

BIM and Sustainability: A Review from Architecture Field

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Abstract: Can BIM technology be applied to create sustainable architectural designs based on ancient constructive materials and techniques? What work has already been developed in this field? Motivated by these questions, this paper offers an overview of the evolution and tendencies of BIM papers in architecture field in academia regarding its relationship with sustainability. The quantitative method of bibliometric analysis was adopted. More than 40 papers, from journals and conferences were examined after a previous selection filtering by combining two keywords: BIM and Sustainability or BIM and Sustainable. None of the previous existing bibliometric studies approached the combination of these two topics. By generating and analyzing these quantitative data, research aims to improve the focus on fields of study that have not been yet properly addressed hence contributing to improve the respective field of knowledge. This analysis offers also new insights indicating gaps and possibilities of themes for future unpublished works.

Key words: BIM, building information modeling, sustainable, sustainability, architecture, bibliometric analysis, literature review

1. Introduction

Is it possible to apply BIM technology in the design of sustainable architecture using ancient materials and techniques? Is there any previous literature addressing this question? What work has already been developed in this field? Those questions motivated a research, that seeks to find what has been published about BIM for sustainable traditional construction processes.

The paper aims to offer an overview of the evolution and tendencies of BIM papers in architecture category, to elucidate its relationship with sustainability and discover if the particular use of earth construction systems has already been approached. In this paper we have in mind the use of earth construction techniques, and in particular earthbag construction processes, because of their advantages regarding sustainability

and easiness of the construction process. Also, because these type of materials were not found in BIM software standards.

This challenge has been addressed by adopting a bibliometric analysis method, an objective tool by which the state of science and technology can be observed by searching through the overall production of scientific literature [1]. There are some previous bibliometric analysis publications regarding BIM and others regarding sustainability topics, but this is the first time that both topics are presented together.

This specific bibliometric analysis offers new insights, indicating the gaps in the literature, regarding our present developments in the use of BIM for representing traditional sustainable earth construction technologies

2. Background

Traditionally, in order to build up a construction it was necessary to generate during the conceptual design

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phase a large set of design documents, essentially drawings describing the formal aspects and materials of the building, and after that, for describing all the technical construction requirements, a set of technical documents defining constructive details, material prescriptions including performance requirements of such materials, construction phases, contractual conditions and so on. In other words, designing and construction planning were tasks that used to happen separately, sometimes involving different teams and representation models that consequently were prone to errors. This division has been changing due to BIM implementation.

The use of BIM by architectural design firms is increasing, also, because the needs of visualization, communication, and design productivity are supported by BIM [2]. During the schematic stage of an architectural design process it is also possible use BIM methodology into the integration of the environmental dimension of sustainability [3, 4].

BIM is an acronym standing for building information modelling, building information model or building information management [5]. In architecture articles, the first definition seems to be the more applied. In BIM software, the design models are representations of real world items (Object-based design), they have identity and quantitative constructive data associated [6-8]. To put in another way, the building Information model is a three-dimensional geometric model that is data rich [9].

3. Methodological Procedure and Data

3.1 Bibliometric Methods

Bibliometric or Scientometrics analysis has become a generic term for a whole range of specific measurements and indicators on scientific literature [1]. Mostly is defined by the quantitative study of bibliographic material. This literature analysis involves counting and tracking papers with attribution by country, by author, the number of citations (to measure the impact of papers), elucidates the evolution of the

quantity of papers and highlights the main journals and conferences in a research field. In our case, the period searched was from 1900 until October of 2018. By analyzing these data, this research aims to find objective information on what topics this research field has more intensive work and which topics still provide large gaps still open for new or more intensive research.

3.2 Selected Data

To analyze the bibliographic information, the elected database was a well-known online repository named Web of Science (WoS), which considers articles from journals and conference proceedings. The database includes material from a wide range of research areas. Currently, it contains more than 140,000 conference proceedings and more than 20,000 journals [10].

