figure 8). Generally, the first purpose of a survey is to produce a complete and accurate description of the site geometry. With 3D survey data, it is clear that all the other 2D representations have been added together with the technical representations (plans, sections, profiles). The 3D data and models can then be used in various other applications.

By mapping the connections between acquisition methods and the specific elements they are applied to, such as villas, vegetation and trees, towers, rockeries, monuments and public buildings, these relationships emphasize the versatility and adaptability of these technologies in addressing the distinct challenges posed by the multifaceted nature of historic gardens.

Additionally, these acquisition methods operate within a broader system of digital technologies, including web-based visualization tools, virtual and augmented reality platforms, machine learning algorithms, Building Information Modeling (BIM), and GIS. This integration underscores the interdisciplinary nature of Cultural Heritage development and the potential for combining multiple technological solutions to enhance the documentation, analysis, interpretation, and dissemination of knowledge regarding historic gardens.

By examining the various end uses of the acquired 3D data, ranging from visualization and research to conservation planning and public engagement, this analysis demonstrated the pivotal role that 3D digital technologies play in facilitating sustainable man-

applying these technologies. This focus on user-centered design and participatory methodologies reflects the growing recognition of the social and cultural dimensions of heritage preservation, as well as the necessity for inclusive and collaborative strategies in safeguarding Cultural Heritage.

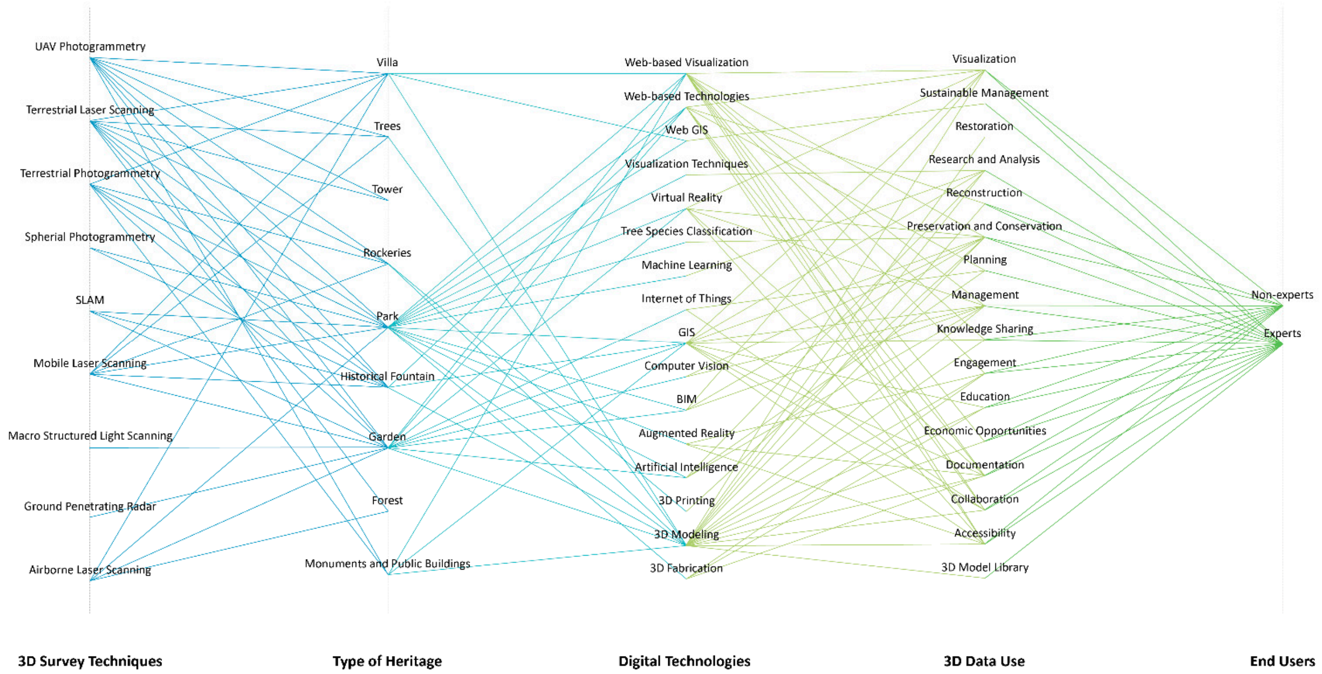

Figure 8. Relationships among 3D digital techniques, heritage objects and end users.

By examining the various end uses of the acquired 3D data, ranging from visualization and research to conservation planning and public engagement, this analysis demonstrated the pivotal role that 3D digital technologies play in facilitating sustainable management practices. These technologies enable innovative research approaches, support restoration efforts, and promote greater accessibility and appreciation of historic gardens among diverse audiences.

Furthermore, the framework recognizes the importance of addressing the needs and perspectives of various stakeholders, including experts and the public, in developing and applying these technologies. This focus on user-centered design and participatory methodologies reflects the growing recognition of the social and cultural dimensions of heritage preservation, as well as the necessity for inclusive and collaborative strategies in safeguarding Cultural Heritage.

3.2. Key Studies

Historic gardens, including gardens and parks, differ in their features, cultural significance, and developmental needs. These differences directly influence the choice of 3D digital technologies and how they are applied. The selected case studies explored a range of 3D representation goals, from capturing individual garden elements to documenting entire garden or park areas.

The case studies also examined the use of geomatics tools and procedures for surveying historic gardens. They discussed the strengths and limitations of these methods and highlighted how 3D digital data could be applied in practical ways. This included supporting conservation efforts and enhancing visitor experiences. The research demonstrated how 3D technologies can be adapted to address the unique requirements of different historic gardens, making them valuable tools for both preservation and sustainable use.

Geomatics techniques represent an effective tool for obtaining the requested technical drawings and 3D representation and making them available to researchers and conservators. In its most diverse forms, surveying is the first essential step and indispensable for studying gardens and organizing and planning their conservation and management activities.

The introduction of new technologies, tools, and methods is transforming site surveying processes and the outcomes of mapping activities. At the same time, it is also shaping how digital data is applied in the development and management of historic gardens.

Heritage **2025**, *8*, x FOR PEER REVIEW 15 of 30

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3.2.1. Survey of Historic Gardens or Parks in the Past

In the past, the surveying process consisted of measuring single points on the field by total station or by GNSS and producing 2D drawings from these data using CAD technologies. Especially in the past, it was crucial to establish an accurate reference network, as described in [43], with well-materialized vertices of known coordinates, unambiguously identifiable and positioned in stable areas. These vertices were measured typically by using total station or, for large areas, by GNSS. This strategy required a lot of time in the field. The expected results consisted of tens or hundreds of measured points chosen by the operator, which were then used to produce 2D technical drawings or basic 3D models (Figure 9).

