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A Bibliometric Review of Maturity Model Studies in the Construction Industry

Kun Chen, *Siaw-Chuing Loo and Anuar Alias

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Abstract: Maturity models have become one of the most used organisational maturity assessment tools in the construction industry. However, bibliometric and visual analysis for this field is still scarce. This study used CiteSpace to analyse 278 articles on maturity models employed in the construction industry from 2000 to 2022 in the Web of Science (WoS) core database. The categories in the WoS database divided the filtered articles into eight categories, which could be roughly divided into three fields: (1) Construction and Engineering, (2) Green Sustainability and Environment, and (3) Integrated Management. The keyword co-occurrence analysis based on frequency, centrality and burst strength revealed that "Building information modelling (BIM)", "System" and "Impact" were relatively significant terms. This finding indicated that maturity models are a systematic assessment tool often used in the BIM domain. The analysis of the evolution of keywords also revealed that maturity-related research could be divided into five stages and that the application of maturity models at each stage focused on different areas within the construction industry. The analyses of the current review direct future research to focus more on the integration of green sustainability with other topics, explore new technologies, investigate the applicability of maturity theories and validation studies and conduct more action-oriented guided research. The results of this study guide researchers to utilise maturity models in the effort to systematically understand current research efforts and future trends of the tool in the construction industry, as well as provide references for managers of building construction companies and government personnel who develop policies for the construction industry.

Keywords: Building information modelling, Construction maturity, Maturity model, Bibliometric review, CiteSpace

INTRODUCTION

The construction industry has been widely criticised for many problems, such as severe waste caused by the inefficient use of resources, the high level of environmental pollution and the never-ending number of accidents (Hasik et al., 2019; Nnaji et al., 2021). As a result, proactive measures are being implemented to address these problems and one common approach is through maturity models (Alankarage et al., 2022). The maturity concept was first proposed by Gibson and Nolan (1973) and was used by the Software Engineering Institute at Carnegie Mellon University in the United States to develop the first capability maturity model in 1986 (Veldman and Klingenberg, 2009). The maturity model is often used to enable progressive improvement for an organisation from low to high levels of targeted competencies (Adekunle et al., 2022). It starts with a systematic collection of elements related to

Centre of Building, Construction and Tropical Architecture, Faculty of Built Environment, Universiti Malaya, Kuala Lumpur, MALAYSIA
*Corresponding author: siawchuing@um.edu.my

the targeted competencies and classifies them into different levels of maturity so that the organisation can first position itself and then adopt improvement strategies according to the maturity model levels (Röglinger, Pöppelbus and Becker, 2012).

Nowadays, maturity models have been applied to many fields in the construction industry, such as the field of the construction supply chain (Broft, Badi and Pryke, 2016), the field of health or safety (Williams, Fugar and Adinyira, 2020) or the field of building information modelling (BIM) (Ferraz, Loures and Deschamps, 2020). Some studies have also reviewed maturity models in diverse areas. For example, Correia et al. (2017) examined 11 studies related to continuous supply chains. The study found the use of maturity grids to be a dominant expression of maturity models within the construction industry and identified nine critical success factors for supply chain maturity. Wang, Siu and Chan (2019) quantified the maturity of the Internet of Things (IoT) research, introduced a novel three-step approach, and validated its effectiveness in identifying research hotspots and future development opportunities.

In short, prior literature reviews from various fields have been subjective and focused on the qualitative analysis of maturity models. They addressed specific segments but failed to describe how maturity models have been used and evolved in the construction industry. Therefore, this study conducted a systematic literature search on 654 studies on maturity models in the construction industry. A total of 278 studies were finalised for a systematic bibliometric study using CiteSpace to identify the application of maturity models in the construction industry and their trends. This research aimed to understand the trends and hotspots in the construction industry by analysing the keywords of the articles related to maturity modelling in this field.

RESEARCH METHODOLOGY

Bibliometrics is a quantitative analysis method that gathers more valid information through a thorough analysis of a specific filtered data set (Donthu et al., 2021), with co-word analysis being its most common component (Ellegaard and Wallin, 2015). Following the preferred reporting items for systematic reviews and meta-analysis (PRISMA) workflow, which pays particular attention to the selection of software and databases (Shahruddin and Zairul, 2020), 278 articles on maturity models in the construction industry were selected. The articles were selected based on the results of (1) publication analysis and (2) co-word analysis to promote an in-depth understanding of how the maturity model is applied in the construction industry (Li, Li and Sang, 2022). The research framework is shown in Figure 1.

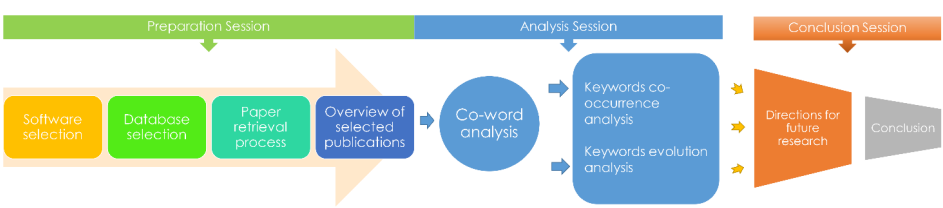

Figure 1. Research framework

Software Selection

There are three categories of bibliometric mapping tools: local-based, web-based and computer language-based. Due to accessibility, local-based tools are usually more popular among researchers (Li, Goerlandt and Reniers, 2021). According to Pan et al. (2018), local-based tools such as CiteSpace, HistCite and VOSviewer were the most frequently mapping software tools in 10 bibliometric studies on native-based. Although VOSViewer is currently the more widely used software in clustering analysis, CiteSpace has more algorithms to extract clustering labels and facilitates more diverse analysis (Gao et al., 2022). This could be because CiteSpace has a better visual experience than Hiscite in terms of graphics presentation (Gao et al., 2022). In addition, Cobo et al. (2011) who studied nine commonly used software concluded that CiteSpace's interactive interface could help researchers explore their chosen database network better. Meanwhile, Van Eck and Waltman (2014) analysed seven common analytical tools and pointed out that the feature that distinguishes CiteSpace from other software is its focus on dynamic visualisation and its deeper analytical capabilities in terms of the temporal evolution of knowledge development. Accordingly, this study decided to use CiteSpace as the visualisation analysis software for this bibliometric research.