Because the conferences usually reveal emerging trends and new ideas before they appear in journals, it is valuable to include proceedings in the analysis.

At first, we searched for the descriptors "BIM" plus "earth" and found 18 papers among journals and proceedings from diverse categories, but no architecture. After an accurate analysis of these papers, all of them were excluded from this research. Sometimes because BIM was an acronym for other science fields, such as "Binary Ability Mechanism", "Born Iterative method", "bisindolylmaleimide-based protein" or "Biologically induced mineralization"; And other times, because the descriptor "earth" would not related to a construction material, but related to the planet earth or "google earth". There was just one paper where both descriptors had the meaning that we meant, but it was not related with architectural constructions [11]. It was in civil engineering category and discussed geotechnical properties of earth-filled dams. This first search made us more confident to restrict this search just to architecture category.

WoS has a specific research category dedicated to architecture, then it is reasonable to select all the

journals and proceedings from this category. Currently, architecture category covers 49 journals, and:

“(…) covers resources that are concerned with the study of the art and science of the building, particularly the design and construction of habitable structures. Also covered in this category are resources on architectural history, landscape architecture as well as urban and country planning and design” [12].

If we search for the descriptor “BIM” in WoS, we can find 8986 papers among journals and proceedings, 342 from the architecture category. When doing the same thing with the descriptor “Sustainable” we find 215801 papers among journals and proceedings, 2390 from architecture category. Then, with the descriptor “Sustainability” we find 117815 papers among journals and proceedings, 1504 from architecture category. Such amounts and its increasing curves allows us to affirm that these became trendy topics of research during the last decade (Fig. 1).

However, these numbers abruptly decrease when searching for research relating two or more descriptors. For this purpose, we selected papers containing the topics “BIM” plus “sustainable” and found only 250 papers among journals and proceedings. We also tried

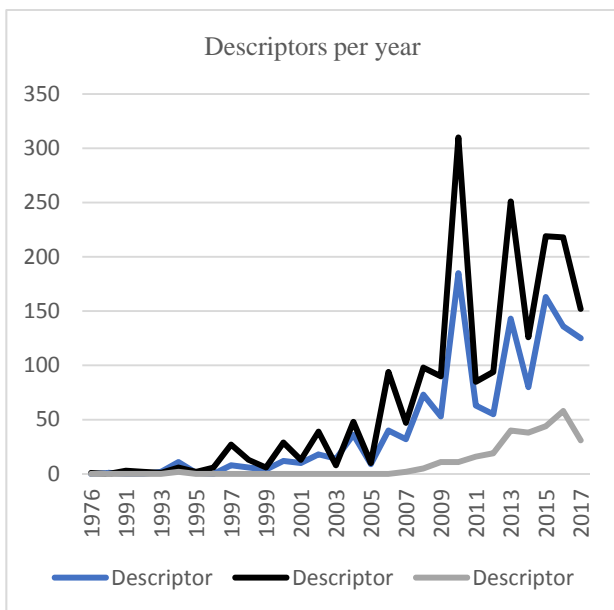


Fig. 1 Descriptors of papers published in journals and conference proceedings per year in Architecture category.

the topics “BIM” plus “Sustainability” and found 224 papers. Every paper covered by the WoS collection is assigned to at least one subject category. The results of this search were categorized through over than 100 different fields of research.

Architecture appears in sixth place with 26 papers (Fig. 2) in first search, following the categories: Construction Building Technology, Engineering Civil, Green Sustainable Science Technology, Environmental Sciences, and Energy Fuels. First, second, third, fourth and fifth place respectively.

Searching with the descriptors BIM plus Sustainability, architecture appeared this time in fifth place, this time with 24 papers, following some of same categories as before. The categories that follow architecture, suffer a slight difference of order and nomenclature (Fig. 3).

