CRITICAL SUCCESS FACTORS FOR IMPLEMENTING BUILDING INFORMATION MODELLING (BIM): A LONGITUDINAL REVIEW

ABSTRACT

Although building information modelling (BIM) is ubiquitous within the construction industry, a review analysis on critical success factors (CSFs) used to measure successful BIM implementation is not well established. This research conducts a comprehensive review and interpretivist study of published studies on CSFs for BIM implementation during the period 2005 to 2015. Analysis reveals that some countries (e.g. USA, UK and South Korea) have developed clear CSFs for measuring successful BIM implementation, although each country implements a different sets of CSFs, some universal CSFs are shared between these countries, namely: *collaboration in design, engineering, and construction stakeholders; earlier and accurate 3D visualisation of design; coordination and planning of construction works; enhancing exchange of information and knowledge management; and improved site layout planning and site safety*. These common factors provide a core basis for establishing a standard evaluation model for measuring the success of BIM implementation and serve to identify areas for further improvement. A checklist of CSFs for BIM implementation is developed, and could render new insight for researchers and practitioners to conduct further empirical studies.

KEYWORDS: Building Information Modelling; Critical Success Factors; Implementation; Review

INTRODUCTION

Building information modelling (BIM) has revolutionised building and infrastructure development within the construction and civil engineering industries over the last decade (Eastman *et al.*, 2011). A plethora of studies expound the virtues of BIM implementation throughout a development's whole life cycle (c.f. Pärn and Edwards, 2017; Barlish and Sullivan, 2012; Azhar, 2011; Eastman *et al.*, 2011). However, BIM implementation has been slow particularly amongst small-to-medium enterprises (Dainty *et al.*, 2017; Eastman *et al.*, 2011; Smith and Tardif, 2009). Many solutions to poor implementation have either focused upon *technical issues* (such as: software interoperability, cost of software and employee training) or *non-technical issues* (such as: legal uncertainties, cultural change, disruption in workflow, project delivery and contracts) (Arayici *et al.,* 2011; Azhar, 2011; Becerik-Gerber and Kensek, 2010; Gu and London, 2010; Kent and Becerik-Gerber, 2010; AIA, 2007). However, resolving these issues requires a deeper and richer knowledge of critical success factors (CSFs) used for measuring the successful implementation of BIM. From the Oxford Dictionary (2005), implementation is the process of putting a decision or plan into effect. According to Rockart (1982, p. 4), CSFs could be defined as the: *"few key areas of activity where favorable results are absolutely necessary for a manager to reach his/her goals."* Martin (1982) concurs with this definition and reiterates the fundamental role that CSFs have in management decision making. CSFs therefore represent a tool for categorising and evaluating strategic goals in management organisations as well as measuring organisational outcomes and activities (Quesada and Gazo, 2007). In this study, when combining these terms together, CSFs for BIM implementation can be defined as a set of key areas and measuring outcomes that drive all key practitioners to change from traditional project delivery using object-oriented computer-aided design (CAD) to successfully implementing BIM collaboratively from early design stage to the facility management stage (Won *et al.,* 2013).

Extant literature reports upon a plethora of BIM studies that utilise CSFs for measuring successful BIM implementation. For example, Eastman *et al.*, (2011) identify that an evaluation of energy analyses during the design stage provides insight as a CSF for a successful BIM implementation. Popov *et al.*, (2010) asserts that BIM implementation facilitates the creation, communication and sharing of information throughout a building's entire life-cycle, while Kymmel (2008) opines that early collaboration among project participants significantly influences BIM implementation. The literature indicates that researchers worldwide are interested in examining CSFs for measuring successful BIM implementation given the projected growth and development of this advanced digital technology (Arayici *et al.,* 2011). Yet despite increased academic attention, a longitudinal analysis of CSFs within existing literature is required to develop a universal set of CSFs for measuring the successful implementation of BIM. Concomitant objectives seek to identify: the annual publication trends of CSFs for implementing

BIM over the period 2005 to 2015; the authors' origin/ country and the types of projects that utilise CSFs; research methods applied within these aforementioned investigations; and salient emergent findings arising. This review study provides a checklist of CSFs for BIM implementation which could help researchers to further conduct empirical research studies. In addition, by identifying a common set of CSFs for BIM implementation, practitioners could better understand the key areas that are worth paying attention to for predicting the probability of successful BIM implementation and take necessary steps to avoid project-based BIM failure.

