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A Bibliometric Analysis of Research on Historical Buildings and Digitization

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Abstract: The wealth of published data are valuable because, in addition to contributing to the advancement of scientific, technical, and policy knowledge, they can also provide critical information and guidance regarding published content, subject changes, and trends that demand greater attention. In the 21st century, digital technologies play an increasingly important role in "data capture", "building management", "virtual reconstruction", and "building restoration". The indispensable role of digital technology in addressing "data capture", "building management", "virtual reconstruction", and "building restoration" has resulted in the publication of several high-quality publications. In this study, we retrieve textual data from Web of Science and mine the content of the documentary data using COOC, VOSviewer, CiteNetwork, and academic influence evaluation (AIE) software to gain insights into the prospects and opportunities for historic architecture and digitization research. The results indicate that greater progress has been made in research on the use of digital technologies for the conservation of historic buildings from 2019 to 2023, but cross-disciplinary, cross-institutional, and cross-border collaboration should be enhanced. The research frontiers identified indicate that photogrammetry, 3D modeling, point cloud, and deep learning will require sustained attention in the near future. Additionally, computational analyses of academic influence reveal that Italian institutions and authors have dominated research in this field in recent years. A new strategy and framework for data-driven bibliometric analysis involving historical architecture and digitization techniques are presented in this study. Based on general bibliometric methods, this study innovatively explores the scientific knowledge base and knowledge flow of highly cited articles, provides comprehensive evaluation indicators such as H-index, G-index, P-index, and Z-index for high-impact journals, institutions, and authors, and proposes a COOC-based idea to address the consistency of data sources among multiple software.

Keywords: historic buildings; digital technology; bibliometric study; mathematical methods

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Citation: Wang, Z.; Sun, H.; Yang, L. A Bibliometric Analysis of Research on Historical Buildings and Digitization. *Buildings* **2023**, *13*, 1607. https://doi.org/10.3390/buildings13071607

Academic Editor: Irem Dikmen

Received: 26 May 2023
Revised: 20 June 2023
Accepted: 21 June 2023
Published: 25 June 2023

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1. Introduction

The preservation of historic buildings is essential in order to protect and enhance their usefulness while preserving the essence and identity of the location. The concept of historic buildings encompasses a wide range of valuable buildings and structures that continue to serve as a witness to civilization, meaningful development, certain historical events, urban and rural environments, as well as historical events. Historic buildings possess both cultural and economic value. Economic value includes land value as well as the value of the building itself, whereas cultural value comprises historical, architectural, cultural, artistic, and social values. Unlike general architecture, although the economic value of historic buildings is relatively clear, indirect economic value and market recognition are influenced by the social economy, social structure, and people's awareness. Furthermore, indirect economic values will significantly change in the future. Some of them follow a general pattern where they become too old to be used or undergo dramatic changes in terms of over-restoration and eventually lose their economic value; others become increasingly rare

over time due to their excellent conservation and gradually become heritage with a high economic value. The cultural value and economic value of historic buildings are closely related, and under certain conditions, cultural value can be transformed into economic value, and the existence of cultural value can also bring economic benefits [1].

The process of cultural (including architectural) heritage conservation is an ongoing practice that requires capturing, analyzing, filtering, recording, monitoring, and regularly updating relevant data. However, digital means can be effectively used to capture and manage data regarding heritage buildings. The "digitization of heritage" project integrates physical 3D measurement techniques, architectural components, inventories, and archival records as a restoration and conservation process [2]. The process of restoring historic buildings follows a workflow that includes data acquisition, registration/recording, processing, and modeling. As part of this process, a series of operations such as surveying, mapping, monitoring, and management are carried out [3]. There are many limitations associated with using traditional architectural mapping tools (e.g., manual tape measures) to measure historic buildings, including the inability to ensure sufficient accuracy, the time involved, and the potential for secondary damage to the structures. For instance, the use of laser scanning techniques can save time compared to traditional measurement tapes [4]; the accuracy with an invar scale rod can be high, especially for close-range photogrammetry [5]. With the development of new mapping instruments and technologies (such as laser scanners, aerial photography, and spatial information), accurate spatial solid models of research objects have become possible, and new mapping methods have resulted in improved spatial data acquisition, management, analysis, and representation methods. The land surveying data of measurements were later converted into engineering 2D or 3D drawings, and these drawings and images provide limited supporting documentation for the reconstruction of historic buildings. Supportively, the International Preservation Strategy supports a focus on digitizing historic and cultural buildings [2]. Therefore, the conservation of historic buildings requires highly sophisticated semantic web-based representation techniques that utilize integrated mechanisms based on digital processes and tools.

In recent years, the study of historical architecture and digitization has produced many scholarly publications as a result of the advantages of digital publishing. However, since reading these hundreds of articles and summarizing the valuable information is a time-consuming process for researchers, relying on human resources to read these overwhelming numbers of research results in a short period of time is not conducive to quickly grasping their hot topics and development directions. It is necessary to conduct rigorous quantitative analyses and statistical proofs based on mathematical models. A new digital application of bibliometrics is data-driven, which applies statistical methods to scientific results [6] with a knowledge-oriented quantitative function [7]. This new application method will be truly effective with the support of digital technology, and the bibliometric approach has begun to mature in recent years as a result of technological advances in computer science, making this extensive collection of literature, data, and analysis a reality. It can decipher the knowledge association between publications by filtering and processing a huge amount of information to uncover the potential knowledge value. Due to its disciplinary basis in mathematics, statistics, and computer science [8], bibliometrics can provide intuitive data analysis and accurate insights for the advancement of scientific research [9]. Therefore, this approach is an important guide for the development of many disciplines, both at the theoretical level and in terms of practical applications. Bibliometrics has been widely used in many high-impact journals to tap into new perspectives in the perception of scientific knowledge. The journal *Nature*, in commemorating its 150th anniversary, even highly praised bibliometrics for its help in contemporary scientific inspiration and trend identification [10]. It is obvious that the use of bibliometric methods to reveal and uncover the development patterns of a research field and to provide new scholarly perspectives is no doubt scientifically valid.

Within this scope, the principal bibliometric analysis tools were compared based on the research conducted by [11]. This paper studies the features of the principal tools available

for bibliometric analysis, which are listed in Table 1. The COOC is richer than the other software in Table 1 and has data processing capabilities to generate tables and other data formats of the underlying data for subsequent analysis, but it is weak in citation analysis and relevance analysis, whereas VOSviewer can be used for a wide variety of data formats and has several advantages in generality and visual presentation. CiteNetwork is able to sort out the knowledge base and knowledge flow between articles through basic data, as well as have some visualization capabilities and versatility. The AIE is capable of analyzing academic impact with the H-index, G-index, P-index, and Z-index as comprehensive evaluation indices, as well as showing correlations among them, as well as its versatility in data analysis. As well as being generalizable, it can be used with data in a variety of ways. Since the purpose of this paper is to explore the frontier trends in historical architecture and digital research over the past five years, out of consideration for functional coverage and operational convenience, a COOC + VOSviewer + CiteNetwork + AIE workflow based on COOC was formed, which integrates data processing, data source consistency, graphical presentation capabilities, frontier domain knowledge, dynamic analysis, and comprehensive evaluation of academic impact in one.

Table 1. Comparison of the characteristics of bibliometric analysis tools. Adapted with permission from Ref. [11]. 2020, Moral-Muñoz, J.A.; Herrera-Viedma, E.; Santisteban-Espejo, A.; Cobo, M.J.

	Bibliometric Analysis Tools									
Functions	**Bibexcel**	**SciMAT**	**Biblioshiny**	**CiteSpace**	**VOSviewer**	**CiteNetwork**	**COOC**	**AIE**	**Bicomb**	**Sci2 Tool**
Relationship construction (co-occurrence matrix)	•	•	•	•	•		•		•	•
Multidimensional relationship construction							•			
Clustering		•	•		•		•			•
Evolution		•	•				•			
Citation analysis	•	•		•	•	•				
Biclustering							•			
Visualization	•	•	•	•	•	•	•	•	•	•
Correlation analysis								•		

A data-based bibliometric analysis framework and strategy for mining the core content of large volumes of documentary data is presented in this study. It presents a comprehensive analysis of research progress in the field of historical architecture and digitization from 2019 to 2023 using current mainstream bibliometric software and methods to provide a unique insight into the field's outlook and development dynamics. Moreover, based on the general bibliometric application method, we also visualize the scientific knowledge base and knowledge flow of highly cited articles in a particular research field and propose calculating the top ten high-impact journals, institutions, and authors based on the comprehensive evaluation index. First, bibliographic frequency analysis, keyword analysis, and publication volume analysis are used to determine the overall profile and collaborative relevance of leading authors, mainstream journals, core classifications, and major countries and institutions. Then, trends and citation relationships in that research frontier area are captured through citation analysis and scholarly impact analysis. This provides clues to discover current research priorities, leading authors, high-impact institutions, and popular journals. More importantly, evolutionary analysis and hotspot identification provide a general perspective on the field's evolution. In the end, conclusions regarding research

on the use of digital technologies for the conservation of historic buildings are presented, along with some recommendations to promote the development of the knowledge field of historic building conservation. The experiment was completed on 5 May 2023.

2. Methodology

2.1. Data Source and Retrieval

This study uses bibliometric analysis techniques to quantitatively assess the scholarly literature by extracting all English language scholarly publications containing the topics "Historical Buildings" and "Digital" from Clarivate Analytics' Web of Science (WOS) core repository for the time period from 2019 to 2023 [7]. The WOS Core Collection (WOSCC) was chosen because it covers (i) a wider range of research areas than Scopus and has more accurate and reliable citation data compared to other databases, including literature data from Google Scholar and Scopus, (ii) high-quality research data, (iii) more authoritative literature data and a broader readership, and (iv) a long history [12].

The primary data used for this analysis were the content of 468 research publications related to historic buildings and digitization obtained from WOSCC. The types of literature included 361 research articles, 91 conference papers, and 14 review articles. The papers were prepared by 201 organizations from 84 countries, covering 70 research directions and 99 WOS categories, including 119 source publications, and containing a total of 197 authors. Most of the literature categories belong to remote sensing, construction building technology, archaeology, and computer science information systems. A flow chart of this study can be found in Figure 1.

