ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 11, Issue, 09, pp. 50532-50536, September, 2021
https://doi.org/10.37118/ijdr.22877.09.2021

RESEARCH ARTICLE OPEN ACCESS

IMPLEMENTATION OF BUILDING INFORMATION MODELING (BIM), A SCIENTOMETRIC STUDY OF THE LITERATURA

Rachel Madeira Magalhães[1]* and [2]Luiz Brasil de Brito Mello

[2]Programa de Pós-Graduação em Engenharia Civil, Universidade Federal Fluminense, Niterói, Brazil.
[1]Campus da Praia Vermelha, Rua Passo da Pátria, 156, São Domingos, Niterói, RJ - Brasil - 24210-240.

ARTICLE INFO

Article History:
Received 05th August, 2021
Received in revised form
16th August, 2021
Accepted 28th September, 2021
Published online 30th September, 2021

Key Words:
Building Information Modeling implementation; Scientometric analysis; Cite Space; BIM.

***Corresponding author:**
Rachel Madeira Magalhães

ABSTRACT

Government policies for Building Information Modeling (BIM) dissemination are driving BIM implementation in markets around the world. This paper aims to map scientific knowledge produced about the subject. The mapping included analysis of 812 articles published between 2011 and 2021 and extracted from the Web of Science. Cite Space analysis software extracted indicators such as frequency of occurrence of words and cluster analysis. These indicators reveal the knowledge base, topics little explored by researchers, and the main research areas on BIM implementation. It is hoped that this paper will help to understand the current state of research on BIM implementation, guiding researchers on the subject for future research.

Citation: ***Rachel Madeira Magalhães and Luiz Brasil de Brito Mello.*** "Implementation of Building Information Modeling (BIM), a scientometric study of the literature*", International Journal of Development Research*, 11, (09), 50532-50536.

INTRODUCTION

Recently the European Union BIM Working Group (EUBIMTG) released the Application of Building Information Modeling (BIM) Manual in the European Public Sector. According to it, BIM is the center of digital transformation in the construction sector. BIM use in construction, execution, and operation of public assets can bring economic, environmental, and social benefits (EUBIMTG, 2016). Countries outside Europe such as Australia, United States, Brazil, Chile, and Singapore (KASSEM *ET AL.*, 2013, 2015; MAGALHÃES, 2019) have also established BIM dissemination strategies. The literature considers government strategies as one of the main drivers of BIM implementation. (AHUJA ET.AL. 2020). Given the points raised, this paper maps the scientific knowledge produced on BIM implementation. The objective is to identify state of art of scientific production regarding BIM implementation. A literature review analyzed 812 articles published between 2011 and 2020 extracted from the Web of Science (WoS) database. The analysis was performed using Cite Space software and was used to extract scientometric indicators. Among the various tool options, Cite Space presents a great diversity of analysis options justifying its choice (LI *ET AL.*, 2017).

Through a network of co-occurrence, indicators related to word citation (frequency and centrality) point to the most investigated and influential research topics and also have received less attention from academia (ZHAO, 2017) while cluster analysis indicates the main areas of research (CHEN, 2014). These indicators can be important for future research, planning, and evaluating research agendas. According to Santos; Kobashi (2009 p. 160), this type of research configures "one of the areas that have been growing sharply in contemporary metric studies".

MATERIALS AND METHODS

This work seeks to identify the state of art on scientific production regarding BIM implementation. For this, clear, objective and quantitative criteria were defined, described in Table 1. In all, 812 articles publishedbetween 2011 and 2020 were investigated. This period corresponds to approximately 95% of the BIM literature produced and published in WoS (Figure 1). WoS was selected for being CiteSpace's main database (CHEN, 2006). Given the outlined objectives and contextualization of contemporary metric studies carried out by Santos; Kobashi (2009) this research focuses on information visualization techniques to "better understand and

understand data manipulated by statistical means" (SANTOS; KOBASHI, 2009 P. 160). Authors such as Li *et al*. (2017), Zhao (2017), He *et al*. (2016); Shi; Liu (2019) were also adept at visualization techniques using CiteSpace to generate co-occurrence networks to extract bibliometric and scientometric indicators. CiteSpace allows to select several types of nodes such as cited journal; author; cited author; reference; keywords, among others. To meet this paper objectives, the type of node keywords was selected.
Co-occurrence networks provide an accurate overview of scientific production (VAN ECK; WALTMAN, 2014).