As the intention of this research is to present an architecture point of view, the selected data considered

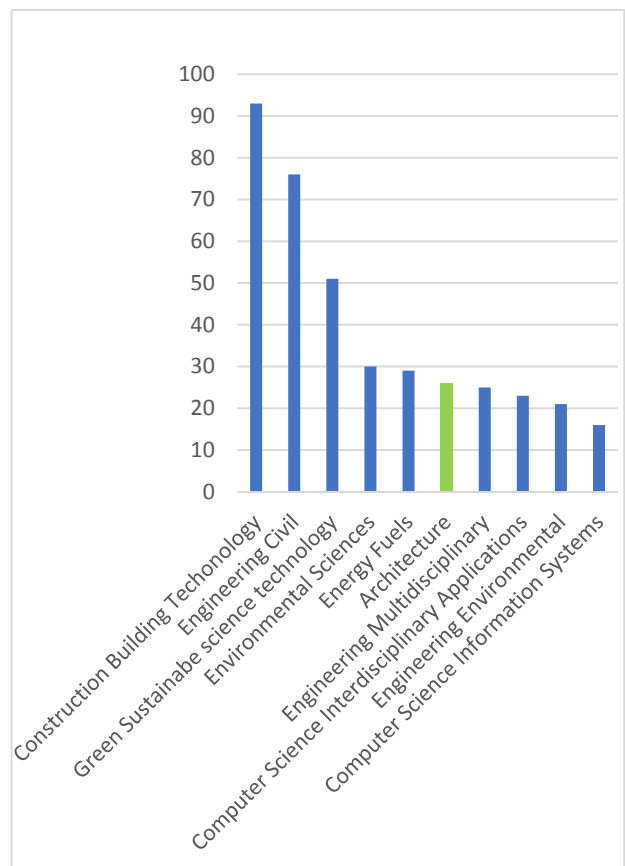


Fig. 2 Top 10 categories search BIM + Sustainable.

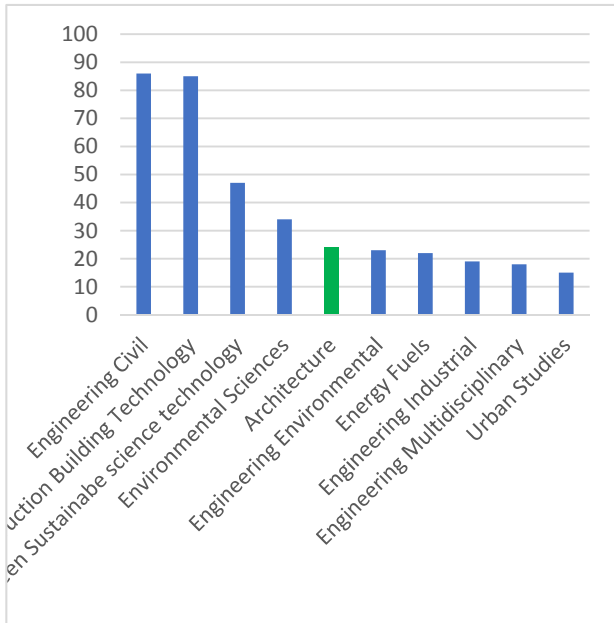


Fig. 3 Top 10 categories search BIM + Sustainability.

only the architecture category. When considering the results of both searches (BIM + Sustainability and BIM + Sustainable), we found 5 duplicated papers, because they were presented in more than one search. Eliminating these duplicates, we have 45 papers in total from journals and conferences in architecture category.

4. Literature Analysis

4.1 The Language Factor

Clearly, the research accent today is in English, and the system is self-perpetuating [1]. To be in WoS, it is mandatory that journals and conferences present their titles, abstracts, keywords and cited references in English. Even considering that WoS accepts papers in other languages, papers have their keywords written in English, but still, most papers found in this analysis were entirely written in English even though many authors come from countries with other mother languages.

4.2 Number of Papers

The results show that the concern for these subjects in academic papers is recent. The first papers

published devoted to the subject of “sustainable BIM”, appeared in the year 2008. That year, there was one paper published in the Oxford conference 2008.