Database Selection

Literature collections can originate from various databases with their respective advantages, such as Google Scholar, ScienceDirect, SpringerLink and PubMed (Gusenbauer and Haddaway, 2020). However, data sources for bibliographic studies are mainly from Web of Science (WoS) and Scopus (Gan et al., 2022). Some studies advocate merging two databases in search of richer content (Caputo and Kargina, 2022), but the complicated operational process makes most researchers choose either one of the two (Echchakoui, 2020).

Although Scopus includes a broader selection of journals (Darko et al., 2020), with 66% more journals than WoS (Pan et al., 2018), Archambault et al. (2009) confirmed that the two databases share a good agreement, especially in the case of bibliometric studies. Nonetheless, many international authoritative journals are represented in WoS compared to Scopus (Gan et al., 2022), which can help reduce the work of rejecting unqualified literature during the screening phase.

Since CiteSpace is developed based on WoS, utilising data from other databases may require conversion and may result in some functions being unavailable (Chen, 2016). WoS is the most used database for CiteSpace knowledge graph analysis (Harzing and Alakangas, 2016), especially among software developers (Chen and Kuljis, 2003; Zhang, Chen and Li, 2009; Synnestvedt, Chen and Holmes, 2005), resulting in WoS a reliable data source.

Article Retrieval Process

According to Tarhan, Turetken and Reijers (2016), the literature search could be divided into six steps when modifying two studies. The first step involved establishing clear research objectives and identifying the essential keywords. The two main keywords of the current study were "maturity models" and "construction industry". During Step 2, a test search was performed and the scope was reviewed. Following

the screening process, a total of 97 articles remained. Due to the small number, it was determined that the core keywords needed to be further analysed and refined. The third step reevaluated the scope by dividing the main keywords into segments. In Direction 1, the term "contractor" was selected due to its synonymous terms, such as "builder" OR "constructor" OR "construction company". For Direction 2, the term "construction project" OR "international project" was selected, as the construction industry primarily focused on project-based work. For Direction 3, three terms that are commonly used but do not accurately represent the distinct sectors within the construction industry were selected: "construction design", "construction performance" and "construction knowledge". The fourth step involved performing a formal preliminary search. There were 307 results for Direction 1, 230 outcomes for Direction 2 and 117 results for Direction 3. A grand total of 654 articles that were relevant to the topic were acquired. In the fifth step, repeated articles were removed. Following the removal process, a total of 599 articles were left. The final step was evaluating the selected literature to verify that it meets the specified criteria for inclusion and exclusion. Following the review process, a total of 278 articles were left.

PUBLICATION ANALYSIS

Temporal Analysis

The annual distribution of 278 articles on maturity models in the construction industry was analysed. The articles can be roughly divided into three stages based on the average annual number. According to Figure 2, the introducing stage, ranged beginning 2000 to 2008, had an average annual number of less than three articles. This stage is mainly to introduce the idea of the maturity model into the organisation of the construction industry (Chinowsky, Molenaar and Realph, 2007) or preliminary exploration of measurement criteria for the application of maturity models in the construction industry, such as the separation of project performance and project schedule measures (Ojiako, Johansen and Greenwood, 2008). The period from 2009 to 2014 was considered a stabilising stage, with an average annual number of more than five. At this stage, maturity models began to be applied to many aspects of the construction industry as a concept. This stage indicates that scholars have recognised the potential of maturity models in the construction industry. Consequently, there has been significant growth since 2015, with the number of articles increasing by over fivefold, from 13 in 2015 to 55 in 2021. This stage is reflected in three characteristics. First, the application of maturity models was further deepened, which not only discussed the development of maturity models but also the application of maturity models in evaluation (Domingues, Sampaio and Arezes, 2016). The second was to focus on the application of maturity models in BIM and virtual design and construction (VDC) and other latest technologies in the construction industry (Kang and Woo, 2015, Liang et al., 2016). The third feature was research focusing on a combination of multiple technologies in multiple fields. For example, the incorporation of BIM and critical success factors, as discussed by Phang, Chen and Tiong (2020), the utilisation of the supply chain operations reference model in conjunction with environmentally friendly practices as proposed by Ntabe et al. (2015), or the implementation of a modelling process that combines fuzzy set theory and neural networks as described by Omar and Fayek (2016). The

characteristics suggested that scholars have gradually deepened their research on maturity models and combined them with cutting-edge technologies in the construction industry.

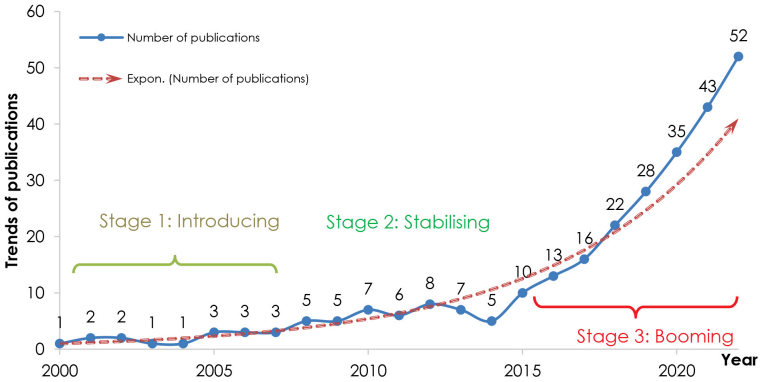

Figure 2. Annual literature on maturity models in the construction industry (2000 to 2022)

Categories Analysis

Category analysis identifies the disciplines involved in a particular knowledge area (Li, Li and Sang, 2022). Table 1 shows the eight categories of the 278 selected articles on maturity models in the construction industry. It should be noted that some articles could statistically fall into more than two categories, so the total number of articles in eight categories was greater than 278. The eight categories could be roughly divided into three fields: Construction and Engineering, Green Sustainable and Environmental, and General Management. Construction and Engineering accounted for the highest proportion of 76%, followed by General Management, which accounted for 36%. This reflected that the focus of maturity models was on the solution of actual construction problems rather than purely organisational management aspects. The 33% proportion on Green Sustainable and Environmental reflected that researchers used maturity models to increase attention to environmental protection as well as economic benefits.