RESEARCH BACKGROUND

Definitions and Concepts of BIM

BIM is synonymous as a digital tool used throughout the whole lifecycle of a facility for visualisation, scheduling, communication and collaboration among project participants (Kymmell, 2008; Eastman *et al.*, 2011). According to Smith (2007), BIM reproduces physical and functional characteristics of a building and affords an opportunity to rectify design errors and/ or implement changes before a project is developed. BIM has received considerable attention from academia and industry because of its latent potential and capability to achieve performance improvement in the architecture, engineering, construction, owner-operated (AECO) sector (Azhar *et al.*, 2008). Although BIM definitions are myriad (c.f. Tse *et al.*, 2005; Succar, 2009), the Associated General Contractors of America (AGC) defines it as:

> *"a data rich object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analysed to generate information that can be used to make decisions and improve the process of delivering the facility."* (AGC, 2006, p. 3).

However, BIM encapsulates more than just the digital representation – rather it represents a paradigm shift in the process of building delivery. This process shift (also known as 'integrated practice' or 'integrated project delivery' (AIA, 2007)) is integral to current industry trends towards fully automating project processes (Russell, 2000). Whilst several contextual definitions of BIM have been established (c.f. Azhar, 2011; Succar, 2009; AIA, 2007; AGC, 2006), for this study BIM is defined as a modelling technology and associated set of processes to produce, communicate and analyse building models (Eastman *et al.*, 2011).

Critical Success Factors of Implementing BIM

Over the last decade, numerous CSFs for implementing BIM in the AECO industry have transpired, especially in enhancing the communication between different project participants (via a common data environment), collaboration among project stakeholders, and extracting cost estimation and quantity take off (Arayici *et al.*, 2011; Azhar, 2011; Eastman *et al.*, 2011; Acharya *et al.*, 2006). Azhar *et al.*, (2008) affirm that a common data environment (CDE) can reduce errors associated with inconsistent and uncoordinated project documents because BIM is capable of holding comprehensive geometric or semantic information. Moreover, the comprehensiveness of data exchange on information augments the project management lifecycle (Popov *et al.*, 2010; Gecevska *et al.*, 2010) and improves sustainable building design (Azhar *et al.*, 2011). Additionally, Kymmell (2008) and Taylor and Bernstein (2009) agree that visualisation is one of the CSFs gained when implementing BIM. For instance, a case study on healthcare facilities by Manning and Messner (2008) reveals that 3D visualisation allows project professionals to more accurately assess the development. Cost reduction is another significant CSF for BIM implementation via semi-automated adjustment of drawings, specifications and bills of quantities (Manning and Messner, 2008). With BIM-based processes, the owner can potentially realise a greater return on investment via an improved design process which increases the value of project information in each phase and decreases the effort required to produce that information (Eastman *et al.*, 2011). Facilities managers use BIM during operation and maintenance (O&M) stages of a building's life cycle given palpable benefits offered, including: maintenance of warranty and service information; quality control; assessment and monitoring of energy and space management; emergency management; and/ or retrofit planning (Becerik-Gerber *et al*., 2011; Arayici, 2008). BIM implementation also helps to synchronise design and construction planning of activities. Specifically, 4D modelling enables construction stakeholders to visualise the constructability, construction sequencing and planning of a proposed construction method (Ting *et al.*, 2007). Similarly, Koo and Fischer (2000) use 4D models to identify and eliminate problems related to off-site construction. 4D and 5D BIM can effectively improve: cost estimation and tendering (Elbeltagi and Dawood, 2011); site planning (Sacks *et al.*, 2010); and safety management (Zhou *et al.,* 2012). Table 1 provides a detailed listing of CSFs for implementing BIM that are cross referenced against extant literature. In order to implement BIM successfully, researchers and practitioners need to identify CSFs of BIM, and thus take measures to ensure the effective implementation of these key areas. As a result, there is a crucial need to conduct a longitudinal review analysis to summarise the CSFs for enhancing BIM implementation in the project lifecycle.