The increase of papers on this subject have not been constant, and had peaks during the years 2011, 2013 and 2015 (see Fig. 4).

4.3 Journal and Conferences

Most of the papers were published in specialized conferences; 32 from the total of 45. The other 13 papers were published in nine journals. The most relevant journals publishing papers regarding “sustainable BIM” are the “Journal of Green Building”, with 3 papers, and “Architectural Design”, with 2 papers (Fig. 5). The other journals have one publication each. They are: Frontiers of Architectural Research; International Journal of Architectural Computing; Materia Architectura; Techne — Journal of technology for Architecture and Environment; International Journal of Architectural Heritage; Journal of Asian architecture and building engineering; Megaron; Estudios del hábitat.

The two most relevant Conferences are the Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA), and the International Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe), with eight publications each (Fig. 6); The World multidisciplinary civil engineering-architecture-urban planning symposium (WMCAUS), with four

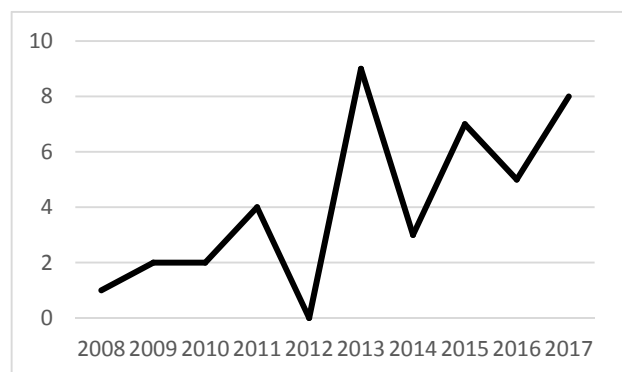


Fig. 4 Number of papers per year

publications; The Conference on Central Europe towards Sustainable Building (CESB), with three publications; and the International Conference of the

Architectural-Science-Association (ASA), with two publications.

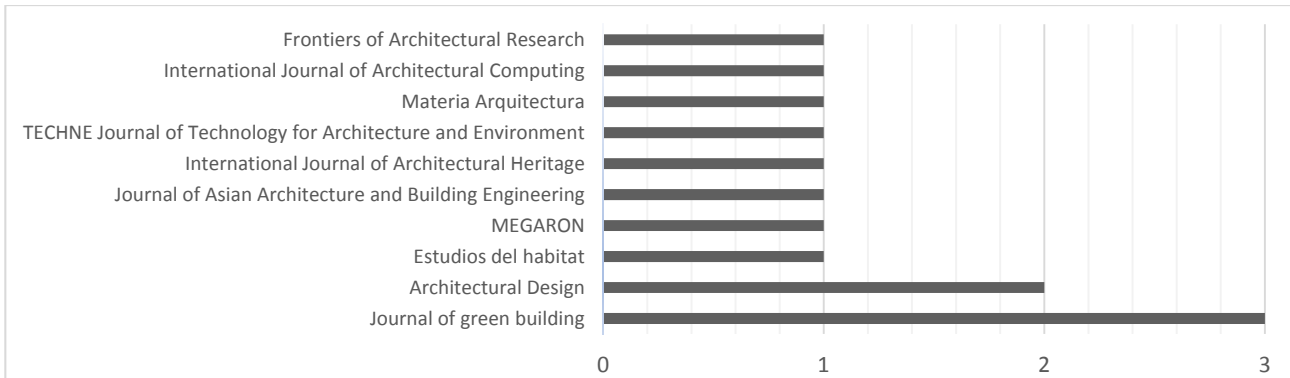


Fig. 5 Number of papers per journal.