Table 1. The summary of category analysis

No.	Category	Count	%
1	Engineering Civil	92	33
2	Construction Building Technology	65	23
3	Engineering Industrial	55	20
	Construction and Engineering	212	76
4	Environmental Sciences	36	13
5	Green Sustainable Science Technology	33	12
6	Environmental Studies	23	8
	Green Sustainable and Environmental	92	33

(*Continued on next page*)

Table 1. *Continued*

No.	Category	Count	%
7	Management	79	28
8	Operations Research Management Science	20	7
	General Management	99	36

Co-Word Analysis

Co-word analysis focuses on the analysis of keywords, which mainly includes two parts: keyword co-occurrence analysis and keyword evolution analysis. Keywords are the most core and condensed words in a study. As a result, the analysis of keywords is a concise and efficient way to understand the trend of publication (Li, Li and Sang, 2022).

Keywords co-occurrence analysis

Since the articles reviewed were retrieved based on the specified keywords, keywords related to the search terms, such as maturity, were excluded. Table 2 shows three statistical categories of the top ten rankings for all keywords in the 278 articles using the co-occurrence analysis feature of CiteSpace. Ranked based on frequency, "Management" was the top-ranked keyword. This suggested that maturity models or concepts have become an important approach in project management analysis. The keyword "BIM" was ranked second. This indicated that BIM research was where maturity models were used the most in the construction industry. "Framework" was ranked third. The keyword was the most popular analytical approach used in combination with maturity models, such as the BIM framework (Succar and Kassem, 2015), the framework matrix (Succar, 2010) and the decision-making framework (Karakhan et al., 2018).

Table 2. Top 10 keywords frequency, centrality and burst strength

No.	Keywords (Frequency)	Keywords (Centrality)	Keywords (Burst Strength)
1	Management (42)	Simulation (0.18)	System (2.85)
2	BIM (29)	Management (0.16)	Innovation (2.42)
3	Framework (27)	Design (0.14)	Barrier (2.20)
4	Implementation (25)	System (0.10)	Impact (2.03)
5	Design (25)	BIM (0.09)	Governance (1.76)
6	System (25)	Temperature (0.09)	Optimisation (1.71)
7	Innovation (18)	Impact (0.07)	Temperature (1.67)
8	Technology (16)	Implementation (0.06)	BIM (1.66)
9	Capability (15)	Coefficient alpha (0.06)	Emission (1.58)
10	Impact (14)	Framework (0.04)	Health and safety (1.57)

In terms of frequency which represents the number of occurrences, centrality was a common concern across different domains. "Simulation", indicating that management simulation based on real engineering or construction projects

that were used by several maturity domains, ranked first (Chen, Agapiou and Li, 2020). The third place was "Design". This indicated that that not only the actual construction process and operation phase had received the attention in maturity models, but also the design phase. Burst strength was used to identify popular topics during a given time. Ranking based on that; the first place was "System". This indicated that building-related problems have appeared in large quantities under the thinking of studying maturity in a certain system context (Domingues, Sampaio and Arezes, 2016).

It is also worth noticing that "BIM", "System" and "Impact" were relatively significant terms since they hold the top 10 positions for frequency, centrality and burst intensity at the same time. The emergence of "Impact" demonstrates that addressing the influence of building projects through maturity models has also become a very significant topic, particularly in the area of construction safety (Karakhan et al., 2018).

Keywords evolution analysis

Figure 3 summarises the evolution trend of keywords of the co-occurrence evolution network diagram from 2010 to 2022. Due to the initial introduction of maturity models in the construction industry and the small average annual volume of articles before 2010, mature keyword clustering was only present from 2010.

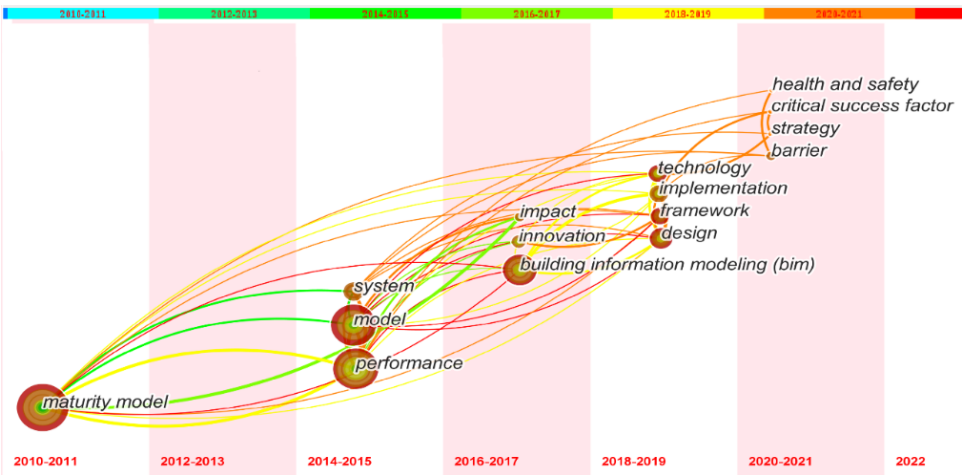

Figure 3. An evolution view of keyword co-occurrence network

In Figure 3, the time range of the node corresponded to the initial appearance of the keywords, while the size of the node indicated the frequency of each keyword. The colour of the node's ring and connecting line indicated the time. In general, maturity models first appeared in 2010 and continued till 2022. It was also one of the largest nodes, confirming that the selected articles were in line with the research purpose. From 2014 to 2015, the keywords evolved into three directions: (1) performance, (2) model and (3) systems.

From the performance perspective, researchers usually first take the final performance as the goal and then work backwards to deduce which methods to improve performance. For example, to determine the relationship between multi-dimensional performances, De Carvalho, Patah and Bido (2015) investigated 1,387 projects in three countries using different management maturity of projects and found that only profit and schedule were positively correlated with the complexity of projects.