<Insert Table 1 about here>

RESEARCH APPROACH

An interpretivist epistemology with elements of positivism was used to conduct a comprehensive review of extant literature, where validity of the publications selected was confirmed via a systematic but simplified steady approach. Thus, this study reviewed articles on CSFs for BIM implementation during the period 2005 to 2015. The research approach used in this study has been extensively used in similar review studies in the construction and engineering management domain (Darko and Chan, 2016; Osei-Kyei and Chan, 2015; Yi and Chan, 2013). This method approach consists of three main stages: (1) selection of target journals; (2) selection of relevant articles; and (3) contributions assessment.

Selection of Target Journals

Academic journals that had published research containing CSFs for BIM implementation were first identified using the 'Scopus' search engine. The Scopus search engine was chosen because it covers most publication databases in different research areas such as business, management, engineering and accounting (Hong and Chan, 2014). Moreover, Scopus performs better in terms of its accuracy and coverage when compared to other search engines such as PubMed, Web of Science and Google Scholar (c.f. Falagas *et al.,* 2008). Furthermore, the Scopus search engine has been adopted in similar construction management studies (Hong *et al.*, 2011; Yi and Wang, 2013). To critically analyse and facilitate a clear utilisation of the trend of CSFs for BIM implementation, a systematic and extensive search was conducted under the 'titles/ abstract/

keyword' fields of the Scopus search engine. It is worth mentioning that CSFs for BIM implementation is a broad research topic with numerous keywords in the literature. In order to obtain relevant articles to address the aforementioned objectives, common keywords, phrases and free-text words were adopted. These phrases included 'critical success factors', 'success factors' and 'critical factors' which were further refined to the area of BIM using phrases such as: 'building information modelling', 'visual design and construction (VDC)', '3D modelling', 'BIM' and 'VDC.' It should be noted that the terms 'success factors', 'critical success factors', and 'key result areas' are synonymous in this study (Bryde *et al.*, 2013). Collin (2002) advocates that in the process of developing key performance indicators (KPIs), the general indicators used to assess the performance of a construction project should focus on the critical success factors or outcomes. In this regard, this review holds the fact that KPIs are related to CSFs for successful BIM implementation. Consequently, a systematic and extensive desktop search was conducted using two main categories of search terms under the 'titles/ abstract/ keyword' field in Scopus. The search was also restricted to articles published from 2005 to 2015 (years inclusive). Moreover, the search was limited to fields such as 'architecture' or 'construction industry' or 'building construction' or 'construction management' or 'construction engineering and management'.

Thus, the full search code for Scopus was: TITLE-ABS-KEY (('critical success factors' OR success factors' OR 'critical factors') AND ('building information modelling' OR 'visual design and construction' OR '3D modelling' OR 'BIM' OR 'VDC') AND LIMIT-TO ('architecture' OR 'construction industry' OR 'building construction' OR 'construction management' or 'construction engineering and management') AND DOCTYPE ('ar' OR 're') AND SUBJAREA ('engi' OR 'manag' OR 'envi' OR 'soci' OR 'deci' OR 'busi') AND PUBYEAR > 2004 AND PUBYEAR < 2016 AND LIMIT-TO (LANGUAGE, "English") AND LIMIT-TO (SRCTYPE, "(j)")). The initial search resulted in 279 references. All references identified from Scopus database were exported into EndNote X7 (Thompson Reuters, New York, USA).

