

REVIEW ARTICLE

Novel technology use for digital transformation of cultural heritage

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Abstract

Novel technology use in Cultural Heritage (CH) research enables cultural sustainability. The aim of this paper is to reveal the current gaps, trends, and future prospects in novel technology use in CH research for Cultural Heritage 4.0 approaches. Data on the 'technology use in CH research' was collected from the Scopus database. This study adopted a scientometric analysis and mapping of bibliometric data. The scientometric analysis tool that is used in this research employ Machine Learning and Natural Language Processing (NLP) methods. The results were discussed and synthesized in detail for the fulfilment of the research scope. The findings shed light on the divergence of research intentions in CH research field, which mainly focuses on data visualization, digital preservation, and remote sensing technologies while the next trending subjects may be digital reconstruction and artificial intelligence for CH. The novel technologies that are used in the digital transformation of CH were further discussed in detail. The paper concludes with prospects for the future research in the field. The paper may enable a higher understanding of the relationship between technologies and concepts. Thereby, CH research field may increase the efficiency and effectiveness of the project results by exploiting the suggested technologies. Because of the analyzing tool's shortfall, the language filter was used. The research input includes also limitations for publication type. These filters led to analyzing only English-written articles only. Future research may use all languages and all publication types for a broader perspective.

1. Introduction

Cultural Heritage (CH) is essential for shaping national identity, connecting the present with history [1]. It goes beyond preservation, focusing on the development of these assets for social and cultural stability [2]. However, CH faces degradation from natural disasters, the environment, and human impact. The safeguarding of CH knowledge, spanning interdisciplinary sciences, necessitates an all-encompassing

approach that transcends the boundaries of physical conservation. Technological developments have spurred a paradigm shift towards the digitalization of CH. This transformation has given rise to Digital Cultural Heritage (DCH), which upholds the fundamental goals of CH preservation and the amplification of public awareness. DCH bears the potential to transcend temporal and spatial constraints. Therefore, DCH offers multifaceted opportunities, influencing various domains of

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education and the tourism sector. It simultaneously addresses the pressing need for enhanced access to CH resources, particularly among individuals with disabilities and the elderly. Beyond these considerations, it is poised to make a substantial contribution to the effective and efficient sharing of information on-site, targeting a diverse and extensive user base [3].

Historical shifts from the Middle Ages to the Renaissance were driven by technologies like the printing press, linear perspective in art, and patent laws. Modern innovations such as n-dimensional (nD) modeling, 3D printing, and Distributed Ledger Technologies hint at a new era. Industry 4.0, powered by Information and Communication Technologies (ICT), has revolutionized multiple sectors, enhancing efficiency and effectiveness. Industry 4.0 has engendered a cascade effect across multiple industries, ushering in a transformative wave of increased efficiency and effectiveness in operational processes. Within this paradigm shift, CH implementations stand as a notable exemplar, leveraging cutting-edge technology to enhance various facets of CH. This extends from CH data visualization and DCH reconstruction to DCH preservation and remote sensing. Additionally, it encompasses CH Knowledge Management (CHKM) and CH reverse engineering, collectively underscoring the potential for innovative applications in CH conservation and exploration [4].

The following section introduces an examination of studies focusing on the application of Novel Technologies Use for the Digital Transformation of CH. Subsequently, a detailed scientometric analysis is conducted to elucidate the prevailing research gaps and emerging trends in the field of Novel Technologies Use for the Digital Transformation of CH. The analytical methodology is comprehensively explicated. The ensuing section provides a thorough exposition of the results obtained through this analytical approach, accompanied by a comprehensive discussion of the identified research gaps and evolving trends within the existing literature. Finally, the study concludes with a concise summary of the research findings

and a discussion of potential directions for future research.

2. Research Background

The fundamental tenet governing the acquisition of CH data is the imperative to preserve the integrity of the CH assets under investigation. Rather than resorting to destructive excavations within CH areas, research endeavors must employ minimally invasive techniques [5]. Remote Sensing Technologies offer the means to discern the physical properties of objects or groups of objects on the Earth's surface, effecting comprehensive assessments across expansive areas without incurring significant costs or damage. Complex topographies are scrutinized by gathering imagery through multiple radar units equipped with Synthetic Aperture Radar (SAR). Additionally, Interferometric Synthetic Aperture Radar (INSAR) enables the precise measurement of millimeter-scale details. Laser Imaging Detection and Ranging (LIDAR) facilitates the detection of enclosed vegetation and forested regions, preserving environmental integrity [6]. Ground Penetrating Radar Systems (GPRS) further extend non-invasive capabilities, enabling imaging and exploration of shallow subterranean layers without the necessity of excavation [7].

Challenges related to the deformation of tangible CH and inadequate documentation, compounded by technical knowledge limitations, have led to a prolonged and costly CHKM process. Digital technologies, such as Photogrammetry and Laser Applications, have become essential for acquiring semantic and spatial data. Photogrammetry excels in delivering high-precision 3D measurements using high-quality images [8]. Employing the principles of Digital Closed Range Photogrammetry (DCRP), hazardous and otherwise inaccessible areas are documented through a meticulous synthesis of photographs and mathematical equations [9]. The advent of Unmanned Aerial Vehicles (UAVs) has facilitated the generation of images closely resembling topographic maps, thereby enabling direct measurements of distances, angles, plane

coordinates, and areas, in concert with the aid of Global Positioning System (GPS) technology for location accuracy [10, 11]. These UAVs are equipped with high-resolution cameras [12, 13].