The model perspective is based on the concept of maturity to construct different models to evaluate and improve certain organisational management methods. The models are generally constructed using semi-structured interviews or questionnaires for four to five levels. For example, Liu, Su and Zhang (2018) built supplier management maturity to improve supplier management for large contractors.

The systems perspective is usually to construct a system with multiple elements to evaluate a certain capability of project management. Qiang et al. (2015) divided 25 different factors governing construction project delivery selection into three groups: project internal, project external and project performance, to form a project delivery system to evaluate the project delivery capability. As for the application of the model, BIM was one of the biggest topics mentioned in the 278 articles analysed. Articles containing BIM in the subject word accounted for 22% of the total articles, amounting to 62 records. It showed that BIM was the most applied field of maturity theory in the construction industry. The result of analysing the relevant articles behind the node proved that three classification methods were generally used.

The successful operation of a project is linked to the division of labour and cooperation of various stakeholders. Therefore, one common division method of BIM application was based on differential stakeholders. From the perspective of small and medium-sized enterprises (SMEs), Hosseini et al. (2018) explored the correlation between the organisational attributes of relevant construction enterprises in Australia and their BIM maturity. In addition, Wang, Gosling and Naim (2019) established a mechanism to evaluate the BIM cooperation capability of the supplier based on the data-driven method of K-means because the supplier was one of the most vulnerable parts of the BIM application in the whole supply chain. Phang, Chen and Tiong (2020) also developed A BIM adoption model from the perspective of precast concrete manufacturers and identified key success factors influencing BIM adoption in the ASEAN. Despite of the common perspectives of manufacturers, suppliers and operators, Mirhosseini et al. (2020) paid attention to the fact that the BIM capability of each stakeholder organisation is ultimately reflected in its leaders, so they developed a BIM capability evaluation model based on the perspective of leaders.

The second was to study BIM from different countries' perspectives. Viana and Carvalho (2021) studied the main risks of BIM implementation in Brazilian public institutions and set priorities for assessment. Meanwhile, Gong et al. (2021) explored and determined the interactions between influencing factors of the implementation of BIM in the field of prefabricated buildings in China. Most BIM studies were carried out from specific micro aspects, such as construction and facility management (Yilmaz, Akcamete and Demirors, 2019) and the relationship between project progress and BIM maturity (Lin and Golparvar-Fard, 2021).

The third category viewed BIM from a macro perspective. Succar and Kassem (2015) introduced five conceptual models of BIM from the macro perspective to address the lack of support for the promotion of new specific markets in the BIM research field. Yang, Zhang and Xie (2020), based on the perspective of ecosystem theory, proposed a planting path that supported BIM from inception, expansion and maturity, providing an innovative BIM development reference theory for the whole architecture, engineering and construction industry. Later, BIM slowly evolved to include "innovation" and "impact".

In terms of "innovation", researchers think about how the BIM model can be constructed from different perspectives and then propose various innovative perspectives to study the construction of BIM. Begić, Galić and Dolaček-Alduk (2022) reviewed the level of automation in phases of design, construction and operation from a digital perspective and provided a reference for the maturity design of BIM models in these phases. Based on the concept of actor-network theory, Edirisinghe et al. (2021) summarised the key experiences in different project phases and proposed a whole BIM model lifecycle with guidelines. For "impact", researchers analysed the various effects that arise from the elements that build the model. Haji et al. (2021) used four-dimensional simulation performance as an entry point to evaluate the impact of different BIM maturity models on the expected benefits during implementation. Meanwhile, Siebelink et al. (2020) examined the barriers to implementing different BIM maturity models and explored the impact these barriers may have on project managers at different organisational levels.

Since 2019, the specific content of BIM research has been more biased towards design, implementation and technical aspects. Regarding design, one was microscopic, specific pre-construction multidimensional design. For example, Fabozzi et al. (2021) studied the interoperability of BIM to finite element model for the use of BIM models in geotechnical engineering The other was the macro management direction for the design of the BIM implementation path.

Implementation is the most important BIM use. The most common problem faced by stakeholders was the effectiveness of BIM model implementation. Olawumi and Chan (2019) reviewed case studies on how to better implement BIM, proposing benchmark models to be used to guide how BIM can be implemented in developing countries. More notably, not only in the field of BIM but also in the broader context of Industry 4.0. For example, Mansour, Aminudin and Mansour (2021) proposed a multi-criteria decision model for assessing the strategic readiness of companies to implement Industry 4.0.

Regarding technology, the main focus was on analysing BIM's features from a technical perspective and combining them with related technologies. To better utilise the capability of BIM data analysis and improvement, Demirdöğen et al. (2021) combined BIM and big data analytics based on the concept of lean management. Lin and Golparvar-Fard (2021) integrated visual three-dimensional (3D) into the BIM maturity model and developed a virtual project control system for construction teams to communicate in real-time about project progress. Although BIM was by far the most commonly used domain for maturity methods, the use of frameworks was the most common method of analysis, which could be due to the reason that the hierarchical nature of maturity was similar to the hierarchical organisation of the framework.

In the area of maturity, framework analysis methods have been applied in several areas, such as a supply chain management framework (Santos et al., 2020), circular economy strategy framework (Chen, Feng and De Soto, 2021) and BIM capability framework for construction owners (Giel and Issa, 2016). The application of this framework approach focused on barriers, strategies and critical success factors. Critical success factors method was first introduced in 1980 in the context of projects and was commonly used to analyse success factors in projects in the manufacturing, construction and other industries (Ayat et al., 2020). For example, the framework for assessing the BIM maturity by Iranian consulting firms was constructed on the identification and weighted analysis of relevant barriers (Abbasianjahromi, Ahangar and Ghahremani, 2018).