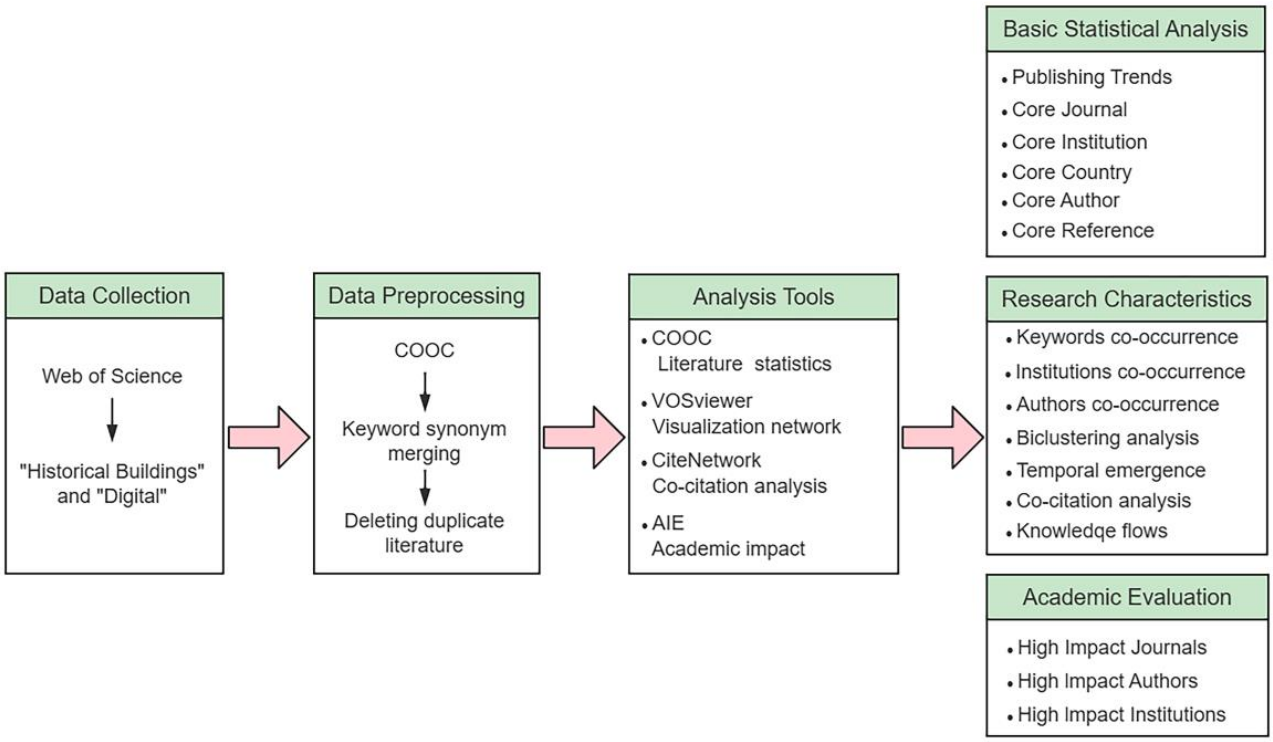


Figure 1. Flow chart of the research process.

2.2. Data Preprocessing

Obtaining reliable analysis results requires preprocessing of the literature data since raw data often contain duplicate documents, meaningless items, or synonymous terms. When improper processing is performed, word frequencies may be underestimated or miscalculated, leading to unreliable or even contrary conclusions. There is currently no relevant research on in-depth text preprocessing in bibliometric systems, so we have

conducted data preprocessing through the comprehensive extraction of items using the late-model bibliometric software Co-Occurrence 13.4 (COOC) [13].

The data preprocessing procedures used in this paper are as follows: (1) Removing duplicate publications. Since some retrieved papers may be contained in different databases simultaneously, they may appear repeatedly. By deleting the duplicate literature, it makes the data more accurate. (2) Deleting meaningless items. Considering the low statistical value of keywords that have only appeared once and the co-occurrence relationship is unclear, the keywords that have only appeared once are removed by frequency statistics. (3) Merging synonyms, as shown in Table 2. Since several different keywords derived from different literature may represent the same meaning, synonym merging is a necessary work to conduct before formal bibliometric research. By reviewing the literature and investigating the connotation of the keywords, this study uses COOC software to merge some keywords with similar meanings, for instance, "Augmented Reality" and "Augmented Reality (Ar)", "Spatial Augmented Reality" and "AR". In the synonym merging algorithm, two main processing principles are followed. First, the main focus is on keywords that occur more frequently than the minimum threshold (for example, $\geq$2) to maximize the preservation of valuable information. Second, the recombination of keywords should be screened carefully to ensure accuracy and generality. The whole COOC software is based on an accurate character segment recognition algorithm, thus it effectively ensures the quality and statistical value of the processed data. In addition, the pre-processed data can be easily converted to common format by COOC and imported into other visualization software for subsequent analysis, such as VOSviewer. The above steps are completed in the COOC software. After keywords merging and cleaning, 425 papers were finally obtained as the samples of the study. The specific retrieved information about the 425 sample papers mainly includes the author information, year of publication, keywords, country information, journal, institution, title, research direction, WOS core collection cited frequency, and abstracts.

2.3. Bibliometric Analysis Methods

Bibliometrics covers structured presentation, dynamic description, assessment, prediction, and scientometrics, so the analysis methods used need to be systematic. Four types of software were used for the econometric analysis in this study, each with different functionalities.

The first is Co-Occurrence 13.4 (COOC), which covers "Data Extraction Module", "Data Cleaning Module", "Descriptive Statistics Module" "Relationship Building Module", "Cluster Mapping Module", "Topic Evolution Module", and "Research Frontiers Module". It is capable of analyzing bibliometric data and extracting and filtering and visualizing data in the form of graphs and maps [13].

The second software tool selected was VOSviewer, which is a software developed by the Centre for Science and Technology Studies (CWTS) at Leiden University (Leiden, the Netherlands) and permits the creation of bibliometric networks based on the co-occurrence network [15].

The third software used is CiteNetwork [13], which can discover important literature in terms of literature citations and explore the flow of scientific knowledge.

The fourth one is academic influence evaluation (AIE) [13], which cannot only calculate the traditional indicators of academic evaluation, such as the number of publications, citation frequency, and average citation, but also the more famous composite evaluation indicators, such as h-index, g-index, p-index, and z-index, and can perform correlation analysis and visualization of the relationship between the indicators.

All these data (i.e., the total number of publications, statistical items, and all keywords) were collected from the WOSCC under text format and preprocessed by COOC.

Table 2. Data cleaning: list of synonyms. Adapted with permission from Ref. [14]. 2022, Siccardi, S.; Villa, V.

Topic	Synonyms	Normalized Term
3D Models	3D Reconstruction, 3D Model, 3D Modeling	3D Modeling
Augmented Reality	Augmented Reality (Ar), Augmented Reality, Spatial Augmented Reality	AR
Historical Buildings	Historical Building, Historical Constructions, Built Heritage, Historical Architecture	Architectural Heritage
Bim	Scan-To-Bim, Building Information Modeling (Bim), Building Information Model (Bim)	BIM
Heritage	Heritage, Cultural–Historical	Cultural Heritage
Dch	Digital Cultural Heritage (Dch), Digital Cultural Heritage	Digital Cultural Heritage
Digital documentation	Digital Archive, Digital Documentation	Digital Documentation
Digital Models	Digital Modeling, Digital Models	Digital Model
Archives	Archives, Heritage Documentation	Documentation
Geographic Information System	Gis, Geographic Information System	GIS
H-Bim	Heritage-Bim, Hbim, Heritage Building Information Modeling (Hbim)	HBIM
Internet Of Things	Iot, Internet of Things	IOT
Structure From Motion	Sfm, Structure from Motion	SFM
Terrestrial Laser Scanner	Laser Scanning, Laser Scanning Technology, Terrestrial Laser Scanning (Tls), Tls	Terrestrial Laser Scanning
Uav	Aerial Photos, Uav	Uav Photogrammetry
Virtual Reality	Virtual Reality, Virtual Reality (Vr)	VR

3. Results

3.1. Literature Development Trends

The number of publications is an important indicator of the development of an academic field. Figure 2 illustrates the annual and cumulative number of publications related to research on historic buildings and digitization. According to the figure, the continued steady growth in the number of publications addressing digitization and historic buildings indicates that the academic community is increasingly inclined to make use of emerging technologies to preserve historical structures.

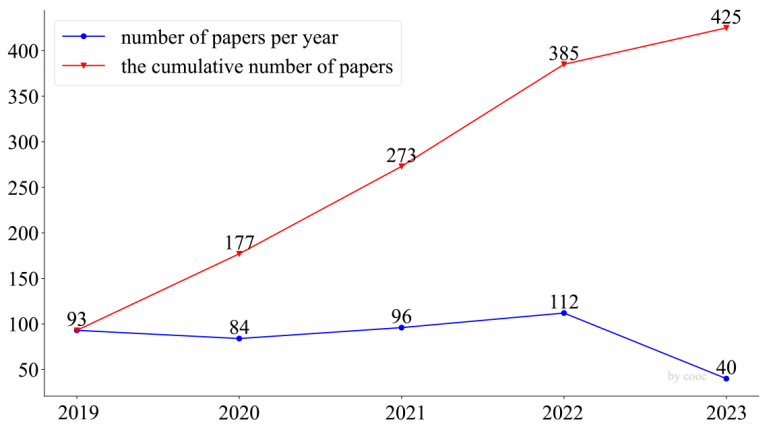


Figure 2. Statistics on the number of articles issued.

In 2019, a non-invasive, non-contact measurement technique in building restoration was studied in Italy, using spatial and morphological filters for the surface detailing of 3D models to detect damage to buildings and to obtain quantitative information on some types of damage [16]. The use of photogrammetry based on UAV photogrammetry has also been proposed as an alternative to terrestrial laser scanning for the HBIM modeling of historic buildings. Also, validation procedures were established to ensure reasonable agreement between the parametric models and ground truth values [17]. The process of creating XR experiences was also improved, starting with 3D surveys of churches and historical record data collection, resulting in a new level of interaction for different types of devices (desktops, mobile devices, VR headsets) and users (experts, non-experts) [18]. Since 2019, these highly cited articles focusing on different directions have provided valuable experience and inspiration for other scholars, and there has been an increase in the number of subsequent articles on the enhancement of historical building measurement techniques and improvements in the authenticity and entertainment of virtual reconstructions.

The number of published papers exceeds 90 and 100 in 2019, 2021, and 2022, respectively. As can be seen in the graph, the overall growth in articles does not show a phased change. This suggests that the topic is receiving sustained and extensive attention from researchers. This trend also implies that historic buildings' preservation with digital technology has considerable scientific relevance. We believe there are two reasons for this. The first is that the application of technology in digitization to architecture has real practical potential. The second is that when used for historic building mapping, digitized building information may be an accurate indicator.

3.2. Journal Publications and Citations

The top ten journals publishing articles on this topic can be seen in Figure 3. From the graph, it is apparent that most of these journals are dedicated to applied sciences, architecture, remote sensing, heritage, and virtual reconstruction, with an emphasis on applied sciences as the primary field.

