BIM in the Malaysian construction industry: a scientometric review and case study

Article

Accepted Version

Tanko, B. L., Zakka, W. P. and Heng, W. N. (2022) BIM in the Malaysian construction industry: a scientometric review and case study. Engineering, Construction and Architectural Management. ISSN 1365-232X doi: https://doi.org/10.1108/ECAM-04-2021-0324 Available at https://centaur.reading.ac.uk/110730/

BIM in the Malaysian Construction Industry: A Scientometric Review and Case-study

Bruno Lot Tanko[a], Wyom Paul Zakka[b,c], Wee Nie Heng[a]

[a]*School of the Built Environment, University of Reading Malaysia, Johor, Malaysia.*
[b]*School of Civil Engineering, Universiti Teknologi Malaysia, Johor, Malaysia.*
[c]*Department of Building, University of Jos, PMB, 2084, Jos, Nigeria.*

b.tanko@reading.edu.my (corresponding author), wpzakka@graduate.utm.my, wee_nie1999@hotmail.com,

Abstract

Purpose: The purpose of this study is to explore existing literature on Building Information Modelling (BIM) in Malaysia and examine the perception of practitioners about the potential of BIM applications in reducing construction waste and enhancing productivity.

Design/Methodology/Approach: First, using 244 bibliographic data extracted from the Scopus database, the paper used scientometric analysis and VOSviewer mapping technique to assess the most impactful publication literature on BIM in Malaysia to identify the existing research gaps. Second, using a structured questionnaire, a total of 100 questionnaires were distributed to practising practitioners who incorporate BIM in the delivery of their projects. Descriptive analysis using cross-tabulation in SPSS software, radar chart, relative importance index, and Pearson's correlation were used to analyse the data.

Findings: The research gaps are in the fields of construction projects, buildings, energy efficiency, life cycle, and housing. The findings of the survey indicate that quantity take-off, clash detection, site utilization planning, digital fabrication as well as 4D stimulation were the main BIM applications used among the practitioners in Johor and Selangor.

Practical Implications: By assessing the state-of-the-art of BIM and BIM applications in this region, the practical implications of this study provide useful insights to construction stakeholders, funding organisations, policymakers, research institutions, professionals, journal editors, reviewers, and researchers to understand the overall trend of BIM in Malaysia and its usage.

Originality: This paper is the first to use science mapping using scientometrics to reveal the current BIM research in 'Malaysia only'. Relying on the identified gaps, the study further examined the usage of BIM applications in Malaysian construction projects.

Introduction

The idea of sustainable building has been broadly adopted over decades, and the effort to practice green construction for a transition in the built environment is continuously gaining awareness among construction industry stakeholders (Saieg et al., 2018). Momade and Hainin (2018) and Sinoh, Othman, and Ibrahim (2020) urged construction teams to transition from traditional construction methods to sustainable construction methods. Although the construction industry is critical to the growth and sustainability of the built environment, it is also a major contributor to environmental deterioration due to the severe negative effects of construction activities on the environment in terms of resource scarcity, electricity use, and greenhouse gas (GHG) emissions (Reza, Halog and Rigamonti, 2017) and waste generation. Construction waste generation is consistently a worldwide issue, for instances, in Hong Kong, 25% of the solid wastes were attributed to the construction activities and ended up in landfills, 32% and 44% of the building-related wastes out of the overall wastes were generated within United Kingdom (UK) and England while in the European Union, the European Commission found out 25% to 30% of wastes induced were from construction activities (Lu et al., 2017). Furthermore, construction wastes accounted for 48 percent and 26 percent of the disposed solid wastes at landfills in South Korea and the United States, respectively, while construction wastes accounted for 20 percent of the total wastes produced in Japan (Won and Cheng, 2017). Malaysia, as a developing nation is no exception in terms of massive waste production as construction activities increased, as it was discovered that C&D wastes accounted for nearly 41% of total solid waste produced (Mah and Fujiwara, 2016).

As a result, many management techniques are being implemented, and at the moment, Building Information Modelling (BIM) is gaining popularity in the architecture, engineering, and construction (AEC) industry due to the ability of the technologies in waste reduction from the design to construction phase more effectively, as approximately 33% of wastes were reported to be effected during the construction phase (Liu et al., 2015). To ensure that a building is operated sustainably, BIM can forecast its lifecycle, remove any design flaws, and improve the design quality through visualization (Tanko and Mbugua, 2022). The application of BIM may considerably aid in attaining sustainable construction through design optimization, cost reduction, risk mitigation, and improved project schedules (Haruna, Shafiq, and Montasir 2021). With the advancement of technologies, BIM can be a widely implemented platform in achieving different performance targets throughout the project lifecycle in terms of productivity, quality as well as value. Yet, no BIM-related tools are specifically developed for construction waste management, but the potential of BIM in aiding the performance of waste reduction is increasingly explored as an effective approach as well as enthusiastically promoted in the recent years.

However, moving from a conventional approach to BIM implementation is difficult and time-consuming, as the construction industry in Malaysia still has a low level of BIM adoption, ranging from 0 to 1 (Zakaria et al., 2013). Similarly, Ahlam and Abdul Rahim (2020); Feng (2021) and Othman et al. (2021) confirmed that BIM is still in its early stages of implementation in Malaysia, and that once it is fully implemented, the benefits will propel the industry to a whole new level (Feng, 2021). Meanwhile, the construction industry's inability to leave the initial conventional platform has compounded the difficulties of BIM implementation in Malaysia (Wong and Gray, 2019). A study by Othman et al. (2021) revealed 13% as the level of BIM implementation by both public and private sectors in Malaysia. The study further attributed slow adaptation and unavailability of a clear guideline as factors responsible for the slow implementation of BIM in the country. This means that attempts to use BIM in waste reduction have yet to be explored, as Malaysia's level and readiness for BIM implementation is inadequate for construction parties to completely inculcate the functions of BIM in waste reduction (Mamter, Rashid, and Aziz, 2016) and productivity enhancement. However, Othman et al. (2021) acknowledged the collaboration between the Malaysian construction industry and the Construction Industry Development Board (CIDB) to promote BIM implementation by engaging with professionals and organisations to adopt the BIM process. In the same vein, Tanko and Mbugua (2022) confirmed that CIDB as a government organisation, encourages the use of BIM technology through seminars and is presently working on a roadmap that will include clear guidance on BIM implementation.

A study of prior, applicable literature is an indispensable aspect of any research project in view of the ongoing growth of science. Literature reviews thus play a crucial role in scientific research. They provide a basis to advance information, promote theoretical progress, and define areas for further study (Viergutz & Schulze-Ehlers, 2018). As the number of scientific publications increase, it is becoming increasingly difficult for researchers to manage literature and carry out literature reviews free of bias. A quantitative method using computational power provides the opportunity for the research community to reduce bias in literature (Zakka et al., 2020).

Quantitative analyses of scientific literature form part of the broad sciences and technology discipline known as scientometrics. In addition to being broad in scale, science literature is often diverse and nuanced. It is a form of big data analysis and mining (Chen et al., 2014). Big data analytics (BDA) is a collection of applications and resources providing more details on the reliability and usefulness of the data used in strategic planning (Galetsi & Katsaliaki, 2019). As stated by Zakka et al. (2020), scientometrics involve visualization of key research areas using co-citation networks and science mapping. Science mapping, centred on information science and technology, is an increasingly emerging interdisciplinary domain. Science mapping is the creation and use of computer techniques to visualise, interpret, and model a wide variety of scientific and technical operations in general. Thus, this paper explores the first scientometric review of BIM in Malaysia and explores the potential of BIM applications that could mitigate construction waste and improve overall productivity.

Literature Review

Building Information Modelling

BIM is a new technique that is gaining traction as an increasing number of studies promote and concentrate on the benefits and advantages that BIM can bring to different industries. There is a need for BIM adoption research in developing countries, according to Shehzad et al. (2020), who noted that most studies are conducted in developed nations like the US and the UK. Al-Ashmori et al. (2020) inferred that the deployment of BIM is driven by trust, commitment, and knowledge; and the benefits include increased productivity, time and cost savings, clash detection and effective communication. According to Lee, Chong, and Wang (2018), in the built environment market, BIM is described as a digital tool that aids in the improvement of the decision-making process across the project lifecycle by using reliable sources obtained through the sharing of information on a facility's resources while promoting cooperation among all parties with their respective roles in the project. BIM is compared to a collective mechanism that efficiently handles knowledge during the life cycle of building projects in this paper. BIM, according to Mamter, Rashid, and Aziz (2016), promotes collective preparation, facilitates communication and collaboration, and facilitates knowledge sharing among the various players involved in the planning process. According to some researchers, the construction industry's existing problems could be effectively solved by the implementation of BIM (Ahuja, Arif and Sawhney, 2018). Nonetheless, major challenges confronting the construction industry are automation, digitization, and better value for capital; BIM, collaborative project delivery, and rich information modelling can provide a competitive advantage (Shehzad et al., 2020). The adoption of BIM in the Malaysian construction ecosystem is threatened by both technical (app/software development) and non-technical (unsustainable app/software user growth, security breaches, selection of the incorrect software development partner, communication, etc.) risk factors, according to a study by Ahlam & Abdul Rahim (2020) on three construction firms in Malaysia. Similarly, a study by Sinoh, Othman, and Ibrahim (2020) identified that non-technical factors such as management, leadership and coordination were more critical than technical factors such as software and hardware. To successfully integrate BIM, Al-Ashmori et al. (2020) advocated that the construction sector should support and help all Small and medium-sized enterprises (SMEs) to create a culture of trust, respect, cooperation, and involvement.

BIM Applications

Prior to making any commitment to use BIM in any project, the first step in understanding BIM is to recognize the benefits of specific BIM applications that can effectively complement the process of achieving project goals in various construction phases (Lee, Chong and Wang, 2018). This crucial step lays the groundwork for determining how BIM will help reduce the amount of waste produced during construction. BIM uses can be expressed as ‘BIM applications' or ‘BIM deliverables,' according to Lee, Chong, and Wang (2018), with the latter having a similar interpretation to the former.