Despite the search restrictions, several unrelated articles still appeared. These articles appeared in more than 25 different journals, according to the search results. The selection of target journals for this study was based on the following criteria: (1) the journal ranks within the top six of Chau (1997) rankings of construction management journals. It should be noted that reference was made to Chau's ranking because it is one of the widely accepted journal rankings in the field of construction engineering and management (Darko and Chan, 2016); and (2) journals that published at least three articles during the period covered by the study (according to the search results). Notably, this criterion was higher than similar criteria used in previous review studies (Darko and Chan, 2016; Osei-Kyei and Chan, 2015).

Given the above criteria, a total of five construction management and engineering journals met the first criterion: Journal of Management in Engineering (JME), Engineering, Construction and Architectural Management (ECAM), International Journal of Project Management (IJPM), the ASCE Journal of Construction Engineering and Management (JCEM), and Construction Management and Economics (CME). Building Research and Information (BRI) was included because it met the second criterion. A total of six construction management and engineering journals on CSFs for BIM implementation were therefore selected for this study.

Selection of Relevant Articles

The six selected journals captured 50 articles out of the 279 initially identified. However, not all of the 50 articles presented relevant research studies on the issue of CSFs for BIM implementation. Therefore the articles were briefly examined by reading their abstracts and full-texts to filter out unrelated articles. A total of 35 articles was finally selected to be valid for further analysis. The sample size of 35 articles was adequate and could provide a good overview of the CSFs for BIM implementation compared with the previous review studies in similar construction management and engineering domains (Osei-Kyei and Chan, 2015). Table 2 summarises the number of relevant articles identified from each journal.

<Insert Table 2 about here>

Contributions Assessment

Content analysis was used to examine and analyse relevant publications based upon: i) the authors' origin/ country of research focus; ii) major findings within publication; and iii) research methodologies adopted. This study adopted the quantitative formula used by Howard *et al.*, (1987) for calculating the contribution of authors to a multi authored paper (also c.f. Yi and Wang (2013); Ke *et al.*, (2009); and Tsai and Wen (2005)). The proposed formula was based on the assumption that the actual contribution of an author to a multi authored paper varies and the first author contributes more than the second author and so on. This formula is expressed as:

$$score = \frac{1.5^{n-i}}{\sum_{i=1}^{n} 1.5^{n-i}} \qquad (1)$$

Where: '*n*' denotes the number of authors of the paper; and '*i*' is the order of each author. A detailed score distribution for authors is presented in Table 3.

<Insert Table 3 about here>

RESULTS AND DISCUSSIONS

Annual Publication Trends of CSFs for Implementating BIM from 2005 to 2015

The annual distribution of selected journal articles between the years of 2005 to 2015 inclusive is shown in Figure 1 and illustrates that CSFs are increasingly being reported upon over the period studied. Research into CSF implementation will continue to grow as industry seeks to capitalise upon the inherent benefits associated with BIM implementation on construction projects (Eastman *et al.*, 2011; Huang *et al.*, 2009). Table 2 reveals that the six targeted journals reviewed had cumulatively published 35 articles on BIM implementation with the highest rate being published by Journal of Construction Engineering and Management (with ten research articles) and the lowest rate being published by Engineering, Construction and Architectural Management (with three articles published).

<Insert Figure 1 about here>

Authors' Origin/ Country Contribution on CSFs for Implementing BIM

The score matrix (presented in Table 3) was used to calculate the authors' origin/ country and a score for each author (within a single publication) was computed. For instance, Seulki Lee (1st author) and Jungho Yu (2nd author), both from South Korea, collaborated with David Jeong (3rd author) from USA to publish an article. Using the score matrix, the score for each of these authors will be 0.47, 0.32 and 0.21 respectively. Therefore, the author origin/ country contribution to South Korea is 0.79 (i.e. 0.47+0.32) is USA was 0.21. Table 4 reports upon the origin/ country with research centres, number of researchers, number of published articles and score for each origin/ country. The USA, UK and South Korea had the highest number of researcher contributions to CSFs with scores of 9.79, 7.74 and 3.85. In descending order, the USA had 31 researchers from 15 different research centres contributing to 17 publications; the UK had 17 researchers from 10 different research centres contributing to 8 articles published; and South Korea had 10 researchers with 4 different research centres contributing to 6 articles published.

