SCIENTOMETRIC ANALYSIS AND MAPPING OF DIGITAL TECHNOLOGIES USED IN CULTURAL HERITAGE FIELD

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BIM and other digital technologies are increasingly applied to buildings under construction with limited attention to existing and heritage buildings. Recent studies, through a critique of the literature, have sought to analyse the application of BIM in heritage. However, excepting the limited number of these studies, attention is often given to a specific digital technology or heritage aspect to the neglect of how other constituents of the entire digital technology regime and the recent developments therein could be applied in the heritage sector. This implies there is a knowledge gap regarding the overview of the application of digital technologies within the heritage sector. This study aims to systematically analyse the recent development of digital technologies such as Building Information Modelling (BIM) or Heritage Building Information Modelling (HBIM) in cultural heritage with the aim to provide insight into the overall potential for future research, current challenges and capabilities of digital technologies within the heritage sector. The chosen methodology for this study is scientometric analysis by using both quantitative and qualitative review processes. The findings from this study reveal that the main emerging digital technology researched in the field of cultural heritage is BIM or HBIM. There is evidence of multidisciplinary research within the body of knowledge and an increase in collaborative research between the areas of remote sensing, image science, computer science, architecture, archaeology and history. However, there is an unbalanced dominance of research partnership among authors and institutions in Europe. Research collaboration with global institutions is therefore encouraged as a necessity for advancing the applicability of digital technologies in the heritage sector. This study has implications for academics, research institutions, practitioners and policy makers, assisting these stakeholders to make vital contributions to advancing intellectual wealth to the research area of digital technology and heritage.

Keywords: BIM, HBIM, digital, cultural heritage, Scientometric Analysis

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INTRODUCTION

The extensive benefits of digital technologies for the Architectural, Engineering, Construction and Operation (AECO) industry are increasingly recognised in academic and professional practice (Logothetis *et al.,* 2015, Manferdini and Galassi 2013, Pocobelli *et al.,* 2018, Xu *et al.,* 2014). A digital technology that has gained significant attention in this industry is Building Information Modelling (BIM) and more recently is its application to the heritage sector, which is the focus of this paper. Diverse building projects involving historic buildings and sites such as, conservation and refurbishment, adaptive salvage, defensive maintenance, heritage management, interpretation, documentation and research have created opportunities for the use of BIM in innovative ways. The combination of BIM with Heritage, also known as HBIM (Heritage Building Information Modelling) can efficiently support design and build decisions resulting in the production of sustainable and inclusive heritage assets. Despite this, BIM is mostly applied to buildings under construction and BIM and other digital technologies for heritage assets are relatively new fields of academic research. Studies have provided an appropriate analysis of BIM in heritage through critical literature reviews by focusing on Computer Aided Design (CAD) and BIM (Logothetis *et al.,* 2015), the use of BIM to capture and store data (Pocobelli *et al.,* 2018), digital tools and techniques for heritage documentation (Cheng *et al.,* 2015, Vandenbulcke *et al.,* 2015). However, excepting the limited number of these studies, attention is often given to a specific digital technology or heritage aspect to the neglect of how other constituents of the entire digital technology regime and the recent developments therein could be applied in the heritage sector. As a result, there is a paucity of research that provides an overview of the application of digital technologies, beyond BIM within the heritage sector.

It is within this context, that this study aims to systematically analyse the recent developments and provide insights into potential future research, current challenges and capabilities of digital technologies within the heritage sector. This is achieved through a scientometric analysis which visualises global trends and patterns of research through mapping top influential authors, journals, articles, countries, institutions and keywords in the field of digital technologies, HBIM and Heritage. The research findings contribute to the global body of heritage and digital technologies knowledge by providing a detailed understanding of the current landscape. The findings call for further interrogation into the application of digital technologies in the heritage sector by identifying where best to focus future research efforts. Furthermore, this study contributes to practice by serving as a valuable and updated reference for supporting policy makers' and practitioners' planning and funding efforts in heritage and area of digital technologies.