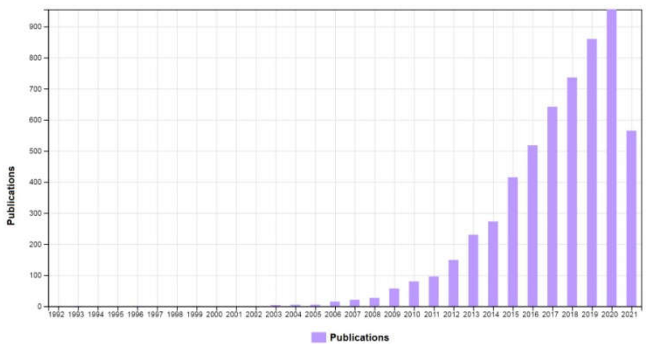

Figure 1.

In the network, the type of node keyword was classified by frequency. To understand the co-occurrence network is necessary to understand some concepts. The frequency (F) of nodes indicates the number of times a given node is cited. The centrality measures connection between nodes. High centrality (C) means a large number of connections with other nodes. High centrality nodes suggest a wide influence on research development (ZHAO, 2017). For classification purposes, nodes of high centrality are considered those with centrality greater than the calculated median, while nodes of high centrality are those whose frequency belongs to classification A of the ABC curve (WILD, 2017) drawn for the frequency distribution. Thus, they are high-frequency nodes 10% of nodes corresponding to 60% of the frequencies approximately. After defining the classification criteria for nodes, the network was pre-processed. The terms Building Information Modeling and its variations were excluded because they formed a high percentage of the domain (approximately 20%), not adding value to the present study, in addition to influencing the cluster precision of the keyword co-occurrence network (HE *ET AL*, 2016). The same concept was used for implementation and adoption terms. Then, the extracted words were normalized to ensure consistent treatment of synonyms. After data acquisition and pre-processing, keyword co-occurrence analyzes and abstract clusters were performed.

RESULTS

Analyzing the co-occurrence network of keywords (Figure 2) it is noticed a dense core with nodes of large sizes and many connections, while in the periphery the size and number of nodes connections are smaller. This configuration suggests that the most explored and influential topics in the BIM literature are found in the core and the least explored and influential in the periphery (HOSSEINI *ET AL*., 2018). In addition, to the network visualization, CiteSpace presents a table with the frequency, centrality, and year in which the nodes first appeared. The distribution of nodes by frequency (Table 2) shows that most nodes combine low frequency and low centrality. Furthermore, few nodes have a high or very high influence on BIM implementation research. This indicator points to a scientific production concentrated on few topics. Another interesting indicator is the distribution of centralities over time (Table 3). This indicator shows that approximately 36% of low centrality nodes are recent. Therefore, they can still become influential in the literature as they attract researchers' interest, such as maintenance, Historical Building Information Modeling (HBIM), Internet of Things (IOT), Lean, Safety, Energy Analysis, Big Data, Georeferencing, Construction Waste, and BIM education, for example. On the opposite face, approximately 18% of the low centrality nodes are primitive. Of these, 59 nodes have a frequency equal to 1 and a centrality equal to zero, indicating possible isolation. Among the fully isolated nodes, nodes that emerge from 2011 stand out. They are configuration management, commerce, effectiveness, computer integrated construction, construction safety, culture, Bim-server, construction database, gaming, digital Project, electronic procurement, change management, cad model. The following indicators are concentrated in the knowledge base on BIM implementation (Indicator 3) and in research areas on BIM implementation (Indicator 4). According to Li *et al*. (2017), nodes that combine high frequency and high centrality configure the knowledge base. In this aspect, the knowledge base on BIM implementation is formed by high-frequency nodes (Table 4) whose centrality is greater than 0.05, namely: Construction, Design, Framework, Model, Management, Technology, Collaboration, Architecture, Energy, System, Interoperability, and Industry Foundation Class (IFC). To determine indicator 4, area of concentration, a cluster analysis was performed. Cluster analysis allows detecting the different lines of BIM research because the data grouped within a cluster have similar characteristics to each other (CHEN, 2014; DE OLIVEIRA *ET AL*., 2008). Cluster analysis has some metrics. For example, modularity (Q) measures the network decomposition. Silhouette (S), whose values vary between -1 and 1, measures the homogeneity of the cluster. Size (s) represents the number of terms in each cluster (CHEN ET.AL., 2010).