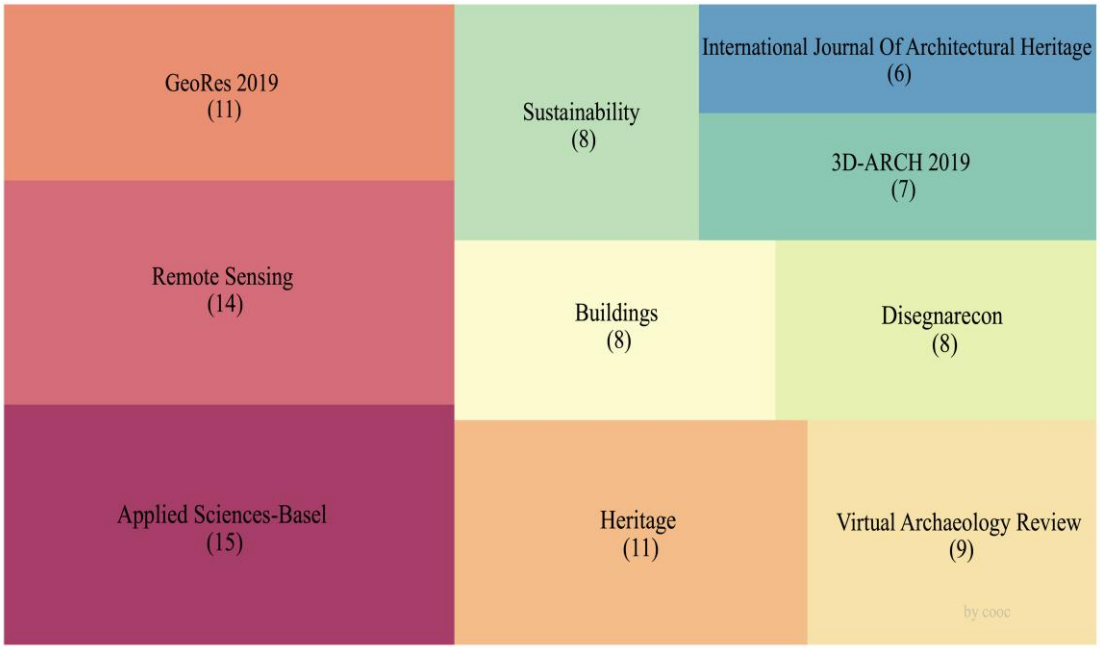


Figure 3. Top 10 published journals.

Further analysis of the cited journal information provides insight into whether the topic has been influenced by papers published in other journals. Table 3 shows the top 10 journals with a high citation frequency. As can be seen from the table, the main journals

cited are remote sensing, especially those related to surveying and mapping. However, these journals do not exactly correspond to those in Figure 3.

Table 3. Top 10 cited journals with the highest frequency.

No.	Freq	Cited Journal
1	71	*Remote Sensing*
2	67	*Computers and Structures*
3	53	*Applied Sciences*—Basel
4	48	*Journal of Cultural Heritage*
5	42	*Smart and Sustainable Built Environment*
6	42	*Virtual Archaeology Review*
7	38	*Building Research and Information*
8	37	*PLoS ONE*
9	33	*Research in Science Education*
10	32	CMC—*Computers, Materials and Continua*

According to Figure 3, the journals relating to applied sciences are primarily concentrated in the lower left corner. A number of journals, however, focus on heritage, archaeology, architecture, and mapping, such as *Heritage*, *Virtual Archaeology Review*, *Buildings*, and *Disegnarecon*. The focus of the research on digitization and historic buildings that emerged from the articles published in these journals was primarily on the application of advanced technologies, as opposed to the building itself. Due to the varying ages of the construction of historic buildings, particularly information on buildings in more serious disrepair and with incomplete building bodies, the virtual reconstruction of historic buildings relies mainly on digital methods, which include drones, laser scanning, and architectural modeling software as a means of building information measurement.

Additionally, the upper right corner of the website shows a number of journals primarily related to environmental science. These journals include *Sustainability*, *International Journal of Architectural Heritage*, and 8th International Workshop 3D-Arch: 3D Virtual Reconstruction and Visualization of Complex Architectures, etc. This means that the study of digital applications of historic buildings is also related to the environment, where the equipment and materials of digital technologies may cause damage or impact the structure and appearance of historic buildings, and where the operation and maintenance of digital technologies may consume large amounts of energy and resources, also an environmental pollution issue of concern.

3.3. Cooperation Network Analysis

3.3.1. Geographic Distribution

In Figure 4, the top 15 national publications are compared. Italian publications account for 32.41 % of all published articles, indicating that this topic is very popular in Italy. USA and Spain are the second and third largest contributors, respectively, with 11.56 % and 10.30 %. China, England, and Germany also contributed significantly to this topic with 6.78%, 5.53%, and 5.53%, respectively. Many European countries, such as Greece, Poland, and Russia, are also represented in the top 15 countries, as well as Australia and Brazil, which are also engaged in this field, indicating a global interest in this issue.

It is not possible to fully reflect the contribution of different countries to the topic by the number of published papers. Portugal accounted for only 3.27% of the total number of papers but ranked eighth in the recent five years in terms of highly cited articles (Table 4); Cuba had fewer publications and was not in the top 15, but Cuba ranked seventh in terms of citations. At the same time, there is some cooperation between different countries on this topic, most likely because the global popularity of the internationalist architectural style has caused the homogenization of the urban landscape and caused great scientific concern for local architectural culture in different countries.

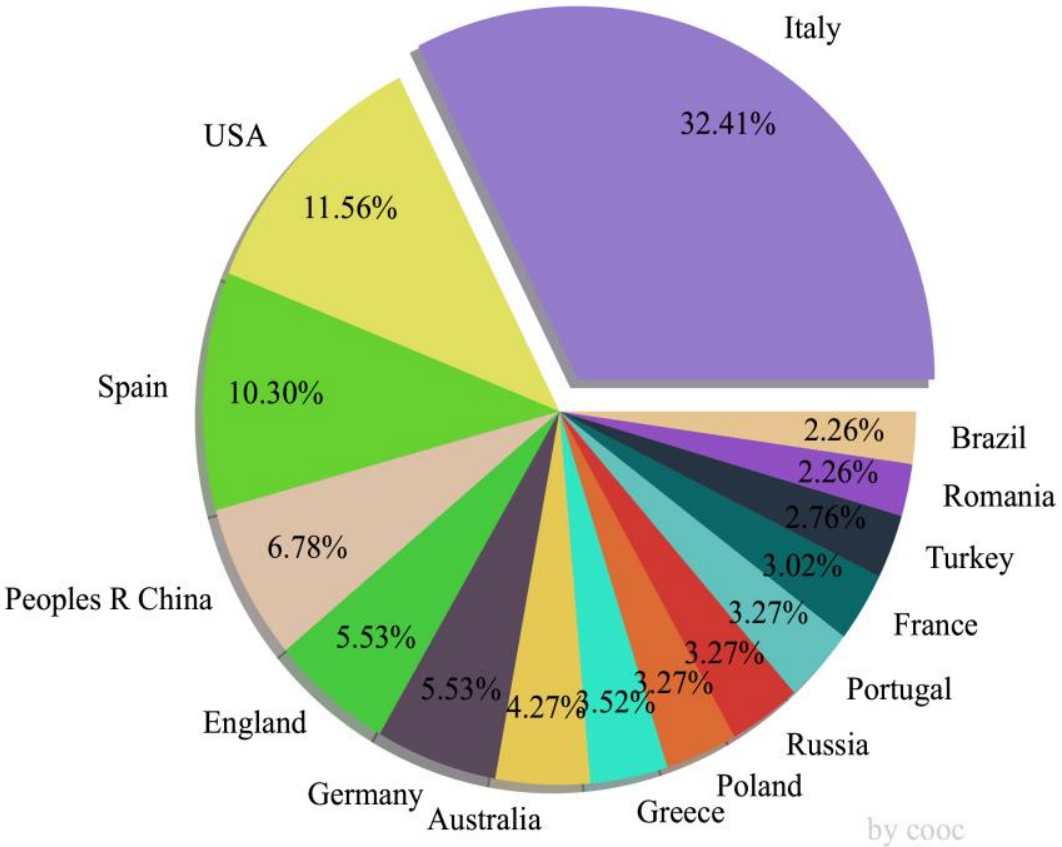


Figure 4. Percentage of publications in the top 15 countries.

Table 4. Top 10 articles cited (remove those irrelevant to the research topic).

Title	Country	Citations
Point Cloud Semantic Segmentation Using a Deep Learning Framework for Cultural Heritage	Italy	71
Development of the Simulation Model for Digital Twin Applications in Historical Masonry Buildings: The Integration between Numerical and Experimental Reality	Italy	67
An Efficient Pipeline to Obtain 3D Model for HBIM and Structural Analysis Purposes from 3D Point Clouds	Italy	53
Advanced Damage Detection Techniques in Historical Buildings Using Digital Photogrammetry and 3D Surface Analysis	Italy	48
Extended Reality and Informative Models for the Architectural Heritage: From Scan-to-BIM Process to Virtual and Augmented Reality	Italy	42
From Point Cloud Data to Building Information Modeling: An Automatic Parametric Workflow for Heritage	Spain; Italy; England	41
Combination of Nadiral and Oblique UAV Photogrammetry and HBIM for The Virtual Reconstruction of Cultural Heritage. Case Study of Cortijo Del Fraile in Nijar, Almeria	Spain; Cuba	38
Web-GIS Approach to Preventive Conservation of Heritage Buildings	Spain; Italy; Portugal	32
Implementation of Ultra-Light UAV Systems for Cultural Heritage Documentation	Turkey	28
GIS and BIM as Integrated Digital Environments for Modeling and Monitoring of Historic Buildings	Greece	28

In the analysis of inter-organizational cooperation networks, one can determine whether cross-regional communications and cooperation exist, as well as identify important research institutions, based on their status and domain connections. The institutional knowledge domain map of the co-authored articles in this study is shown in Figure 5, but the nodes represent the institutions. As shown in Figure 5, the University of Naples Federico II, Politecn Torino, University of Bologna, and Sapienza University Roma are the institutions at the heart of this field, with the richest field partnerships. The collaborative network as a whole has Italian institutions as the main centers of research collaboration who dominate the volume of publications. In terms of academic exchange, the University of Massachusetts (Boston, MA, USA) and the University of Seville (Sevilla, Spain) are closely behind, playing an important role. Among other Italian institutions, the University of Naples Federico II has the largest network of collaborations in the world, as illustrated by research collaborations with the University of Bradford (Bradford, UK), Shenzhen University (Shenzhen, China), Cent South University (Changsha, China), and the University of Aveiro (Aveiro, Portugal).