Laser Scanning technology is pivotal in generating detailed 3D models from dense point cloud data, especially when combined with digital photogrammetry [14]. This approach offers precise insights into architectural structures and facilitates the creation of high-accuracy 3D models [15]. Terrestrial Laser Scanning, a specialized subdomain, swiftly captures 3D spatial data with the help of laser beams from a specific distance above the ground. Its attributes, including speed and portability, enable efficient scanning of extensive historical areas [10]. Additionally, 3D scanning, a non-contact technique using lasers, light, or X-rays, captures object surface details through point cloud generation. In the manufacturing industry, 3D printing streamlines processes accelerates production, and reduces material waste [16].

The Heritage Building Information Modeling (HBIM) platform has emerged as an extension of Building Information Modeling (BIM), specifically designed for the digital modeling and documentation of historical buildings. This platform integrates documents obtained through techniques such as photogrammetry and laser scanning into a 3D model. Within the HBIM platform, documents pertinent to CHKM, including 3D models, programs, details, plans, and sections, are meticulously organized [17]. The primary objective of the HBIM platform is to optimize the cost of CH restoration and enhance the efficiency of preservation projects. Even in cases where CH may be lost, the HBIM model serves as an invaluable repository for knowledge transfer [18].

The growing public interest in CH has driven the need for its modernization and presentation using contemporary technologies [19]. IoT systems enable interconnected physical objects to communicate through the internet and also facilitate the CH degradation processes by detecting deterioration through sensor data, allowing for timely intervention [20]. Emerging technologies facilitate CH visualization and the transition of

artifacts to digital platforms, bridging the gap between visitors and CH [21]. Various visualization tools are employed, including Virtual Reality (VR) for a combined experience of real and virtual world objects [22]. Augmented Reality (AR) for real-time integration of virtual and real-world elements. Mixed Reality (MR) systems create immersive environments where physical and digital objects coexist and interact. Expanded Reality (XR) unifies the capabilities of VR, AR, and MR [23, 24].

The main aim of this study is to provide an overview of the current state of the use of digital technologies in the field of CH by identifying challenges and trends in scientific research, while addressing research gaps that need to be focused on.

The main contribution of this research is a comprehensive investigation of new technologies used for the digital transformation of CH. The article provides information on solution suggestions for the Cultural Heritage 4.0 concept of digital technologies. Furthermore, the article presents a scientometric analysis of digital technologies that will increase efficiency in CH research. Additionally, the article sheds light on the developing literature and potential future directions in this field by identifying emerging trends in CH research, research challenges, and trends of digital technologies.

3. Methodology

This study involved a rigorous bibliometric inquiry designed to elucidate the current landscape and prospects of Novel Technology Use for Digital Transformation of CH. The research aimed to gather data for subsequent scientometric analysis and mapping. The bibliometric search, combined with the scientometric analysis approach, unfolded in a systematic four-step process outlined as 'Preparation of Research Plan,' 'Data Collection,' 'Data Analysis,' and 'Documentation'.

This paper aims to answer a key question:

RQ1. How can novel technologies contribute to digital transformation of CH?

To answer this question, below-listed sub-questions are responded in this paper.

SRQ1. What are the challenges in Technology Use for Digital Transformation of Cultural Heritage?

SRQ2. What are the research areas related to Technology Use for Digital Transformation of Cultural Heritage?

SRQ3. What are the gaps in Novel Technology Use for Digital Transformation of Cultural Heritage?

SRQ4. What are the trends in Novel Technology Use for Digital Transformation of Cultural Heritage?

SRQ5. What are the future prospects for Digital Transformation of Cultural Heritage?

3.1. Preparation of research plan

CH represents a vast global resource, serving as a reflection of the social characteristics of historical epochs. The adoption of novel technologies within CH research has become increasingly prominent, primarily driven by the imperative of CHKM [1, 18]. The integration of novel technologies in CH offers numerous advantages, including the prevention of time and cost inefficiencies and the facilitation of knowledge transfer to future generations [1, 8, 16]. This study comprehensively explores the historical and prospective use of novel technologies in CH research.

3.2. Data collection

Bibliometric search is an established method employed to scrutinize vast datasets for valuable insights. The SCOPUS database stands out as a comprehensive and ever-expanding resource for literature searches [25]. In this study, SCOPUS was chosen as the primary database for bibliometric search due to the advantages of its Boolean Syntax API [26]. Therefore, a bibliometric search was meticulously executed on the SCOPUS platform to gather pertinent data concerning the utilization of Novel Technologies in CH (Fig. 1).

3.3. Data analysis

Scientometric Mapping, a method employed to cluster research areas and elucidate the structure and evolution of a scientific field, offers valuable insights into the landscape of a given topic. This

approach not only provides a snapshot of the structural facets gleaned from a comprehensive literature review but also offers a forward-looking roadmap for future research directions [26]. The utilization of VOSviewer software, developed for the creation and display of Scientometric Analysis and Mapping, further advances this analysis. Leveraging natural language processing and text mining techniques [27], this software allows for the meticulous examination of data derived from the Scopus database. The analysis encompasses articles and keywords related to research of Novel Technology Use for Digital Transformation of CH.