This study draws from the initial studies undertaken within a larger research project, " IT INDIAN HERITAGE PLATFORM: Enhancing cultural resilience in India by applying digital technologies to the Indian tangible and intangible heritage". The overall aim of the project is to enhance the cultural resilience of the Indian tangible and intangible cultural heritage, challenged by rapid urbanisation, by exploiting the potential of digital technologies applied to the heritage (Gupta and Jha, 2018; Mansuri and Patel, 2018). Therefore, this paper is divided into four broad sections. Section two discusses the methodology used for developing this study including the data collection and selection of the scientometric tool and data acquisition. This is followed by a discussion of the findings from the scientometric analysis and mapping in section three and section four concludes the discussion with recommendations.

METHODOLOGY

Scientometric analysis

Drawing on the aim of the study as discussed above, the chosen methodology is scientometric analysis. A significant range of research areas in the field of digital technologies and heritage exist and therefore it is challenging to represent and summarise the entire knowledge domains through a manual conventional literature review process. Furthermore, conventional reviews are inclined to be subjective and present biased opinions (Yalcinkaya and Singh 2015). This method limits the study exploration to "what" questions, rather than "how" and "why". Consequently, it is suitable for providing a possibility to comprehensively and quantitatively analyse literature resources in a generic way that can yield valuable information and provide a broad view on the topic and its current status and relevance.

Scientometric analysis is defined as the "quantitative study of science, communication in science, and science policy" (Hess 1997). It measures the impact of authors, articles, journals, institutes and understanding of citations, mapping scientific fields and visualisation of indicators for policy making and management (Leydesdorff and Milojević 2012). This method is ideal for this study because it identifies and analyses the evolution of the research over time. It is a quantitative approach that visualises and maps the development of research (Konur 2012) by relying on largescale bibliographical data to assess the development of the research domain through different qualitative indexes (Mingers and Leidesdorff, 2015).

Data collection

Data collected from the Web of Science (WoS) core collection database was used for this study. WoS is the world's leading citation database, covering over 12,000 high-impact journals. This database possesses a wide range of publication coverage including indexing among science citation index (SCI), social science citation index (SSCI), conference proceeding citation index and emerging source citation index. A limitation to this method is the dependence on the database extracted for the study and therefore any limitations of the coverage of publications. An additional limitation is that the analysis only covered literature indexed in WoS core collection with publications in the English language. A study comparing numerous databases for scientometric analysis by Mingers and Leidesdorff, (2015) has shown that the WoS database has accurate and reliable information and can be considered sufficient to showcase the patterns and trends of digital technologies in the heritage sector.

Selection of scientometric tool and data acquisition

For the purposes of this study, the Java application "CiteSpace (5.3.R4 version (64-bit)" is used. According to a comparative review of scientometric software conducted by Cobo *et al.,* (2011), several scientometric tools such as Bibexcel, CiteSpace, CoPalRed, IN-SPIRE, Leydesdorff's Software, Network Workbench Tool, Sci2Tool, VantagePoint, and VOSViewer, have been developed within the last few years resulting from emerging interest in identifying the fundamental foundations and trends of a research area(s). Cobo *et al.,* (2011: 1400) conclude that although the comparative review does not incorporate all the science mapping software tool, a thorough scientometric analysis within any field could be carried out using any of the tools. The study described CiteSpace as a comprehensive tool that is suitable for identifying the hidden connections between the different scientific contributions with an advanced network visualisation feature. It also possesses all the features and characteristics required to compute the WoS database which has further motivated the choice to its use in this study.

Searching attempts were conducted from the detailed search section by syntax using the following phrase: "TS = (digital technology* OR building information model* OR BIM AND (heritage OR historic* OR as-built OR hbim))". The search results were further refined manually resulting in the removal of irrelevant and misleading titles from the database. By manually reading titles and abstracts, all the related and relevant articles were sorted and later exported for analysis in CiteSpace. The final search results contain a total of 194 articles dated up to March 2019. Out of these records, 67 are journal articles, 125 are proceedings papers and 3 are review papers. Analysis of these documents is explored in the following sections.