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Afterward, topographic surveying techniques evolved rapidly and continuously, and today, the classic ones are flanked with the data generated by a laser scanner or image elaboration.

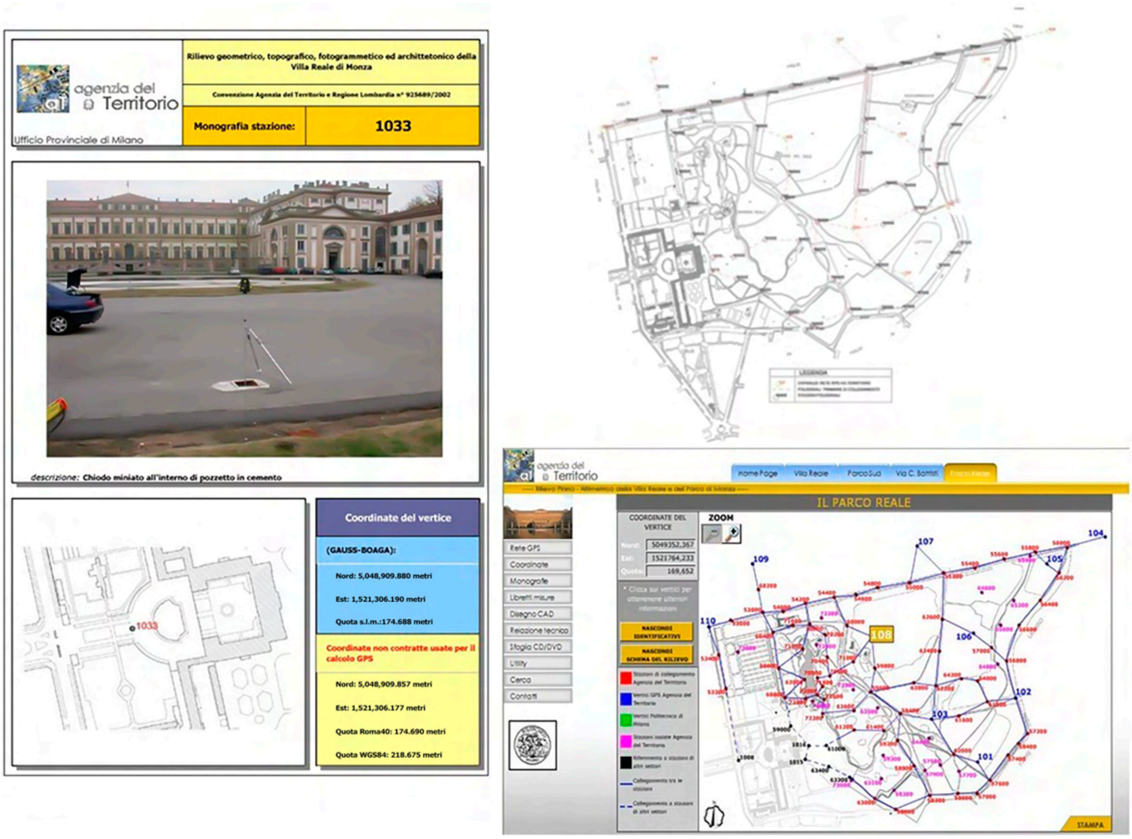

Figure 9. Topographic reference network practice and visual representation, extended to cover the complete garden of the **Villa Reale di Monza** [43].

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3.2.2. 3D Survey of Historic Gardens

The elements of a garden are diverse and intricate. Each feature, from plants to architectural structures, holds symbolic meanings connected to culture, philosophy, or religion. These meanings are also reflected in the spatial relationships between elements. For a long time, the preservation and development of gardens relied mainly on 2D mapping tools and techniques.

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Now, advanced technologies provide more options for capturing 3D data. In gardens, especially classical ones, different 3D surveying methods are being explored to collect detailed information about individual objects. Researchers also combine various techniques to create full 3D models of entire gardens. These models are used with other tools, supporting conservation and management, offering a deeper understanding of the garden as a whole.

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Terrestrial Laser Scanners can capture reality with a massive number of points and resolutions selected according to the project's final target. The process of capturing 3D reality has become more efficient and fast compared to the labor-intensive task of conducting a comprehensive survey using a total station. However, the post-processing efforts of managing the vast quantity of data obtained by the TLS have significantly increased compared to the restitution activity required by a classical survey.

Currently, TLS is widely used in heritage conservation due to its ability to capture detailed 3D models of complex structures. This makes it especially suitable for historic gardens with diverse elements and intricate layouts, even when they cover relatively small areas. For example, Jia and colleagues used TLS to collect detailed 3D spatial data of the Jianxin Courtyard, a representative site of Chinese royal gardens, covering an area of 5257 m^2. The survey included 102 sites with point cloud data (Figure 10) [44].