For strategy, there were two scenarios. One was to analyse the maturity from the perspective of strategy, such as sustainable construction from a strategic partnership perspective (Jensen et al., 2018) or BIM systems from a value strategy perspective for prioritising benefits in delivery decisions (Chen, Agapiou and Li, 2020). Another common scenario was to summarise the response strategy at the end of the article (Ayinla and Adamu, 2018). Although the circle of health and safety was the smallest in the evolutionary chart, it was one of the hottest directions at present. This may be attributed to the fact that the different requirements for safety levels in different building processes can be well represented in the building construction maturity model, such as the safety maturity model for construction contractors (Karakhan et al., 2018), safety, health and environment management capability maturity model (Asah-Kissiedu et al., 2021) and safety culture maturity model (Musonda, Lusenga and Okoro, 2021).

DIRECTIONS FOR FUTURE RESEARCH

For future research, more research on green sustainability combined with other topics should be conducted. In addition to the traditional areas of construction and engineering, the topic of green sustainable and environmental has become an emerging trend. Keywords related to this topic, such as temperature, impact and emission, appear frequently and this is also confirmed by the fact that the two keywords health and safety and barrier occupy the most recent years in the evolution charts. However, the combination of green sustainability and other hotspots in maturity models, such as critical success factors, construction supply chain and BIM, has not yet received sufficient attention from scholars. For example, although similar articles have received academic attention, such as combining supply chain and BIM (Deng et al., 2019), green sustainability in the supply chain has not been explored in depth.

In addition, more topics can be refreshed by the introduction of new technologies. An analysis of the co-occurrence and evolution of keywords reveals that innovation is a crucial element in maturity models. When maturity-related articles were analysed, new technologies such as 3D printing, unmanned aerial vehicles (UAVs) and cloud computing were introduced into topics such as BIM and brought new technological perspectives. Currently, it is already possible to see how wearable sensing devices can be used in health and safety (Nnaji et al., 2021). However, there is a lack of studies on how it be used in lean construction to build maintenance or knowledge management or its success factors for pervasive use in the construction industry. There are so many topics in the construction industry that

the different perspectives brought by any of the emerging technologies may allow old topics to be refurbished.

Third, more research on the applicability of maturity theories and validation studies could be conducted. As can be seen from the relevant studies represented behind the highly recurring keywords such as BIM, design and barrier, studies on maturity models tend to focus on the practical function of building construction but less on the applicability of the underlying supporting theory (Röglinger, Pöppelbus and Becker, 2012). Also, the focus has been on model building but is weak on practical validation and evaluation (Tarhan, Turetken and Reijers, 2016). There are articles focusing on the standardisation of model building, but their primary consideration was on the applicability of a maturity model (e.g., Röglinger, Pöppelbus and Becker, 2012; Gökalp and Martinez, 2021). Thus, studies on standards criteria focusing on theory applicability and validation evaluation are extremely lacking.

There is also a need for more action-oriented guided research. In browsing the research about maturity in the construction industry, many studies mainly combine maturity models to build a theoretical model or evaluate a particular capability of a company through this model. This feature is also evidenced by the fact that the keywords—model and system—are at an influential position of the keyword evolution network. However, these are often not very helpful to actual building construction enterprises, especially for most SMEs to guide their development through a suitable BIM route. Research that is more relevant to the actual needs of enterprises and oriented to action guidance should receive more attention.

CONCLUSIONS

In recent years, increasing studies have focused on the application of maturity models in the construction industry, but the fragmented studies are not systematic and a comprehensive and quantitative review is urgently needed to understand the current status and evolutionary trends in the field. In this study, based on bibliometrics, 654 articles were searched and 278 were finally identified for quantitative analysis. The entire selected literature was visually analysed by using CiteSpace in two areas: publication analysis and keyword analysis.

The temporal analysis identified three stages of development of maturity models, with a significant increase in the number of articles from 2008 to 2022 and in particular a boom period from 2015 onwards. The categories through the WoS database show that the articles were mainly divided into eight categories, which could be roughly divided into three fields: Construction and Engineering, Green Sustainability and Environment, and Integrated Management, among which the proportion of the Construction and Engineering field is 76%, ranking first.

Through co-occurrence keywords analysis, "Management", "System" and "Framework" were ranked high among hundreds of keywords, indirectly proving that maturity models have been used in the construction industry as a management framework for systemic analysis. The top-ranking keywords also include technical terms such as "BIM", "Simulation" and "Design", indicating the prevalent use of maturity models in the design phase in the construction industry sector, in addition to the construction phase. The evolution of the keywords was also analysed and the keywords can be divided into five stages, each of which explained different areas of maturity model application in different years.

This study followed the PRISMA workflow and summarised potential future trends based on an analysis of the clusters. Accordingly, more research on green sustainability combined with other topics should be conducted. Also, more topics can be refreshed by the introduction of new technologies. More research can be conducted on the applicability of maturity theories and validation studies besides more action-oriented guided research.

This study had limitations. Firstly, only WoS was chosen as the database may cause some bias to the analysis results, future studies can choose other databases such as Scopus, or even consider the combination of multiple databases. In addition, this study was based on co-word analysis, thereby using the keywords in the maturity model article to analyse the trend which may require further validation of co-citation and citation analysis. However, the combined approach of this study using bibliometrics and systematic searches following the PRISMA workflow allowed insights into the future trends of maturity models in other fields, especially the architectural field.

The findings of this study aid the understanding of the current state of application of maturity models in the construction industry and inspire the exploration of future trends in the field. At the same time, this study also provides valuable references for government departments working to optimise the construction industry.