3.4. Documenting

This study employs a quantitative approach to conduct an in-depth analysis of Novel Technology Use for Digital Transformation of CH. The data extracted from the bibliometric database offers a comprehensive overview of the domains and tools in which Novel Technology has been applied within the realm of CH. Furthermore, the findings of this analysis serve to identify gaps and emerging trends in the existing literature, informed by the results of scientometric analysis.

4. Scientometric Analysis Results

4.1. Bibliometric search

A bibliometric search was conducted by querying the Scopus database using the following keywords in the TITLE-ABS-KEY ({technology} AND {heritage sites} OR {heritage building} OR {built heritage}). This search yielded 5,838 results. To refine the dataset, a language restriction was applied, resulting in 5,483 articles in the English language. Additionally, the search was further narrowed down to 4,843 documents by selecting relevant disciplines, including Engineering, Computer Sciences, Social Science, Energy, Arts and Humanities, Environmental Science, Energy, Economy, Decision Science, Business, and Management. To focus on scholarly articles, the document type "article" was specified, resulting in 2,745 articles. Subsequently, the search was refined by limiting the source type to journals, yielding 2,046 articles.

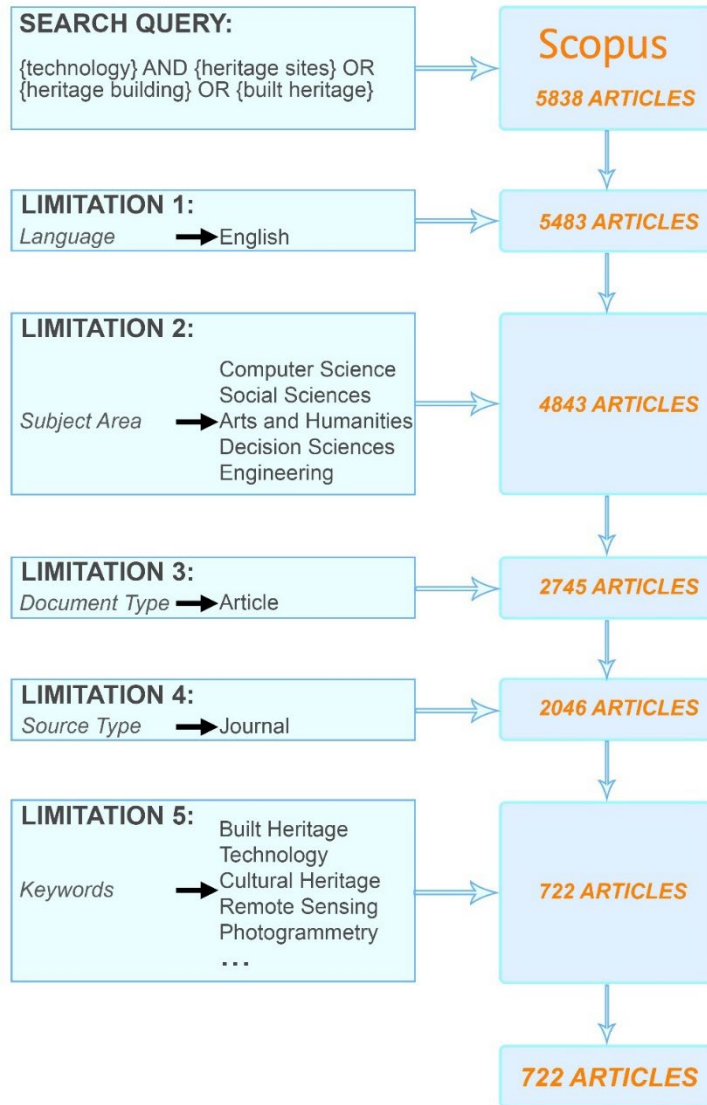


Fig. 1. The workflow of data acquisition and data preprocessing for keyword co-occurrence analysis

Further filtering was applied by using keywords relevant to the research, leading to a final dataset of 722 articles (Fig. 1).

4.2. The literature sample size

The first Scopus-indexed article on the subject of Novel Technology Use for Digital Transformation of CH was published in 1991. The annual publication trends are visually represented in Fig. 2. A noteworthy upward trajectory is evident in the number of articles published over the years, signaling a growing interest in this research

domain. Notably, in 2008, the field witnessed a remarkable surge in research output, registering an astounding growth rate of 275%. The last five years have witnessed a significant uptick, with twice as many studies conducted compared to the cumulative number of articles published in prior years (Please note that the total number of articles for the year 2022 could not be fully examined at the time of this article's preparation). The steep ascent observed between 2018 and 2020 underscores a surge in research interest across scientific platforms.