Many researchers have highlighted the benefits of BIM in addressing construction-related issues, but the first step in completely using BIM resources is to understand BIM applications before implementing BIM. Current conditions modeling, 4D scheduling, 3D coordination, cost estimation, and site analysis for pre-construction phases, according to Latiffi et al. (2013), are some of the most successful and prevalent BIM applications studied for pre-construction phases. Lee, Chong, and Wang (2018) conducted research on streamlining digital modeling and BIM uses for oil and gas projects, reviewing a total of 38 different BIM uses. To summarize the standard BIM uses in the pre-construction and construction phases, they include existing conditions modeling, site analysis, cost estimation, 5D cost analysis, 4D phase planning, design authoring, design review, design validation, 3D coordination, digital fabrication, material management, 3D control and planning, site utilisation planning and construction system design, and desirability analysis.

Before delving into the factors restricting the application of BIM, Sun, Jiang, and Skibniewski (2017) examined six major BIM uses in the construction industry, covering 3D visualization, code testing, clash identification, fabrication, 4D time management, and 5D cost management.

In the research of Gholizadeh et al. (2018), three intrinsic BIM functions were found to be widely adopted by most construction firms, namely 3D visualization, clash identification, and constructability analysis, out of the fourteen BIM functions investigated. According to Memon et al. (2014), the three main uses of BIM are 4D preparation, 5D cost estimation, and clash identification by 3D coordination. In Jung and Lee's (2015) report, approximately 25 BIM deliverables were demonstrated, with 3D coordination, current situation modeling, structural analysis, design authoring, and cost estimation being the five most commonly used BIM uses found. Meanwhile, Feng, Mustaklem, and Chen (2012) investigated eight BIM applications in the construction management area, including phase planning (4D model), 3D coordination, 3D control and planning, construction system design, cost estimation, digital fabrication, site utilization planning, and code testing.

BIM Applications in Mitigating Construction Waste

The efficacy and practicability of which BIM applications may be applied to assist in the process of construction waste management will be evaluated after examining the literature on BIM applications that were widely adopted by most of the construction players. However, since there are limited resources available, the issues of using BIM applications as a possible method to perform construction waste management have yet to be addressed. For example, while Cheng and Ma (2013) developed a waste estimation system based on BIM technology, since BIM encompasses a broad variety of functions, it was difficult to determine which particular BIM uses may be effective in reducing construction waste. Meanwhile, Liu et al. (2015) developed a BIM-aided construction waste minimisation system, in which they investigated the capabilities of BIM in improving project management without specifying requirements in BIM applications. Won, Cheng, and Lee (2016), on the other hand, centered on the BIM-based design validation process, demonstrating the amount of construction waste that could be avoided by using BIM design validation. Simultaneously, the advantages of quantity take-off, 4D stimulation, site utilization preparation, and pre-fabrication were highlighted as viable and effective waste minimization applications. Additionally, Won and Cheng (2017) summarized approximately twenty-three BIM uses that can be applied to various construction phases, ranging from planning to demolition, while the results further analyzed only eight primary BIM uses that could create a relationship with construction waste management and minimization. Phase planning, cost estimation, design analysis, clash identification, site utilization planning, construction system design, digital fabrication, and 3D control and planning were all listed as possible BIM applications.

Furthermore, Ahuja, Arif, and Sawhney (2018) conducted research on delivering lean and green project outcomes using BIM, and thirty-three BIM capabilities were converged on fifteen capabilities that were analyzed for linkages between lean and green project outcomes. Green concepts in lean construction have been shown to be reasonably important and to establish synergy effects in reducing all forms of waste through process and performance enhancement, with the implications theoretically becoming greater with the integration of BIM (Ahuja, Arif and Sawhney, 2018). In particular, 64 percent of material wastes were examined to see whether they could be removed by lean construction, which yielded positive environmental effects (Cheng, Won and Das, 2015).

Materials and Methods

Scientometric-Based Review

A scientometric review procedure to establish the present domain of BIM in Malaysia was adopted (Hu et al., 2019). This allows a statistical analysis and graphical interpretation of the synthesised network centred on scientific articles to reflect the conceptual, analytical and social framework of a scientific area (Zheng et al., 2020). The study is performed in consecutive stages in selecting instruments, collecting data, transforming and evaluating data, visualising and presenting the results, interpreting and discussing them. The first was to develop networks with document co-citation analysis, co-currence analysis of keywords and an analysis of cluster recognition (Xiao et al., 2019).

This approach is appropriate for this analysis because the progression of research over a certain period of time is highlighted and analysed. It uses a quantitative outlook that visualises and maps as well as links the research progress to evaluate the advancement of a research field using quality indexes using broad bibliographic data (Mansuri et al., 2019). With numerous scientific articles, it is vital to recognize which databases are most reputable to produce materials. Scopus and the web of science, with Scopus being the broader-based database and more current journals were the two most comprehensive, effective and objective literature search databases used. In terms of visibility and citations, the two databases rank journals which show the journal's impact, its reputation and its influence (Aghaei et al., 2013)

For this study, along with Scopus analyzer, VOSviewer software was used. VOSviewer, an open-source programme developed for bibliometric map creation and analysis. Unlike other applications used to map bibliometrics, VOSviewer takes the graphic representation of bibliometric maps into particular regard. The utility of VOSviewer as a tool for data mining is incredibly beneficial for easily viewing large bibliometric maps. Science mapping analysed clusters and the relations between keywords, scientists, publications and institutions. Data from researchers and keywords provide a time-lapse of the latest trends in academic study in the particular field of BIM in Malaysia. A case study was added to provide a practical picture of how far BIM adoption has gone in Malaysia.

Quantitative Research Design

To support the findings of the research, descriptive research was reviewed to be the most relevant means to explicitly respond to the research questions as the research requires the identification of the potential of BIM applications in reducing construction wastes from the perspectives of the construction players to gather their opinions for further analysis. To explain descriptive research in detail, it is defined as a research method utilised to describe systematically and accurately the existing phenomena and its characteristic of a given population or area of interest, focusing more on what instead of how or why certain phenomena happened (Nassaji, 2015). Descriptive research tends to use questionnaire to conduct research to describe the variability in different phenomena whereas the ‘observed phenomena’ suggested in this research is on the current state of BIM applications in construction waste management. To distribute the questionnaire, the characteristic of the sample chosen are similar where it comprises of construction players like contractors, project manager, engineer, architect and quantity surveyors from different companies of construction sector as these professionals are most likely to be involved in the implementation of BIM. Johor and Selangor states were chosen for this study having a significant population presence with high construction output due to several factors including location, administrative, etc. The sampling method adopted was ‘simple stratified sampling’ and the questionnaire was distributed to 100 participants. To approach the participants, the self-administrated internet-mediated questionnaires were mainly sent through email address which was the easiest way to reach the participants and consents on permission to participant in the research were provided.

Opinion-based questions in the form of 5-Likert scale were examined using the cross-tabulation of the SPSS software which recorded the frequencies of respondents that have specific characteristics and analysed the relationship of different professionals’ perspectives with the variables (Tanko, 2018). The relative importance index (RII) was calculated using Equation 1 to obtain the ranking of the variables and identify the most important factors in the findings. Moreover, the Radar chart was used to show the pattern and skewness of the data, while the Pearson’s Correlation indicates the relationship among practitioners regarding the use of BIM applications.

$$\text{RII} = \sum \frac{ni.pi}{Rv.N} (0 \leq \text{index} \leq 1) \qquad (1)$$

The qualitative (scientometric analysis) and quantitative (casestudy using questionnaire survey) methods are presented in Figure I.

