SCAN TO BIM: a systematic literature review network analysis

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Abstract. Building information modelling (BIM) has transformed the AEC industry tremendously, and its adoption has been reported to be high due to the immense latent benefits. One of the inherent benefits of BIM is information management and the ability to integrate with other technologies to achieve this has become the gap being explored by researchers. Laser scanning technology is one of the technologies integrated with BIM. This is done to achieve BIM compliance of pre-BIM edifices. In recent years, substantial research has been conducted on the integration of BIM and laser scanning technologies. This study performed a state of the art review of these research efforts using Systematic literature review network analysis (SNLA) (this is a combination of systematic literature review (SLR) and citation network analysis (CNA). The objective of the study is to identify research trends and gaps for further research. The coverage of this study is from 2007 to 2020. Data was sourced from the Scopus database of published research works and analysed using network analysis. The study identified the publication trends, research trends among others. The study identified quality control and the integration of photogrammetry as the hot topics in this space. This study provides researchers with an insight into the scan to BIM research globally.

1. Introduction
The idea of BIM was first conceptualized as building design system (BDS) by Eastman, (1975). Eastman’s work, “The Use of Computers Instead of Drawings in Building Design”, described the functionalities of the currently known Building information modelling. Although the transformation of Eastman’s concept took 25 years before its actualization, and it is still being developed to achieve his predictions [2]. However, presently BIM has metamorphosised and new horizons are being unravelled to achieve a seamless information management process in the construction industry. BIM is a technological platform that supports the collaboration of professionals to achieve the planning, design and construction throughout the construction project lifecycle. It allows for the management of a building throughout its lifecycle. It promotes productivity, efficiency, precision and accuracy.
Heretofore, the construction industry has experienced the migration from lines and arcs to 2D and 3D but the BIM is an all-encompassing model beyond object dimensions. BIM is beyond 3D but nD; it has added time, cost, resource management, sustainability, among others in the fourth, fifth, sixth, seventh dimensions [3]. The BIM dimension has also been extended to the tenth dimension; this consists of the following dimensions: sixth dimension (sustainability and CO₂ accounting), seventh dimension (operation and maintenance), eighth dimension (Health and Safety), ninth dimension (Lean management) and tenth dimension (digitisation) [4]. Although Koutamanis, (2020) argues that BIM should not go beyond the fourth dimension as the other dimensions do not qualify as dimensions. Generally, BIM dimensions, especially beyond the third dimension, is not standardized and thus are not harmonized [6]. These latter dimensions beyond the fourth do not have a synchronized characterization by researchers.

For this study, the crux of these different BIM dimensions is that BIM is central to many transformations in the construction industry. Also, it possesses potentials that can be unravelled with time, these latent potentials are achievable through its integration with other technologies. Overall, its inherent dimensions are directed towards industrializing and transforming the construction sector [4]. Hence, it is expanding in dimensions in order to achieve its benefits of efficiency, data accuracy, productivity real-time data delivery, among others. However, the most significant purpose is the achievement of clients’ objective and not been confined to the dimensional boundaries.

In order to achieve this, BIM has been exploring and conquering more technological boundaries through the integration with other emergent technologies in the construction industry. These emergent technologies, especially in the area of the field to BIM processes, includes but not limited to radio frequency identification (RFID), ultra-wideband (UWB), global navigation satellite system (GNSS), 2D imaging, photogrammetry, 3D terrestrial laser scanning, among others. An important integration of technologies is the application of laser scanning for a field-to-BIM process as opposed to the more popular BIM-to-field processes. The former is employed mostly in the creation of BIM, where it is inexistent. It can be employed in new buildings (without a preexisting BIM model), existing building (with or without a preexisting BIM model) [7,8]. Laser scanning technology is one of the techniques employed; it produces 3D point clouds to generate as-built information for existing buildings through lasers(amplified lights) [9]. This study is aimed at observing the trend in the global scan to BIM research. Various studies have been conducted on the integration and application of these two technologies in the construction industry. This study seeks to explore the trend and status of the integration using a SLNA approach.

2. Methodology
To achieve the objectives, a systematic literature review network analysis (SLNA) was adopted. This methodology is a combination of systematic literature review (SLR) and citation network analysis (CNA) [10]. Other researchers have adopted this method in carrying out reviews [11,12].