These results illustrate that the concept of BIM implementation within developed countries is well implemented and widespread over the period studied mainly because governments within these countries have authorised all public construction projects to be BIM based. Moreover, several of these developed countries, such as USA and UK, have created agencies to promote BIM implementation and standards development. For example, since 2006 within the USA the General Services Administration (GSA) has included spatial programme BIMs as part of the minimum requirement for submissions to the office of the Chief Architect for final concept approval (US-GSA, 2008). Similarly, in 2016 the UK government mandated BIM level 2 for all public construction projects. Developing countries such as Malaysia are trailing on CSFs implementation with comparatively low implementation levels. This may be because the full potential of BIM is not yet fully explored in these countries and hence, very few publications appeared in the selected journals. Alternatively, it could be because target journals did not give priority to research produced within developing countries. Future work is required to explore this issue more definitively.

<Insert Table 4 about here>

Target Project Applications on CSFs for Implementing BIM

In order to provide insight into the types of projects that have been involved in successful BIM implementation, the included articles were classified based upon their target project application of implementing BIM. Figure 2 presents the distribution of target project applications of BIM implementation and illustrates that the majority of target project applications (i.e. 71.1%) focused upon building construction projects. This may be because the building construction industry utilises data and information throughout the entire project's life cycle or additionally because projects integrate several participants who coordinate, communicate, collaborate and plan activities for making informed decisions. Moreover, building construction projects are known to utilise documentation that contains voluminous information (e.g. drawings, specifications and bills of quantities) (Sun and Howard, 2004). Furthermore, implementing BIM technologies enables construction stakeholders to visualise designs in a 3D format, analyse clash detection, estimate quantities and integrate designs from various design disciplines for efficiency (Li *et al.*, 2009, pp. 365). Notably, the total number of target project applications is > 36 because some studies considered more than one targeted project application (e.g. Wright *et al.*, (2014) critically assessed engineering procurement construction projects life cycle with respect to nuclear power projects). With an exception to building construction project applications for BIM implementation, all the other target applications had not more 3 project applications. Again, one possible explanation for this is that BIM implementation has been driven in the global building construction chain to work collaboratively for enhancing building project-based BIM, rather than lonely firm-based BIM implementation. The limited number of articles in other project applications for BIM implementation (Figure 2) can be deemed crucial as research gaps for researchers to conduct more studies to investigate the CSFs of BIM implementation in many countries, including developed and developing countries.

<Figure 2 about here>

Previous Research Methods Used in CSFs for Implementing BIM

A detailed analysis was conducted on the methods adopted to explore CSFs for BIM implementation within selected journal articles. These methods were: case study; survey; literature review; and mixed method (survey, case study and interviews) (refer to Figure 3). Of these four categories, the case study was most frequently used with 18 articles; this is most likely because a case study investigates contemporary phenomenon within a real-life context especially with unclear boundaries evident (Yin, 2003). In addition, case studies are useful for explaining the implementation of new methods and techniques in organisations (McCutchean and Meredith, 1993) and are well suited to problem solving - often discerning new phenomenon and theoretical underpinnings (Yin, 2003). Alternatively, survey and mixed method were ranked as second and third with 9 and 7 articles respectively. Survey has been a widely used method in construction management and engineering research because it presents a direct and relatively easy way to simultaneously collect data from various experts and practitioners (Holt, 2010), which is useful for sensitive issues like CSFs for implementing BIM. Only a single article used literature review as a method adopted in the study (i.e. Lu *et al.*, 2015). Notably, each method has its own advantages and disadvantages. The use of a particular method is dependent upon the time, scope, project applications, and specific research background.