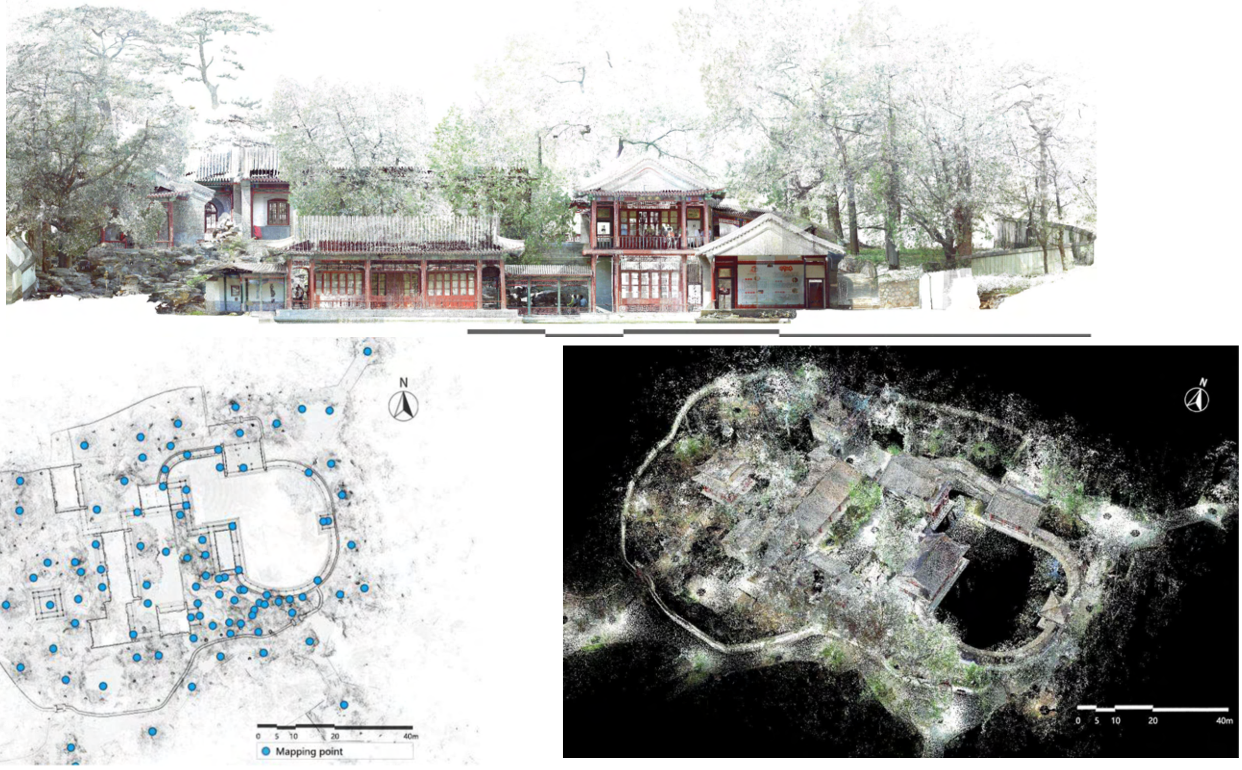

Figure 10. Results of a 3D survey by laser scanner: on the top, garden-wide point cloud model orthogonal maps; below on the left, the positions of the static scans; below on the right, the Garden-wide point cloud model of Jianxin courtyard in Jingyi garden [44].

Using the point cloud data of the entire Jianxin Courtyard, the study classified and extracted garden elements, including the water body, vegetation, rockery, architecture, and surrounding environment. These data were then used to build information models, which ultimately supported the conservation and management of these elements.

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Compared with TLS, UAVs enable rapid data collection over large areas, accessing challenging terrains that TLS may not reach. UAV photogrammetry is generally more cost-effective and provides high-resolution imagery, facilitating the creation of detailed 3D models and orthophotos. While TLS excels in precise geometric measurements of manufactured objects and structures, the flexibility and efficiency of UAV photogrammetry make it a valuable complement, particularly for documenting complex landscapes and structures in vast Cultural Heritage contexts that require an approach at a cartographic scale.

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In another case study, Liang et al. [45] used a combination of TLS, Terrestrial Digital Photogrammetry (TDP), and Unmanned Aerial Vehicle Digital Photogrammetry (UAVDP) to document Huanxiu Shanzhuang (HXSZ), a Chinese classical garden and UNESCO World Heritage site. The garden covers an area of 2179 m^2 and features rich spatial layers and diverse landscape elements. This approach created accurate 3D models and 2D drawings of the garden's intricate spatial elements (Figure 11).

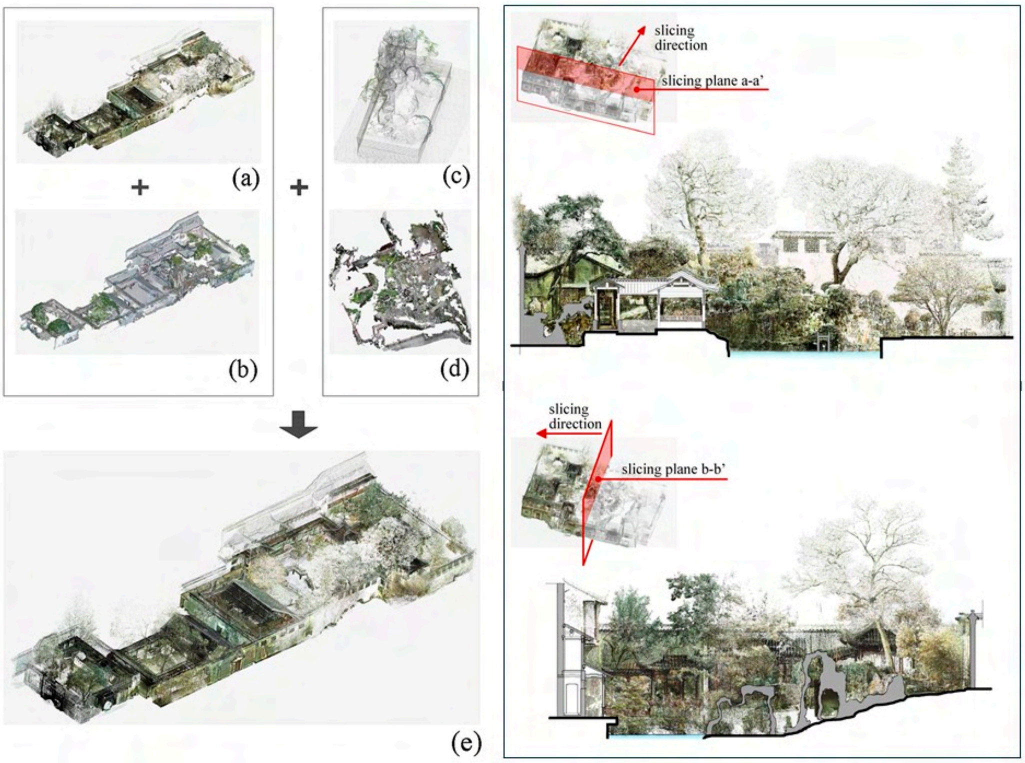

Figure 11. An overview of the Huanxiu Shanzhuang (HXSZ) project. On the left, mixed survey techniques: the garden HXSZ in Suzhou, China; (**a**) aerial view of the TLS point cloud model; (**b**) aerial view of the UAVDP point cloud model; (**c**) aerial view of the Terrestrial Digital Photogrammetry point cloud model of monolith A; (**d**) aerial view of the TDP point cloud model of monolith B and the piled mountain; (**e**) aerial view of the integrated point clouds from TLS, TDP and UAVDP. On the right, slicing of landscape elements in the backyard based on a point cloud [45].

Different surveying techniques were combined to map various garden elements. For large-scale features or areas, such as garden buildings, vegetation, and water bodies, UAVDP and TLS were used together to capture point cloud data. For smaller, more structurally complex objects like rockeries, TLS and TDP were combined to ensure detailed information.

Unlike the Jianxin Courtyard case, the HXSZ project includes an integration process involving both coarse and fine registration of point clouds from TLS and UAVDP. This is followed by the incorporation of TDP data. This multi-step process ensures the final models are highly precise and complete, capturing the garden's complex spatial relationships and diverse elements.

From Chinese gardens to Italian gardens, the survey of the Giardino delle Camelie (304 m^2), a small but significant portion of the Boboli Gardens in Florence, combined photogrammetry and TLS to document the garden's geometric and material characteristics

Heritage **2025**, *8*, x FOR PEER REVIEW 18 of 30

(Figure 12) [46]. Challenges like dense vegetation, poor lighting, and narrow spaces were addressed through careful planning. This included setting up a strong topographic network and using integrated data acquisition methods. Laser scans provided high-resolution spatial data, while photogrammetry captured detailed surface textures, resulting in a comprehensive 3D model. This model allowed for the creation of accurate orthophotos and CAD drawings, which were essential for planning restoration work.