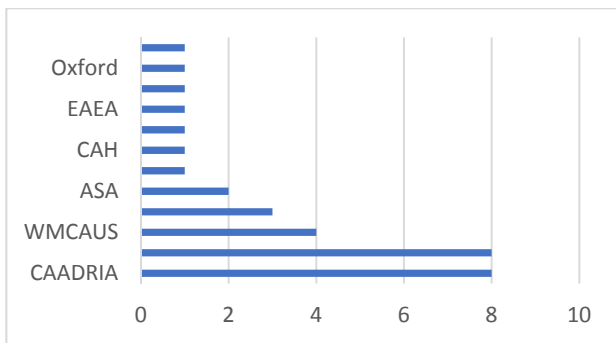


Fig. 6 Number of papers per conference.

All the other conferences present a single publication. They are: International Society for photogrammetry and Remote Sensing Congress (ISPRS); Conference on Conservation of Architectural Heritage (CAH); Association for Computer Aided Design in Architecture (ACADIA); Envisioning Architecture: Design, Evaluation, Communication (EAEA); International Conference on Ecological Architecture; The Oxford conference; and Mediterranean Conference of HVAC Historical Buildings Retrofit in the Mediterranean Area (CLIMAMED).

We tracked also the countries where the conferences occurred and the journal editor countries (Fig. 7). Among the 19 countries, Czech Republic stands out on the top of the list with seven publications. Followed by the United States of America and Italy with 6 papers each. The third place is shared with Australia, England

and Singapore with 3 papers each. The fourth place is shared with Turkey, Switzerland, Slovenia, and Japan and with 2 papers each. The fiftieth place is shared with South Korea, Netherlands, Lithuania, Israel, Egypt, China, Chile, Canada, and Argentina with one paper each.

When grouping these events and Journal editor location per continents (Considering Turkey as Asia and Egypt as Africa), Europe goes to the top of the list with 22 papers. Asia goes in second place with 10 papers. America goes to the third place with 9 papers. Oceania goes in fourth place with 3 papers and Africa goes to fiftieth place with one paper (Fig. 8).

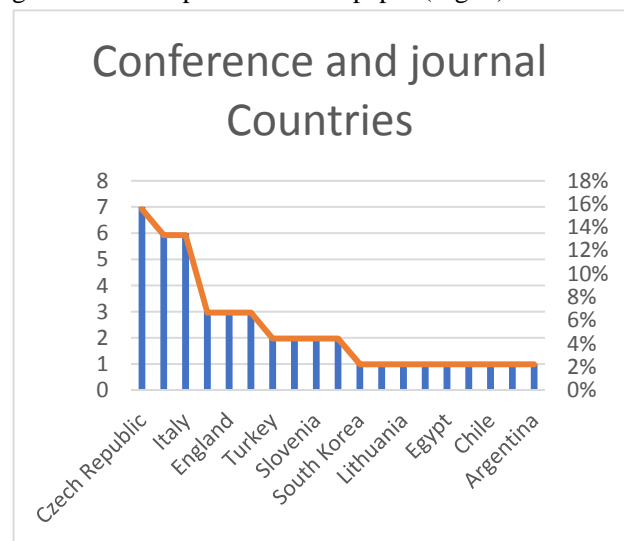


Fig. 7 Conference and journal countries.

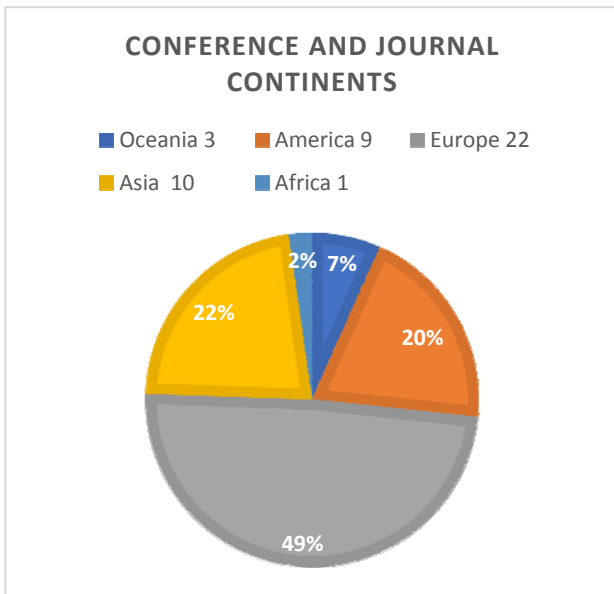


Fig. 8 Conference and journal countries.