FINDINGS

Scientometric analysis and mapping

The findings from the scientometric visualisation and analysis are presented in this section. Emerging technologies, research areas, influencing authors, countries and journals are visualised by co-author, co-word and co-citation analysis which are described in the following sub-sections.

Digital technologies (frequent keywords)
The keyword network provides an opportunity for the revelation of scientific knowledge which reflects the relationship, pattern and covered topics. Therefore, this study categorised the context and concept of research articles with the associated keywords. The keywords are the representing words and concise description which serve as the reference in finding and retrieving the article concept and content. As a result of this co-word analysis, the highly frequent (n) keywords in the network reveal the emerging technologies in the field of cultural heritage, which are as follows: "BIM" (n = 67), "HBIM" (n = 34), "cultural heritage" (n = 31), "point cloud" (n = 22), "laser scanning" (n = 14), "architecture" (n = 11), "documentation" (n = 10), "conservation" (n = 10), "architectural heritage" (n = 10), "photogrammetry" (n - 10), "laser" (n = 9).

The digital technologies through the network of keywords (as indicated in Figure 1) reveal three key findings within the global heritage literature.

- The overall research area can be divided into two main categories: (1) digital tools and (2) digital technologies. The top 10 keywords reflect digital tools such as laser scanning, point cloud and photogrammetry while the main digital technologies are BIM and HBIM.
- Figure 1 shows that several research areas (nodes) are in isolation with the core network. This suggests that areas such as object recognition, algorithm, free/open source software and digital documentation remain unexplored or under researched. The availability and accessibility of areas such as open source software can determine the development of digital technologies for cultural heritage. Other areas such as photogrammetric restitution, geometric modelling and digital documentation are also isolated and not of noticeable importance in current literature but have significant potential for future development in cultural heritage.
- Future research areas can be identified from this analysis. Several potential research areas such as heritage management, digital heritage documentation and information system are forming a substantial body of literature. However,

there is a visible gap from the main research areas such as BIM and HBIM. This reveals opportunities for future research to fill that gap. Additionally, there is huge potential of development in the field of Virtual Reality, Artificial Learning, machine learning, object detection and algorithms, which can advance automation in the field of cultural heritage documentation and conservation.

Figure 1: Digital technologies (network of keywords)

Emerging research areas (WoS Subject categories)

This study used the subject classified bibliographic records by WoS based on the scope of the corresponding article and journal to determine the main subject categories and the emerging technologies in cultural heritage. One article can be assigned more than one subject category.

The analysis revealed 10 top subject categories in the corpus of digital technologies for cultural heritage: (1) Remote sensing, (2) Image science, (3) Photographic technology, (4) Computer science, (5) Physical geography, (6) Architecture, (7) Archaeology, (8) Construction and building technology, (9) Geosciences, (10) History. As illustrated in Figure 2, the research in the field of digital technologies for cultural heritage is very diverse and from different disciplines. This advancement of multidisciplinary research illustrates an increase in collaborative research between the remote sensing, image science, computer science, architecture, archaeology and history.

Figure 2: Research areas (Network of subject categories)

The network of subject categories shows that areas such as remote sensing, image science, photographic technology and computer science are making significant contributions towards the development of digital technologies in the field of cultural heritage. This may include increasingly popular technologies such as Internet of Things, nanotechnologies and robotics. Whilst areas such arts and humanities remain unusually isolated area in the network despite the potential to elevate the heritage research field. The circuit of geology, archaeology and geoscience also has huge potential to merge with the main research body to contribute to cultural heritage.

Most contributing authors, institutions and countries

As part of this study, the scientometric analysis conducted, revealed the most contributing authors, their institute and country of research (Table 1) to the field of digital technologies and heritage. This is meaningful for developing a picture of the collaboration network of the authors and institutions which have high investment and interest in heritage and digital technologies. Additionally, this information is useful in identifying research groups and assisting research partnerships and policy-making. According to the analysis, the most influential authors are based in Europe with core active authors publishing from Italian institutes, particularly the Polytechnic University of Milan. This suggests that the top institutes (Table 1) are successful in providing the infrastructure facilities as well as the expertise to support the undertaking of research in the multidisciplinary area of digital technologies for cultural heritage.