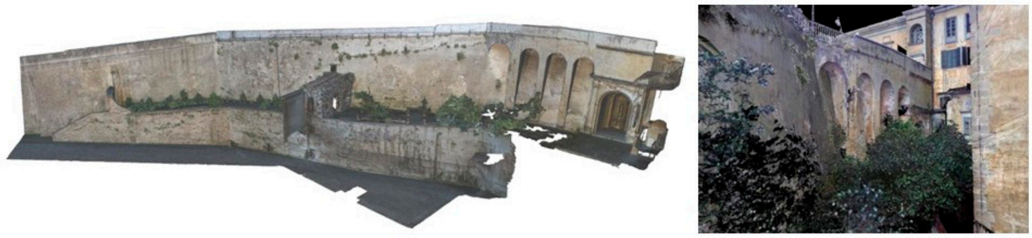

Figure 12. 3D models of the Giardino delle Camelie: on the left, a mesh model of the whole survey area; on the right, a point cloud showing details of the upper retaining wall [46].

In this case, the authors discussed the challenges of acquiring 3D data for historic gardens, particularly the difficulties in accessing certain areas and obtaining data for vegetation. The combination of different survey campaigns provides elements to know and describe the characteristics of the garden, both in its surface (botanical, architectural, and decorative) and spatial composition.

3.2.3. 3D Survey of Natural Elements

In the surveying of historic gardens, artificial elements such as buildings and rockeries in Chinese gardens, or villas and fountains in European gardens, have benefited from 3D digital technologies. These technologies, inspired by their use in historic buildings and sites, have been adapted for garden surveying. However, the documentation of natural elements is still being explored, and new techniques are being developed. Several case studies illustrate this ongoing process.

Mobile Mapping Systems (MMS) are advanced surveying tools that combine multiple sensors, such as LiDAR and high-resolution cameras, to collect spatial data while moving through an environment. In historic garden surveying, MMS is being increasingly applied. It allows for fast and efficient data collection over large or complex areas, producing detailed 3D point clouds that accurately represent terrain features, vegetation, and architectural elements. This approach significantly reduces the survey time and improves data accuracy compared to traditional static scanning methods.

Among the most essential elements in gardens are trees. As living heritage and key parts of the garden ecosystem, trees need to be documented using various techniques. These methods support their inventory, preservation, and management.

A case study was conducted in the Villa Burba historical garden, Italy [12], with an area of about 16,000 m^2. The authors evaluated the Heron Backpack Mobile Mapping System (MMS) [47] and the Ant3D multi-camera photogrammetric system [48] to analyze their effectiveness in creating detailed point clouds for garden characterization, particularly focusing on tree inventory metrics like Diameter at Breast Height (DBH) and canopy footprint. The Heron Backpack proved to be a practical choice for fast, complete surveys of large areas, especially for tree characterization (Figures 13 and 14). Its ability to cover both trunks and canopies efficiently make it highly effective, though the noise in its data limits its use for highly detailed analysis. The Ant3D system excels in creating detailed, noise-free models of architectural and ground-level features, making it suitable for projects where precision and detail are prioritized over speed.

In Villa Burba, a combination of MMS and UAVDP point clouds was used to extract a DTM of the entire garden, which was represented by contour lines, and a 2D CAD drawing was produced. The measurements and drawings included the canopies of the trees, denoted by green circles, the trunk sections of the trees at a standard height of 1.30 m from the ground (Figure 15), and the internal and external plans of all the structures, including the Manor House and other buildings situated on the property.

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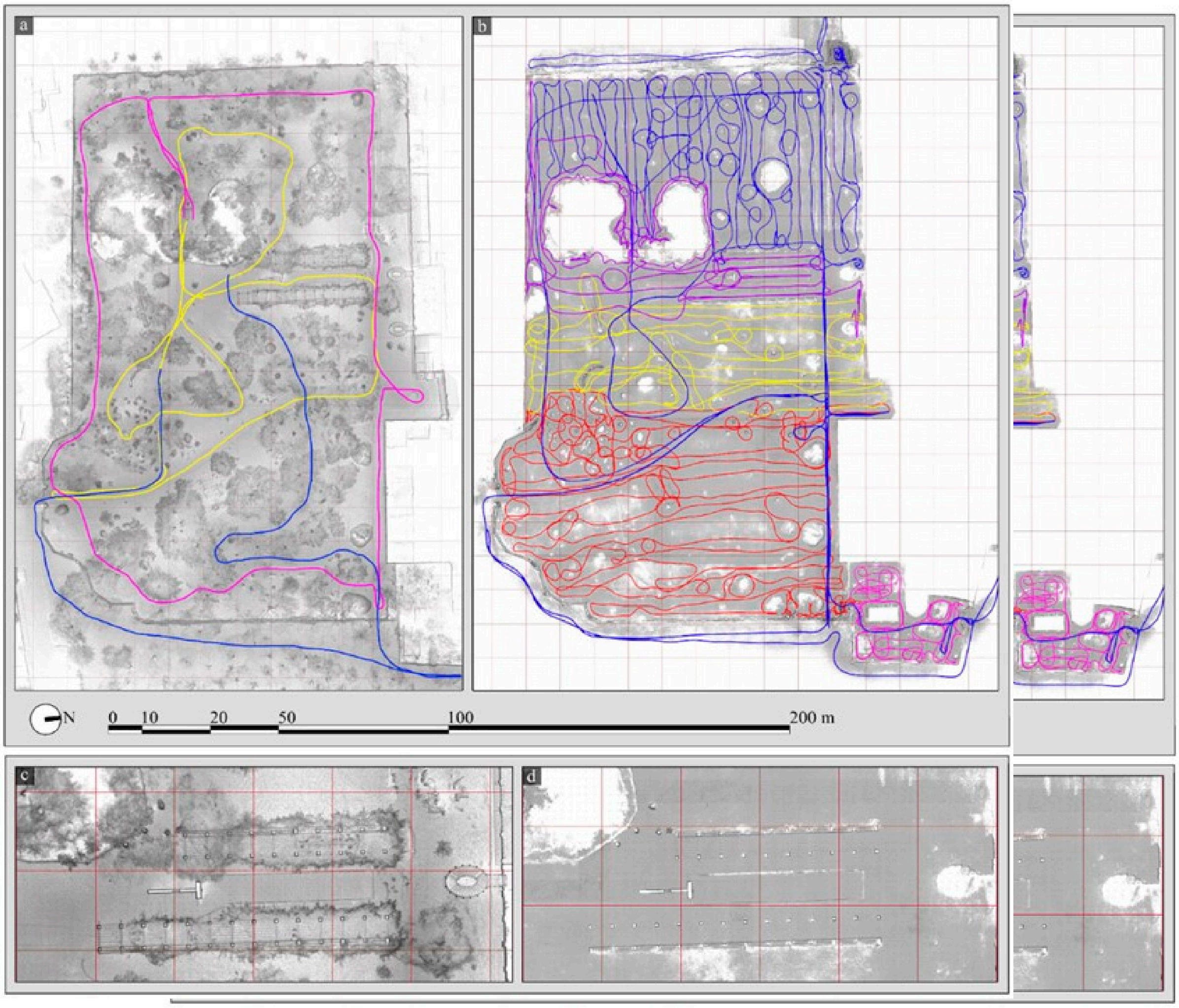