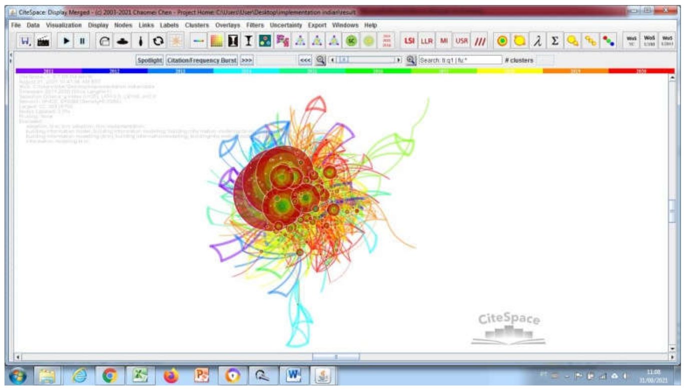

Figure 2.

According to He*et al*. (2017), modularity values greater than 0.03 (Q>0.03) indicate that the network is reasonably divided into loosely coupled clusters, while silhouette values greater than 0.65 suggest robust and significant results (LI *ET AL*., 2017). Through the cluster explorer tool, CiteSpace allows exploring the cluster characteristics, main candidate terms for the label, main year of publication of the articles that make up the cluster, and consulting the bibliography referring to the cluster. CiteSpace performs the labeling of clusters automatically. For this, terms present in the title, abstract, or keywords can be selected (CHEN, 2006). The best-rated nominal terms are candidates for the cluster label (HOSSEINI *ET AL*., 2018). CiteSpace has three algorithm options for calculating labels, such as Log-Likelihood Ratio (LLR) test, the Term Frequency-Inverse document frequency (TFIDF), and Mutual Information (MI) test. In this paper, we chose to have terms present in the abstracts, following the premises of Li *et al*. (2017) and by the standard CiteSpace LLR algorithm (Shi; Liu, 2019). However, this labeling mechanism can lead to misinterpretations (He *et al*., 2017). For this reason, all articles abstracts were read and classified according to the approach of most of them. In all, 26 clusters were identified, with 9 being the main clusters. Table 5 presents the characteristics of each cluster. Cluster 0 is the largest of the clusters, with 56 terms formed by 79 articles published, mainly in 2015. According to the reading of the abstracts, cluster 0 addresses issues related to the BIM implementation process. Among the main topics discussed are BIM implementation in small and medium-sized companies, BIM maturity, the new work organization that comes with BIM implementation, organizational learning, motivations that lead to BIM implementation in

Table 1. Research conduction criteria

Searchstrategy	Objective	Descriptions
Definition of search terms	Define terms that represent the research topic and that allows returning relevant articles in the search.	"*building information model**" and ("implementation" or "adoption" or "difusion")
Selection of databases	Select databases that return the greatest amount of relevant work on the subject.	*Web of Science* (WoS)
Boundary conditions	Define the boundary conditions for research.	Articles published in journals (YALCINKAYA; SINGH, 2015), between 2011 and 2020. Conference papers and review articles were not included.
Criteria for selecting articles	Define selection and exclusion criteria for articles returned from the databases. Enable efficient and effective screening for evaluation.	Non-repeated articles, articles in English, presence of search terms in the title, abstract, or keywords.
Search date	August 27, 2021	
Results	812	

Table 2. Indicator 1 - distribution of centralities by frequency

Frequency	Centrality – median 0,055												Total
	Low			Mean			High			Very high			
	0	0,01	0,02	0,03	0,04	0,05	0,06	0,07	0,08	0,09	0,1	0,13	
1-9	297	36	9	1	0	0	0	0	0	0	0	0	343
10-19	0	6	11	4	3	2	1	0	0	0	0	0	27
20-29	0	0	0	2	4	2	0	2	0	0	0	0	10
30-39	0	0	2	2	2	2	1	1	0	0	0	0	10
40-49	0	0	0	0	0	0	0	0	0	0	0	0	0
50-59	0	1	0	2	0	0	0	0	0	0	0	0	3
60-69	0	0	0	0	2	0	0	0	0	0	0	0	2
70-79	0	0	0	0	0	0	0	0	1	0	0	0	1
80 – 89	0	0	0	0	0	0	1	0	0	0	0	0	1
90-99	0	0	0	0	0	0	0	0	0	1	1	0	2
100-149	0	0	0	0	0	0	0	0	1	0	0	0	1
150-174	0	0	0	0	0	0	0	0	0	0	1	1	2
Total	297	43	22	11	11	6	3	3	2	1	2	1	402