To add to the results from Table 1 is the illustration of the collaboration network of different countries leading in digital technologies research for cultural heritage in Figure 3. In this Figure, the size of the font size and the influence circle discloses the contribution of research in the field. The results from the analysis of network support the author analysis by revealing the top five most contributing countries having more than 10 articles (n) published as: (1) Italy (n = 66), (2) China (n = 24), Spain (n = 17), Germany (n = 13) and Canada (n = 12).

Italy stands out as the most contributing country along with significant contributions from USA, Spain, Germany, England and Canada. The linkage or research collaboration are not as strong as desired because, all the countries are connected with links but there is no cross inter connection which demonstrates a need for all the countries to redefine their collaboration efforts and policies.

Table 1: Top 10 most contributing authors

Sr. No.	Author Name	Institute	Country	No. of Articles
1	Maurice Murphy	Dublin Institute of Technology	Ireland	7
2	Fabrizio Banfi	Polytechnic University of Milan	Italy	5
3	Luigi Barazzetti	Polytechnic University of Milan	Italy	5
4	Daniela Oreni	Polytechnic University of Milan	Italy	5
5	A. Adami	Polytechnic University of Milan	Italy	4
6	Jan Boehm	University College London	United Kingdom	4
7	F. Chiabrando	Polytechnic University of Turin	Italy	4
8	Stefano Cursi	Sapienza University of Rome	Italy	4
9	Stephen Fai	Azrieli School of Architecture and Urbanism, Canada	Canada	4
10	F. Fassi	Polytechnic University of Milan	Italy	4

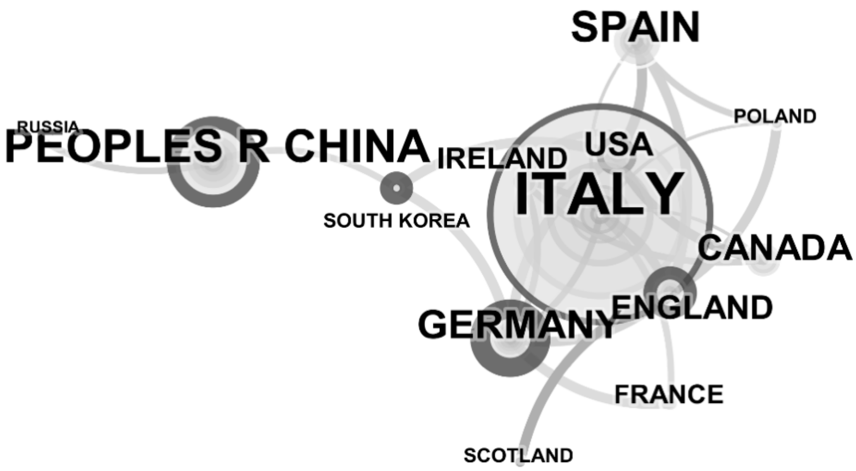

Figure 3: Collaboration network of countries

China appears disconnected from the main body research community, suggesting that the institutions in these countries could benefit from promoting collaboration and knowledge exchange in the digital technologies and heritage knowledge domain. Other countries like Russia, Scotland, South Korea and Poland have weak collaboration networking with the main community. This needs to be taken into consideration by redefining their research collaboration policies. The Euro-dominance illustrated from this analysis also reveals a paucity in collaborative contribution from Global South countries like India, Brazil and Mexico and regions of Africa. Although these locations have a significant number of UNESCO World Heritage Sites, the underrepresentation in the network suggests a lack of resource, expertise and awareness of digital applications within the heritage sector.