Figure 13. Blueprints of the two obtained point clouds and the respective trajectories followed during the acquisition are highlighted. Heron Backpack survey (a), Ant3D survey (b), zoom of Heron Backpack blueprint (c), zoom of Ant3D blueprint (d). The red grid has a spacing of 10 × 10 m [12].

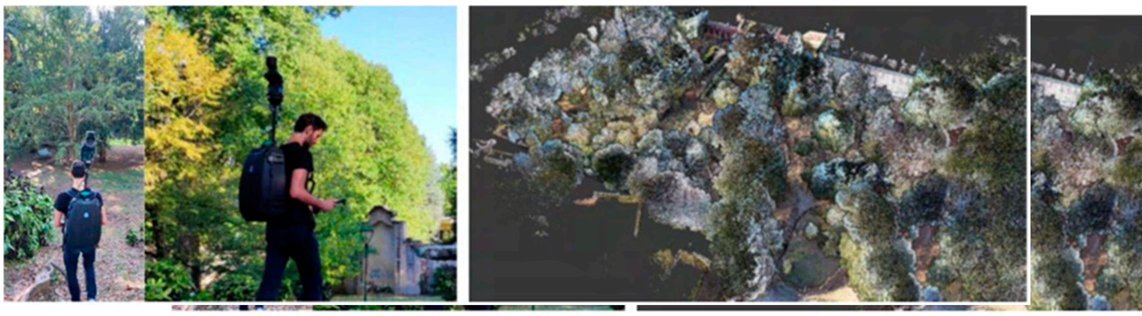

Figure 14. An overview of the Villa Burba Garden survey with MMS: on the left, the survey activities carried out with the Heron Backpack in the Villa Burba Garden; on the right, point clouds obtained for the survey carried out with the Heron Backpack [12].

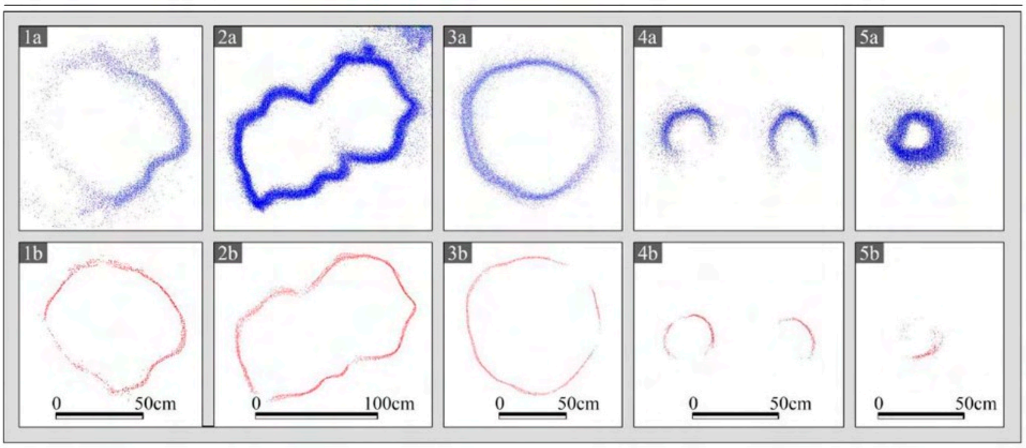

Figure 15. Tree plan section at breast height extracted from the Heron Backpack point cloud (**1a–5a**) and from the Ant3D point cloud (**1b–5b**) [12].

Another case study [36] was conducted in a 2400 m^2 wooded area in Monsanto Forest Park, Lisbon, Portugal. This area, with its mix of natural and recreational features, including uneven terrain, dense tree cover, and elements like wooden furniture and bins, provided a good environment to test the capabilities of MLS and TLS for garden documentation (Figure 16).

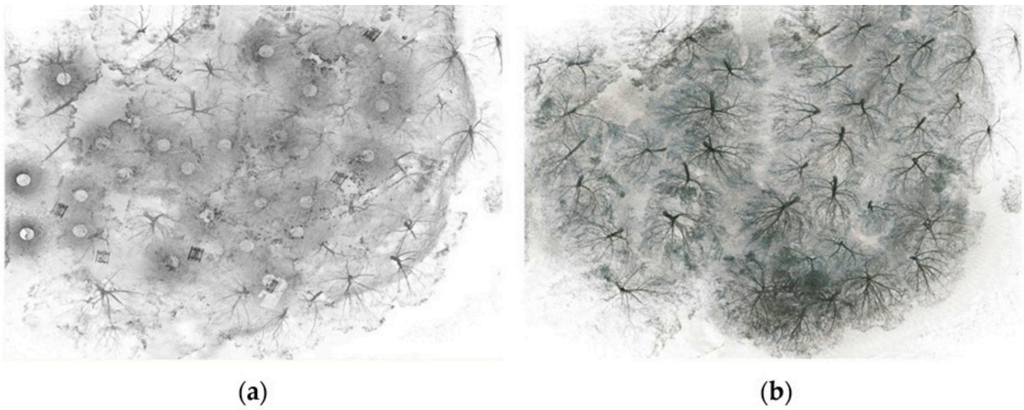

Figure 16. Point clouds of the scope area obtained with the TLS (**a**) and MLS (**b**). Differences in density, detail accuracy, and level of noise are already noticeable from this top view [36].

This case highlighted the trade-offs between precision and efficiency in garden surveys (Figure 17). The TLS system is ideal for detailed surveys that require high-quality, low-noise point clouds, especially for tasks like measuring tree diameters at breast height (DBH) or capturing detailed trunk boundaries. However, TLS is time-consuming and requires extensive setup. In contrast, the MLS system, while producing noisier data, excels in speed and flexibility. It is better suited for large-scale surveys or projects with time constraints. The MLS system's SLAM technology enables seamless data collection, even in challenging environments like dense forests or uneven terrain.

In the future, improvements in noise reduction for MLS data or enhancements to SLAM algorithms could make MLS a more competitive option for surveying the natural parts of gardens.