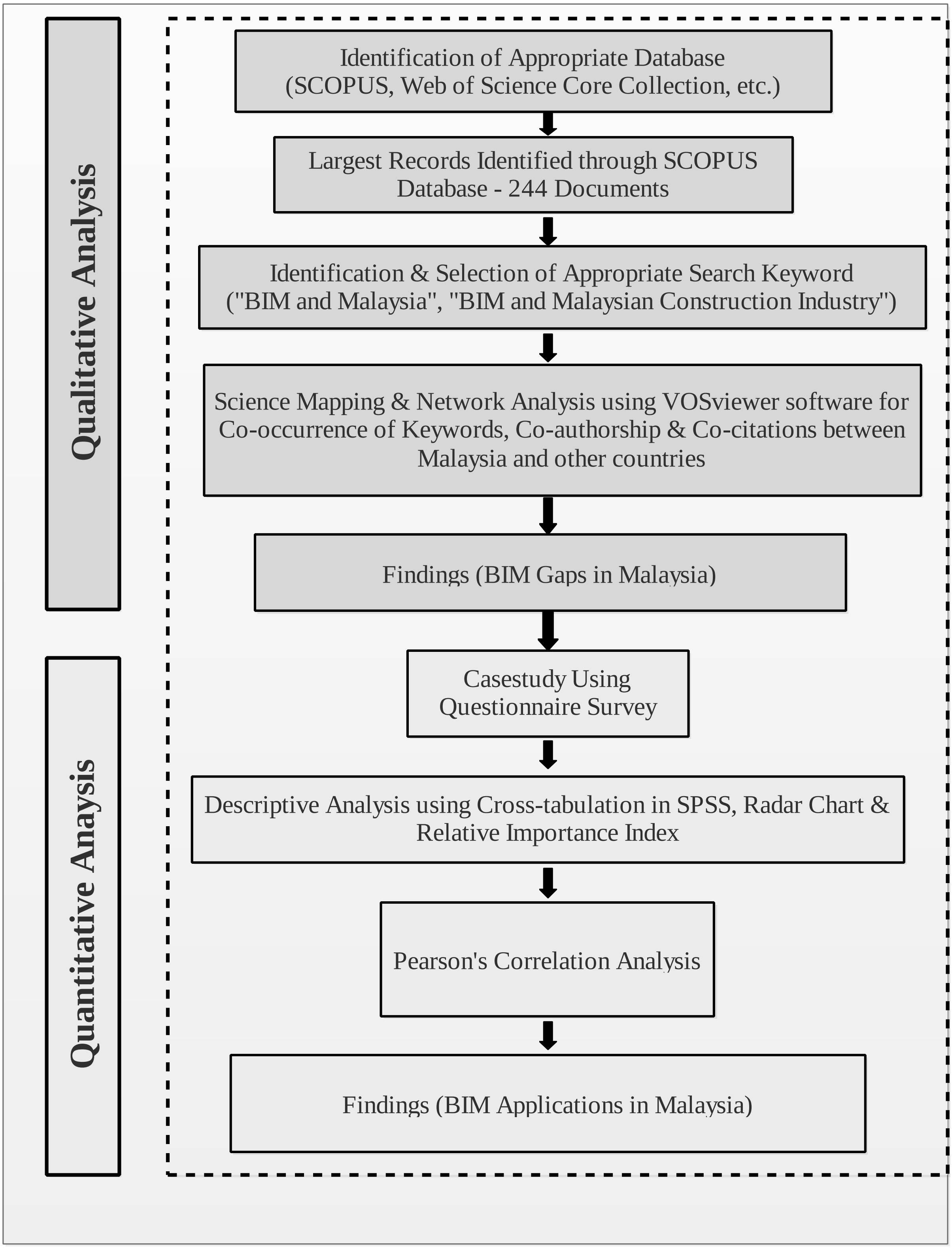

Figure I. Research Procedure of the Study

Findings and Discussions

Scientometric Analysis

A total of 244 articles were identified from the literature search performed on the Scopus database. The literature samples indicate that over a decade of research into BIM, the application has kicked up a notch. However, compared to other countries, BIM studies in Malaysia is still relatively new, and many policy decisions have been predisposed with respect to its complete adoption in Malaysia. This approach, as indicated by Zakka et al. (2020), demonstrates a trend of being thematic and can be grouped into different clusters based on similarities of content and problems addressed'. Using the Scientometric approach, these papers were analysed to show some clarification on the total sample of literature, research keywords, source of publication, most prominent funding agencies, most cited articles, collaborating countries, and institutions that are actively involved in BIM studies. Figure II depicts a visual overview of the types of documents present in the data obtained from the Scopus database; 51.2 % and 38.1 p% are journal articles and conference papers, comprising a collective 89.3 percent of the document database on BIM studies in Malaysia. As the key source of data, the analysis focuses on journal papers and conference papers, since they make up about 90% of the data. Figure III presents the number of documents produced by authors with respect to BIM in Malaysia. Ali, K.N has the highest number of documents (10) followed by Enegbuma, W.I and Nawi, M.N.M with 9 documents each.

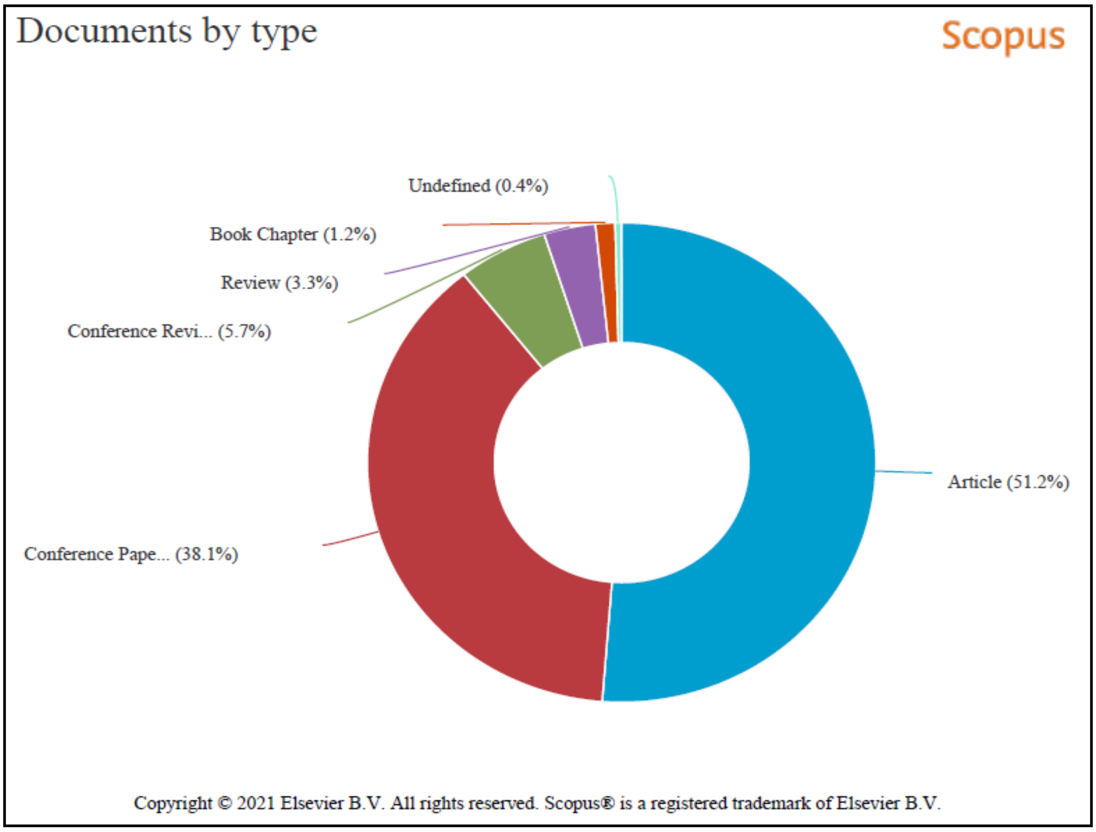

Figure II. Document Types Collected

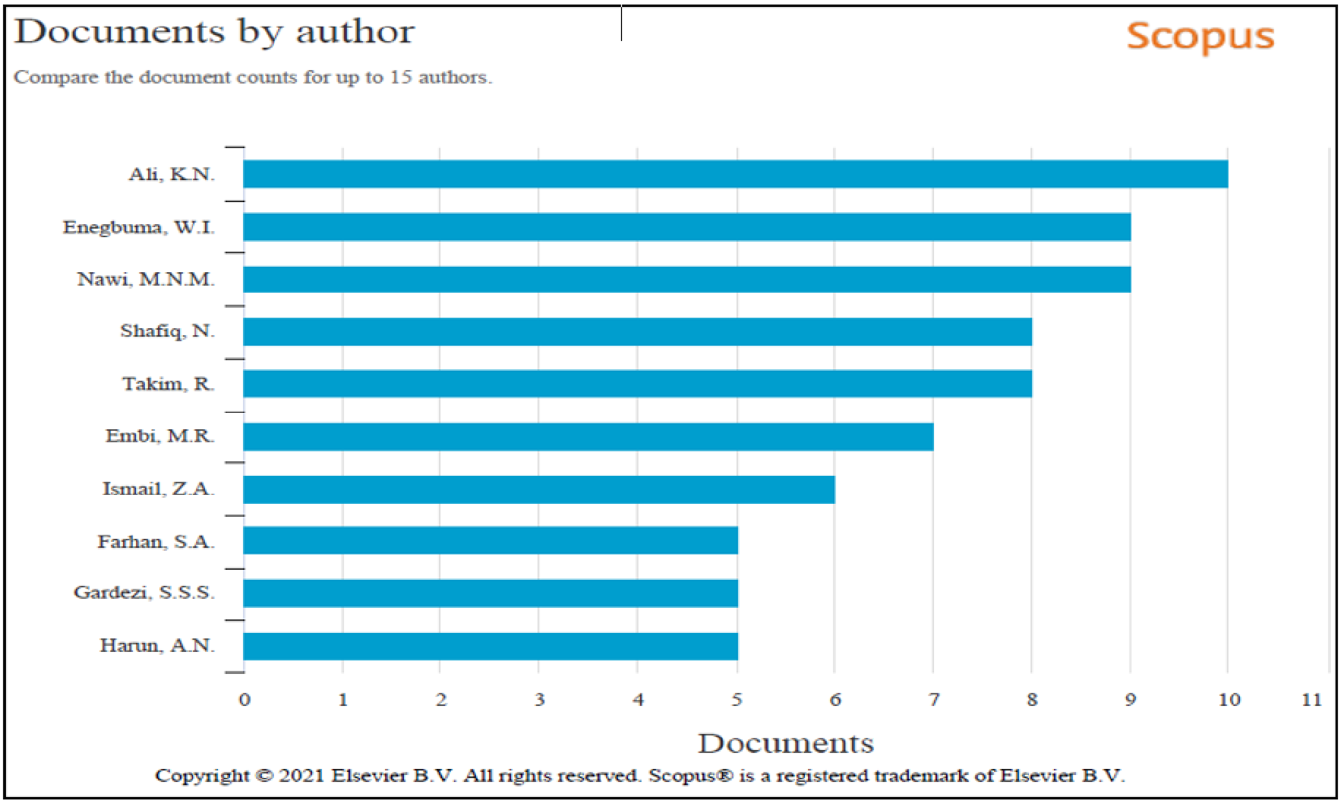

Figure III. Number of Document by Top Authors

Literature sample

Figure IV shows the literature sample on BIM between 1993 to 2021. The trend shows that prior to 2010, research into the use of BIM in Malaysia was relatively unknown. However, from 2010, there has been an increase in publication in the area of BIM in Malaysia. It is expected that because of their growing interest in BIM globally that research in BIM use in Malaysia will reach a zenith in the coming years as Malaysia pushes towards becoming a developed nation.