DISCUSSION AND RECOMMENDATIONS

Results from the scientometric analysis discussed in the previous sections demonstrate that the current global body of digital technologies and heritage knowledge still has gaps and limitations, which become evident when the large corpus of literature is analysed. It is clear that the main emerging digital technology researched in the field of cultural heritage is Building Information Modelling (BIM) or Heritage Building Information Modelling (HBIM). To date, special attention has been directed to BIM and HBIM while being biased toward other themes such as the use of laser scanning, point cloud and photogrammetry and digital technologies explored as a means to facilitate the modelling and documentation of monuments, sites and artefacts results into BIM. This is illustrated in studies such as Quattrini *et al.,* who developed a 3D model for complex architectural shapes by using the Terrestrial Laser Scanning (TLS) (Quattrini *et al.,* 2015). In the same vein, Xu *et al.,* developed a digital point cloud model using the camera-equipped unmanned aerial vehicle and the TLS (Xu *et al.,* 2014). Laser scanning is confirmed in studies as an accurate tool for recording geometric information but, it is very costly affair, while photogrammetry can become the substitute for modelling and documentation, which is possibly a cost-effective solution. More economical combinations have been explored by Manferdini and Galassi who review the use of traditional topographic techniques with range-based (laser scanning) and photogrammetry. Their study concluded that the combination of traditional technologies and photogrammetry are more economical but require high accuracy and skills (Manferdini and Galassi 2013).

Some studies have focussed particularly on the application of digital technologies for the documentation of heritage assets. A framework for the documentation of cultural heritage sites is proposed by Baik *et al.,* based on Jeddah HBIM by integrating 3D BIM and 3D Geographic Information System (GIS) (Baik *et al.,* 2015). Using laser scanning and photogrammetry, Cheng *et al.,* further explored the potential of digital tools for heritage documentation (Cheng *et al.,* 2015). The comparison of laser scanning and the photo modelling for as-built BIM is also reviewed by Vandenbulcke *et al.,* (2015) and concluded that both techniques result in high resolution documentation (Vandenbulcke *et al.,* 2015). However, there is still a need for further research and development in the area of photogrammetry in order to gain higher accuracy. The literature suggests that BIM is a relevant and valuable digital asset for the documentation of the cultural heritage. On the contrary, there are other tools and technologies available for as-built geometric modelling, but these tools are to some extent not capable of documenting the artistic and monumental parts of the cultural heritage. Artificial Intelligence tools such as object recognition and algorithms can assist in developing the applicability of these tools to build accurate models fast and cost effective. Other technologies such as Computer Aided Design (Logothetis *et al.,* 2017), Virtual Reality (Rua and Alvito 2011) and Augmented Reality (Osello *et al.,* 2018) also present the opportunity for further exploration in the cultural heritage sector and HBIM.

The findings of this study reveal evidence of multidisciplinary research within the body of knowledge (Figure 1 and 2) and an increase in collaborative research between the areas of remote sensing, image science, computer science, architecture, archaeology and history. However, notwithstanding the benefits of research collaboration, there is an unbalanced dominance of research partnership among authors and institutions in Europe and particularly, Italy (Table 1 and Figure 3). This study therefore recommends that research collaboration with global institutions should be encouraged as a necessity for advancing the applicability of digital technologies in the heritage sector. Focus should be given to the formulation of policies to encourage collaborative research by funding agencies to underrepresented regions such as Global

South countries in South America, Asia and Africa. Additionally, this study recommends the attention of digital technologies such as Artificial Intelligence, CAD, Virtual Reality and Augmented Reality by authors in this field as well as further exploration into the development of open source software for research and development purposes to further advance the applicability and research of these digital technologies.

CONCLUSIONS

This paper represents the results of a scientometric analysis of digital technologies and BIM in cultural heritage and provides a detailed overall picture of the body of knowledge. Key research concerns along with opportunities and recommendations for further research have been identified. The methodology of the study, scientometric analysis was carried out using 194 articles indexed by the WoS. Moreover, the study is based on a qualitative analysis of literature and minimum subjective judgments therefore the findings are justified and reliable. Methodological limitations discussed in section two of this study create opportunities for future research. This overall review explored by this study confirms that digital technologies are valuable to both researchers and practitioners to develop better products and solutions for the conservation, preservation and management of cultural heritage. Further updates of the overall status of this research area can be updated at key intervals in the future to assess the updated existing body of knowledge in the field of digital technologies for cultural heritage.

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