APPLICATION OF BUILDING INFORMATION MODELING (BIM) IN CHINA'S MEGAPROJECTS: BIBLIOGRAPHIC ANALYSIS

Qinghua He[1], Ge Wang[1*], Qian Shi[1], and Yaxian Zhou[1]
[1]*Research Institute of Complex Engineering & Management, School of Economics and Management, Tongji University, Zhangwu Road 1, Shanghai 200092, China*
[*] *Corresponding author (2014_wangge@tongji.edu.cn)*

ABSTRACT

Construction megaprojects management is confronted with great challenges due to its increasing complexity such as the complicated and varied relations between numerous stakeholders. As a revolutionary technology and process, Building Information Modeling (BIM) was widely used in megaprojects to address these issues. In order to establish a comprehensive and in-depth understanding of the application of BIM over the last decade in China, a bibliographic analysis is conducted based on the China National Knowledge Infrastructure (CNKI) database. The results show that current BIM-related research is relatively focused, mature, and well-developed. Furthermore, cross-case synthesis indicates that BIM's applications in China's megaprojects concentrate on clash detection, data management and visualization, scheduling, and quantity takeoff rather than on expert functionalities attached to BIM, such as jobsite safety, risk scenario planning, or recycling management. Future research should explore the potential use of BIM for expert applications to fill these research gaps.

Keywords: *BIM, Megaproject, Co-word analysis, Cross-case synthesis*

1. INTRODUCTION

BIM is the most common denomination for a new way of approaching the design, construction and maintenance of buildings (Bryde et al. 2013). It has been defined as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle" (Succar 2009). BIM has been widely utilized on China's megaprojects, such as Shanghai Tower, which, at 632m, will be the second tallest building in the world on completion in 2015. The term megaproject is a social construct referring to a large-scale and complex construction (Altshuler and Luberoff 2003).

Given the importance of BIM in Chinese architecture, engineering, and construction (AEC) industry, researchers have reviewed related literature to identify research development and barriers within this field (He et al. 2015). However, much of the effort has only considered particular subfields of BIM, and the conclusions were drawn from purely descriptive and qualitative analysis. At this point, little is known about the distribution and structure of BIM research themes in China. Additionally, one strand of the BIM literature is to document in detail the use of BIM on a specific megaproject case, such as Shanghai Disneyland, Lanzhou West Railway Station, Kunming Changshui International Airport. What is lacking, though, is any cross-case synthesis to ascertain the extent to which BIM applies to China's megaprojects. The major goal of this paper is to address these gaps and limitations by providing a system analysis of research status within BIM and its application in China's megaprojects over the past decade. Fig. 1 shows the annual number of BIM-related papers, indicating a sharply increasing research interest in BIM since 2011, which could be explained by the released program for developing information technology in AEC industry from 2011 to 2015 in China.

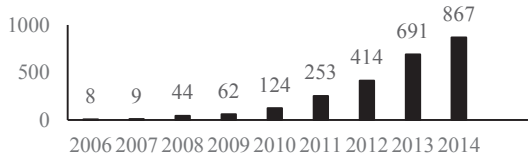

Fig. 1. Number of BIM-related papers published yearly from 2006 to 2014 in China.

2. METHODOLOGY

There were two important stages in this study:

(1) Using co-word analysis to capture the current distribution and structure of research themes of BIM in China.

(2) Identifying the extent to which BIM applies to China's megaprojects based on cross-case synthesis.

2.1 Co-word analysis

The method of co-word analysis was derived from co-citation analysis (Small and Griffith 1974). Co-word analysis uses sets of shared keywords instead of citations to analyze co-occurrence frequency of paired words. Researchers further apply social network analysis to co-word analysis and describe the intellectual structure of a research field through network indices (e.g., centrality, network density).

Centrality measures the correlation of a keyword with the others. Keywords with high centrality could be defined as lying on a central and critical position in the network, or in the entire research field (Lee, 2008). Network density indicates the strength of correlation between one keyword and another, within its corresponding research themes (Coulter et al. 1998). Specifically, it is reasonable to assume that the higher the centrality, the more centrally a research theme is situated within the whole field; and the higher the density, the more mature or potential a research theme is (Hu et al. 2013).

Co-word analysis have been successfully used to reveal the distribution and structure of research themes in specific fields, including library and information science (Hu et al. 2013), renewable energy (Romo-Fernandez et al. 2013), and recommendation system(Hu and Zhang, 2015).