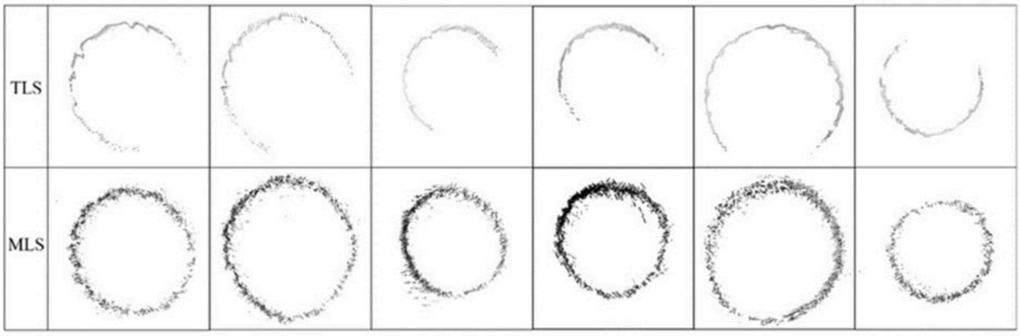

Figure 17. Horizontal sections of the trees on the periphery area obtained by TLS and MLS. Although there is more noise, MLS is able to better define the sections in less scanning time [36].

3.2.4. 3D Survey of Historic Parks

Unlike existing classical or private historic gardens, some gardens that were once private have now become public spaces or historical parks. These gardens typically feature large-scale areas with complex and varied terrain and elements. This means that a single 3D surveying technique cannot meet all their needs. From individual objects to the broader geographic context, it is necessary to choose and integrate the right 3D technologies.

For larger heritage areas, aerial LiDAR has become an essential tool, capturing high-resolution 3D data for detailed mapping of complex landscapes, including topographical variations, vegetation distribution, and architectural features.

A case study of the Wormsloe State Historic Site, a 400 ha historical park in Savannah, GA, USA, was documented using multiple 3D technologies. These included aerial LiDAR, TLS, and Structure from Motion (SfM) techniques applied to images captured by UAVs and handheld cameras. This study explored point cloud mapping methods [49]. It highlighted the importance of precise 3D point clouds for assessing cultural landscapes, which included both physical structures and the ecological context of the site. Additionally, after comparing different techniques, the findings suggested that even lower-cost solutions, such as UAV and handheld photogrammetry, could produce point clouds that were comparable in quality to those generated by more expensive laser scanning.

In addition, unlike the conservation and management of typical historic gardens, the creation of 3D model documentation alone cannot meet the needs of historical parks as open spaces in modern society. The different land uses within historical parks are also influenced by local urban planning. This means that, unlike gardens, the collection of 3D data is not only for preserving and managing the cultural and historical values but also needs to be utilized for planning and developing the park. The 3D surveying technologies here must be integrated with other digital tools, making the data usable by people from various fields.

A case study from an archaeological garden in Naxos, Sicily, illustrates this well. This historic park spans about 250,000 m^2, and the survey used MLS and UAV photogrammetry for the entire park area, with higher resolution terrestrial laser scanning for the archaeological areas and buildings [50]. A topographic network was established across the entire park, with targets measured by both scanners and UAVs.

The survey was the first step in an extensive project to remove architectural and cognitive barriers for visitors to the archaeological site and museum [51]. The project involved experts from geomatics, restoration, diagnostics, and architectural design. Unlike typical 3D information systems built for the conservation and management of historic gardens, the survey data in this case needed to be interpreted and made available to different users, assisting in park activities planning and the development of internal facilities.

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A web-based platform, such as Cintoo [52], was chosen to manage the survey products, including point clouds, orthophotos, and 2D vector drawings (Figure 18). The platform also stored and shared documents and data from the project team and Park Management, practical for park planning and construction.

Figure 18. An overview of the Naxos project. On the left: 22 trajectories of the Naxos Archaeological Park from the MMS survey. On the right: survey products in the Cintoo platform—a 360° image from the MMS trajectory, accessible from the 3D view (**top**), 3D mesh models built from point clouds in Cintoo (**middle**), and folders from the document repository available on the platform (**bottom**) [50,51].

3.2.5. Other 3D Digital Technologies for Historic Gardens

In the application of 3D digital technologies in historic gardens, the majority of case studies have still focused on the technical breakthroughs in data collection within the field of geomatics. However, it is worth noting that only a few cases have explored the impact of digital technologies on 3D modeling and visualization of point cloud data in historic gardens.

For instance, after acquiring point cloud data from Japanese gardens using laser scanning technology, Kumazaki and Kunii [18] extracted point clouds of trees. Based on this, they generated mesh models and created detailed 3D tree models using 3D modeling techniques. These models included detailed information about the leaves, branches, and trunks, as well as their physical shape and color (Figure 19). This work contributed to the development of a database for different types of elements in Japanese gardens. Trees, being an important feature of many gardens, are no longer merely obstacles blocking access to significant artificial elements. 3D point clouds help create detailed and accurate 3D models, which are essential for the conservation and management of gardens.

In addition to the essential elements that compose a garden, spatial relationships and visual characteristics are also key features. These aspects are clearly reflected in the overall 3D point cloud data through visualization. To better support professionals in the protection and management of gardens, one case study used point cloud data to highlight the spatial and visual relationships within the garden. Jichang Garden, a historic garden in Wuxi,

Heritage 2025, 8, x FOR PEER REVIEW

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Figure 19. Examples of tree modeling (from left to right): polygon model of black pine trunk, application to deciduous trees in autumn, and red pine trunk model [18].