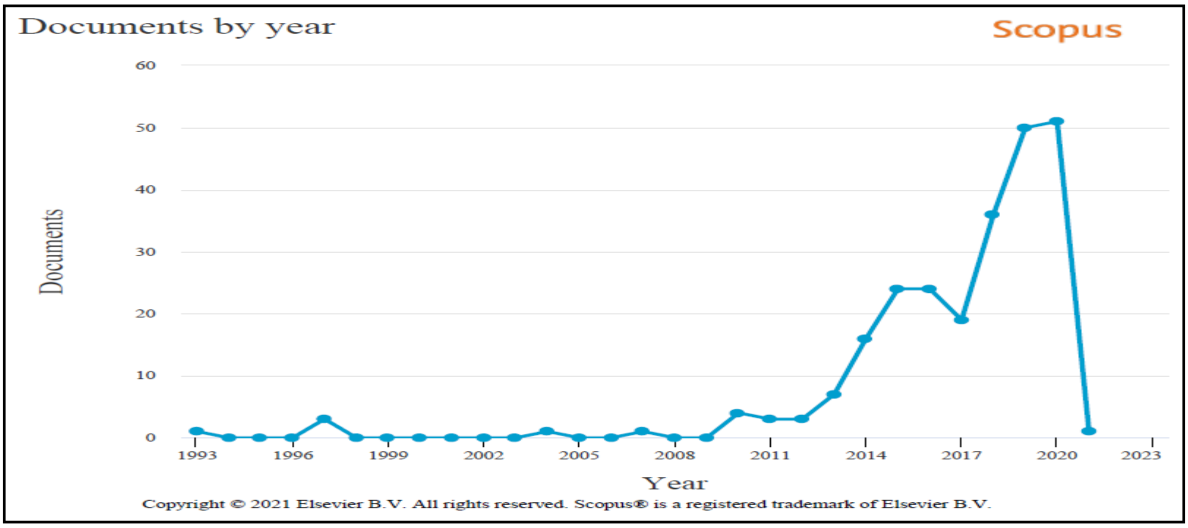

Figure IV. Literature sample and year of Publication

Research Keywords

Keywords are an important part of scientometric studies. Keywords provide an overview of the present research domain in a subject area as they provide a basis for finding studies in a particular field. Figure V shows the visualization of keywords using the VOSviewer software. The visualization presents a timeline in which these keywords were most prominent in the study of BIM in Malaysia. The circles present the level of co-occurrence for the keywords as the larger cycles show that studies in these areas are the most frequent. Also, the thickness between the lines connecting the various keywords show the link strength between each keyword. The closer the distance between two points the greater their relatedness. Table I presents the top 22 keywords with their number of occurrence and link strength.

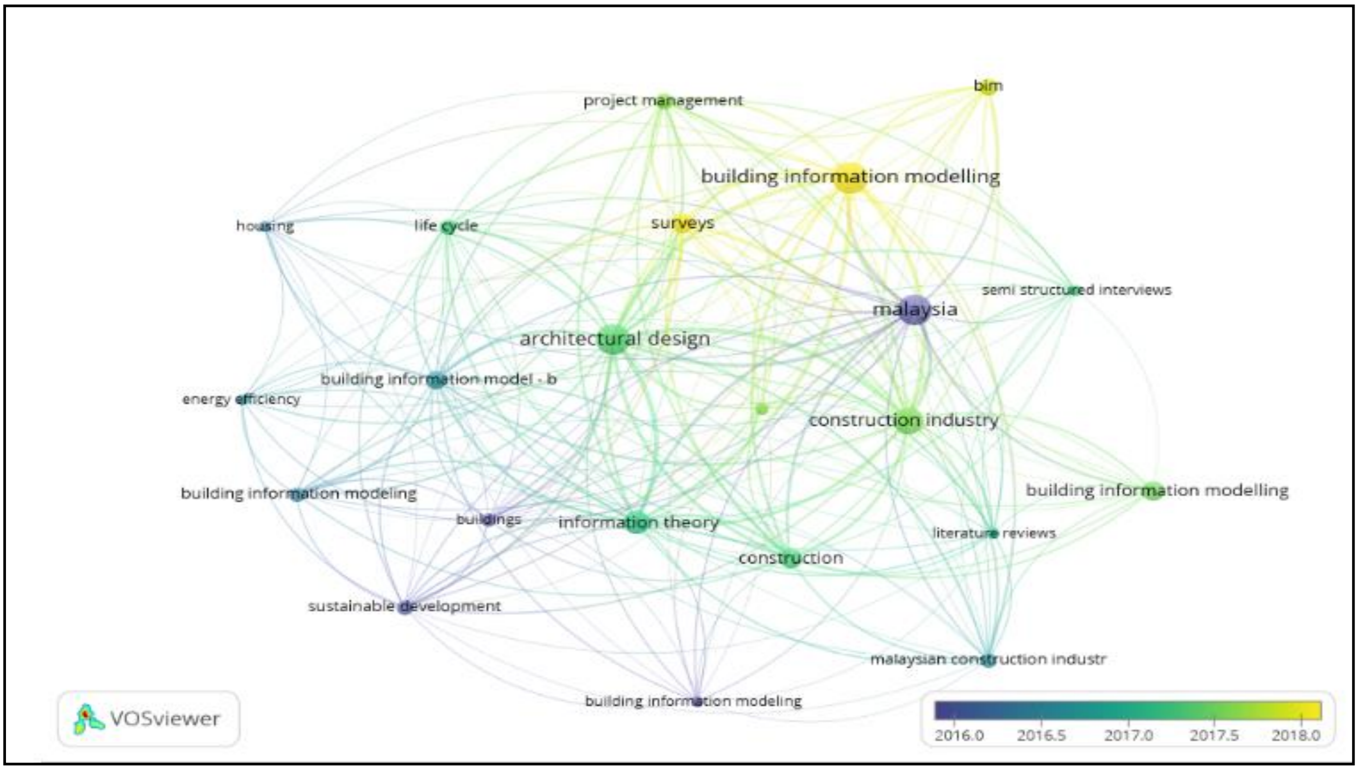

Figure V. Visualization of Keyword

Table I. Co-occurrence of Keywords

S/N	Keywords	Occurences	Total link Strength
1	Architectural Design	70	348
2	BIM	21	52
3	Building Information Model - BIM	24	140
4	Building Information Modeling	16	63
5	Building Information Modeling (BIM)	9	32
6	Building Information Modelling	71	243
7	Building Information Modelling (BIM)	29	49
8	Buildings	13	60
9	Construction	29	168
10	Construction Industry	55	257
11	Construction Projects	11	70
12	Energy Efficiency	10	43
13	Housing	9	41
14	Information Theory	38	230
15	Life Cycle	16	89
16	Literature Reviews	9	59
17	Malaysia	67	180
18	Malaysian Construction Industry	16	76
19	Project Management	20	113
20	Semi Structured Interviews	9	55
21	Surveys	29	146
22	Sustainable Development	16	74

Sources of Documents

Table II presents the various organisations involved in the study of BIM in Malaysia. Also, the number of documents per organisation and citations are presented in the table. Figure VI shows results from Scopus Analyzer where the top 15 institutions involved in the study of BIM. The figure shows that Universiti Teknologi Malaysia has the highest number of studies on BIM in Malaysia on the scopus database with 50 documents. Universiti Teknologi Mara follows closely with 30 documents. There is an increased interest in the study of BIM in Malaysia as seen in the number of documents produced. Figure VII shows the visualization of the institutions involved in the study of BIM. The lack of interconnectivity shows that there is barely collaboration between these institutions in studying BIM in Malaysia.

Table II. Sources of Documents

S/N	Organisaton	Documents	Citations	Total link Strength
1	Centre of Building and Resilient Development (CEBSD), Faculty of Engineering and the Built Environment, Segi University	2	0	2
2	Centre of Interior Architecture Studies, Faculty Of Architecture, Planning and Surveying, Universiti Teknologi Mara	2	5	4
3	Centre of Studies for Construction Management, Faculty Of Architecture, Planning And Surveying, Universiti Teknologi Mara (UITM)	2	1	4
4	Centre of Studies For Postgraduate Studies, Faculty Of Architecture, Planning And Surveying, Universiti Teknologi Mara (UITM), Seri Iskandar Campus, Seri Iskandar, Perak, 32610, Malaysia	3	3	5
5	Centre of Studies for Postgraduate Studies, Faculty Of Architecture, Planning and Surveying, Universiti Teknologi Mara (UITM), Shah Alam, Malaysia	2	1	0
6	Construction Industry Development Board, (CIDB), Menara Dato' Onn, Pwtc, Kuala Lumpur, 50480, Malaysia	2	17	0
7	Construction Research Centre, UTM CRC, Universiti Teknologi Malaysia, Johor, Johor Bahru, 81310, Malaysia	2	0	2
8	Construction Research Institute of Malaysia (CREAM), Malaysia	3	41	7
9	Department of Architecture, Faculty Of Built Environment, Universiti Teknologi Malaysia, Johor, Malaysia	2	5	4
10	Department of Architecture, Faculty of Built Environment, University of Malaya, Kuala Lumpur, Malaysia	2	3	0
11	Department of Building, Faculty of Architecture, Planning And Surveying, Universiti Teknologi Mara (UITM), Seri Iskandar Campus, Seri Iskandar, Perak, 32610, Malaysia	3	3	5
12	Department of Civil And Structural Engineering, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia	2	13	2
13	Department of Civil Engineering, College of Engineering, Prince Sattam Bin Abdulaziz University, Alkharj, 11942, Saudi Arabia	2	2	2
14	Department of Civil Engineering, Faculty of Engineering and IT, Amran University, 9677 Quhal, Amran, Yemen	2	2	2
15	Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Selangor, 43400, Malaysia	2	3	3

16	Department of Interior Design, Faculty of Architecture, Planning And Surveying, Universiti Teknologi Mara, Seri Iskandar Campus, Perak, Malaysia	2	5	4
17	Department of Management of Technology, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur, 54100, Malaysia	2	3	3
18	Department of Structures And Materials, School Of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor, Johor Bahru, 81310, Malaysia	2	0	2
19	Faculty of Civil Engineering, Universiti Malaysia Pahang, Gambang Kuantan, Pahang, 26300, Malaysia	2	41	6
20	Faculty of Technology Management And Business, Universiti Tun Hussein Onn Malaysia (Uthm), Parit Raja, Batu Pahat, Johor, 86400, Malaysia	2	12	0
21	Lafarge's Regional Construction Development Laboratory (Cdl) (Structural System), Lafarge Malaysia Berhad, Malaysia	2	41	6
22	Pusat Citra Universiti, Universiti Kebangsaan Malaysia, Malaysia	2	0	1
23	Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia"	2	8	0
24	School of Built Environment, University College Of Technology Sarawak, Sibu, Sarawak, Malaysia	2	0	2
25	School of Engineering and Built Environment, Griffith University, 170 Kessels Road, Nathan, Qld 4111, Australia	2	1	0
26	School of Environmental Engineering, Universiti Malaysia Perlis, Arau, Perlis, Malaysia	2	13	2