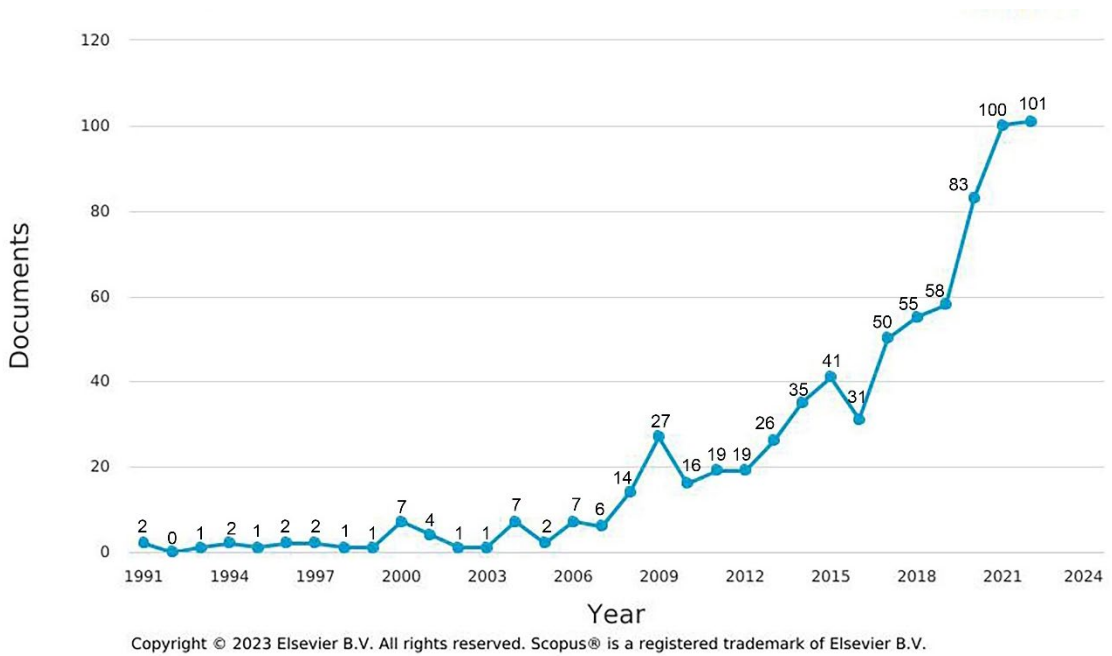


Fig. 2. Yearly number of papers about Novel Technology Use for Digital Transformation of Cultural Heritage 1991 to 2022

4.3. Results of keyword co-occurrence analysis

Scientometric mapping, a method for analyzing bibliometric data encompassing authors, journals, and articles, can be generated based on co-occurrence data using VOSviewer. Keywords serve as fundamental components for discerning critical aspects of research. Scientometric maps, as pioneered by [27], unveil the relationships between research topics and the organization of information. Co-occurrences provide a means to extract data regarding articles in which keywords appear together. In this context, bibliometric data was harnessed to construct a map visualizing keyword associations (Fig. 3). The colors assigned to keywords indicate their clustering, as determined through Keyword Co-occurrence Analysis. The results of the analysis reveal the segregation of keywords into six distinct clusters:

1. Facility Management for Built-Heritage (red-coded)
2. Remote Sensing Technologies for Heritage Areas (green-coded)
3. Cultural Heritage Sustainability (blue-coded)
4. Digital Reconstruction (yellow-coded)

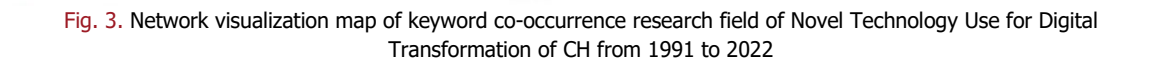
5. Digital Heritage Countries (purple-coded)

6. Visualization of Cultural Heritage Areas (turquoise-coded)

Keywords are visually represented using circles in the analysis, with the size of each circle corresponding to the relative importance of the associated word. The distance between two keywords on the map reflects the degree of semantic relatedness between them. Six clusters of keywords are presented in Table 1, showcasing only the most robust connections among them. The link value, a positive numerical value, signifies the collective strength of connections between two keywords, denoting the number of articles in which these keywords co-occur.

The meanings of the column headings in Table 1 are elucidated below:

- 'Number of Links' quantifies the degree to which a keyword is associated with other keywords.
- 'Total Link Strength' measures the overall strength of a keyword's associations with other keywords.
- 'Occurrence Frequency' indicates the frequency with which a keyword appears within the research domain.



Keywords	Link	Total Link Strength	Occurrence Frequency	Average Publication Year	Average Citation	Average Normalized Citation
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Cluster 1-Facility Management for Built-Heritage (red-coded)						
Artificial intelligence	12	19	11	2016,36	24,82	0,91
Building Information Modelling	13	17	5	2020,80	7,20	1,62
Database Visualization	10	16	5	2010,60	58,20	1,13
Database Systems	11	14	5	2000,00	54,00	0,74
Decision Making	18	24	10	2016,30	13,60	0,85
Environmental Technology	8	9	5	2017,80	4,40	0,57
Heritage Buildings	24	42	13	2017,38	14,54	1,56
Historic Preservation	31	59	16	2018,06	14,00	1,39
ICT	9	11	7	2017,29	16,57	0,77
Information Management	17	19	10	2014,20	5,11	0,55
Information Technology	27	38	20	2011,25	20,85	0,79
Internet	15	20	10	2011,40	5,50	0,40
Internet of Things	16	22	11	2020,00	8,91	1,43
Preventive conservation	10	14	5	2020,00	14,40	2,16
Restoration	16	18	7	2016,43	13,71	0,95
Visualization	31	44	12	2012,25	37,33	0,95