Table 3. Indicator 2 – distribution of centralities over time

Centrality		Primitive			Olden		Modern		Present-day			Total
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Low	0	18	23	25	25	26	22	30	34	52	42	297
	0,01	1		1	4	11	3	8	6	8	1	43
	0,02	3		1	3	6	3	5	1			22
Mean	0,03	1	1		3	2		4				11
	0,04	2		2	4	1	1	1				11
	0,05			1	2		3					6
High	0,06			3								3
	0,07	1		1	1							3
	0,08			1		1						2
Very High	0,09			1								1
	0,1	2										2
	0,13	1										1
Total		29	24	36	42	47	32	48	41	60	43	402

Table 4. High Frequency Nodes

Node	F	C	% Ac.	Node	F	C	% Ac.
Design	174	0.10	5,95%	Impact	31	0.03	48,10%
Construction	158	0.13	11,36%	Simulation	30	0.05	49,13%
Management	139	0.08	16,11%	Information Technology	28	0.04	50,09%
Model	95	0.09	19,36%	Project Management	25	0.04	50,94%
Framework	91	0.10	22,48%	Barrier	25	0.03	51,80%
System	83	0.06	25,32%	Integration	24	0.03	52,62%
Technology	70	0.08	27,71%	Architecture	24	0.07	53,44%
Performance	64	0.04	29,90%	Knowledge	24	0.05	54,26%
Innovation	61	0.04	31,99%	Energy	23	0.07	55,05%
Construction Project	59	0.01	34,01%	Case Study	21	0.04	55,76%
Information	57	0.03	35,96%	Building	20	0.05	56,45%
Project	52	0.03	37,74%	Facility Management	20	0.04	57,13%
Industry	37	0.04	39,00%	IFC	19	0.06	57,78%
Benefit	37	0.02	40,27%	Visualization	19	0.05	58,43%
ConstructionIndustry	35	0.03	41,46%	Construction Management	19	0.04	59,08%
Collaboration	34	0.07	42,63%	CriticalSuccessFactor	18	0.02	59,70%
Sustainability	33	0.05	43,76%	Diffusion	17	0.03	60,28%
Challenge	33	0.02	44,89%	Optimization	16	0.04	60,83%
Life Cycle	32	0.04	45,98%	Facilities Management	15	0.01	61,34%
Interoperability	31	0.06	47,04%	Cost	15	0.02	61,85%

Table 5. Characteristics of clusters

ID	s	S	Y	AutomaticLabel	AdoptedLabel	Papers
0	56	0.672	2015	Megaproject Delivery; Medium-Sized Enterprises; Institutional Theory; Utility Tunnel; Innovative Capability.	Implementation	79
1	47	0.713	2017	Carbon Emission; Life Cycle Assessment; Facilities Management; Building; New Workflow.	Facilities Management	51
2	46	0.687	2016	Excavation Schedule; Construction Scheduling; Further Research; Excavation Method); Rock Mass Properties.	Construction Planning AndControl	51
3	45	0.705	2017	AEC Project; Individual Perception; Managerial Aspect; Practical Experience; Statistical Analysis.	Barriers	40
4	41	0.768	2013	Labor Productivity; Early Stage; Systemic Innovation; Second Part; Infrastructure Project.	Maintenance&Operations	88
5	34	0.786	2017	Green Business Model; Key Driver; Sustainability Practice; Historical Building; Key Benefit.	SustainabilityPractice	52
6	34	0.819	2016	Risk Factor; Different Data Source; Off-Site Manufacture; Extended Function; Data Integration.	Data Integration	28
7	30	0.754	2016	Virtual Reality; Site Worker; Digital Model; Vr Technologies; Preventive Conservation.	Industry 4.0	32
8	30	0.803	2017	Top Management Support; Business Value; Top-Management Support; External Service; Acceptance Model.	Bim AcceptenceModel	20