2.2 Cross-case synthesis

To explore the extent to which BIM applies to China's megaprojects, secondary data documenting megaprojects that implemented BIM were gathered. The sources of the data were case studies in academic journals from CNKI database. Those 20 case studies found what functionalities of BIM were mentioned were sourced as suitable for further analysis as a convenience sample. According to the existing functional classification of BIM by Volk et al. (2013), cross-case synthesis was done to identify the proportion of each functionality used in 20 cases.

3. Results and Discussion

In this study, records of 2853 articles were retrieved based on the following search strategy:

"Keywords=Building Information Modeling OR BIM; timespan=unlimited; databases=CNKI"

It's important to note that keywords from China National Knowledge Infrastructure (CNKI) which indexes almost all Chinese journal articles were used as the source of data. Due to inconsistencies in data format, WoS and EI have not yet been included. It's also the limitations of this study.

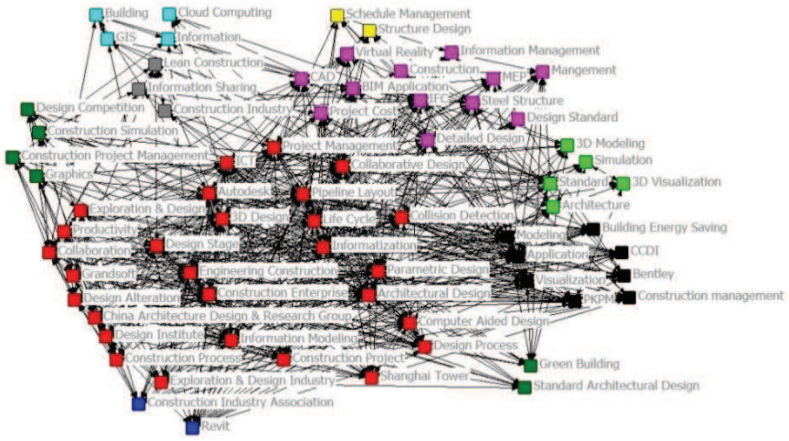

Fig. 2. The keywords network structure with k-cores

And 283 of them were manually excluded or removed because they belonged to irrelevant disciplines, such as medicine & public health, agriculture etc. As a result, records of 2570 articles were selected for analysis. Statistical Analysis Tool for Informetrics (SATI) was used for data pre-processing. Through using SATI, 12,054 keywords were extracted from these article records (4.69 keywords per article). It was noted that not all the keywords provided by authors were normalized; thus, the extracted keywords were normalized to ensure consistent treatment of the unifying synonyms, and clarity of homonyms. For instance, *IFC Standard* was replaced by *IFC*; *Construction Organization* was replaced by *Construction Enterprise* etc. Additionally, it was found that three common keywords, such as *Building Information Modeling*, *BIM* and *BIM Technology*, could influence the accuracy of social network analysis, and were therefore excluded from the selected keywords. In other words, BIM, as a research object in this analysis, is meaningless. Finally, co-word correlation matrix that includes top 75 keywords with a total frequency

of 2732 were determined to represent the main contents of BIM research in China. Based on the co-word correlation matrix, the density of the overall keywords network was calculated. The value of density (0.2342) is relatively high (Hu et al. 2013). Compared with other domains, this result indicates that research on BIM in China has gradually become focused and mature. According to the high degree centrality and from the perspective of the whole network structure, these keywords were noted as the main focuses of BIM in China: *3D Design*, *Life Cycle*, *Clash Detection*, and *Collaboration*. Meanwhile, because of the high betweenness centrality, these keywords were defined as the important bridges connecting other research themes or subfields, such as *Project Management*, *Collaborative Design*, *Pipeline Layout, IFC, and 3D Design*. Note that research on *Collaboration* (e.g., *Collaboration*, *Collaborative Design*), and *Clash detection* (e.g., *Clash detection*, *Pipeline Layout*) revealed that these were the significant research themes in BIM.

The network structure with k-cores shows that color and shape of nodes to represent qualitative differences among keywords can be based on classifying keywords according to their position in the graph, how they are embedded, rather than on some inherent features of the keywords itself (e.g. technical or non-technical). Fig.2 shows that BIM-related keywords were aggregated together into one large clusters and eight small clusters. It was inferred that research on BIM was relatively integrated and focused at present. The largest cluster includes research on *Architectural Design* (e.g., *Design Stage*, *3D Design*, *Collaborative Design, Exploration & Design, Design Alteration, Design Process, Computer Aided Design, Parametric Design, etc.*). However, the studies focusing on other building life cycle stages, such as prefabrication, operations and maintenance or deconstruction, are lacking yet. Additionally, *Cloud Computing* and *GIS,* which belong to the same cluster, have begun to appear. It is therefore possible that these themes could emerge as the new focuses in China, which was also supported in the findings of a study by Le et al. (2015).