Table 1. Cont'd

Cluster 2-Remote Sensing Technologies for Heritage Areas (green-coded)						
Egypt	7	7	5	2016,40	19,40	3,39
Experimental Technology	8	17	16	2012,06	50,75	1,18
GIS	40	102	57	2013,18	16,04	0,76
Lidar	17	32	14	2016,79	27,79	1,13
Mapping	12	15	6	2012,67	6,00	0,33
Remote Sensing	41	108	55	2015,00	21,69	1,04
Reverse Engineering	6	8	5	2010,60	13,80	0,64
Satellite Data	8	17	5	2014,60	20,20	0,90
Satellite Imaginary	19	41	13	2012,08	24,00	0,66
South Africa	7	9	5	2011,80	69,20	1,47
Spatial Analysis	23	37	12	2015,83	13,50	0,88
Technology	36	77	85	2013,59	21,64	0,89
Technology Adoption	6	9	12	2016,83	17,67	1,03
Turkey	16	21	8	2012,25	28,00	0,82
United States	13	20	11	2012,36	18,45	0,91
Cluster 3-Cultural Heritage Sustainability (blue-coded)						
China	23	41	18	2016,56	13,72	0,75
Cultural Heritage	62	225	120	2017,08	10,37	0,87
Economic Development	16	18	6	2016,00	18,00	1,12
Energy Efficiency	15	26	7	2017,29	17,86	1,63
Energy Utilization	15	31	8	2017,62	18,00	1,34
Heritage Conservation	25	46	13	2019,00	6,54	0,80
Heritage Tourism	14	25	7	2016,71	13,71	1,29
Optimization	19	26	6	2015,83	17,33	1,13
Spatial data	13	19	5	2012,20	41,60	2,28
Sustainability	24	46	17	2019,89	4,72	0,83
Sustainable Development	33	70	19	2018,42	9,00	0,91
Technology Transfer	15	18	10	2018,42	9,00	0,91
UNESCO	26	39	11	2014,55	11,45	0,81
World Heritage Site	32	56	15	2013,47	21,33	1,07
Cluster 4-Digital Reconstruction (yellow-coded)						
3D Printing	5	8	6	2020,67	2,33	0,69
Algorithm	15	22	7	2011,86	37,43	1,23
Automation	12	18	6	2014,00	54,17	2,36
Computer-Aided Design	23	30	7	2008,43	44,00	1,28
Computer Simulation	27	36	13	2013,08	26,15	0,97
Data Acquisition	37	55	14	2012,43	14,71	1,20
HBIM	5	7	5	2020,20	21,80	5,18
Laser Applications	17	22	6	2012,17	22,00	1,37
Laser Scanning	16	22	7	2018,86	5,43	1,04
Photogrammetry	41	85	50	2017,28	10,10	1,22
Reconstruction	14	18	9	2015,22	17,22	1,00
Three-Dimensional Modelling	38	75	26	2014,50	21,81	1,46
UAV	11	17	7	2019,29	21,57	1,79

Table 1. Cont'd

Cluster 5-Digital Heritage Countries (purple-coded)						
Aerial Photography	17	24	7	2010,14	15,00	0,64
Archeological Site	13	17	6	2013,83	31,83	0,75
Data Processing	21	30	6	2012,17	10,50	0,54
Digital Photogrammetry	15	22	6	2013,50	8,67	0,70
Eurasia	34	70	16	2007,69	43,25	1,19
Europe	26	54	16	2009,38	31,00	0,89
Italy	27	52	18	2015,06	11,33	0,83
Jordan	8	11	5	2017,20	3,60	0,20
Southern Europe	13	25	5	2007,80	32,20	0,74
Spain	17	21	5	2007,80	32,20	0,74
United Kingdom	11	16	7	2011,43	22,71	1,57
Cluster 6-Visualization of Cultural Heritage Areas (turquoise-coded)						
3D Reconstruction	9	16	6	2018,67	9,50	1,07
Augmented Reality	19	40	18	2016,44	12,94	1,09
Digital Technologies	12	16	8	2019,38	3,75	0,52
Heritage Sites	20	30	9	2013,44	7,22	0,31
Image Analysis	20	28	7	2007,88	24,50	0,45
Image Reconstruction	20	28	7	2008,86	33,29	0,84
Virtual Archeology	10	21	10	2015,50	37,10	1,54
Virtual Reality	42	89	48	2014,98	15,92	1,12
Virtual Reconstruction	8	13	5	2018,60	4,60	0,88

- 'Average Published Year' provides insight into whether the research associated with the keyword is recent or historical.
- 'Average Citation' signifies the mean number of citations for scientific content featuring the keyword.
- 'Average Normalized Citation' offers an indicator of the influence of documents containing the keyword. These findings, derived from scientometric analysis, are presented in Table 1.