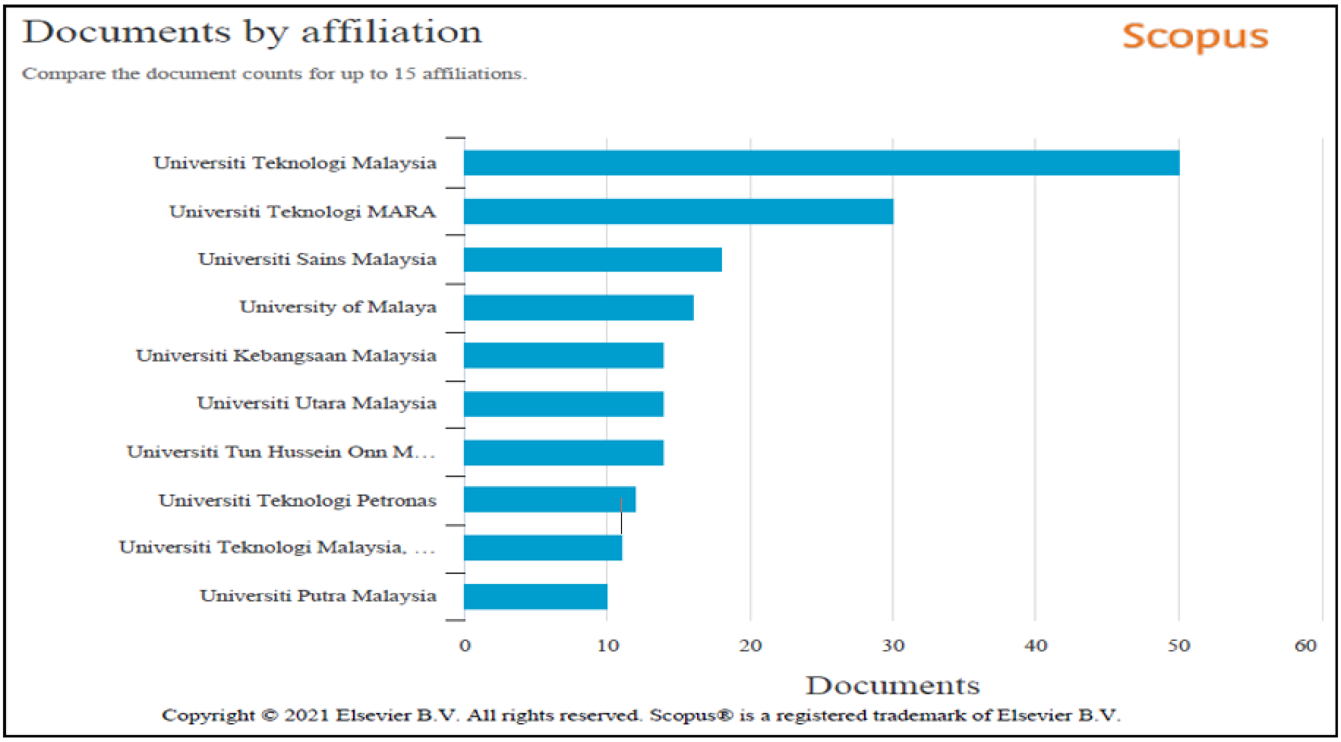

Figure VI. Documents by institutions

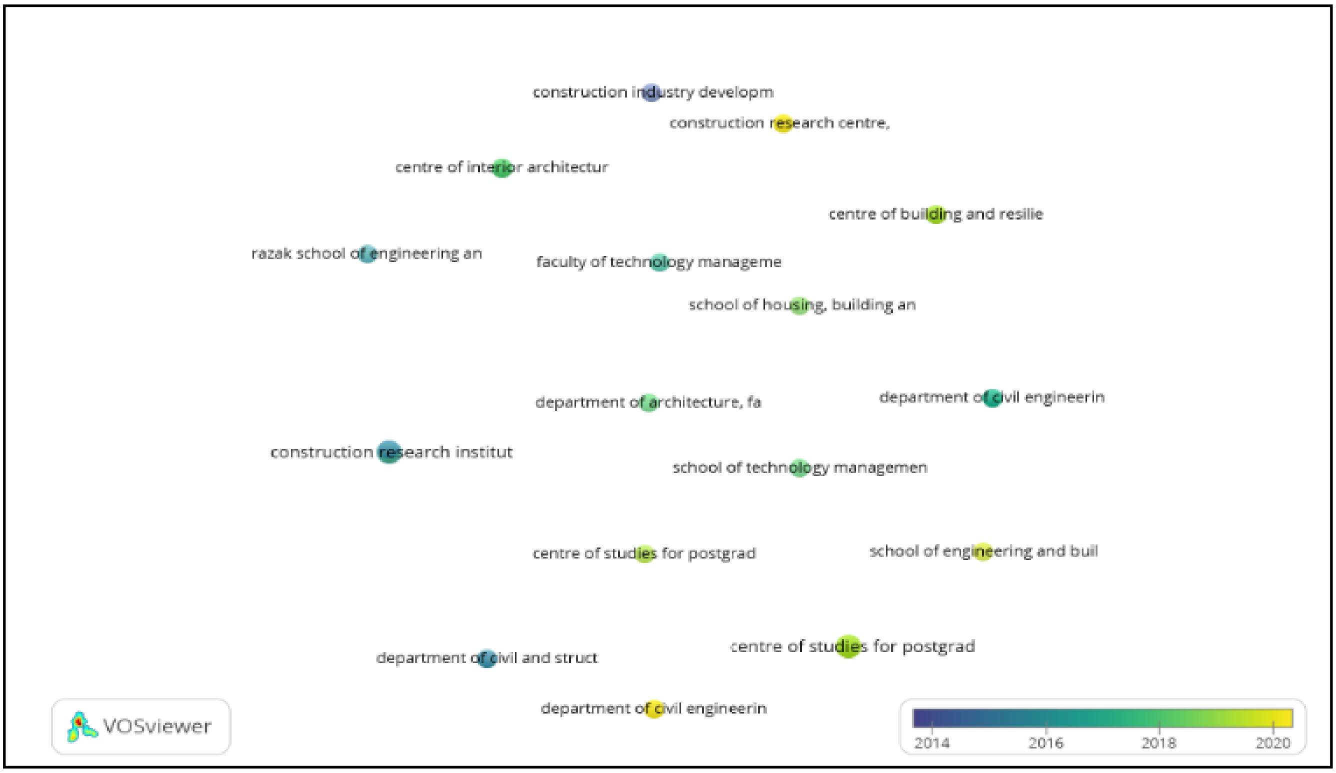

Figure VII. Visualization of Research Institutions

Authorship analysis

Table III presents the list of top authors involved in studying the use of BIM in Malaysia. From Figure III, we can deduce that Ali, K.N is the most active researcher based on the number of articles published. The author also has the highest number of citations totalling 88. Enegbuma, W.I follows closely with 9 documents and 82 citations. The study of BIM in Malaysia is still in its early stages which provides a basis for studies like this to bring to the fore how far BIM in Malaysia has come.

Table III. Authors with the highest citations

S/N	Authors	Documents	Citations	Total Link Strength
1	Ali K.N.	10	88	10
2	Embi M.R.	7	13	2
3	Enegbuma W.I.	9	82	8
4	Farhan S.A.	5	32	8
5	Gardezi S.S.S.	5	57	8
6	Haron N.A.	5	12	6
7	Harun A.N.	5	14	7
8	Ismail S.	5	6	3
9	Ismail Z.A.	6	13	0
10	Latiffi A.A.	6	25	1
11	Nawi M.N.M.	9	51	4
12	Shafiq N.	8	61	10
13	Takim R.	8	13	3

Impact of Countries

Figure VIII shows the visualization of co-citation between studies in Malaysia and other countries. Figure IX shows that the country with the highest amount of co-citation with Malaysia is the United Kingdom where 13 documents are involved with a citation count of 134. Australia is placed second with 9 documents and 90 citations. There is still a global outlook that is lacking between studies on BIM in Malaysia as seen from Table IV, Figure VIII, and Figure IX.