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REFERENCE

Abbasianjahromi, H., Ahangar, M. and Ghahremani, F. (2018). A maturity assessment framework for applying BIM in consultant companies. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, 43: 637–649. https://doi.org/10.1007/s40996-018-0194-0

Adekunle, S.A., Aigbavboa, C., Ejohwomu, O., Ikuabe, M. and Ogunbayo, B. (2022). A critical review of maturity model development in the digitisation era. *Buildings*, 12(6): 858. https://doi.org/10.3390/buildings12060858

Alankarage, S., Chileshe, N., Samaraweera, A., Rameezdeen, R. and Edwards, D.J. (2022). Organisational BIM maturity models and their applications: A systematic literature review. *Architectural Engineering and Design Management*, 19(6): 567–585. https://doi.org/10.1080/17452007.2022.2068496

Archambault, É., Campbell, D., Gingras, Y. and Larivière, V. (2009). Comparing bibliometric statistics obtained from the Web of Science and Scopus. *Journal of the American Society for Information Science and Technology*, 60(7): 1320–1326. https://doi.org/10.1002/asi.21062

Asah-Kissiedu, M., Manu, P., Booth, C.A., Mahamadu, A.-M. and Agyekum, K. (2021). An integrated safety, health and environmental management capability maturity model for construction organisations: a case study in Ghana. *Buildings*, 11(12): 645. https://doi.org/10.3390/buildings11120645

Ayat, M., Imran, M., Ullah, A. and Kang, C.W. (2020). Current trends analysis and prioritization of success factors: a systematic literature review of ICT projects. *International Journal of Managing Projects in Business*, 14(3): 652–679. https://doi.org/10.1108/ijmpb-02-2020-0075

Ayinla, K.O. and Adamu, Z. (2018). Bridging the digital divide gap in BIM technology adoption. *Engineering, Construction and Architectural Management*, 25(10): 1398–1416. https://doi.org/10.1108/ecam-05-2017-0091

Begić, H., Galić, M. and Dolaček-Alduk, Z. (2022). Digitalization and automation in construction project's life-cycle: A review. *Journal of Information Technology in Construction*, 27: 441–460. https://doi.org/10.36680/j.itcon.2022.021

Broft, R.D., Badi, S. and Pryke, S. (2016). Towards supply chain maturity in construction. *Built Environment Project and Asset Management*, 6(2): 187–204. https://doi.org/10.1108/BEPAM-09-2014-0050

Caputo, A. and Kargina, M. (2022). A user-friendly method to merge Scopus and Web of Science data during bibliometric analysis. *Journal of Marketing Analytics*, 10: 82–88. https://doi.org/10.1057/s41270-021-00142-7

Chen, C. (2016). *CiteSpace: A Practical Guide for Mapping Scientific Literature*. Hauppauge, NY: Nova Science Publishers.

Chen, C. and Kuljis, J. (2003). The rising landscape: A visual exploration of superstring revolutions in physics. *Journal of the American Society for Information Science and Technology*, 54: 435–446. https://doi.org/10.1002/asi.10229

Chen, Q., Feng, H. and De Soto, B.G. (2021). Revamping construction supply chain processes with circular economy strategies: A systematic literature review. *Journal of Cleaner Production*, 335: 130240. https://doi.org/10.1016/j.jclepro.2021.130240

Chen, Z., Agapiou, A. and Li, H. (2020). A benefits prioritization analysis on adopting BIM systems against major challenges in megaproject delivery. *Frontiers in Built Environment*, 6: 26. https://doi.org/10.3389/fbuil.2020.00026

Chinowsky, P., Molenaar, K. and Realph, A. (2007). Learning organizations in construction. *Journal of Management in Engineering*, 23: 27–34. https://doi.org/10.1061/(asce)0742-597x(2007)23:1(27)

Cobo, M.J., López-Herrera, A.G., Herrera-Viedma, E. and Herrera, F. (2011). Science mapping software tools: Review, analysis and cooperative study among tools. *Journal of the American Society for Information Science and Technology*, 62: 1382–1402. https://doi.org/10.1002/asi.21525

Correia, E., Carvalho, H., Azevedo, S.G. and Govindan, K. (2017). Maturity models in supply chain sustainability: A systematic literature review. *Sustainability*, 9(1): 64. https://doi.org/10.3390/su9010064

Dadashi Haji, M., Taghaddos, H., Sebt, M., Chokan, F. and Zavari, M. (2021). The effects of BIM maturity level on the 4D simulation performance: An empirical study. *International Journal of Engineering*, 34(3): 606–614. https://doi.org/10.5829/ije.2021.34.03c.03

Darko, A., Chan, A.P.C., Adabre, M.A., Edwards, D.J., Hosseini, M.R. and Ameyaw, E.E. (2020). Artificial intelligence in the AEC industry: Scientometric analysis and visualization of research activities. *Automation in Construction*, 112: 103081. https://doi.org/10.1016/j.autcon.2020.103081

De Carvalho, M.M., Patah, L.A. and de Souza Bido, D. (2015). Project management and its effects on project success: Cross-country and cross-industry comparisons. *International Journal of Project Management*, 33(7): 1509–1522. https://doi.org/10.1016/j.ijproman.2015.04.004

Demirdöğen, G., Diren, N.S., Aladağ, H. and Işik, Z. (2021). Lean based maturity framework integrating value, BIM and big data analytics: Evidence from AEC industry. *Sustainability*, 13(18): 10029. https://doi.org/10.3390/su131810029

Deng, Y.C., Gan, V.J.L., Das, M., Cheng, J.C.P. and Anumba, C. (2019). Integrating 4D BIM and GIS for construction supply chain management. *Journal of Construction Engineering and Management*, 145(14): 04019016. https://doi.org/10.1061/(asce)co.1943-7862.0001633

Domingues, P., Sampaio, P. and Arezes, P.M. (2016). Integrated management systems assessment: A maturity model proposal. *Journal of Cleaner Production*, 124: 164–174. https://doi.org/10.1016/j.jclepro.2016.02.103

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N. and Lim, W.M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, 133: 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Echchakoui, S. (2020). Why and how to merge Scopus and Web of Science during bibliometric analysis: The case of sales force literature from 1912 to 2019. *Journal of Marketing Analytics*, 8: 165–184. https://doi.org/10.1057/s41270-020-00081-9

Edirisinghe, R., Pablo, Z., Anumba, C. and Tereno, S. (2021). An actor-network approach to developing a life cycle BIM maturity model (LCBMM). *Sustainability*, 13(23): 13273. https://doi.org/10.3390/su132313273

Ellegaard, O. and Wallin, J.A. (2015). The bibliometric analysis of scholarly production: How great is the impact? *Scientometrics*, 105: 1809 –1831. https://doi.org/10.1007/s11192-015-1645-z

Fabozzi, S., Biancardo, S.A., Veropalumbo, R. and Bilotta, E. (2021). I-BIM based approach for geotechnical and numerical modelling of a conventional tunnel excavation. *Tunnelling and Underground Space Technology*, 108: 103723. https://doi.org/10.1016/j.tust.2020.103723