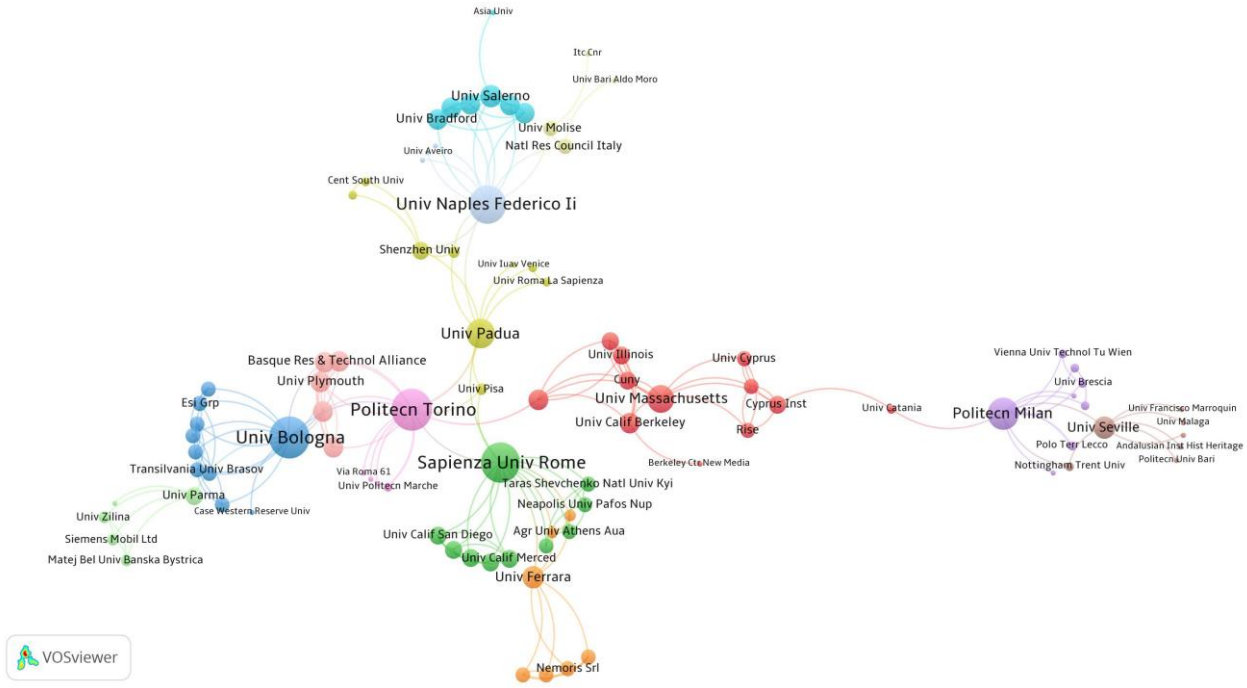


Figure 5. Institutional co-occurrence network.

Although marginalized schools such as the Polytechnic University of Bari and the University of Catania have a strong influence on scientific output and collaborate with other institutions, the scope of the cooperation is not broad enough and the research links are not strong enough. As a result, strengthening large-scale collaborations (across regions and backgrounds) for the conservation of historic buildings using digital technologies will be a priority in the future.

3.3.2. Researcher Analysis

As the research on historic architecture and digitization covers 99 categories, the WOSCC database contains over 200 relevant authors. Despite the small number of co-occurring relationships among authors posting in this field, only 18 between authors were obtained using VOSviewer, with the relevant bibliometric indicators presented in Figure 6.

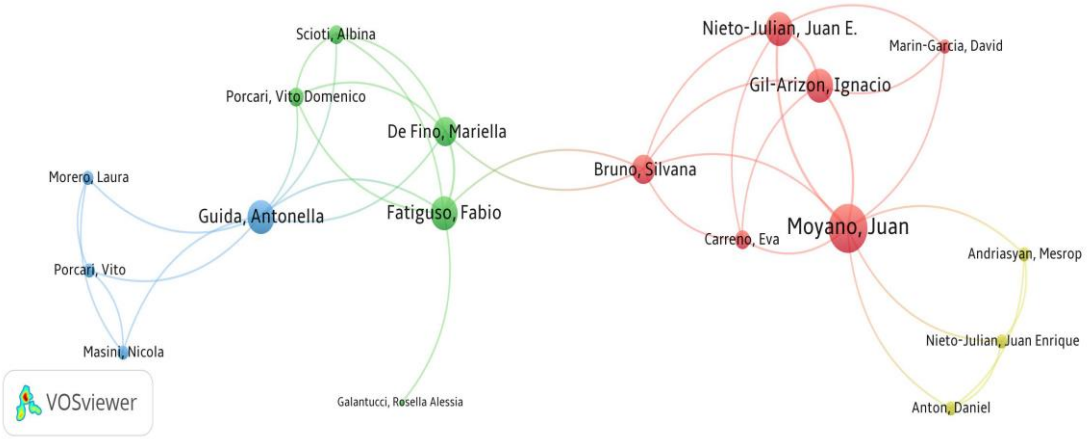


Figure 6. Author cooperation network.

As well as providing valuable information for analyzing authors' contributions and connections in the field, the co-authorship network map can help identify potential collaborative teams and partners for future research combining historic architecture with digital technology. Figure 6 illustrates how the authors' co-authored knowledge domain mapping can be mapped using VOSviewer. This is to clarify that the clustering theory for co-authorship networks is different from the theory for literature coupling networks. In the former, the co-occurrence matrix is used, whereas in the latter, the coupling matrix is used. Community clustering is based on Euclidean distance relationships between item units in the statistical database for both of these methods [13]. Due to the fact that there is a clear trend toward internal collaboration among institutions conducting research on historic buildings and digitization, analysis that is based on a co-authored mapping of knowledge areas is more accurate.

In Figure 6, there are close-cooperation author clusters with strong subcluster connections, such as the red and yellow clusters with Moyano, Juan, Nieto-Julian, Juan E, and Gil-Arizon, Ignacio as their core; the blue and green clusters have Guida, Antonella, Fatiguso, Fabio, and De Fino, Mariella as the core blue and green clusters. Additionally, authors in the red cluster focus on environmental sciences and ecology, geology, remote sensing, imaging science, and photographic technology; archaeology, construction, and building technology; and engineering, construction and building technology, and engineering. Authors in the green cluster focus their research on archaeology, art, chemistry, geology, materials science, spectroscopy, computer science, and architecture. Authors in the yellow cluster focus their research on computer science and architecture. The yellow cluster is similar to the red cluster, while the blue cluster is similar to the green cluster.

However, most collaborations occur primarily between authors of the same nationality or with the same institutional background. It is important, therefore, to emphasize cross-disciplinary, cross-institutional, and cross-national collaborations, as well as interdisciplinary efforts, in order to develop historical architecture and digital research. Collaborations of this type facilitate mutual learning between teams, contributing to the transformation of historical architecture preservation.

3.4. Research Hotspots Analysis

3.4.1. Topic Keywords Map

The co-occurrence analysis of keywords allows us to describe the core content and structure of the academic field of historical architecture and digitization while indicating the research frontiers of the field. A node's strength of association is determined by its line width, with the hot words of similar research topics clustered in the same color. Figure 7 shows five core clusters of research on historic buildings and digitization: (1) research in the field of historic buildings and digital measurement techniques (red); (2) research in the

field of informatization of architectural heritage (green); (3) research in the field of digital transformation of the structural foundations of historic buildings (blue); (4) research in the field of the historical communication of heritage buildings (purple); and (5) problems facing historic buildings (yellow).

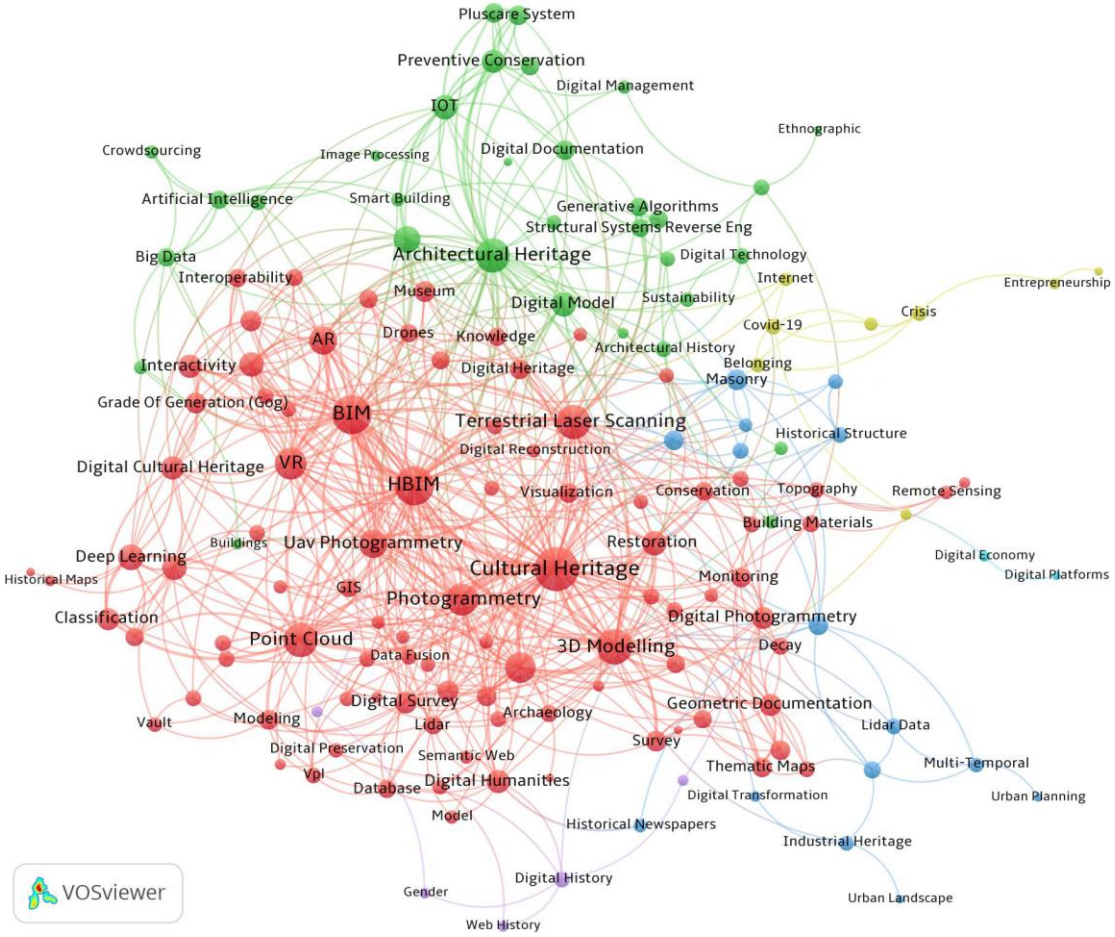


Figure 7. Co-occurrence network of keywords in biochar-related research.

In addition, the higher the frequency of the co-occurrence of two keywords in the co-occurrence graph of VOSviewer, the stronger the correlation between them and the greater the reliability of the information in that subject area. Highly related items are close together in the co-occurrence matrix and grouped into the same aggregation unit. Combined with the knowledge graph results, the relatively high density of red and green clusters indicates that research in these two fields, namely historical architecture and digital measurement technology, is more popular than research in the field of information about architectural heritage.