4. ANALYSIS OF BIM APPLICATION CASES IN MEGAPROJECTS

Table 1. Summary sheet of BIM functionalities

Functionality	Case No.																				Proportion
	Skyscraper						Transport Hub								Venue						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Clash detection			X	X	X	X	X	X	X	X					X		X	X	X	X	65%
Data management and visualization		X		X	X	X	X	X			X		X	X		X		X	X	X	60%
Scheduling			X		X	X				X	X	X					X		X		40%
Quantity takeoff					X	X	X	X			X				X		X				35%
Construction process simulation						X	X			X	X	X							X		30%
Energy/thermal analysis	X			X		X			X							X				X	30%
Operations and maintenance(O&M)		X				X											X		X		20%
Daylight simulation				X		X														X	15%
Deviation analysis						X											X	X			15%
Jobsite safety					X		X				X										15%
Prefabrication					X	X											X				15%
Localization of building components															X					X	10%
Risk scenario planning																					0%
Recycling and rubble management																					0%

The 20 megaproject cases were reported in the CNKI over a 3 year period (2013–2015), dividing into three major categories of skyscraper, transport hub and venue. Haikou Tower (No.1), Z15 Tower (No.2), Chengdu Financial City (No.3), Wuhan Center (No.4), Tianjin 117 Building (No.5), Shanghai Tower (No.6) and Yangtze River Media Building (No.7) are typical skyscrapers. Shanghai Subway Line 12 (No.8), Urumqi High-speed Rail Station (No.9), Lanzhou West Railway Station (No.10) and Xingfen Highway (No.11) can be attributed to transport hubs. While Fuzhou Olympic Stadium (No.12), Zhuhai Opera House (No.13), Bicycle Gymnasium in Tianjin Sport Center (No.14), Wuhan Optical Valley Tennis Center (No.15), National Exhibition and Convention Center (No.16), Shanghai Disneyland

Fantasy Castle (No.17), Jiangsu Grand Theatre (No.18), Fuzhou CBD Wanda Plaza (No.19) and Chongqing International Circus City (No.20) belong to venues. Case 1 is expected to begin construction in mid-2015. Case 3, 8, 9, 10, 11, 12, 14, 16, 19, 20 have already been built. The rest of 9 cases have yet been built. It is worth noting that a third of the cases shown in Table 1 are skyscrapers. This is probably due to the skyscraper boom of the early-2000s in China and hence there are currently a relatively higher number of scholars and professional bodies publishing articles about BIM's applications in skyscrapers. Each documented case was considered, using content analysis to identify the functionalities of BIM. The content analysis process developed by Harris (2001) was followed. The unit of analysis adopted was the "phrase," which may vary from a single word to a whole sentence. In this case the phrase represented each functionality in Table 1. Yet alternative approaches utilising secondary data have their disadvantages, including distortions or loss from original information source. Table 1 displays major examples of inherent and expert functionalities applied in megaprojects. Functionalities are either inherent in 3D, 4D or 5D BIM (e.g. quantity takeoff, scheduling, cost calculation) or they are attached to BIM as independent expert applications (e.g. deviation analysis, energy analysis, jobsite safety) (Volk et al. 2013). According to the statistics in Table 1, applied functionalities concentrate on clash detection, data management and visualization, scheduling, quantity takeoff rather than on expert applications. The result is similar to and further confirms what has been reported through co-word analysis.

5. CONCLUSIONS

The conducted co-word analysis reveals the distribution and structure of BIM research themes during the period of 2004–2015 in China. BIM-related keywords were aggregated together into one large clusters and eight small clusters. According to the keywords network density, research on BIM is relatively mature and well-developed. Besides, based on the distribution and structure of BIM research themes in China, applied functionalities concentrate on architectural design rather than on prefabrication, operations and maintenance or deconstruction. Despite the increasing BIM usage in China's new projects, implementation of BIM in existing buildings, such as refurbishment, renovation, and demolition planning, is still limited yet. Cross-case synthesis revealed that expert applications of BIM, such as jobsite safety, risk scenario planning, and recycling management have great potential to develop further in China.

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