organizations and projects, perceptions of individual information about BIM, identification of activities and readiness for BIM implementation in projects, factors that induce and inhibit BIM implementation, identification of critical success factors for BIM implementation. In turn, cluster 1 is dedicated to BIM implementation in Facilities Management. The main topics explored by cluster 1 are interoperability, management of infrastructure assets such as highways, development of models and frameworks, in addition to the presentation of case studies. Moving forward, cluster 2 addresses issues related to BIM implementation for managing construction activities. Through the abstracts reading were identified the topics ontologies for estimating activity costs and durations, schedule automation, use of Unmanned Aerial Vehicles (UAV) to control schedules, radio frequency identification (RFID) location systems for remote construction monitoring. Next, cluster 3 is dedicated to the barriers that hinder the BIM implementation process. The main topics explored by cluster 3 are: (i) need for cultural change; (ii) shortage of skilled labor, lack of BIM training in universities, lack of guidance for BIM implementation, influence of type and size of organization/projects on BIM implementation, risks contractual and legal, moral hazard, climate & BIM culture, collaboration, motivation. Cluster 4 is dedicated to BIM implementation to support maintenance and operation steps. The main topics explored are maintenance activities management; benefits of implementing BIM; effects of BIM on collaborative work; BIM applications in infrastructure projects including maintenance and facilities management. Continuing theclusters analysis, cluster 5 is dedicated to implementing BIM to support environmentally sustainable practices.

The main topics explored are benefits and potentialities of BIM implementation in relation to sustainability; identifying and evaluating reasons that lead to implementation of sustainable practices; barriers and critical success factors for implementing sustainable practices in construction projects; improving energy efficiency; reverse logistics and circular economy; green business; BIM integration – Lean – Sustainability and carbon emissions. Cluster 6 is the most homogeneous cluster being dedicated to sharing data, information & communication. Topics such as IFC and interoperability, query language, proposition of tools for exchanging information applied to various uses, automatic verification of project licensing codes, conflict detection, and environmental performance are explored. Cluster 7 is related to industry 4.0 exploring themes such as virtual reality, augmented reality, extended reality, cloud-based computing, geographic information system, collaborative virtual reality (CoVR), 3D printed models, serious games, machine learning, Internet of Things (IoT), big data, Digital twin. Finally, cluster 8 is the second most homogeneous cluster (S=0.803). The articles that make up cluster 8 investigate BIM acceptance models in order to identify which factors lead to BIM adoption in organizations, markets, and educational institutions. Technology Acceptance Model (TAM), Structural Equation Model (SEM), Innovation diffusion theory (IDT), Institutional theory, Technology Organization Environment (TOE) are the most adopted theories in these studies. Top management is one of the main factors influencing BIM adoption.

DISCUSSION

According to the keyword co-occurrence network, the scientific literature on BIM implementation is based on few topics such as Construction, Design, Framework, Model, Management, Technology, Collaboration, Architecture, Energy, System, Interoperability, and Industry Foundation Class (IFC). As a result, there are many areas to be explored in future research such as BIM integration with other technologies, environmental sustainability practices, construction stage management, and education that are examples of recent topics. However, there are still topics that remain unexplored such as BIM-sever, Change Management, Electronic procurement, Commerce, Culture, and Construction Safety. These nodes can configure potential knowledge gaps. For example, Love *et al*. (2020) highlights that to achieve the expected benefits, BIM implementation must be accompanied by robust change management and a well-defined implementation strategy. However, according to the co-occurrence network outlined, there are few studies dedicated to change management. Another highlight is the term Culture. Investigations into barriers and critical success factors point to changing mindsets and cultural factors as important barriers to BIM implementation (ULLAH ET, 2020).

However, the co-occurrence network points to few studies dedicated to the impacts of cultural issues in this process. More broadly, BIM implementation research is focused on the process of implementing, adopting & diffusing BIM across markets, projects & organizations including investigations into barriers and critical success factors, implementation drives & BIM acceptance models. The second front of knowledge domains includes BIM implementation to support specific activities such as facility operation and maintenance; facilities management; construction management; implementation of environmentally sustainable practices; data integration, information exchange, communication, and interoperability; and the integration of BIM with other technologies related to industry 4.0. The present paper shows that the literature on BIM implementation is vast with many directions to be explored. However, due to the need for synthesis, it was not possible to provide in-depth detail of these directions, this study is limited to the presentation of topics that form the knowledge base and the main areas of research on BIM implementation processed by CiteSpace of 812 articles extracted from WoS. Therefore, the result presented by this study does not reflect the totality of publications regarding BIM implementation. Thus, it is suggested that further research be conducted including articles extracted from other databases and processed by other textual analysis tools. Despite the limitations pointed out, it is hoped that this article has contributed to a better understanding of the literature on BIM implementation.

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