Ferraz, C., Loures, E.R. and Deschamps, F. (2020). BIM maturity models evaluated by design principles. In J. Pokojski, M. Gil, L. Newnes, J. Stjepandić and N. Wognum (eds.), *Transdisciplinary Engineering for Complex Socio-technical Systems: Real-life Applications; Proceedings of the 27th ISTE International Conference on Transdisciplinary Engineering, July 1–July 10, 2020*. Vol. 12. Amsterdam: IOS Press, 504–513. https://doi.org/10.3233/ATDE200111

Gan, Y., Li, D., Robinson, N. and Liu, J. (2022). Practical guidance on bibliometric analysis and mapping knowledge domains methodology: A summary. *European Journal of Integrative Medicine*, 56: 102203. https://doi.org/10.1016/j.eujim.2022.102203

Gao, R., Mu, B., Lyu, S., Wang, H. and Yi, C. (2022). Review of the application of wearable devices in construction safety: A bibliometric analysis from 2005 to 2021. *Buildings*, 12: 344. https://doi.org/10.3390/buildings12030344

Gibson, C. and Nolan, R. (1973). Managing the four stages of EDP growth. *Hypothesis*, 399.

Giel, B. and Issa, R.R. (2016). Framework for evaluating the BIM competencies of facility owners. *Journal of Management in Engineering*, 32: 04015024. https://doi.org/10.1061/(asce)me.1943-5479.0000378

Gökalp, E. and Martinez, V. (2021). Digital transformation maturity assessment: Development of the digital transformation capability maturity model. *International Journal of Production Research*, 60(20): 6282–6302. https://doi.org/10.1080/00207543.2021.1991020

Gong, C., Xu, H., Xiong, F., Zuo, J. and Dong, N. (2021). Factors impacting BIM application in prefabricated buildings in China with DEMATEL-ISM. *Construction Innovation*, 23(1): 19–37. https://doi.org/10.1108/ci-06-2021-0115

Gusenbauer, M. and Haddaway, N.R. (2020). Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of Google Scholar, PubMed and 26 other resources. *Research Synthesis Methods*, 11: 181–217. https://doi.org/10.1002/jrsm.1378

Harzing, A.W. and Alakangas, S. (2016). Google Scholar, Scopus and the Web of Science: A longitudinal and cross-disciplinary comparison. *Scientometrics*, 106: 787–804. https://doi.org/10.1007/s11192-015-1798-9

Hasik, V., Escott, E., Bates, R., Carlisle, S., Faircloth, B. and Bilec, M.M. (2019). Comparative whole-building life cycle assessment of renovation and new construction. *Building and Environment*, 161: 106218. https://doi.org/10.1016/j.buildenv.2019.106218

Hosseini, R., Parn, E., Edwards, D., Papadonikolaki, E. and Oraee, M. (2018). Roadmap to mature BIM use in Australian SMEs: Competitive dynamics perspective. *Journal of Management in Engineering*, 34(5): 05018008. https://doi.org/10.1061/(asce)me.1943-5479.0000636

Jensen, P.A., Maslesa, E., Berg, J.B. and Thuesen, C. (2018). 10 questions concerning sustainable building renovation. *Building and Environment*, 143: 130–137. https://doi.org/10.1016/j.buildenv.2018.06.051

Kang, T.W. and Woo, J.Y. (2015). The development direction for a VDC support system based on BIM. *KSCE Journal of Civil Engineering*, 19: 1573–1584. https://doi.org/10.1007/s12205-015-0677-5

Karakhan, A.A., Rajendran, S., Gambatese, J. and Nnaji, C. (2018). Measuring and evaluating safety maturity of construction contractors: Multicriteria decision-making approach. *Journal of Construction Engineering and Management*, 144(7): 04018054. https://doi.org/10.1061/(asce)co.1943-7862.0001503

Li, J., Goerlandt, F. and Reniers, G. (2021). An overview of scientometric mapping for the safety science community: Methods, tools and framework. *Safety Science*, 134: 105093. https://doi.org/10.1016/j.ssci.2020.105093

Li, Y., Li, M. and Sang, P. (2022). A bibliometric review of studies on construction and demolition waste management by using CiteSpace. *Energy and Buildings*, 258: 111822. https://doi.org/10.1016/j.enbuild.2021.111822

Liang, C., Lu, W.S., Rowlinson, S. and Zhang, X.L. (2016). Development of a multifunctional BIM maturity model. *Journal of Construction Engineering and Management*, 142(11): 06016003. https://doi.org/10.1061/(asce)co.1943-7862.0001186

Lin, J.J. and Golparvar-Fard, M. (2021). Visual and virtual production management system for proactive project controls. *Journal of Construction Engineering and Management*, 147: 04021058. https://doi.org/10.1061/(asce)co.1943-7862.0002045

Liu, K.N., Su, Y.K. and Zhang, S.J. (2018). Evaluating supplier management maturity in prefabricated construction project-survey analysis in China. *Sustainability*, 10(9): 3046. https://doi.org/10.3390/su10093046

Mansour, H., Aminudin, E. and Mansour, T. (2021). Implementing Industry 4.0 in the construction industry-strategic readiness perspective. *International Journal of Construction Management*, 23(9): 1457–1470. https://doi.org/10.1080/15623599.2021.1975351

Mirhosseini, S.A., Kiani Mavi, R., Kiani Mavi, N., Abbasnejad, B. and Rayani, F. (2020). Interrelations among leadership competencies of BIM Leaders: A fuzzy DEMATEL-ANP approach. *Sustainability*, 12(18): 7830. https://doi.org/10.3390/su12187830

Musonda, I., Lusenga, E. and Okoro, C. (2021). Rating and characterization of an organization's safety culture to improve performance. *International Journal of Construction Management*, 21: 181–193. https://doi.org/10.1080/15623599.2018.1512030

Nnaji, C., Awolusi, I., Park, J. and Albert, A. (2021). Wearable sensing devices: Towards the development of a personalized system for construction safety and health risk mitigation. *Sensors*, 21(3): 682. https://doi.org/10.3390/s21030682