A Pearson correlation analysis was conducted to assess the relationships among the factors presented in Table 2. The findings reveal significant correlations among several quantitative factors. Notably, 'Total Link Strength' exhibits a strong and positive correlation with both 'Occurrence Frequency,' as indicated by a correlation coefficient of 0.909, and the 'Number of Links' associated with keywords, with a correlation coefficient of 0.926. Furthermore, the 'Number of Links' exhibits a substantial correlation, with a coefficient of 0.793, with 'Occurrence Frequency.' The analysis also

discloses that 'Average Citation' demonstrates a noteworthy positive correlation, with a correlation coefficient of 0.608, with the 'Average Year Published.' However, 'Average Citation' displays a weaker positive correlation, with a coefficient of 0.094, when assessed in relation to the 'Average Normalized Citation' of keywords. It is essential to note that the results presented in Table 1 indicate that 'Average Citation,' 'Average Normalized Citation,' and 'Average Year Published' remain largely independent of the 'Number of Links,' 'Total Link Strength,' and 'Occurrence Frequency' values within the context of research studies. Furthermore, the relationship between 'Average Year Published' and 'Average Normalized Citation' is deemed statistically insignificant.

4.3.1. Number of links

The 'Number of Links' serves as an indicator of the extent to which a keyword is interconnected with other keywords within the research context.

Table 2. Pearson correlation analysis of the measurement factors for keyword co-occurrence analysis

Measurement Items	Statistical Values	Number of Links	Total Link Strength	Occurrence Frequency	Average Citation	Average Normalized Citation	Average Year Published
Number of Links		1					
Total Link Strength	r	0,766333	1				
	p - value	<0.001					
Occurrence Frequency	r	0,639991	0,794181	1			
	p - value	<0.001	<0.001				
Average Citation	r	0,038784	0,104389	0,090831	1		
	p - value	.303	.345	.422			
Average Normalized Citation	r	0,071498	0,025547	0,051177	0,451122	1	
	p - value	.179	.254	.422	.001		
Average Year Published	r	0,063492	0,0311	0,009743	0,65199	0,03608	1
	p - value	.588	.868	.543	<0.001	.072	

Notably, the keyword 'Cultural Heritage' (62) exhibits the highest number of connections. It is followed by 'Virtual Reality' (42), 'Photogrammetry', and 'Remote Sensing' (41), in the realm of research on Novel Technology used for the Digital Transformation of CH. The significant number of links associated with these keywords underscores their centrality in the digitization of CH and their pivotal role in supporting CHKM. Conversely, keywords such as 'Virtual Reconstruction' (8) 'Egypt' (7), and 'Reverse Engineering' (6) exhibit the lowest numbers of connections, respectively. This observation can be attributed to the relatively limited research efforts in the domains of virtual reconstruction and reverse engineering within the context of CH. These areas have not yet received extensive scholarly attention. The application of Novel Technologies in CH offers the potential to create a CH Digital Twin, thereby establishing innovative platforms to bolster CHKM.

4.3.2. Total link strength

The keywords 'Cultural Heritage' (225), 'Remote Sensing' (108), and 'GIS' (102) emerge as the top three terms in terms of 'Total Link Strength.' It is notable that 'Cultural Heritage' not only possesses the highest 'Total Link Strength' but also exhibits the most occurrence frequency, indicating the increased Novel Technology Use for Digital

Transformation of CH. Subsequently, 'GIS' ranks as the second most prominent keyword. The data harnessed through Geographic Information Systems (GIS) play an integral role in amalgamating with other technologies, facilitating the digitalization of CH elements. As a result, GIS finds widespread and effective utilization across diverse research domains. Furthermore, 'Remote Sensing' claims the highest 'Total Link Strength.' The proficiency of remote sensing technologies in rendering CH in a precise and environmentally benign manner underscores its status as one of the most sought-after and extensively explored technologies in this domain. On the other hand, keywords such as 'Environmental Technology' (9), '3D Printing' (8), and 'HBIM' (7) exhibit relatively lower link counts. These areas necessitate further examination regarding their contributions to production and development in the future.

4.3.3. Occurrence frequency

The Occurrence Frequency serves as a metric indicative of the extent to which a word is emphasized within the research domain. The term 'Cultural Heritage' (120) boasts the highest value. It is important to note that the bibliometric search includes 'Cultural Heritage' as an essential keyword, hence its prominence in this regard. Subsequently, 'GIS' (57) emerges as the second-highest keyword. GIS technology plays a pivotal

role in the storage and analysis of geographic data, making it a significant component of research in this field. 'Remote Sensing' (55) ranks third, reflecting the efficacy of remote sensing technologies in the collection of data about CH. Conversely, keywords such as 'HBIM' (7), 'Energy Efficiency' (7), and 'Optimization' (6) exhibit notably lower 'Occurrence Frequency' values, indicating a substantial research gap in these areas. Bridging this gap could potentially lead to the development of more sustainable practices within CHKM.

4.3.4. Average citations

The keywords 'South Africa (69.20),' 'Database Visualization (58.20),' and 'Database Systems (54.00)' have demonstrated the highest values. These findings underscore the vital role of Information and Communication Technologies (ICT) in the digitalization of CH data. Through the utilization of ICT, CH data can be efficiently visualized and structured into databases, rendering them readily accessible. The notable increase in the 'Average Citation' value across these keywords is indicative of the active utilization of these technologies within the field of CH research. Keywords such as 'Virtual Reconstruction (4.60),' 'Digital Technologies (3.75),' and 'Jordan (3.60)' exhibit considerably lower values. This suggests an existing research gap within these specific domains, warranting further attention and exploration.