2.1 Data collection
The data collection was done through SLR. The SLR includes the selection of keywords and a systematic approach to identifying themes in the field of study. This study adopted an automated search approach to achieve its data collection systematically. The data was collected from Scopus. Scopus is one of the two largest indexing databases; the other one is Web of Science, Scopus, however, have a wider coverage (Mongeon and Paul-Hus, 2016). This position of Scopus having a wider coverage more than other databases and is more informative was alluded to by [14]. Consequently, this study adopted the Scopus database as its automated search source. The search string for the study is given below:
The search focused on the studies that examined the BIM and laser scanning and adopted the use of the Boolean connectors: “AND” and “OR”. The study, however, was non-restrictive in terms of the document type. This is in order to achieve a wider coverage of publications. The coverage for this study were all research publications in the study focus area between 2007 and August 2020.

![Figure 1: Publication type](image)

The search included all publications without exclusions in order to achieve an all-inclusive and wide coverage of data. Figure 1 gives an overview of document types constituting the data collected for this study.

### 2.2 Data analysis

To achieve the objective analysis of the collected data through CNA, the VOS viewer software was adopted. It is an open-access software for data visualization, the positions of analysed data on the visualization reflect their relationship [15]. It is also flexible and easy to use with a great graphical presentation compared to other bibliometric visualization tools. It has been adopted in previous bibliometric visualisation studies, for instance [16,17].

### 3. Discussion

#### 3.1 Annual publication trend

The trend of publication is presented in Figure 2 from 2007 to 2020. It is evident that the first publication in BIM-3D scanning integration was in 2007. The publication has risen steadily from 1 number to 12 numbers as of August 2020 although irregular.
Figure 2: Annual publication trend

The publication trend evidences the growing interest in the application of these two technologies to achieve the field to BIM objectives.

Figure 3: Publication type network

Figure 3 shows, the publication trend based on the publication type. The size of the node indicates the relative magnitude of the variable and the links shows the relationship between the nodes [18]. These links are represented by the lines in the network (Figure 3). It is evident that Articles are the most published, followed by conference papers.
3.2 Country-wise publication trend
Most publications were contributed by the United States of America, the United Kingdom, China, Spain, and Germany. The output in these countries is not unexpected as they are advanced in BIM research, for instance, USA, South Korea, England (UK) [19]. Thus, they are expected to be advanced in the integration with emergent technologies. However, it is encouraging to note that Egypt and some other developing countries are on the list, it shows that BIM research is gaining momentum in the developing countries.

![Country-wise publication trend](image)

**Figure 4: Country-based publication trend**

3.3 Publication sources
According to the data collected from the Scopus website, publications in the BIM and scanning research is from different sources. The sources include but not limited to journals and conference proceedings. Table 1 and figure 5 shows the various publication sources. The study identified the top 20 most productive publication sources. From table 1, Automation in construction occupies the first place with 60 documents and 2653 citations. It is good to note that this source is observed as being productive and a leading contributor to BIM research in the construction industry. This is alluded to by the study results by [19–22]; hence it can be said that this journal is very productive in this research area.

| Source title                                                                 | Documents | Citations |
|-----------------------------------------------------------------------------|-----------|-----------|
| 1 Automation in Construction                                                | 60        | 2653      |
| 2 ISPRS Annals of The Photogrammetry, Remote Sensing and Spatial Information Sciences | 29        | 102       |
| 3 Journal of Computing in Civil Engineering                                 | 17        | 321       |
| 4 32nd International Symposium on Automation and Robotics in Construction and Mining: Connected to the Future, Proceedings | 7         | 53        |
| 5 Applied Sciences (Switzerland)                                            | 7         | 94        |
| 6 Congress on Computing in Civil Engineering, Proceedings                   | 6         | 15        |
| Number | Journal Title                                                      | Volume | Issue |
|--------|-------------------------------------------------------------------|--------|-------|
| 7      | Computer-Aided Civil and Infrastructure Engineering               | 5      | 185   |
| 8      | Engineering, Construction and Architectural Management            | 5      | 13    |
| 9      | Journal of Building Engineering                                    | 5      | 38    |
| 10     | Proceedings of the 36th International Symposium on Automation and Robotics in Construction, ISARC 2019 | 5      | 3     |
| 11     | Sensors (Switzerland)                                             | 5      | 21    |
| 12     | Computing in Civil Engineering 2019: Visualization, Information Modeling, and Simulation - Selected Papers from the ASCE International Conference on Computing in Civil Engineering 2019 | 4      | 6     |
| 13     | ISARC 2016 - 33rd International Symposium on Automation and Robotics in Construction | 4      | 24    |
| 14     | Journal of Management in Engineering                              | 4      | 76    |
| 15     | Sustainability (Switzerland)                                      | 4      | 5     |
| 16     | Construction Innovation                                           | 3      | 30    |
| 17     | Construction Research Congress 2018: Construction Information Technology - Selected Papers from the Construction Research Congress 2018 | 3      | 7     |
| 18     | IOP Conference Series: Materials Science and Engineering          | 3      | 4     |
| 19     | Journal of Cleaner Production                                     | 3      | 104   |
| 20     | Journal of Construction Engineering and Management                | 3      | 28    |