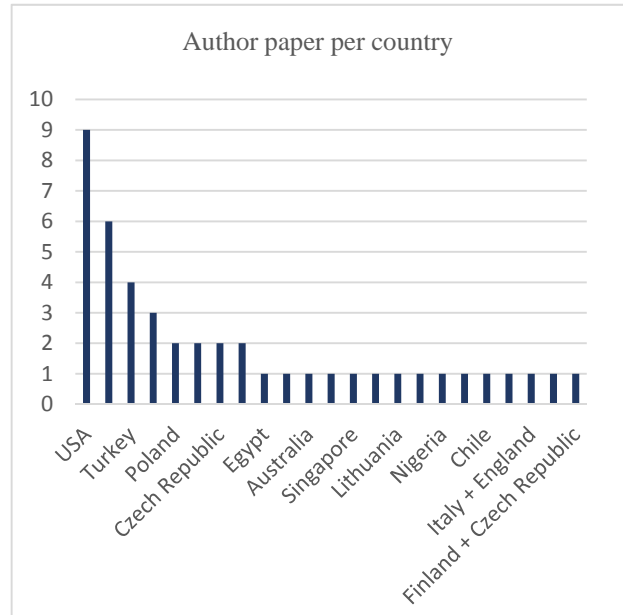


Fig. 9 Papers per author country.

4.4 Author's Origins

Among 21 countries with researchers publishing papers regarding the theme “sustainable BIM”, the United States stands out at the top of the list with 9 papers. South Korea appears in second place, followed by Turkey, with 6 and 4 papers, respectively. Italy goes in fourth place with 3 papers. Poland, Spain, Czech Republic and Slovakia has published two papers each. Egypt, Switzerland, Australia, England, Singapore, Germany, Lithuania, China, Nigeria, France and Chile have published one paper each. In four papers, the author and co-authors are researchers from different countries, they are New Zealand plus China; Italy plus England; Netherlands plus Portugal; Finland plus Czech Republic (Fig. 9).

When grouping the publications by continent (Considering Turkey as Asia), Europe goes to the top of the list with 42% of the papers. Asia appears in second place with 27%, America with 22% followed by and Africa and Oceania, with 4% each (Fig. 10).

4.5 Most Cited Papers Per Author

Some authors have made fundamental contributions to the development of this field. This section presents a summary of these contributions according to the

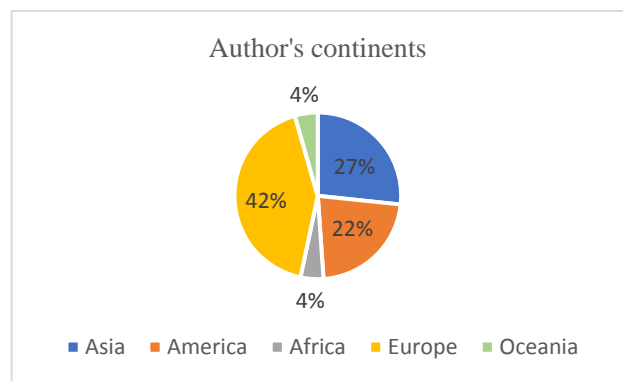


Fig. 10 Papers percentage according to author's continent.

information found in the web of science. These results include some of the most popular researchers in BIM plus Sustainability and BIM plus Sustainable.

From the total sample, 15 papers were cited by others in the Web of Science database. The top ten most cited authors represents (Table 1). The most cited of them has 5 citations and proposes a new design methodology for Hanok — traditional buildings of Korea — based on a parametric design using a BIM software — Revit [13].