4.3.5. Average normalized citations

The keywords 'HBIM (5.18),' 'Egypt (3.39),' and 'Automation (2.36)' have surfaced as the top three terms, boasting the highest 'Average Normalized Citation' values. The integration of nD (n-Dimensional) information into the HBIM platform assumes paramount significance in preserving the sustainability of CH data. This synergy between nD information and the HBIM platform allows automation within historical contexts, leveraging the potential of digital technologies. 'Mapping (0.33),' 'Image Analysis (0.31),' and 'Jordan (0.20)' exhibit notably lower 'Average Normalized Citation' values. This observation underscores the necessity for further exploration and research in

these areas, where the potential for scholarly engagement remains untapped.

4.3.6. Average publication year

Keywords such as '3D Printing (2020.67),' 'HBIM (2020.20),' and 'IoT (2020.00)' have gained prominence in the field of CH. 3D printing serves as a valuable tool for assessing interventions in CH preservation by recreating physical artifacts, with a focus on sustainability through the use of recyclable materials. HBIM enables the digital modeling of CH, bridging the gap between historical assets and the digital realm. IoT technology has become increasingly significant due to its real-time data collection capabilities via embedded sensors in physical structures. This upsurge in research activity aims to establish a DCH platform, offering real-time data and enriched digital representations. This growing research trajectory points to a promising future for the field, with expectations of further advancements soon.

VR is a predominant technology in CH research, enabling immersive experiences of historical sites without the need for physical construction, and extending remote access to a broad audience. Remote sensing technologies are pivotal for non-invasive data acquisition, preserving the physical integrity of CH assets. Photogrammetry is instrumental in digitally capturing physical CH information. The integration of novel technologies has contributed to preserving interdisciplinary knowledge and consolidating expertise on a single platform [28, 29]. However, the practical implementation of these technologies is still evolving.

5. Discussions

Novel Technology Use for Digital Transformation of CH present research tendencies and identify research gaps according to the bibliometric search and scientometric analysis results.

5.1. Research challenges

Although the adoption of Novel Technology Use for Digital Transformation of CH research showed promising developments in 2007, 2013, and 2016,

a significant increase in research activities emerged after 2018 (Fig. 2). Novel technologies offer the potential for sustainable practices within CHKM. However, their adoption presents multifaceted challenges in environmental, social, and economic realms. Environmental challenges are linked to the production of technological devices, with potential adverse impacts on natural resources and biodiversity. Social challenges encompass issues of equitable internet access and transparent decision-making processes. Economic challenges revolve around the need to account for the comprehensive costs of digital technologies, including potential drawbacks [30].

5.2. Addressed research topics, gaps, and trends

The scientometric analysis of keyword results has revealed that the most significant impact and connections exist in the domains of 'Facility Management for Built-Heritage,' 'Remote Sensing Technologies for Heritage Areas,' and 'Cultural Heritage Sustainability' within the existing body of research. This conclusion is drawn from the total link strength, occurrence, and average normalized citation values, as displayed in Fig. 3 and Table 1. However, the results also underscore existing gaps in the domains of 'Digital Reconstruction,' 'Digital Heritage Countries,' and 'Visualization of Cultural Heritage Areas' research.

5.2.1. Facility management for built-heritage

CH items represent a global treasure that enriches exhibitions, museums, archaeological sites, and monuments. The sustainability of CH relies on effective conservation, knowledge management, and knowledge sharing. The judicious utilization of novel technologies has the potential to catalyze advancements in CHKM. The proliferation of ICT has spurred numerous innovations in CH, fostering a closer integration between the physical and digital realms [1, 31, 32, 33]. ICT not only broadens access to information but also offers sustainable methods for CHKM [32]. It transcends the constraints of time and space, opening new avenues for research. The role of ICT, particularly in technology-assisted learning, remains a prominent subject of

investigation. Learning models and methodologies contribute significantly to the broader dissemination of CH knowledge. Moreover, ICT allows for real-time monitoring of CH elements.

5.2.2. Remote sensing technologies for heritage areas

CH plays an important role in illuminating the social, cultural, economic, and technological trajectories of the past, offering valuable insights into the historical evolution of societies. As a result, the evidence derived from CH research holds significant value. The integration of Novel Technologies has ushered in practical, cost-effective, and non-invasive methods for acquiring CH data. Technology finds broad application in various aspects of documentation preparation, with GIS, remote sensing technologies, and laser scanner tools emerging as the most frequently employed innovations. The application of remote sensing technologies has contributed to the exploration of previously uncharted areas while minimizing environmental impact [6]. The convergence of remote sensing technologies with ICT promises to enhance interoperability and data integration [34].

5.2.3. Cultural heritage sustainability

Built heritage significantly contributes to the urban landscape, serving as a magnet for tourists and augmenting environmental quality within urban environments. Hence, legal safeguards are often implemented to preserve their visual appeal. The integration of modern materials and construction techniques into CH architecture during physical restoration is essential. Equally significant is the transition to sustainable energy systems and the renewal of the city's building stock, which is important in the environmental and energy aspects. Renovation encompasses the restoration of architectural, structural, and technical facets while considering environmental factors. The HBIM platform facilitates the integration of energy data into the digital representation of historical structures, yielding valuable insights [35, 36]. The concept of sustainability concerning CH extends beyond environmental considerations to encompass sociological and cultural dimensions.