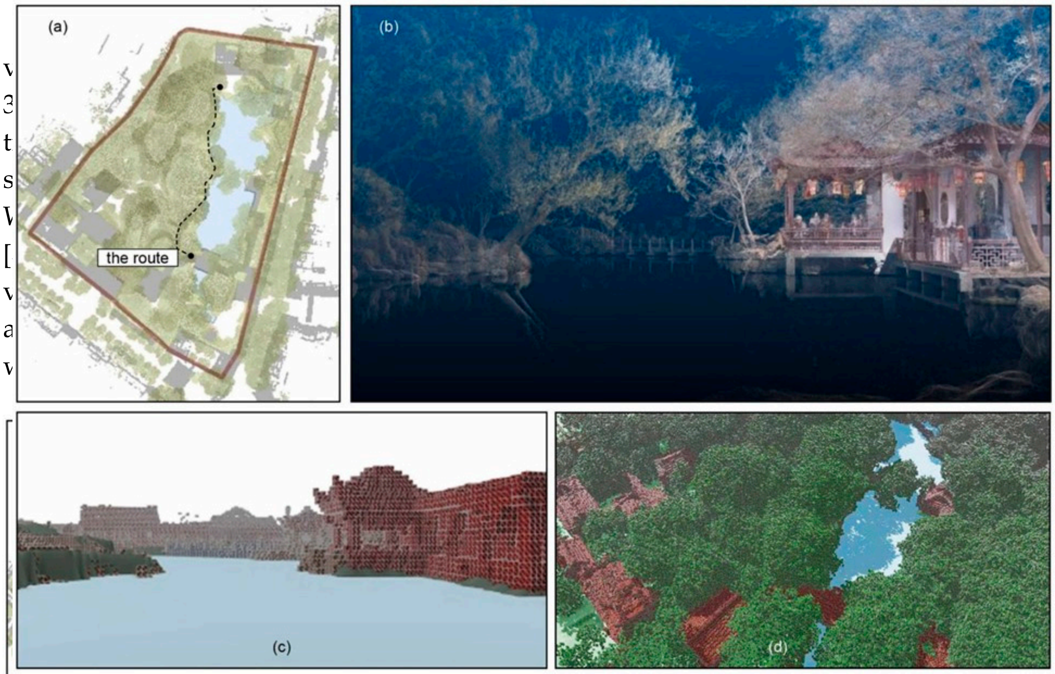

Figure 20. A case study of Jichang Garden. (a) Master plan of the garden; (b) a typical scene visualized with point data; (c) the voxels for buildings; (d) the voxels for vegetation [31].

In contrast to the previous case studies, where the 3D datasets primarily served professionals, this research demonstrated the application of 3D digital technologies for both public engagement and scholarly use. Leveraging point cloud data captured through laser scanning, a dynamic 3D model of the Tropical Botanical Garden in Lisbon, Portugal, was developed using GIS tools [53]. A spatial database was created to organize data from diverse sources, including 3D models of plants, buildings, and sculptures, complemented by webpages (JBT 3D) containing historical and contextual information. Furthermore, interactive 3D scenes were made available, integrating VR functionality (Figure 21). This case exemplifies the synergy of multiple 3D digital technologies, providing the public with access to the garden's historical and botanical data, while also offering researchers and park managers a comprehensive understanding of the garden's current condition. Such integration is instrumental in supporting informed spatial planning and effective management of heritage spaces.

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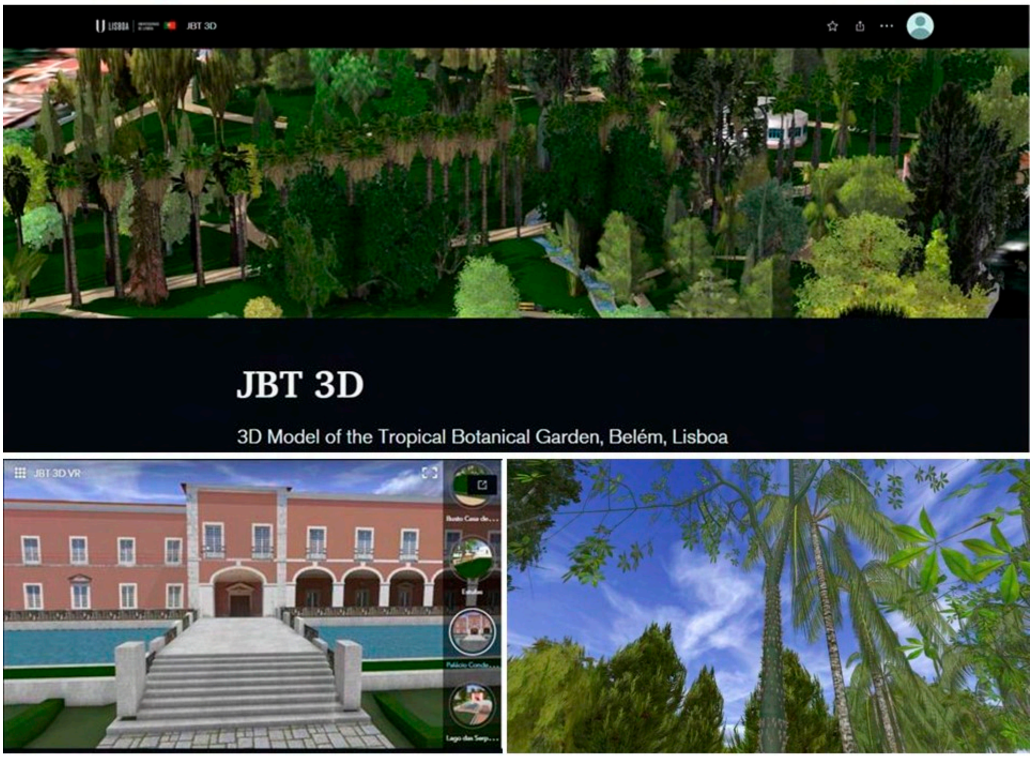

Figure 21. An overview of a JBT 3D webpage. On the top, front page of the JBT 3D StoryMap; on the bottom, examples of the VR360 views in JBT 3D. The ribbon shows some of the spots with Virtual Reality scenes: below on the left, a spot of Palácio dos Condes da Calheta; below on the right, a spot of Ceiba speciosa and other tree species [53].

4. Discussion

The application of 3D digital technologies has progressively spread in historic gardens and related fields, particularly in the past decade. Current studies demonstrated the considerable potential for further development and research in this area.

Various technologies, such as TLS, ALS, photogrammetry, and UAVs, have been employed in obtain digital models of historic gardens. However, most current studies on acquiring 3D models of historic gardens still apply a single 3D digital technology as the primary method, probably because it is easily available and offers a balance between time and cost.

When applying 3D digital technology to historic gardens, it is important to first consider the type of garden. The type of garden influences the choice of methods and tools, as different layouts, sizes, and features may require different approaches.

The "Historical Garden" is a complex organism made up of multiple and different elements; the survey must be able to respond to different needs that often cover very different representational scales (from the almost cartographic scale to the detailed scale of architectural objects). The intricate composition of elements within these landscapes presents unique challenges. In this sense, the contribution that different techniques and sur-vey tools can make is evident. Whether researching historic gardens as a whole or investigating individual components within them, integrating the strengths of different technologies should be a key focus of future research.

Combining aerial and ground-based 3D surveying technologies is the most suitable approach right now. TLS works well for quickly capturing high-resolution data of regular and complex structures. Photogrammetry is flexible, adaptable to site conditions, and low-cost. Ground-based photogrammetry can add more details about smaller objects to data collected with TLS. UAV photogrammetry can cover larger areas effectively. ALS can capture even bigger areas and provide information about terrain and landscape patterns. New mobile mapping systems also bring clear advantages. They allow fast and efficient collection of 3D digital data. This makes them useful for large and complex sites where traditional methods may take longer or be less practical. These systems can combine data from different technologies, improving both speed and accuracy.