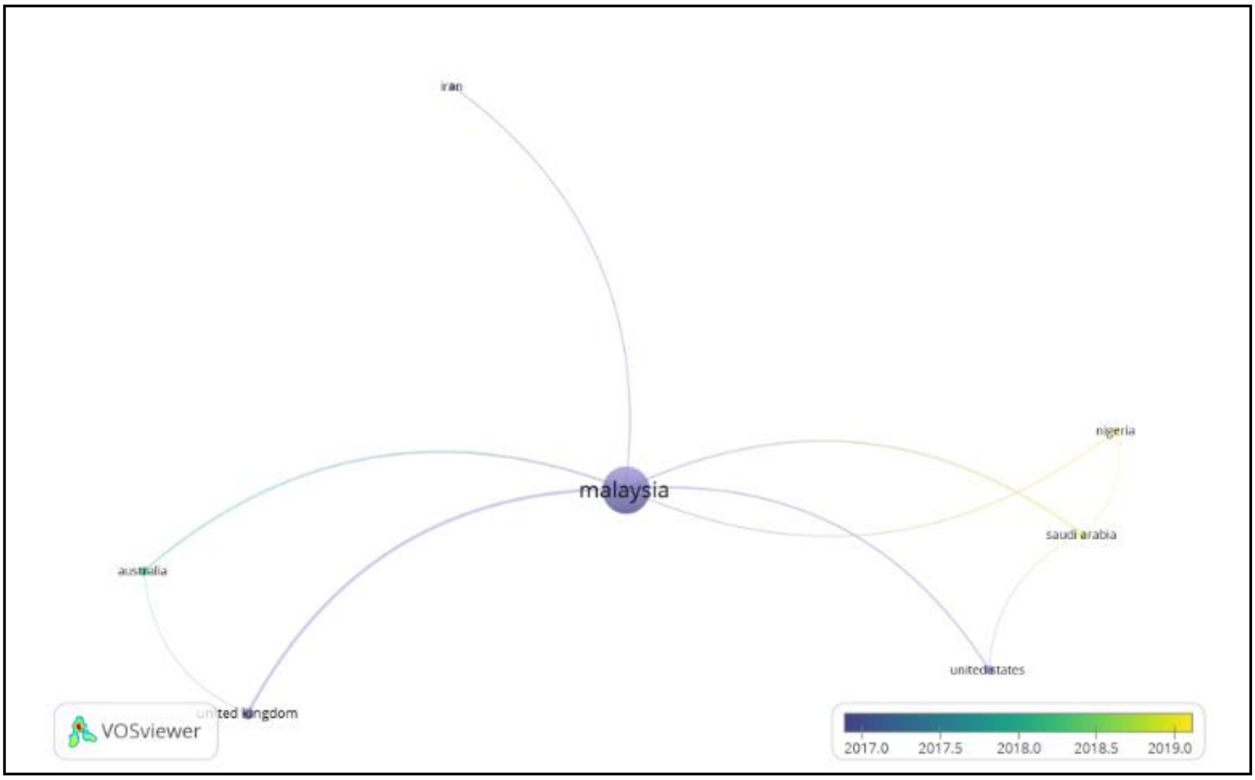

Figure VIII. Visualization of Co-citation with other Countries

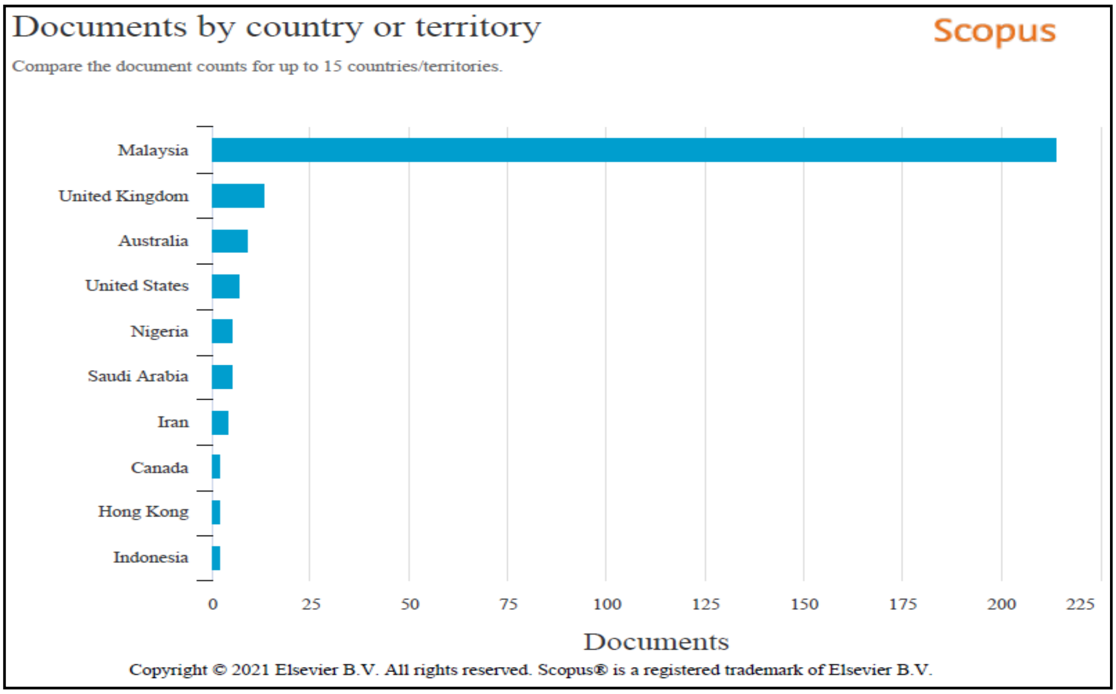

Figure IX. Documents by Country

Table IV. Countries where most of the research were co-cited with Malaysia

S/N	Countries	Documents	Citations	Total Link Strength
1	Australia	8	90	8
2	Iran	4	48	3
3	Malaysia	212	737	35
4	Nigeria	5	2	4
5	Saudi Arabia	5	15	7
6	United Kingdom	13	134	13
7	United States	8	33	6

Case Study Analysis

This case study is focussed on engineers, architects, quantity surveyors and contractors in Johor and Selangor who implement BIM in their project execution. The case study focussed on BIM Applications in Construction Waste Minimisation. The demographic analysis revealed that the respondents had the necessary experience to carry out this research survey because 46% of the respondents had at least 6 years working experience, while 54% had less than 5 years' experience in the construction industry. The analysis also revealed the specialisations of the respondents; 42% are Quantity Surveyors, 34% Engineers, while Architects, Project Managers, and contractors constitute 8% each. Considering the organisation's role of the respondents, 61% of the respondents are main contractors, 27% are consultants while 8% and 4% are from the quantity surveying and developer companies respectively. The findings of the case study are highlighted in Sections 4.2.1 and 4.2.2.

Perception of BIM Applications in Construction Waste Minimisation

Figure 9 shows the potential of BIM applications in curtailing construction waste, while Table 6 depicts the ranking of ten (10) BIM applications among professionals using the RII. The BIM applications are Phase Planning - 4D stimulation (**BIM1**), Quantity take-off - Cost estimation (**BIM2**), Design Review (**BIM3**), 3D coordination - Clash Detection (**BIM4**), 3D Control and Planning (**BIM5**), Control and Planning Construction System Design (**BIM6**), Digital Fabrication (**BIM7**), 3D Visualisation - Design Authoring (**BIM8**), Design Validation (**BIM9**), and Site Utilization Planning (**BIM10**). The respondents were asked to indicate their opinions on which BIM applications are having 'an excellent' to 'very poor' potential in terms of minimization of construction waste. Hence, the potential of BIM applications in reducing construction waste was established on a 5-Likert scale (1= very poor potential; 2= poor potential; 3= fair potential; 4= good potential; and 5= excellent potential as shown in Figure 1. The findings revealed that, the BIM applications with the most excellent potential are 'quantity take-off (5D Cost Estimation)' followed by 'clash detection - 3D coordination' and 'phase planning - 4D stimulation'. Similarly, the RII derived from the frequencies of cross-tabulated data was used to establish the potential of these applications among the professionals by ranking them. From the viewpoint of the engineer, quantity take-off - cost estimation (BIM2) and digital fabrication (BIM7) are ranked as the highest BIM applications in minimising waste, while the architect perceived quantity take-off - cost estimation (BIM2) and 3D coordination - clash detection (BIM4) as the top applications.

From the perspective of the contractors, BIM applications with the highest potential include phase planning 4D stimulation (BIM1), quantity take-off - cost estimation (BIM2), 3D coordination - clash detection (BIM4), and digital fabrication (BIM7). Next, the project managers indicate that phase planning - 4D stimulation (BIM1), 3D coordination - clash detection (BIM4), digital fabrication (BIM7) and site utilization planning (BIM10) are the most important BIM applications in reducing construction waste. Lastly, the opinions of the quantity surveyor revealed that quantity take-off - cost estimation (BIM2), 3D coordination - clash detection (BIM4) as well as site utilization planning (BIM10) are the top three BIM applications to reduce construction waste.

It is worthy of note to state that the three (3) BIM applications with high construction waste mitigating potential as perceived by all the professional are quantity take-off - cost estimation (Av.RII = 0.963), 3D coordination - clash detection (Av.RII = 0.933), and site utilization planning (Av.RII = 0.896).

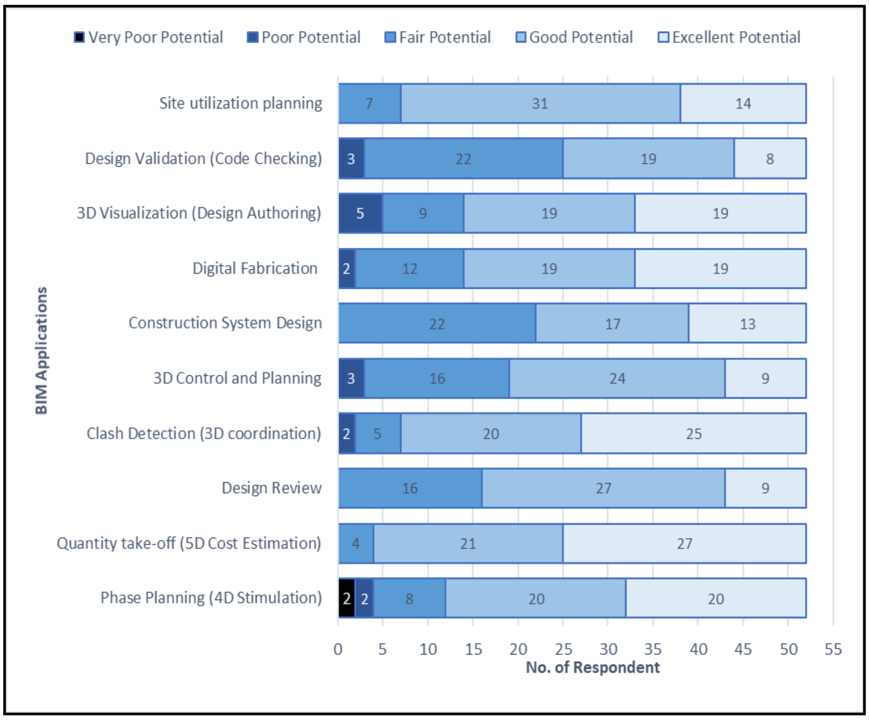

Figure X. Potential of BIM applications in minimising construction waste

Table V. Ranking of BIM applications among Practitioners

BIM Applications	Engineer		Architect		Contractor		Project Manager		Quantity Surveyor		Overall	
	RII	Rank	RII	Rank	RII	Rank	RII	Rank	RII	Rank	RII	Rank
BIM1	0.283	8	0.075	3	0.071	2	0.079	1	0.367	6	0.875	5
BIM2	0.317	1	0.083	1	0.071	2	0.075	2	0.417	1	0.963	1
BIM3	0.275	9	0.058	8	0.054	8	0.067	6	0.383	4	0.838	7
BIM4	0.300	3	0.083	1	0.075	1	0.075	2	0.400	2	0.933	2
BIM5	0.275	9	0.067	6	0.050	10	0.063	7	0.358	7	0.813	9
BIM6	0.292	6	0.075	3	0.067	5	0.054	8	0.342	9	0.829	8
BIM7	0.317	1	0.058	8	0.071	2	0.075	2	0.358	7	0.879	4
BIM8	0.300	3	0.075	3	0.067	5	0.050	9	0.375	5	0.867	6
BIM9	0.292	6	0.058	8	0.054	8	0.046	10	0.333	10	0.783	10
BIM10	0.300	3	0.067	6	0.063	7	0.075	2	0.392	3	0.896	3