The density visualization is presented in Figure 5, the cluster around Automation in construction is the most accentuated. This is followed by the ISPRS Annals of The Photogrammetry, Remote Sensing and Spatial Information Sciences, and Journal of Computing in Civil Engineering.
3.4 Country wise productivity

From the analyzed data, Table 2 shows that scholars from the United States of America rank first in terms of the number of publications and citations. This is followed by the United Kingdom. However, moving down the countries, it is observed that there is no direct correlation between the number of document and citation garnered. For instance, China has 14 documents and 78 citations whereas countries like Spain, Canada, Hong Kong, Italy, South Korea have 10, 6, 6, 6 and 6 documents respectively but with 479, 208, 180,104 and 399 citations, respectively. It can be inferred that the number of documents does not automatically command the same number of influence in terms of citations. An analysis based on the geographic location of these countries reveals that most of the productive countries are from Europe and Asia. However, there is an African country (Egypt) with two documents, this shows that this research domain is busy with activities from both developing and developed countries.

Figure 6 provides the network visualization of the country productivity. It can be observed that countries like Singapore, Italy and the Netherlands have more recent publications in this research area. This is shown in the time bar at the bottom right corner of the figure. The colour scheme represents the annual publication trend, the colour on the timeline denotes the year against the country node on the figure. Thus, the USA, UK and China cannot be said to have recent publications like the earlier listed countries. Their publications are around 2017.

| S/N | Country       | Documents | Citations |
|-----|--------------|-----------|-----------|
| 1   | United states| 34        | 1715      |

Table 2. Details of the first 20 countries productivity
| Rank | Country           | Count | Total |
|------|-------------------|-------|-------|
| 1    | United Kingdom    | 18    | 546   |
| 2    | China             | 14    | 78    |
| 3    | Spain             | 10    | 479   |
| 4    | Germany           | 9     | 124   |
| 5    | Canada            | 6     | 208   |
| 6    | Hong Kong         | 6     | 180   |
| 7    | Italy             | 6     | 104   |
| 8    | South Korea       | 6     | 399   |
| 9    | Malaysia          | 5     | 21    |
| 10   | Australia         | 4     | 50    |
| 11   | Portugal          | 4     | 58    |
| 12   | Russian federation| 4     | 1     |
| 13   | Ireland           | 3     | 172   |
| 14   | Netherlands       | 3     | 24    |
| 15   | Turkey            | 3     | 20    |
| 16   | Denmark           | 2     | 0     |
| 17   | Egypt             | 2     | 0     |
| 18   | Singapore         | 2     | 1     |
| 19   | Sweden            | 2     | 1     |

*Figure 6: country productivity network*

### 3.5 Research trend

To achieve the visualization of the research trends in the scan to BIM research publications, a co-occurrence map of the bibliographic data using the keywords was generated. The use of keywords to achieve the patterns and research clusters has been adopted in studies such as [16,17,22] The default number of 5 occurrences was adopted for this study. A critical look at the clusters generated shows that there exist 5 clusters representing five research trends. It is observed that the research focus has been on the
application of scan to BIM to facility management, retrofitting and especially for historic preservation. The second focus was majorly on the integration of Augmented reality (AR) and Virtual Reality (VR) in this field for information management in the area of project management, and construction management. also, the research focus has been aimed at the adoption of laser scanning for lifecycle management through reverse engineering and surface analysis. Research focus four and five are aimed at the introduction of quality control and the integration of photogrammetry in this space. Clusters four and five however are emergent and thus are regarded as hot topics.

Figure 7: Research clusters

4. Conclusion
This study focused on the state-of-the-art review of the scan to BIM integration focusing mainly on the use of laser scanner technology. The major area of focus for this study are the country trend, annual publication trend and the research trend.

The field of scan to BIM has received attention especially in integrating erstwhile non-BIM buildings into BIM. This study focused on articulating the research efforts in this area and also established the various research trends heretofore. It is worthy to mention that there is a lot to explore in the BIM space in order to achieve its adoption especially while integrating it with other emerging technologies. However, there exists some limitation from this study as there are other areas not covered like author productivity and influence, citation networks, co-citation networks among others. Also, the data was sourced from one database, Scopus. Thus, further work can still be done in this space.

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