Cluster 1 (red) focuses on the "Point Cloud", "HBIM", "BIM", "Photogrammetry", "Terrestrial Laser Scanning", and "3D Modelling" keywords, with the highest number of occurrences and connections in Cluster 1. The keywords "Terrestrial Laser Scanning" and "3D Modelling" have the highest number of occurrences and connections in cluster 1. The keywords "Terrestrial Laser Scanning" and cluster 2 (green) core keywords "Structural Systems", "Reverse Engineering", and "Generative algorithms" are closely related. Given the high degree of intersection and co-occurrence frequency between the green cluster and the red cluster, the results of keyword co-occurrence indicate that the cross-focus between the technical or equipment aspects within the red cluster and the green cluster predominantly involves the application of algorithms and models to enhance the data obtained from historical architecture scanning.

3.4.2. Keyword Relevance Analysis

The frequency of keyword occurrences was also utilized to construct a confusion matrix between keywords (Figure 8). As indicated in the figure, BIM, HBIM, 3D modeling, point clouds, and photogrammetry are the main methods of capturing historical building information using digital technologies, and the majority of the studies focus on establishing historic building documentation. The BIM system, however, is the most relevant to digital twin and is often used in conjunction with VR, AR, and point cloud technologies to conduct research on the virtual reconstructions of historic buildings. The use of UAVs for building data measurement is becoming increasingly popular due to their low cost and speed advantages, and the combination of UAVs and point cloud research has some promise in terms of data collection, which may result in improved data accuracy. With the widespread development and application of artificial intelligence, deep learning and machine learning have also started to be applied with point cloud. However, because of the characteristics of both models, deep learning is more highly relevant to point cloud research in the field of historic building conservation, and these models could also be utilized to improve the detail of the 3D data of historic buildings.

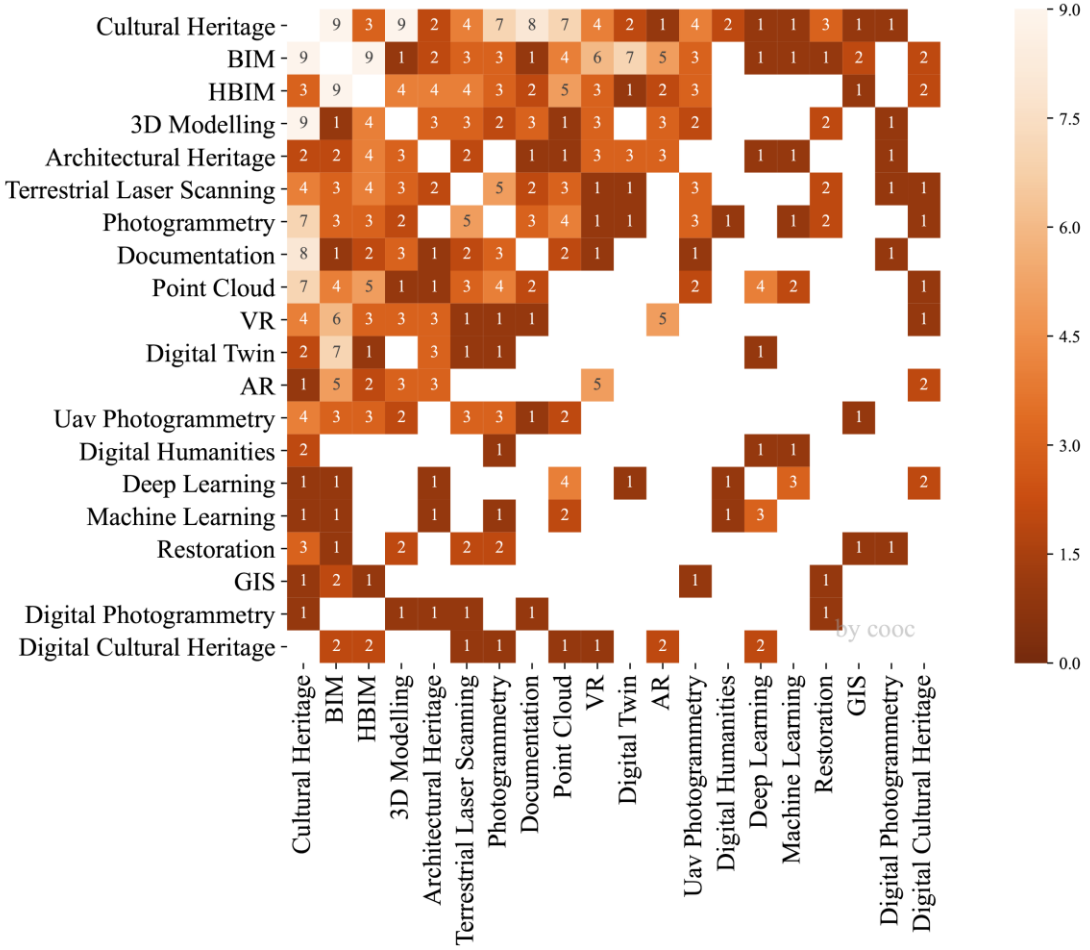


Figure 8. Confusion matrix of keywords.

3.4.3. Journal and Keyword Double Cluster Analysis

An analysis of hierarchical clustering can directly demonstrate how closely related keywords are as well as determine their relevance [19]. The closer keywords are to each other in a hierarchical cluster analysis graph, the greater their similarity, while keywords with a longer distance from each other form branches. This study uses Co-Occurrence 13.4 (COOC) software to create a two-mode matrix for hierarchical clustering based on

keywords and journals with a high frequency. A hierarchical clustering analysis based on a two-mode matrix significantly improves the analysis of a traditional systematic clustering algorithm in one dimension by achieving the simultaneous clustering of keywords and journals simultaneously. In the cluster analysis, the distance algorithm between samples was Euclidean distance, the clustering method was Ward's minimum variance method, and the matrix standardization method was the Z-score standard. The keyword frequency limit (≥8) and journal frequency limit (≥5) were set.

A bi-directional clustering result for publications in the historic building and digital technology fields is presented in Figure 9. The vertical clustering tree represents the clustering results of high-frequency keywords, while 17 high-frequency subject terms are listed at the bottom of the figure. An analysis of the horizontal clustering tree illustrates the clustering results of high-frequency journals, with 14 high-frequency journals listed on the right. The box indicates the column–row corresponding high-frequency keyword-journal units, and the color depth indicates the frequency of occurrence.

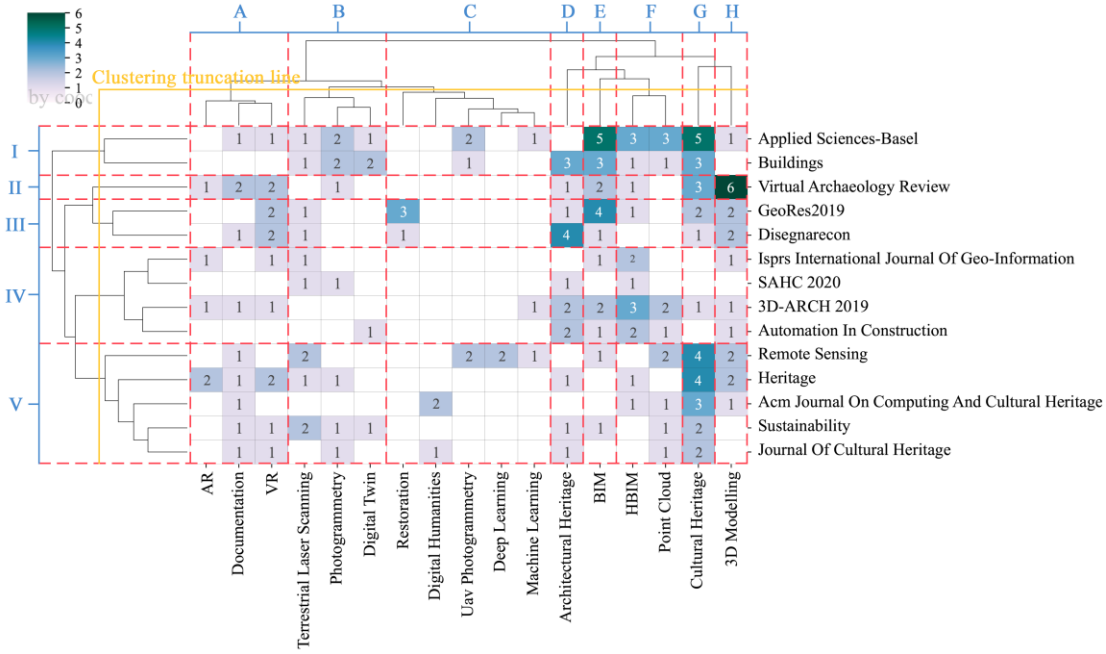


Figure 9. Biclustering of journals and keywords.

The hot spots focus on eight areas: (A) research on various types of immersive reality technologies to create digital archives of buildings, mainly including "AR" and "VR"; (B) research on measurement technologies, including "Terrestrial Laser Scanning", "Photogrammetry", and "Digital Twin"; and (C) the research and development of artificial intelligence to optimize measurement equipment to achieve the restoration of historical buildings. (C) To optimize measurement equipment for the restoration of historic buildings with the help of artificial intelligence research and development, including "Digital Humanities", "Uav Photogrammetry", "Deep Learning", and "Machine Learning"; (D) architectural heritage research; (E) building information modeling; (F) architectural datasets, including "HBIM" and "Point Cloud"; (G) cultural heritage; and (H) realistic 3D reconstruction. Similarly, the popular journal clusters can be divided into five areas according to unit relevance: (I) the "Applied Sciences and Structural Research" cluster; (II) "Virtual Archaeology" cluster; (III) "Geoinformation, Restoration and Mapping" cluster; (IV) "Building Analysis and Automation" cluster; and (V) "Cultural Heritage and Sustainable Development" cluster.

It is noticeable that D, E, F, G, and H are the most popular research areas in the field, while I, II, and III are journals with a larger research scope in the field. *Applied Sciences*—Basel

is associated with most of the hotspots, with significant two-dimensional correlations with BIM, HBIM, and the clustering of E and F represented by point cloud. It can be seen that there is a strong two-dimensional connection between the (I) journal cluster and the (D, E, F, G) keyword cluster, indicating that the intersection and integration of historical architecture and digital technology will be further enhanced in response to the requirements of heritage conservation. In addition, *Virtual Archaeology Review* focuses on the study of heritage buildings using the technique of realistic 3D reconstruction and shows the highest relevance among all units.

3.4.4. Keyword Burst Detection

The burst detection method is a more advanced method of identifying publications that are receiving research community attention at various stages of development than the citation count or download method. According to Figure 10, the top 20 outbreak keywords, as well as the duration of the outbreaks, are shown. All other keywords, except digital history, did not last as long as 2020. The emerging fem, computer vision, masonry, digital collections, and digital humanities in 2020 only lasted one year, whereas UAV photogrammetry and artificial intelligence continued into 2021. In addition to historical structure and GIS, machine learning and GIS also appear for only a short period of time in 2021. It is noteworthy that research in the emerging field of deep learning in 2022 continues into 2023 and becomes the focus of a new field along with circular economy, procedural modeling, and extended reality, four directions that are yet to be invested in and expanded on by researchers. Researchers have yet to invest in and expand on these four areas, and they are likely to become important topics in historical architecture and digital research in the future.