Ntabe, E.N., Lebel, L., Munson, A.D. and Santa-Eulalia, L.A. (2015). A systematic literature review of the supply chain operations reference (SCOR) model application with special attention to environmental issues. *International Journal of Production Economics*, 169: 310–332. https://doi.org/10.1016/j.ijpe.2015.08.008

Ojiako, U., Johansen, E. and Greenwood, D. (2008). A qualitative re-construction of project measurement criteria. *Industrial Management and Data Systems*, 108: 405–417. https://doi.org/10.1108/02635570810858796

Olawumi, T.O. and Chan, D.W.M. (2019). Development of a benchmarking model for BIM implementation in developing countries. *Benchmarking: An International Journal*, 26: 1210–1232. https://doi.org/10.1108/bij-05-2018-0138

Omar, M.N. and Fayek, A.R. (2016). Modeling and evaluating construction project competencies and their relationship to project performance. *Automation in Construction*, 69: 115–130. https://doi.org/10.1016/j.autcon.2016.05.021

Pan, X., Yan, E., Cui, M. and Hua, W. (2018). Examining the usage, citation and diffusion patterns of bibliometric mapping software: A comparative study of three tools. *Journal of Informetrics*, 12: 481–493. https://doi.org/10.1016/j.joi.2018.03.005

Phang, T.C.H., Chen, C. and Tiong, R.L.K. (2020). New model for identifying critical success factors influencing BIM adoption from precast concrete manufacturers' view. *Journal of Construction Engineering and Management*, 146: 14. https://doi.org/10.1061/(asce)co.1943-7862.0001773

Qiang, M., Wen, Q., Jiang, H. and Yuan, S. (2015). Factors governing construction project delivery selection: A content analysis. *International Journal of Project Management*, 33: 1780–1794. https://doi.org/10.1016/j.ijproman.2015.07.001

Röglinger, M., Pöppelbus, J. and Becker, J. (2012). Maturity models in business process management. *Business Process Management Journal*, 18: 328–346.

Santos, D.D., Quelhas, O.L.G., Gomes, C.F.S., Zotes, L.P., Franca, S.L.B., De Souza, G.V.P., De Araujo, R.A. and Santos, S.D.C. (2020). Proposal for a maturity model in sustainability in the supply chain. *Sustainability*, 12(22): 9655. https://doi.org/10.3390/su12229655

Shahruddin, S. and Zairul, M. (2020). BIM requirements across a construction project lifecycle: A PRISMA-compliant systematic review and meta-analysis. *International Journal of Innovation, Creativity and Change*, 12(5): 569–590.

Siebelink, S., Voordijk, H., Endedijk, M. and Adriaanse, A. (2020). Understanding barriers to BIM implementation: Their impact across organizational levels in relation to BIM maturity. *Frontiers of Engineering Management*, 8: 236–257. https://doi.org/10.1007/s42524-019-0088-2

Succar, B. (2010). Building information modelling maturity matrix. In J. Underwood and U. Isikdag (eds.), *Handbook of Research on Building Information Modeling and Construction Informatics: Concepts And Technologies*. Hershey, PA: IGI Global, 65–103. https://doi.org/10.4018/978-1-60566-928-1.ch004

Succar, B. and Kassem, M. (2015). Macro-BIM adoption: Conceptual structures. *Automation in Construction*, 57: 64–79. https://doi.org/10.1016/j.autcon.2015.04.018

Synnestvedt, M.B., Chen, C. and Holmes, J.H. (2005). CiteSpace II: Visualization and knowledge discovery in bibliographic databases. *AMIA Annual Symposium Proceedings*, 724–728.

Tarhan, A., Turetken, O. and Reijers, H.A. (2016). Business process maturity models: A systematic literature review. *Information and Software Technology*, 75: 122–134. https://doi.org/10.1016/j.infsof.2016.01.010

Van Eck, N.J. and Waltman, L. (2014). Visualizing bibliometric networks. In Ding, Y., Rousseau, R. and Wolfram, D. (eds.), *Measuring Scholarly Impact: Methods and Practice*. Cham, Switzerland: Springer, 285–320. https://doi.org/10.1007/978-3-319-10377-8_13

Veldman, J. and Klingenberg, W. (2009). Applicability of the capability maturity model for engineer-to-order firms. *International Journal of Technology Management*, 48: 219–239. https://doi.org/10.1504/ijtm.2009.024917

Viana, V.L.B. and Carvalho, M.T.M. (2021). Prioritization of risks related to BIM implementation in Brazilian public agencies using fuzzy logic. *Journal of Building Engineering*, 36: 102104. https://doi.org/10.1016/j.jobe.2020.102104

Wang, D., Siu, M. and Chan, P. (2019). Maturity model of IoT technologies and applications in construction. Paper presented at the CIB World Building Congress 2019. Hong Kong, China, 17–21 June.

Wang, Y.L., Gosling, J. and Naim, M.M. (2019). Assessing supplier capabilities to exploit building information modelling. *Construction Innovation*, 19(3): 491–510. https://doi.org/10.1108/ci-10-2018-0087

Williams, J., Fugar, F. and Adinyira, E. (2020). Assessment of health and safety culture maturity in the construction industry in developing economies: A case of Ghanaian construction industry. *Journal of Engineering Design and Technology*, 18: 865–881. https://doi.org/10.1108/jedt-06-2019-0151

Yang, Y., Zhang, Y. and Xie, H. (2020). Exploring cultivation path of building information modelling in China: An analysis from the perspective of an innovation ecosystem. *Sustainability*, 12(17): 6902. https://doi.org/10.3390/su12176902

Yilmaz, G., Akcamete, A. and Demirors, O. (2019). A reference model for BIM capability assessments. *Automation in Construction*, 101: 245–263. https://doi.org/10.1016/j.autcon.2018.10.022

Zhang, J., Chen, C. and Li, J. (2009). Visualizing the intellectual structure with paper-reference matrices. *IEEE Transactions on Visualization and Computer Graphics*, 15: 1153–1160. https://doi.org/10.1109/tvcg.2009.202