The two second most cited has 5 citations each. One presents a case of study where the researcher experimented the use of a visual programming language (VPL) plus BIM (Dynamo + Revit) with a

building energy simulation package [14]. The other presents some experiments and applications of 3D survey techniques, 3D scanning, building information modelling, and augmented reality applied to historical buildings [15].

The third most cited has 3 citations and proposes a new informatic tool named “A thousand BIM”, that can quickly generate several buildings typologies [16].

Table 1 Top 10 authors.

	AUTHORS	PAPER TITLE	CITATIONS	PERCENT
1	Park, Jungdae	BIM-Based Parametric Design Methodology for Modernized Korean Traditional Buildings	7	19%
2	Chiabrando, F.; Sammartano, G.; Spano, A.	Historical buildings models and their handling via 3d survey: from points clouds to user- oriented HBIM	5	14%
3	Kensek, Karen	Visual programing for building information modeling: energy and shading analysis case studies	5	14%
4	Park, Juhong; Nagakura, Takehiko	A THOUSAND BIM A rapid value-simulation approach to developing a BIM tool for supporting collaboration during schematic design	3	8%
5	Kensek, Karen; Ding, Ye; Longcore, Travis	Green building and biodiversity: facilitating bird friendly design with building information models	2	6%
6	Pazhoohesh, Mehdi; Shahmir, Raja; Zhang, Cheng	Investigating thermal comfort and occupants position impacts on building sustainability using CFD and BIM	2	6%
7	Vital, R.; Cory, J	Digital documentation integrated in BIM for building reuse and sustainable retrofit	2	6%
8	Asl, Mohammad Rahmani; Zarrinmehr, Saied; Yan, Wei	Towards BIM-Based parametric building energy performance optimization	2	6%
9	Gil, Jorge; Beirao, José; Montenegro, Nuno; Duarte, José	Assessing Computational Tools for Urban Design Towards a “city information model”	2	6%
10	He, Yi; Schnabel, Marc Aurel; Chen, Rong; Wang, Ning	A parametric analysis process for daylight illuminance. Influence of Perforated Facade Panels on the Indoor Illuminance	1	3%
11	Samuel, Egwunatum I.; Joseph-Akwaru, Esther; Richard, Akaigwe	Assessment of energy utilization and leakages in buildings with building information model energy	1	3%
12	Nyvt, Vladimir; Pruskova, Kristyna	Building Information Management as a Tool for Managing Knowledge throughout whole Building Life Cycle	1	3%
13	Rea, Pierluigi; Pelliccio, Assunta; Ottaviano, Erika; Saccucci, Marco	The Heritage Management and Preservation Using the Mechatronic Survey	1	3%
14	Fathi, Ahmed; Saleh, Ahmed; Hegazy, Muhammad	Computational design as an approach to sustainable regional architecture in the Arab world	1	3%
15	Salgueiro, Inti Baeza; Ferries, Bernard	An “Environmental BIM” Approach for the Architectural Schematic Design Stage	1	3%
	Total		36	100%

Five papers shares the fourth position with 2 citations each, they themes are: (1) Present an educational tool applied to Dynamo + Revit that characterizes whether a proposed building design can avoid bird collisions [17]; (2) Present an intelligent control system to automate the thermal comfort decisions focusing on the knowledge of the occupants [18]; (3) Present a case of study on the documentation and design intervention in a historical building in Israel using BIM software — Revit [19]; (4) Creates a

tool “Revit2GBSOpt” to facilitate integration between parametric BIM and building energy performance simulation [20]; (5) evaluate software tools for sustainable urban design in a perspective of having a CIM — City Information Model [21]. This last paper focuses on the topic of urbanism and not exactly architecture.

The last six papers shares the fifth place with one citation each.