Table V shows the correlation among the practitioners on the use of BIM applications in reducing wastes and improving productivity. The values are all positive, meaning there is a relationship on the perception of BIM applications among all the practitioners. Nevertheless, in statistics, it is generally accepted that the following scale can be used to estimate the correlation between variables; r=+/-0.5 is large, r=+/-0.3 is medium, while r=+/-0.1 is small. It can be deduced from Table VI that, there is a strong correlation between the perception of Contractors and Engineers, Contractors and Architects, Quantity Surveyors and Architects, and Project Managers and Quantity Surveyors. However, the radar chart in Figure 10 which plots the data across the five practitioners indicates that only the Engineers and Quantity Surveyors commonly use BIM applications (BIM2-cost estimation and BIM4- Clash Detection) in minimising construction waste.

Table VI. Correlation Ratings of BIM applications among Practitioners

	Engineer	**Architect**	**Contractor**	**PM**	**QS**
Engineer	1				
Architect	0.287756	1			
Contractor	**0.678302**	**0.659912**	1		
PM	0.254661	0.254755	0.497403	1	
QS	0.363852	**0.550646**	0.416066	**0.629817**	1

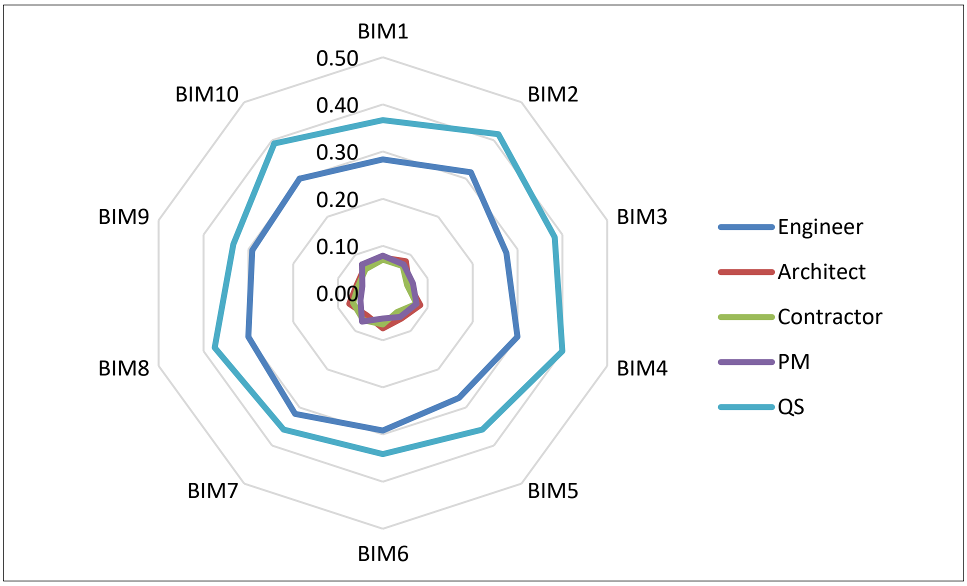

Figure XI. BIM applications among Practitioners

Ranking of BIM Applications in Construction Waste Minimisation

The overall ranking of BIM Applications is presented in Table 5. The ranking is based on the values of the RII obtained from the results of cross-tabulated data. The study revealed that, the first five commonly used BIM applications are quantity take-off - cost estimation (BIM2) with an Av.RII of 0.963; 3D coordination - clash detection (BIM4), Av.RII= 0.933, site utilization planning (BIM10), Av.RII= 0.896, digital fabrication (BIM7), Av.RII= 0.879, and phase planning 4D stimulation (BIM1) with an Av.RII of, 0.875.

i. *Quantity Take-off (Cost Estimation)*

Most practitioners consider quantity take-off, which is a tool for estimating a project's cost, to be the most important BIM application for reducing construction waste and increasing productivity. Won and Cheng (2017) argued that BIM-based quantity take-off could be used to enhance the procurement process by estimating the materials needed for the construction site in terms of transportation and labor by extracting quantity information from BIM models. As a result, this application may be used to visualize the procurement and waste management processes while also improving site management coordination, reducing costs, and improving productivity. Additionally, a study Won and Cheng (2017) demonstrated a reduction of 1.6 percent in structural reinforcement waste when quantity data is used to identify the length of rebar, optimizing the reuse rate of excess rebar.

ii. *3D Coordination (Clash Detection)*

Clash detection is a form of 3D coordination that can improve the efficiency of a design by enhancing the coordination of multi-disciplinary teams such as architects, structural, mechanical, electrical, and plumbing (MEP) engineers on various components or systems of a building (Cheng, Won and Das, 2015). It could be accomplished by comparing and coordinating 3D models of building systems prior to the construction process to resolve any building part interferences or collisions. This will better optimize the design disputes and mistakes, which would be helpful in minimizing the need for rework that would otherwise arise, and the amount of construction waste would be partly mitigated as a result. Clearly, most practitioners were in agreement about the potential of clash detection in waste minimization, with it being listed as one of the top three choices for various professionals. Whereas, with clash detection capabilities, the application's implications were linked to the effects developed through clash detection, which enhanced communication and teamwork while minimizing design errors and rework. With the evidence in hand, BIM-based 3D coordination was identified as one of the possible BIM applications in mitigating construction waste.

iii. Site Utilization Planning

Aside from quantity take-off and clash detection, the survey revealed that site utilization planning was the third most promising application for minimizing construction waste. Site utilization planning is an efficient method in terms of managing materials by study of site layout on space and time conflict or phase change, as construction materials are one of the major issues on waste generation (Cheng, Won and Das, 2015). This finding is maintained by Lee, Chong and Wang (2018) who put forward that, this application requires an application of a 4D model to achieve a construction schedule and planning for logistic details prior to construction, which increases project stakeholder collaboration and communication as well as site space planning for construction materials (Lee, Chong and Wang, 2018). Similarly, Won and Cheng (2017) advanced that site logistics could be managed by using site utilisation planning to conduct space inventory according to time, equipment, temporary facility, and material specifications, minimizing the risk of inappropriate material handling and producing unnecessary waste. Therefore, the results of using BIM-based site utilization planning have validated a few studies primarily on communication and visualisation of site conditions, making site utilization planning a possible application to minimize construction waste.

iv. Digital Fabrication

Digital fabrication is another BIM application worth highlighting as the fourth highest potential BIM application, as argued by most researchers after reviewing the literature. This application, however, is limited to construction projects that use the Industrialized Building System (IBS). In general, digital fabrication encourages the extraction of accurate and automated geometrical details from BIM models of any prefabricated building part to produce shop drawings that prefabricators may use to manufacture the component (Lee, Chong and Wang, 2018). The accuracy and details of prefabricated components could be increased with the help of digital fabrication to remove any inconsistencies or discrepancies that may occur during site erection that could result in unnecessary waste generation (Cheng, Won and Das, 2015). Moreover, digital fabrication encourages lean construction to reduce waste generation, making the process of intensive planning of materials handling on site easier. For example, according to Won, Cheng, and Lee

(2016), digital fabrication resulted in a 52 percent average waste reduction. Thus, the most important implication of digital fabrication as one of the commonly used BIM applications is the reduction of rework.

v. Phase Planning (4D Stimulation)

The finding of the study conducted as one of the high potential BIM applications in mitigating construction wastes were that a well-planned and use of the phase planning application could effectively enhance the waste management process to minimize the risk of unnecessary wastages, where defects, rework, and waste generation could be minimized. Phase planning incorporates a 4D model to conduct successful scheduling and planning of the project's phased occupancy, where it improves communication and collaboration among project stakeholders by providing a consistent project milestone and specifications for various construction sequences (Lee, Chong and Wang, 2018). It could combine manpower, equipment, and material requirements to maximize resources by associating building elements with construction activities to avoid construction time conflicts. Cheng, Won and Das (2015) concluded that, one of the critical problems on site is the procurement process, which could be easily coordinated or scheduled using 4D Stimulation by assessing the right time and right amount of products to be delivered to prevent any material damage due to weather or transportation (Cheng, Won and Das, 2015).

Conclusion and Recommendations

The study evaluated and determined scientometric data obtained from the Scopus database, revealing five (5) research gaps in energy efficiency, housing, life cycle, construction projects, and buildings. The scientometric findings revealed the most influential publication sources, the most used keywords, the most involved researchers and institutions, funding sources, and studies with the greatest effect on BIM in Malaysia. Second, the findings of the survey revealed which BIM applications are most widely used by contractors, project managers, engineers, architects and quantity surveyors in Johor and Selangor. The most prevalent BIM applications used by practitioners were quantity take-off (cost estimation), clash detection, site utilization planning, digital fabrication as well as 4D stimulation, according to the study. The paper further revealed that Engineers and Quantity Surveyors are the most popular users of BIM applications, particularly cost estimation, and clash detection. All construction stakeholders, funding organizations, policy makers, research agencies, professionals, journal editors, reviewers, and researchers will benefit from the findings of this report, which will help them understand and appreciate the use of BIM applications as well as the overall trend of BIM in Malaysia.