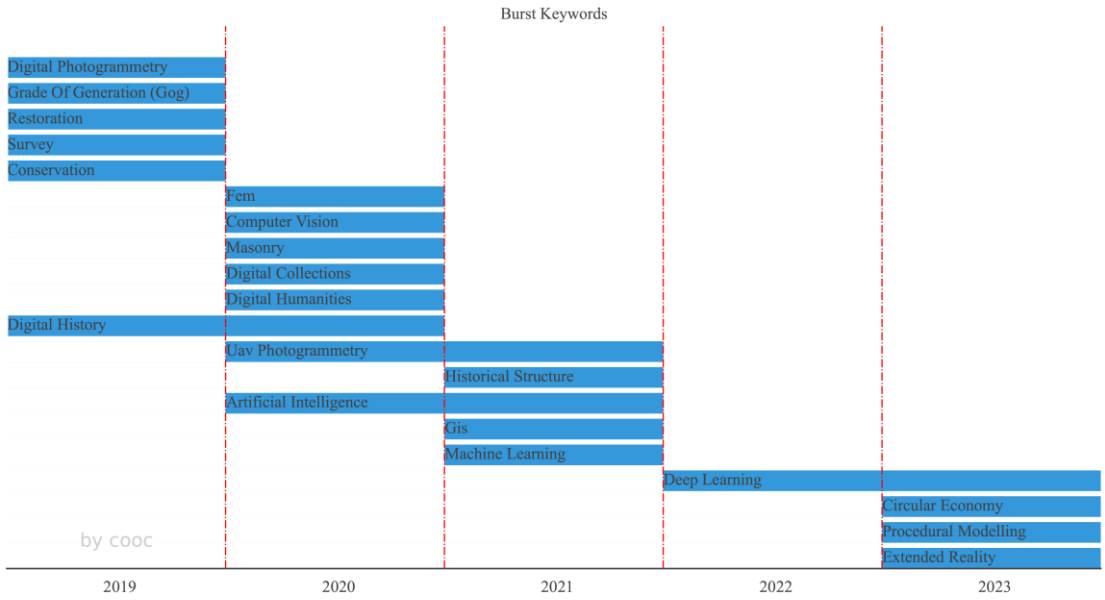


Figure 10. Top 20 keywords temporal emergence.

3.5. Citation Analysis

Several studies have demonstrated that co-citation analysis is an effective method of peer review that contributes to an accurate assessment of scientific performance in a given field. Considering its definition, classification, and necessity [20], this section focuses on the analysis of citations of the first authors in the literature using CiteNetwork to determine knowledge base and knowledge flow in the fields of historical architecture and digital research.

3.5.1. Literature Co-Citation Analysis

Considering the impact of citations, co-citation analysis of articles helps researchers find potential collaborative units [21]. The citation network of articles published in this area in the last five years is largely based on the articles in the center of Figure 11, where there are many studies of interest, such as EXtreme-DataCloud, an EU H2020-funded project to develop scalable technologies for federating storage resources and managing data in highly distributed computing environments [22]; evaluating "digital twin" models to simplify process simulation and enable efficiency optimization, prediction, early warning, and so on, to show how to improve the stability of digital twin interactions [23]; A new maturity model for the SME to support its transition to Industry 4.0 [24]; promoting the way of communication between the current implementation of new technologies and industrial equipment, erasing the boundaries between the real environment and the virtual world [25]; digital twin refers to a virtual representation of a physical product or process that integrates data from various sources, such as data API, historical data, embedded sensors, and open data, describing the basic concepts, reference architecture, features, and components of the IoTwins project [26]; developed a distributed architecture that provides machine learning practitioners with a suite of tools and cloud services that cover the entire machine learning development lifecycle, from model creation, training, validation, and testing to model provisioning as a service and sharing and publishing [27]; overview of the specific challenges and future research needs for control, networking, and computing systems and the adoption of machine learning in I-IoT environments [28]; developed INDIGO-DataCloud to integrate existing services and allow public and private e-infrastructures to facilitate seamless access to electronic infrastructures [29]; and, finally, summarizes the key issues of Industry 4.0 interoperability and presents its conceptual framework, discussing the challenges and trends for future research [30].

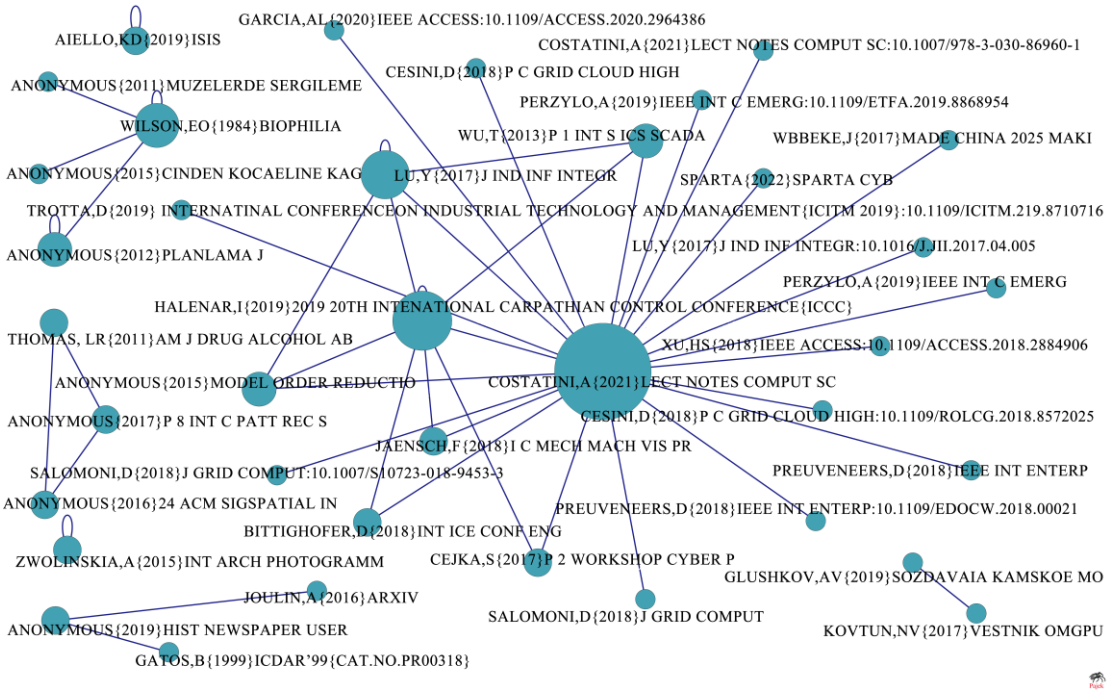


Figure 11. Literature co-citation network [22–30].

The above involved various aspects and fundamental studies which have contributed some boost to the articles published in the last five years in the field of historical architecture and digital research, and the subsequent researchers working on this topic are urged to pay attention to these results.

3.5.2. Citation Relationship among Highly Cited Literature

Considering that the literature co-citation network can only reflect the knowledge base of co-citation between published articles in the field of historical architecture and digital research, it does not clearly sort out the relationship between the highly cited literature. In order to more systematically explore the flow of scientific knowledge in historical architecture and digital research in the last five years, this study draws the relationship between the top 30 highly cited literature with the help of CiteNetwork, as shown in Figure 12.

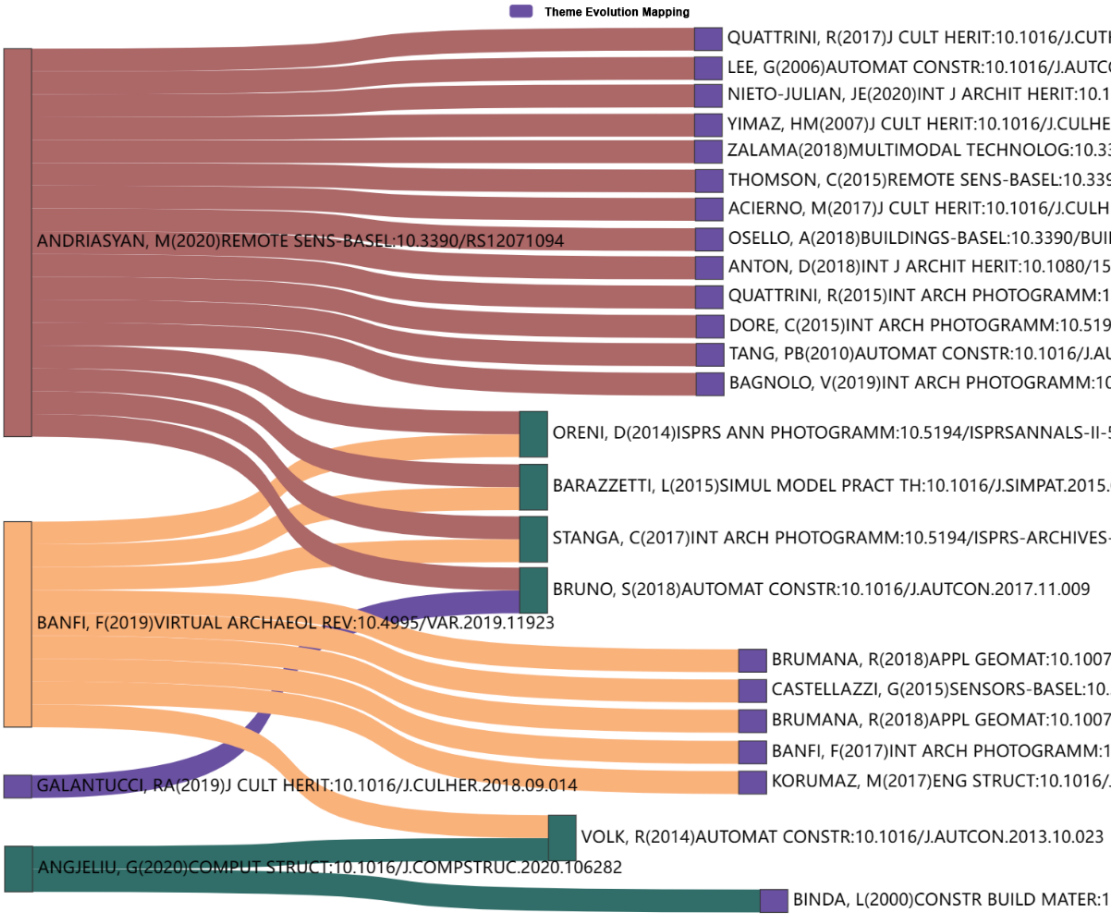


Figure 12. Highly cited article Sankey diagram [31–35].