Technological advancements facilitate the digital transformation of structures, ushering in an era of CHKM. Simultaneously, technology breaks down barriers of distance and time, promoting innovative approaches to cultural tourism.

5.2.4. Digital reconstruction

With the continuous advancement of technology and increased accessibility to sophisticated tools, photogrammetry, laser scanning, and 3D printing have gained more widespread usage in CH. Recent years have witnessed significant developments in both hardware and software for photogrammetry, laser scanning data processing, and the transformation of 2D images into 3D representations [37]. The domain of Novel Technologies continues to evolve, offering fresh prospects for CHKM. The challenge of 3D visualization for expansive and intricate CH sites has gained prominence with the advent of novel technologies. The integration of 3D reconstruction tools and visualization technologies has the potential to yield unique, visually compelling, and aesthetically pleasing environments. This development paves the way for the accessibility of ancient and remote sites to a wider audience [38]. Despite the increasing use of digital reconstruction in CH research, scientometric analysis reveals a paucity of studies focused on data visualization and digital reconstruction integration. The linkage among digital reconstruction studies appears limited, pointing to an existing research gap within the CH.

5.2.5. Digital heritage countries

The tourism sector significantly leverages the appeal of CH. The economic contribution of tourism to national development is undeniable, with CH research in countries catalyzing both economic and cultural progress. It is posited that technology-driven innovations may open new avenues for employment in the tourism industry. While harnessing Novel Technologies for CH entails investments, the sector holds substantial potential for bolstering a country's development [39]. Several nations, including Italy, Spain, and the United Kingdom, have embarked on the use of digital

technologies as a means to preserve and promote their CH. Initiatives often commence with technologies like digital photogrammetry and aerial photography, laying the groundwork for the digitalization of CH assets and data.

5.2.6. Visualization of cultural heritage

CH holds a special place in society's collective memory and serves as a focal point in cities with their iconic architecture. They significantly contribute to the local economy by sustaining the tourism sector. Therefore, there is an increasing need for contemporary CHKM supported by today's technologies. These components often face deterioration due to factors like natural disasters and conflicts, underlining the importance of comprehensive documentation studies [1]. The relationship between technology and CH is intricate and often dialectical. Innovative technological applications and location-based services offer opportunities for aesthetically preserving CH and advancing the CHKM approach [21]. Virtual technologies hold great tourism potential, as they overcome distance barriers, making them crucial for the future. These technologies offer valuable educational platforms for students and academics [40]. Research findings reveal that Novel Technology Use for Digital Transformation of CH covers a broad spectrum of topics. VR technology is expected to gain prominence in future research due to its ability to store CH items in virtual environments, providing access without geographic constraints (Fig. 3 and Table 1).

5.3. Research limitations

Novel Technology Use for Digital Transformation of CH incorporates keyword and author analysis based on Scopus data. Furthermore, an examination of journals, institutions, and countries through metrics like citations, common citations, and bibliographic coupling provides in-depth insights into the field. Certain limitations are worth noting in this bibliometric search. Firstly, the inclusion of all languages facilitates global coverage but may also introduce language-specific biases. Additionally, the study is solely based on data from the Scopus database, without integration from other

databases. Future research can enhance comprehensiveness by incorporating data from multiple sources. The static nature of this research, constrained by a specific date range, highlights the need for a dynamic system that allows for continuous data updates in future studies. While technology has enormous potential for CHKM, the study's focus remained largely theoretical, with limited exploration of practical applications. The development of a robust platform supporting knowledge exchange, information sharing, and interoperability is crucial for more effective CHKM in future research.

6. Conclusions

This study aims to uncover the evolving trends in Novel Technology Use for Digital Transformation of CH. To achieve this goal, keyword co-occurrence analysis was conducted, shedding light on the cost and time-saving potential of these technologies. Research results indicate that they also enhance efficiency. Nevertheless, scientometric mapping highlights a notable gap concerning the integration of information technologies into CHKM. Bridging this gap is

crucial for the sustained preservation of CH. Furthermore, technology-driven tools, capable of translating CH into digital formats, hold the potential to create new economic and social opportunities. With technology, CHKM is carried out more efficiently, restoration data becomes more accessible, and records are centralized on a common platform. This research, in theory, contributes to the comprehensive transfer of CH to future generations. However, despite the theoretical advantages of technological knowledge in the digital archiving of CH, standardization processes have raised concerns regarding the preservation of CH expertise and the uniqueness of each site. Addressing these challenges necessitates the collaboration of diverse experts in CHKM processes. Developing a platform that effectively supports knowledge sharing and interoperability remains a formidable challenge, despite the extensive literature on this topic and limited practical implementation. In the future, the interoperability of specialized systems can offer a solution to maximize the benefits of technological information structures in CHKM, ultimately enhancing its efficiency and ensuring CH's sustainability.

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Author Contributions

G. B. Ozturk: Conceptualization, Methodology, Formal Analysis, Writing- Original Draft, Supervision; B. Ozen: Methodology, Software, Formal Analysis, Writing- Original Draft, Visualization; F. Soygazi: Writing- Review and Editing, Supervision.

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Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Ethics Committee Permission

Not applicable.

Conflict of Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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