Consequently, upcoming studies could prioritize comparing and benchmarking these technologies in the context of historic gardens, considering their specific requirements, such as capturing delicate garden features, vegetation, and topography.

In addition to integrating existing technologies to leverage their advantages in this field, future research could focus on enhancing current techniques or developing novel technologies. Further development and adaptation of 3D digital tools are necessary to better cater to the specific requirements of these unique Cultural Heritage assets. One promising research area is the development of specialized sensors and platforms optimized for historic garden documentation.

These customized integrated solutions would enable researchers to obtain detailed and accurate 3D models of historic gardens without compromising the integrity of the site or its components.

Compared to its use in other cultural heritage fields, such as historical buildings or monuments, the application of 3D digital technologies to historic gardens is still in the early stages. There are very few examples of processing or applying 3D data, such as point clouds, in gardens. Most studies focus on mapping specific elements, like synthetic structures or 3D tree models. A garden, however, is a whole area with many interconnected elements. Capturing the 3D point clouds of individual features is only the first step in using 3D technology for gardens.

After obtaining a full 3D point cloud of a garden, it is important to go further. Advanced processing and analysis of the data are needed to understand spatial relationships and visual characteristics within the garden. This is the second step. For example, analyzing the arrangement of pathways, structures, and vegetation can reveal key design patterns. However, gardens are dynamic spaces where natural elements change over time. Capturing these changes requires adding a time dimension to the 3D data. This is the third step and is essential for a more accurate representation of historic gardens.

At present, most research focuses on the first step. Applications that address the second and third steps are still rare. Combining methods for 3D modeling with time-based data collection could help reveal the spatial and temporal dynamics of gardens, making this an area with significant potential for further exploration.

4D documentation systems are important for capturing and analyzing the spatial details and temporal changes in historic gardens. They can help develop better strategies for conservation and management. Research could focus on creating real-time or near-real-time 3D data collection and processing methods. These methods would allow for fast detection and assessment of changes in garden conditions.

Integrating sensor networks, like environmental monitoring systems and remote sensing platforms, with 3D GIS and web platforms can help build detailed and dynamic models of historic gardens. These 4D models could support decision-making by simulating different scenarios. For example, they could show the impacts of climate change, test restoration plans, or manage visitor flow. These models could also be useful for public engagement and education, allowing people to explore and interact with gardens in a virtual space. They could also show how gardens have changed over time.

Developing standardized protocols and guidelines for 4D documentation could help ensure consistent and reliable data. This would make it easier to share knowledge and best practices among researchers, conservators, and managers. Such efforts could play a key role in preserving historic gardens and increasing public appreciation of these important cultural heritage sites.

The final products of applying 3D digital technology to historic gardens must ultimately be usable by stakeholders, but how these products are used remains underexplored. Beyond the primary 3D point cloud, the outputs often include raw data like images and metadata, as well as information-rich 3D models and interactive products generated from the point cloud.

For some historic gardens, the main need is conservation and management. A 3D garden information database could meet the requirements of internal staff working within the garden. However, for gardens requiring cross-regional or international protection and management, challenges increase due to the complexity of coordination and data sharing. Additionally, many historic gardens face demands from urban development or changes in surrounding environments, requiring ongoing planning and redesign. In these cases, a dynamic system for integrating and updating 3D data and information is essential.

Some studies highlight the importance of web platforms for storing, co-managing, and editing 3D data related to historic gardens. In the future, a web platform integrated with a 4D documentation system could be a promising research direction. This would allow for centralized access, real-time updates, and collaborative use of garden data across various stakeholders.

Stakeholders play a key role in this process. When exploring the application of 3D digital technologies to historic gardens and related heritage objects, it is not enough to focus solely on the garden itself. It is also necessary to consider whether the solutions address the needs of stakeholders. By aligning the outputs of 3D technology with the specific requirements of conservationists, planners, and the public, the full potential of these tools can be realized.

Another promising direction is the integration of AI, including machine learning and deep learning techniques, into the processing and analysis of 3D garden data. While AI is already widely used in the built environment, its application in cultural landscapes is only beginning to develop. AI algorithms tailored to automatically detect, classify, and segment garden features could greatly improve the efficiency and accuracy of documenting historic gardens.

Using AI can simplify the creation of detailed 3D models and inventories, making it easier to represent historic gardens comprehensively and precisely. For example, AI could quickly identify and categorize elements such as trees, pathways, or architectural structures within a garden. This would save time and reduce manual effort while ensuring consistent results. By incorporating AI into 3D documentation processes, the digital management and future development of historic gardens could become more intelligent and efficient.

5. Conclusions

This scoping review provided a comprehensive overview of the application of 3D digital technologies in historic gardens and related Cultural Heritage. The analysis revealed a growing interest in research activity in this field, particularly since 2016. The geographic distribution of researchers and institutions highlights the international nature of this research, with significant contributions from Europe and Asia. Key journals and archives have been identified, providing valuable resources for future studies. Using bibliometric methods and visualization tools, this review examined the technical methods employed in the field, as well as the types and distribution of research cases. After that, the synthesis presented the collaboration of diverse 3D digital techniques in garden heritage objects for end users, with some case studies offering detailed insights. Finally, the evaluation of the review results provided a critical assessment of the current research limitations and potential technological applications.

This review emphasizes the importance of continued research in this area, stressing the need for interdisciplinary collaboration to drive further progress in the field. Developing standardized methodologies and user-friendly tools is essential for ensuring the sustainable development and preservation of historic gardens. By promoting a more unified and accessible approach to the use of 3D digital technologies, researchers, conservators, and managers can collaborate effectively to safeguard and enhance the long-term protection of these invaluable cultural heritage assets. Additionally, involving the public can deepen appreciation and engagement, ensuring that these gardens remain cherished and well-preserved for future generations.

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Abbreviations

The following abbreviations are used in this manuscript:

3D	Three Dimensional
UAV	Unmanned Aerial Vehicle
CH	Cultural Heritage
ICOMOS	The International Council on Monuments and Sites
UNESCO	The United Nations Educational, Scientific and Cultural Organization
CAD	Computer-aided Design
ALS	Airborne Laser Scanning
MLS	Mobile Laser Scanning
TLS	Terrestrial Laser Scanning
GIS	Geographic Information Systems
VR	Virtual Reality
AR	Augmented Reality
PRISMA-ScR	Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews
BIM	Building Information Modeling
GNSS	Global Navigation Satellite System
TDP	Terrestrial Digital Photogrammetry
UAVDP	Unmanned Aerial Vehicle Digital Photogrammetry
HXSZ	Huanxiu Shanzhuang
MMS	Mobile Mapping Systems
IMMS	Indoor Mobile Mapping Systems
DBH	Diameter at Breast Height
SLAM	Simultaneous Localization and Mapping

SfM	Structure from Motion
AI	Artificial Intelligence

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