Acknowledgments

Our sincere gratitude to the School of Built Environment, University of Reading Malaysia and Department of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia for their valuable guidance throughout the entire process of this study.

References

Aghaei Chadegani, A., Salehi, H., Md Yunus, M. M., Farhadi, H., Fooladi, M., Farhadi, M. and Ale Ebrahim, N. (2013), “A comparison between two main academic literature collections: web of science and scopus databases”, *Asian Social Science*, Vol. 9 No. 2, pp.18–26.

Ahlam, B.Q.A. and Abdul Rahim, Z. (2020), “A review of risks for BIM adoption in Malaysia construction industries: multi case study”, *IOP Conf. Series: Materials Science and Engineering*,1051, 012037. doi:10.1088/1757-899X/1051/1/012037

Ahuja, R., Arif, M. and Sawhney, A. (2018), “Developing organizational capabilities to deliver lean and green project outcomes using BIM”, *Engineering, Construction and Architectural Management*, Vol. 25 No. 10, pp.1255–1276.

Al-Ashmori, Y.Y., Othman, I., Rahmawati, Y., Amran, Y.H.M., Sabah, S.H.A., Rafindadi, A.D. and Mikic, M. (2020), “BIM benefits and its influence on the BIM implementation in Malaysia”, *Ain Shams Engineering Journal*, 11, 1013–1019.

Chen, C., Dubin, R. and Schultz, T. (2014), “*Science Mapping. Encyclopedia of Information Science and Technology”*, Third Edition, August, 4171–4184. DOI: 10.4018/978-1-4666-5888-2.ch410

Cheng, J. C. P. and Ma, L. Y. H. (2013), “A BIM-based system for demolition and renovation waste estimation and planning”, *Waste Management*, Vol. 33 No. 6, pp.1539–1551.

Faria, P.S., Sotelino, E.D., Nascimento, D. and Caiado R. (2018), “Interactions of building information modelling, lean and sustainability on the architectural, engineering and construction industry: a systematic review”, Journal of Cleaner Production, Vol. 174 pp. 788–806.

Feng, C. W., Mustaklem, O. and Chen, Y. J. (2012), “The BIM-based Information Integration Sphere for Construction Projects”, In *Proceedings of the 28th ISARC Conference*, Seoul, Korea, pp. 156–161.

Feng, N. T. (2021), “Implementation of BIM in residential building in Malaysia”, final year project (bachelor)”, Tunku Abdul Rahman University College.

Galetsi, P. and Katsaliaki, K. (2019), “Big data analytics in health: an overview and bibliometric study of research activity”, *Health Information & Libraries Journal*, Vol. 37, No. 1, pp. 5–25.

Gholizadeh, P., Esmaeili, B. and Goodrum, P. (2018), “Diffusion of building information modelling functions in the construction industry”, *Journal of Management in Engineering*, Vol. 34 No. 2, doi: 10.1061/(ASCE)ME.1943-5479.0000589.

Haruna, A., Shafiq, N. and Montasir, O.A. (2021), “Building information modelling application for developing sustainable building (Multi criteria decision making approach)”, *Ain Shams Engineering Journal*, 12, 293–302.

Hu, W., Dong, J., Hwang, B. gang, Ren, R., & Chen, Z. (2019), “A scientometrics review on city logistics literature: research trends, advanced theory and practice”, *Sustainability*, Vol. 11 No. 10, pp. 1–27.

Jung, W. and Lee, G. (2015), “The status of BIM adoption on six continents”, *International Journal of Civil, Structural, Construction and Architectural Engineering*, Vol. 9 No. 5, pp. 406–410.

Latiffi, A. A., Mohd, S., Kasim, N. and Fathi, M.S. (2013), “Building information modelling (BIM) application in Malaysian construction industry”, *International Journal of Construction Engineering and Management*, Vol. 2 No. 4A, pp.1–6.

Lee, C., Chong, H. and Wang, X. (2018), “Streamlining digital modelling and building information modelling (BIM) uses for the oil and gas projects”, *Archives of Computational Methods in Engineering*, Vol. 25 No. 2, pp. 349–396.

Liu, Z., Osmani, M., Demian, P. and Baldwin, A. (2015), “A BIM-aided construction waste minimisation framework”, *Automation in Construction*, Vol. 59 pp. 1–23.

Lu, W., Webster, C., Chen, K., Zhang, X. and Chen, X. (2017), “Computational building information modelling for construction waste management: moving from rhetoric to reality”, *Renewable and Sustainable Energy Reviews*, Vol. 68 No. 1, pp. 587–595.

Mamter, S., Rashid, A. and Aziz, A. (2016), “Holistic BIM adoption and diffusion in Malaysia”, *MATEC Web of Conference*, 66(00094), pp. 1–8.

Mansuri, L., Udeaja, C., Trillo, C., Kwasi, G., Dilip Patel, Kumar Jha, C. B. M. and Gupta, S. (2019), “Scientometric analysis and mapping of digital technologies used in cultural heritage field”, In: Gorse, C and Neilson, C J (Eds) *Proceedings of the 35th Annual ARCOM Conference*, 2-4 September 2019, Leeds, UK, Association of Researchers in Construction Management, 255-264.

Memon, A. H., Rahman, I.A., Memon, I. and Aqilah Azman, N.I. (2014), “BIM in Malaysian construction industry: status, advantages, barriers and strategies to enhance the implementation level”, *Research Journal of Applied Sciences, Engineering and Technology*, Vol. 8 No. 5, pp. 606–614.

Momade, M.H. and Hainin, M.R. (2018), “Review of sustainable construction practices in Malaysian construction industry”, *International Journal of Engineering & Technology*, 7 (4), 5018-5021. doi: 10.14419/ijet. v7i4.26559

Nassaji, H. (2015), “Qualitative and descriptive research: data type versus data analysis”, *Language Teaching Research*, Vol. 19 No. 2, pp. 129–132.

Othman, I. Al-Ashmori, Y.Y., Rahmawati, Y., Y.H. Amran, Y.H.M. and Al-Bared, M.A.M. (2021), “The level of building information modelling (BIM) implementation in Malaysia”, *Ain Shams Engineering Journal*, 12, 455–463.

Reza, M., Halog, A. and Rigamonti, L. (2017), “Resources, conservation and recycling strategies for minimizing construction and demolition wastes in Malaysia”, *Resources, Conservation & Recycling*, Vol. 120 pp. 219–229.

Shehzad,H.M.F., Ibrahim,R., Yusof, A.F., Khaidzir, K.A.M., Shawkat, S. and Ahmad, S. (2020), “Recent developments of BIM adoption based on categorization, identification and factors: a systematic literature review”, *International Journal of Construction Management*, DOI:10.1080/15623599.2020.1837719

Sinoh, S.S., Othman, F. and Ibrahim, Z. (2020), “Critical success factors for BIM implementation: a Malaysian case study”, *Engineering, Construction and Architectural Management*, 27 (9), 2737-2765.

Sun, C., Jiang, S. and Skibniewski, M. J. (2017), “A literature review of the factors limiting the application of BIM in the construction industry”, *Technological and Economic Development of Economy*, Vol. 23 No. 5, pp. 764–779.

Tanko, B.L. (2018), “*Roadmap for Implementing Value Management in the Nigerian Construction Industry*”, PhD Thesis, Universiti Teknologi Malaysia.

Tanko, B.L. and Mbugua, L. (2022), “BIM Education in Higher Learning Institutions: A Scientometric Review and the Malaysia Perspective”, *International Journal of Built Environment and Sustainability*, 9(1), 23-37.

Viergutz, T. and Schulze-Ehlers, B. (2018), “The use of hybrid scientometric clustering for systematic literature reviews in business and economics”, DARE Discussion Papers 1804, Georg-August University of Göttingen, Department of Agricultural Economics and Rural Development (DARE).

Won, J. and Cheng, J. C. P. (2017), “Identifying potential opportunities of building information modelling for construction and demolition waste management and minimization”, *Automation in Construction*, Vol. 79 pp. 3–18.

Won, J., Cheng, J. C. P. and Lee, G. (2016), “Quantification of construction waste prevented by BIM-based design validation: case studies in South Korea”, *Waste Management*, Vol. 49 pp. 170–180.

Wong, S. Y. and Gray, J. (2019), “Barriers to implementing building information modelling (BIM) in the Malaysian construction industry”, in *IOP Conference Series: Materials Science and Engineering*, 495(1), p. 012002. doi: 10.1088/1757-899X/495/1/012002.

Xiao, X., Skitmore, M., Li, H. and Xia, B. (2019), “Mapping knowledge in the economic areas of green building using scientometric analysis”, *Energies*, Vol. 14 No. 15, doi.org/10.3390/en12153011

Zakaria, B., Nasly, M., Haron, A.T. and Marshall-Ponting, A. (2013), “Exploring the adoption of building information modelling (BIM) in the Malaysian construction industry: a qualitative approach”, *International Journal of Research in Engineering and Technology*, Vol. 2 No. 8, pp. 384-395.

Zakka, W. P., Abdul Shukor Lim, N. H. and Chau Khun, M. (2020), “A scientometric review of geopolymer concrete”, *Journal of Cleaner Production*, Vol. 280, 124353. https://doi.org/10.1016/j.jclepro.2020.124353

Zheng, C., Yuan, J., Zhu, L., Zhang, Y. and Shao, Q. (2020), From digital to sustainable: a scientometric review of smart city literature between 1990 and 2019”, *Journal of Cleaner Production*, Vol. 258, 120689. https://doi.org/10.1016/j.jclepro.2020.120689