From the 15 most cited papers, Karen Kensek appears authoring two papers. This means this author have combined 7 citations, sharing, the first place of most cited author in this field, with the author Jungdae Park.

4.6 Sustainable BIM

Sustainability is a subject that involves every knowledge field, including architecture. One of the most acceptable definitions of sustainability was published in a report, after the 1987 World Commission on Environment and Development (WCED). It says: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [22].

In architecture the term Sustainability has been applied with diverse meanings. Since 1987 other derivatives of the term were created to characterize sustainable architecture, such as: Green architecture, ecologic architecture, Low impact architecture, bioconstructions, bioclimatic architecture, Net Zero Energy Buildings, and others. However, within this diversity of terms, most of them agree that sustainable buildings must have minimal environmental impact and efficient energy use. One way to achieve this is using ancient techniques with natural materials, other is developing materials that cause less harm to the environment.

Keeping this in mind, we classified the consulted literature between those resorting to New and those resorting Ancient techniques. In this case, the “New” category regards the research that explores the use of BIM related to applications of new materials to decrease the environmental impact, like improving the building energetic performance, or recycling construction waste for the development of new sustainable materials. The “Ancient” category explores the use of BIM related with use of ancient materials and techniques (like earth construction) or cultural heritage.

Seven papers were excluded from this classification because it was not possible to find any relations with the mentioned topics. From the 38 papers remaining, 6 were categorized as “Ancient” and 32 were categorized as “New”. In the “Ancient” category, the five objects studied were: Historical Buildings [15]; Historical buildings and historical center of Frigento — historic town in the province of Avellino [23]; Regional Islamic Architecture [24]; Historical buildings in Israel [19]; Hanok (Traditional buildings in Korea) [13]; Valcomino historical city in Italy [25].

5. Conclusion

The first objective of this paper was to present a literature review of BIM and Sustainable/Sustainability research in order to find whether there was already any research on the implementation of ancient/traditional construction techniques in BIM. There were find 6 papers matching with this premise that presents studies of historical buildings using some BIM tool in their methodological procedures.

The review used a bibliometric analysis to select a sample of more than 40 papers from the Web of Science, considered to be the most reliable source for academic publications. In this analysis it was confirmed that the subjects of BIM, Sustainability and sustainable had been increasing during the years but when combined together, the increase was not constant and had peaks in some years.

Among the WoS’s categorization, architectural journals and conferences have been taking the sixth or fifth place in research combining the topics: BIM and Sustainable/Sustainability. Authors have preferred to publish more in conferences than in journals, 71% of the papers came from conferences, and the other 29% came from journals.

Considering the geographic scope, it is curious verify that Africa, the continent where earth construction has always been most applied actually has the lowest percentage index in hosting conferences, editors and authors in this field. The percentage of

author publications per continent is close to the percentage of the location of publication per continent. This fact would evidence that there is a tendency for authors to publish on their geographical area or in other words that researchers mobility tends to be mostly within the continent where their affiliation resides. Still, because authorship is related to affiliation and not nationality of the authors, the analysis may be misleading in regard to the researchers' nationality.

Furthermore, other than conventional bibliometric analysis that usually is restricted to quantitative data, we also presented a subjective analysis on the papers, pointing those referring to ancient materials and techniques. Those papers present less than 16% of the total. Most of them are dedicated heritage architecture, even though the examples were considered sustainable, this was due to the memory preservation and not because of the materials applied, which were essentially not natural materials.

Regarding the initial objective, to show if there was any research relating BIM to the use of earth construction, we concluded that in the architectural category on WoS database, there are no publications relating these topics, and the publications of other categories the given keywords did not have the same meaning as meant in this research. This conclusion evidences a gap in research showing that there is no work involving the development of BIM tools for earth construction techniques. It might be possible to find some publication in this topic out of the database used here. Nevertheless, considering the world wide acceptance of WoS, it is valid to affirm that this is not a well explored topic in literature and it would be a challenge to find some consistent work on this matter.

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