Figure 12 shows that the highly cited articles appearing in the field in 2019–2023 are related to five articles, and all five papers are cited by at least two of the highly cited articles published in the recent five-year time span. The Historic Building Information Model (HBIM) of Basilica di Collemaggio is part of the restoration of buildings severely damaged by the 2009 earthquake part of the project; Oreni D created a detailed HBIM through photogrammetric and laser scanning surveys, required for interpretation and modeling, to manage the analysis phase, structural behavior simulation, economic evaluation of the project, and final restoration, with special attention paid to the procedures used to preserve the complexity given by the photogrammetric and laser scanning data [31].

Barazzetti, L introduced an innovative two-step approach (Cloud-to-BIM-to-FEM) to develop a reliable structural simulation procedure to convert historical BIM into FEM models for structural simulation, achieving realism in historical building models, and avoiding shape oversimplification. And he verified through a real case that the Cloud-to-BIM-to-FEM workflow can generate accurate historical BIM from a set of laser-scanned point clouds [32].

Stanga, C. rediscovered the vast wealth of traditional architectural notes through the collection of surveys and data on the Basilica of S. Ambrogio in Milan, realizing a virtual notebook, based on a 3D model that supports the collection of information. A mobile application was developed, which is potentially understandable and accessible to anyone. It was used to explore different historical phases, from the most recent layers to the oldest ones, through a virtual subtraction process, following an architectural and archaeological approach [33].

Bruno, S presented different perspectives integrated with cognitive automation, focusing on the automation of performance assessment. Data collection was performed mainly on HBIM/BIM contributions of existing buildings and infrastructures, with key assessment work based on selected criteria, and a special focus on performance assessment in HBIM. In this context, he proposes a new approach for Diagnosis Assisted Historical Building Information Modeling and Management (DA-HBIMM), mainly as a framework dedicated to intelligent knowledge acquisition, collection, and notification of assessment results and potential risks in the future through cognitive automation and artificial intelligence [34].

Volk, R believes that BIM applications in existing buildings are still rare, mainly due to the high cost of modeling and converting building data into semantic BIM objects, data updates in BIM, and the difficulty of handling uncertain data, objects, and relationships in existing buildings. Despite the rapid development and popularity of BIM technology, research is needed in areas such as process automation and adaptation of BIM to the needs of existing buildings to achieve the efficient management of existing buildings [35].

3.6. Academic Influence Analysis

The traditional indexes of academic influence evaluation can no longer meet the needs of complex academic evaluation. In order to evaluate the academic influence of journals, institutions, and authors more comprehensively and objectively, the indexes of H-index, G-index, P-index, Z-index, total publications, total citations, and citations per paper are computed. Among these, the H-index is used to objectively compare the "scientific achievements" of researchers based on the number of publications that have received at least h citations [36]. It has rapidly become one of the most popular measures of scientific output [37]. The G-index is defined "as the highest number g of papers that together received g2 or more citations" [38] and is higher than the H-index. In 2010, Prathap, G proposed the p-index [39] and analyzed it from the perspectives of institutions [40], scholars [41], and journals [42], showing that the p-index can balance the quantity and quality of scholars' paper output. The z-index is a new comprehensive evaluation index which was proposed by Prathap, the originator of the p- index, in 2014 to compensate for the fact that the p-index does not reflect the concentration of citations [43]. He also believes that the z-index is a new type of 3D energy efficiency index, which is a high-grade journal evaluation index compared to the previous evaluation indexes [44].

In order to clarify whether there is a correlation among the indicators of academic impact evaluation, the following will be based on academic influence evaluation software to draw a visual correlation chart of impact evaluation indicators; the items that are not statistically significant among the indicators are without figures and blank.

3.6.1. The Most Productive and Influential Journals

The computed top ten most influential journals are shown in Table 5, which differs from the results based on a single classification of citation frequency, with only *Applied Sciences*—Basel, *Remote Sensing*, and *Virtual Archaeology Review* journals remaining in the top ten. These journals cover the topics of remote sensing, geoinformation, mapping, heritage, archaeology, and environmental protection, covering a wide range of disciplines and representing the main direction of research in the field. However, the results in Table 5 are basically consistent with the previous tree diagram, and the study speculates that it may be due to the visualization of the correlation of impact indicators in Figure 13, which shows that total publications and total citations of the traditional impact main indicators are

correlated to the values of H-Index, G-Index, P-Index, and Z-Index, and the more articles are cited and published, the larger the values of each remaining indicator will be, so the top ten most influential journals in Table 5 are basically consistent with the results of the previous tree diagram.

Table 5. Journal impact indicators.

Journal	TP	TC	CPP	H-Index	G-Index	P-Index	Z-Index
Applied Sciences—Basel	15	202	13.47	7	14	13.96	10.40
Remote Sensing	14	174	12.43	5	13	12.93	8.62
2nd International Conference of Geomatics and Restoration	11	30	2.73	4	5	4.34	2.77
Heritage	11	45	4.09	4	6	5.69	4.41
Virtual Archaeology Review	9	71	7.89	3	8	8.24	5.42
Disegnarecon	8	8	1.00	2	2	2.00	1.47
Sustainability	8	62	7.75	4	7	7.83	6.05
Buildings	8	38	4.75	4	6	5.65	4.31
8th International Workshop 3d-Arch	7	44	6.29	4	6	6.52	5.32
International Journal of Architectural Heritage	6	34	5.67	2	5	5.78	3.95

TP: total publications. TC: total citations. CPP: citations per paper.

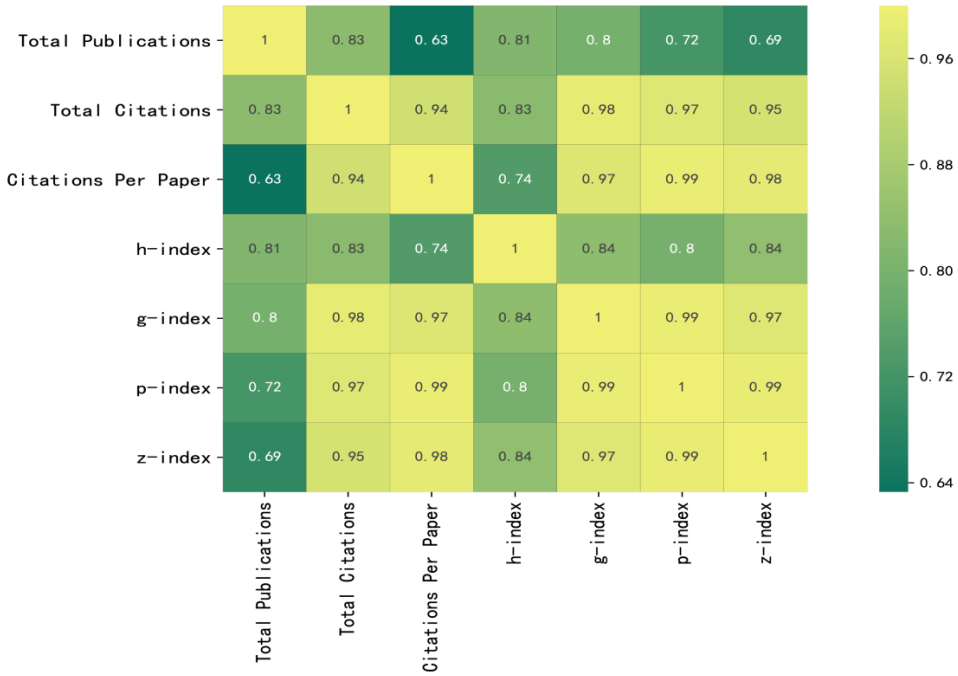


Figure 13. Correlation among impact indicators of journals.

3.6.2. The Most Productive and Influential Institutions

Figure 14 shows that the total publications of the institution are correlated with the total citations, H-Index, and G-Index; total citations is only not correlated with citations per paper; citations per paper is only relevant to P-Index, and total citations is only correlated with citations per paper; citations per paper is only related to P-Index and Z-Index; H-Index and G-Index are only not linked to citations per paper; and P-Index and Z-Index are only not linked to total publications.

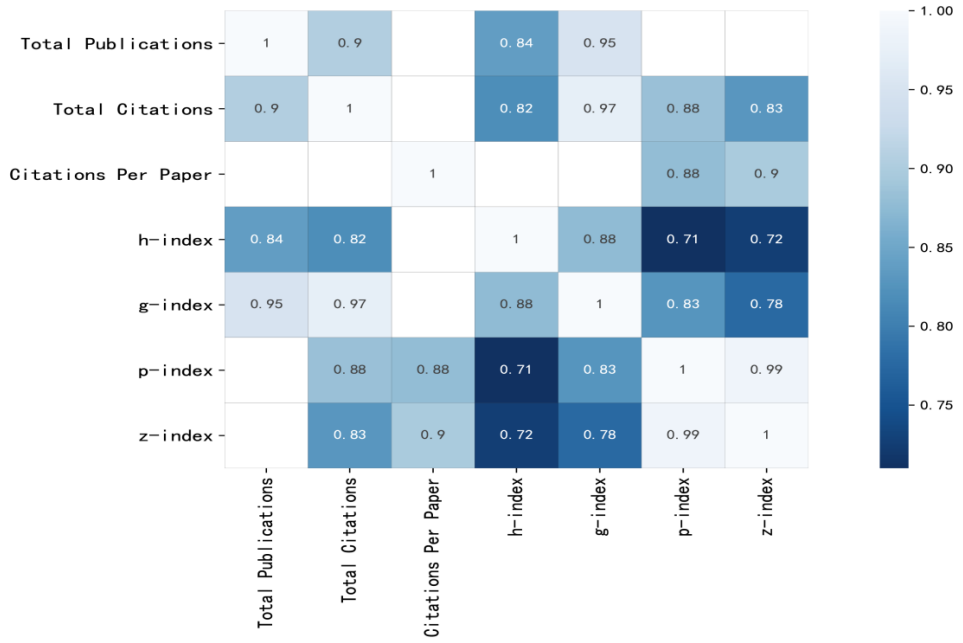


Figure 14. Correlation among impact indicators of institutions.

The regional distribution of the top ten most influential institutions in Table 6 shows a predominance of institutions from the European region, with schools from Italy occupying five of the top ten positions, followed closely by Spain, which occupies three positions. This is probably due to the fact that Europe is the center of Western culture, and Italy is the closest to the European cultural tradition and is the place with the strongest cultural inculcation. Moreover, in addition to the five institutions in Italy that deserve attention, the University of Alicante, the University of Seville, and the University of Salamanca in Spain, the University of Oxford in the UK, and the University of Minho in Portugal all require the attention of scholars working in the field of historical architecture and digital research.

Table 6. Institutional impact indicators.

Institution	TP	TC	CPP	H-Index	G-Index	P-Index	Z-Index
Polytechnic Milan	22	214	9.73	6	14	12.77	7.98
Univ Seville	10	58	5.80	5	7	6.95	5.30
Polytechnic Torino	7	118	16.86	4	7	12.58	8.78
Univ Naples Federico II	5	4	0.80	1	2	1.47	1.01
Univ Minho	5	45	9.00	2	5	7.40	5.23
Sapienza Univ Rome	4	32	8.00	3	4	6.35	4.75
Univ Salamanca	4	37	9.25	2	4	6.99	4.83
Univ Alicante	4	26	6.50	2	4	5.53	3.97
Univ Oxford	4	36	9.00	2	4	6.87	4.66
Univ Bologna	4	12	3.00	2	3	3.30	2.43

TP: total publications. TC: total citations. CPP: citations per paper.

3.6.3. The Most Productive and Influential Authors

Figure 15 shows that authors' total publications are correlated with H-Index, G-Index; total citations is only not related to total publications; citations per paper is correlated with total citations, P-Index, and Z-Index; H-Index and G-Index are only unrelated to total publications; P-Index and Z-Index are only unrelated to total publications; H-Index and

G-Index are not correlated with citations per paper; and P-Index and Z-Index are both not relevant to total publications.

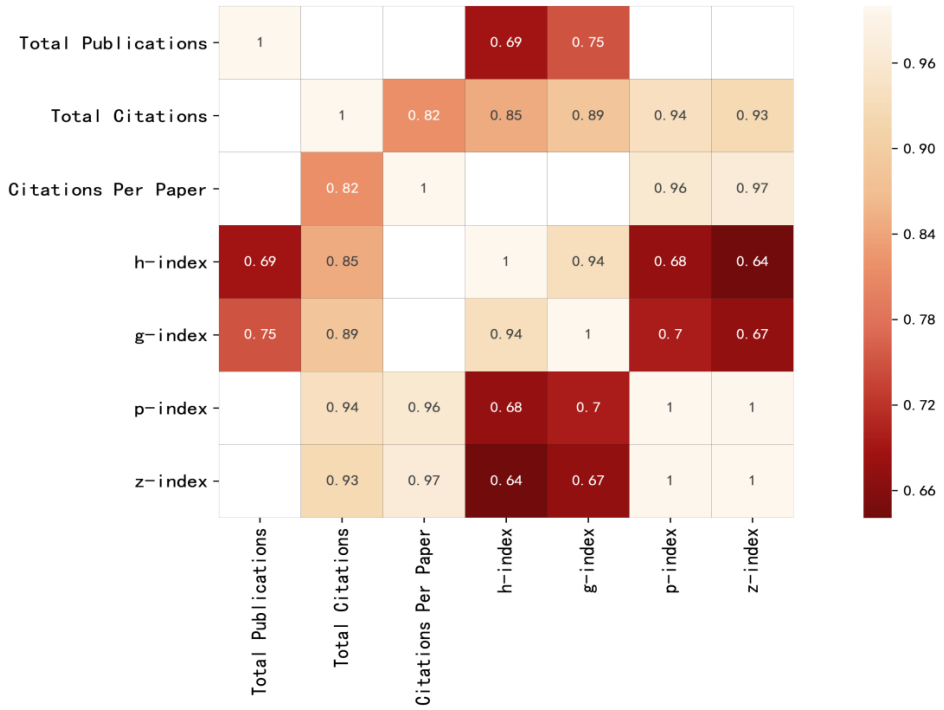


Figure 15. Correlation among authors' influence indicators.

The top ten most influential authors are shown in Table 7. They are mainly from Italy, Spain, and Portugal in the European region, and the top ten authors in this field are mainly working in the areas of archaeology, architecture, geography, imaging science, and remote sensing. In addition, construction and building Technology, computer science, and materials science are also areas of interest to leading scholars. It is worth noting that Wang, X from China and Previtali, M and Barazzetti, L from Italy have made important contributions to the application of computer technology in the study of historic buildings conservation; Banfi, F and Previtali, M focused on materials science in addition to their major efforts in the field of remote sensing.

Table 7. Author academic influence index.

Author	TP	TC	CPP	H-Index	G-Index	P-Index	Z-Index
Banfi, F	8	86	10.75	5	8	9.74	7.26
Previtali, M	6	14	2.33	2	3	3.20	2.64
Barazzetti, L	5	7	1.40	2	2	2.14	1.49
Stanga, C	4	52	13.00	3	4	8.78	6.32
Brumana, R	4	56	14.00	4	4	9.22	6.95
Oliveira, Dv	3	36	12.00	2	3	7.56	5.64
Nieto-Julian, Je	3	52	17.33	2	3	9.66	7.67
Moyano, J	3	52	17.33	2	3	9.66	7.67
Fabbrocino, G	3	1	0.33	1	1	0.69	0.48
Wang, X	3	3	1.00	1	1	1.44	1.22

TP: total publications. TC: total citations. CPP: citations per paper.

4. Conclusions and Research Outlooks

Considering the extensive and complex nature of research on historical architecture and digitization, it is difficult to comprehend the rapid growth of scientific documentary information in a clear and comprehensive manner. The concept of bibliometrics is an emerging topic in the field that is becoming increasingly relevant. Data-based bibliometric analysis is used in this study to develop a strategy and framework for investigating the evolution of research related to historic architecture and digitization over the period of 2019 to 2023. The relevant results include the following:

(1) The overall trend shows that research on historic buildings and digitization made significant progress between 2019 and 2023. It is generally in a phase of sustained and steady small growth, with a slight slowdown in the previous two years. After 2019, published papers exhibit a small downward trend but then return to growth again. Statistical descriptive analysis was conducted to determine the regional distribution of research institutions. It is Italy that is the most active country; the quality of Italy's publications is the highest, possibly due to the richness of Italian cultural heritage, and the fact that researchers are aware of how important it is to preserve their culture. Comparatively, academic influence computation, as compared to the list of core institutions, relies on traditional indicators. It is evident that Politecn Milan, Politecn Torino, the University of Naples Federico II, Sapienza University Rome, and the University of Bologna are among the core institutions in Italy. These institutions have contributed significantly to historical architecture and digitalization over the past five years. Italy's central position in this field may be due to the following aspects: In terms of heritage tourism, there are studies showing that intangible cultural heritage (ICH) can contribute to sustainable tourism development in rural areas, confirming the great potential of ICH-based initiatives for sustainable tourism development in rural areas in Italy [45], and tourism is one of Italy's pillar industries. Italy is ranked first on the World Heritage List in terms of the number of heritage sites, and a number of universities offer architectural heritage conservation programs. In previous years, some researchers noted that the University of Bologna was 174th (192nd in 2008) among a select group of Italian universities [46]. However, according to the Italian press, 40% of all Italian universities listed in the 2023 Quacquarelli Symonds (QS) World University Rankings rank among the top 300 worldwide in terms of research. Additionally, Spanish, Portuguese, and UK institutions constitute the core of the organization. However, in terms of collaboration, intra-institutional collaboration, and intra-cohort collaboration are dominant, so it is crucial to emphasize cross-background, cross-institutional, cross-border, and cross-disciplinary collaboration in order to facilitate team learning and diversification.

(2) As a result of keyword analyses, it has been gradually observed that attention on the conservation of historic buildings with digital technology has shifted from photogrammetry, geographic, computer vision, and digital history to artificial intelligence, deep learning, extended reality, and procedural modeling over the past five years. Terrestrial laser scanning, HBIM, 3D modeling, point cloud, and VR have emerged as hot topics in the field of historic architecture and digitization, forming a new generation of frontier research groups. A hot topic in architectural data capture is the application and research of image science, so the current and future frontier issues that must be addressed are photogrammetry, 3D modeling, point cloud, and deep learning.

(3) For the analysis of literature co-citations, studies on Industry 4.0 technologies dominate the co-citation network of articles published in the past five years, resulting in the emergence, communication, in-depth research, and rapid development of digital tools for historic building conservation. According to the citation relationship analysis of the highly cited literature, BIM is the core theme cited in the highly cited articles, and, among them, diagnostic-assisted information modeling and performance assessment of the management and rehabilitation of historic buildings using scanned data, as well as the development of structural simulation programs to convert HBIM into finite element models to achieve the realism of historic building models for the efficient management of existing buildings are the hot research topics in the past five years. It is worth noting that there is a considerable

amount of research on scanning, BIM processes, virtual and augmented reality, automated parametric workflows for architectural heritage, damage detection in historic buildings, and simulation models for digital twin applications in historical masonry buildings. Moreover, based on the systematic clustering results of the two-mode matrix, research in 3D modeling is most relevant to journals such as (A) *Virtual Archaeology Review*—the most frequent interactions are among BIM and point cloud—and (B) *Applied Sciences*—Basel journals, all of which are prominent directions for historic architecture research.

(4) This study provides a novel bibliometrics-based workflow for statistical analysis of literature data in order to ensure consistency of data sources and rich functional coverage. Unlike the bibliometric application methods in recent years, this study not only can analyze the collaboration networks, research hotspots, characteristics, and development trends within the research field, but can also generate the co-citation networks of the cited literature of highly cited articles through CiteNetwork to further explore the knowledge base and flow of highly cited articles. The analysis of CiteNetwork of the results shows that the knowledge base of the highly cited articles is mainly based on the technology applications related to Industry 4.0, and the scientific knowledge flow between the highly cited articles published in the last five years is mainly focused on the research of technology improvement of BIM. In addition, the dynamics of frontier fields require researchers to pay attention to the latest journals, institutions, and authors with a high academic influence, while the traditional academic influence evaluation indexes can no longer meet the needs of complex academic evaluation. In order to more comprehensively and objectively evaluate the academic influence of journals, institutions, and authors, AIE software was used to calculate H-index, G-index, P-index, Z-index, total publications, total citations index, and citations per paper. In this field, the ranking of the academic influence of journals is similar to that of publications: five Italian institutions and three Spanish institutions dominate the top ten ranking of academic influence of institutions; Italy and Spain accounted for the majority of the top ten authors in this field. It is estimated that the top ten authors in this field are working primarily in archaeology, architecture, geography, imaging science, and remote sensing. Construction and building technology, computer science, and materials science are also areas of interest to leading scholars.

As an emerging study using bibliometric analysis in the field of historical architecture and digitization, this study provides a new data-driven scientific tool for quickly identifying and analyzing current research hotspots, evolutionary trends, scholarly influence, and scientific knowledge flows within a rapidly emerging field of research. Bibliometrics, however, still has some limitations, so we suggest the following reference directions to enhance future research: (i) despite the fact that Web of Science text data are essential for bibliometric analysis, the retrieved articles have some minor shortcomings in terms of consistent subject matter; (ii) data pre-processing is not perfect, and accuracy could be improved further in order to reduce manual screening and merging; (iii) a problem with VOSviewer is the lack of flexibility in the parameter setting of the visualization; and, finally, (iv) CiteNetwork's visual diagram of the citation network does not provide a clear and easy-to-read display of the literature information.

Author Contributions: Conceptualization, Z.W.; methodology, Z.W. and H.S.; software, H.S. and L.Y.; validation, H.S.; formal analysis, H.S.; investigation, H.S. and L.Y.; resources, H.S.; data curation, L.Y. and H.S.; writing—original draft preparation, H.S. and L.Y.; writing—review and editing, H.S.; visualization, H.S. and L.Y.; supervision, Z.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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