<Figure 3 about here>

Analysis of Key Findings from Studies on CSFs for Implementing BIM

A summary of findings for 35 publications is presented in Tables 5 and 6. Table 5 summarises the findings from studies on CSFs for implementing BIM during 2005 to 2015. Likewise, the findings from studies on identified CSFs for implementing BIM with their respective publications is shown in Table 6. A list of 35 publications on CSFs for BIM implementation in selected journals is presented in Table 7. Also, the frequency that a CSF was identified by author(s) is accumulated and presented, and this was used to rank the identified CSFs for BIM implementation.

<Insert Tables 5, 6, and 7 about here>

Even though several factors accounted for successful BIM implementation, the analysis reveals that the five key CSFs for BIM implementation during the studied period were: i) *collaboration in design, engineering, and construction stakeholders;* ii) *earlier and accurate 3D visualisation of design;* iii) *coordination and planning of construction works;* iv) *enhancing exchange of information and knowledge management; and* v) *improved site layout planning and site safety*. The findings could help clarify what the high prioritised factors are, and could also be used as an assessment tool to evaluate the successful implementation of BIM.

Collaboration in Design, Engineering and Construction Stakeholders

BIM is recognised by both researchers and practitioners as an emerging disruptive technology (Pärn and Edwards, 2017; Pärn *et al.,* 2017). Various authors have demonstrated how BIM can significantly improve collaboration during the design, construction and occupancy and maintenance of a development (Cerovsek, 2011; Jung and Joo, 2011; Dossick and Neff, 2010; Gu and London, 2010). For example, Dossick and Neff (2010) utilised over 12 months' ethnographic observations for two commercial construction projects across the USA and demonstrate the collaboration between members of the design and construction team. Collaboration amongst project stakeholders is a prerequisite requirement to achieving the desired levels of project cost and quality in the AECO sector. Any flaws and errors found in the data can partly be seen as a lack of collaborative design or collaboration between designers and site personnel, not as errors within the software. This highlights the need to develop design processes and increase collaboration between different project parties so that designers can gain a better understanding of the information that models should include and the level of detail at which the information should be presented (Tarja and Hannele, 2015). Collaboration should also include negotiations and agreements conducted during the project about the tasks the models will be used for, the information included in the models, and the way that models should be created to ensure that information is usable for construction and maintenance tasks *(ibid*).

Efficiently utilising BIM as a collaborative modelling tool has a significant impact upon engendering effective communications and project performance (Choi *et al.,* 2014; Luth *et al.,* 2014; Bryde *et al.,* 2013; Barlish and Sullivan, 2012;). For example, Eriksson *et al.,* (2008) affirm the significance of collaboration with client organisations as a competitive advantage for achieving project success. Additionally, several studies (c.f. Cheung *et al.,* 2013; Laan *et al.,* 2012; Love *et al.,* 2010; Chan *et al.,* 2003) confirm that collaborative team relationships significantly augment project performance. The Construction Industry Institute (CII) found that scheduling shares a mutual relationship with cost performance when collaboration exists among project participants (CII 1999a). Similarly, Won *et al.*, (2013) report upon the importance of collaboration among project participants to enable information sharing, knowledge transfer and the effective use of BIM on projects. Eastman *et al.*, (2011) place core emphasis of BIM as a mechanism to foster significant collaboration between project participants, namely:

> *"human activity that ultimately involves broad process changes in construction (p.11)."*

Earlier and Accurate 3D Visualisation of Design

3D visualisation of design allows all components of a building to be viewed as an integral whole within a federated BIM (i.e. combining architectural, structural, landscape, mechanical, electrical and plumbing models). Nitithamyong and Skibniewski (2007) acknowledge that visualisation provides a differentiated appearance of information in enlightening the design and construction process. For instance, Shiratuddin and Thabet (2011) provide a virtual design review system for project participants in the realisation of 3D visualisation of designs. Federated BIM is used to visualise design at the early stages of the construction process with the anticipation of consistent views of dimensions (Eastman *et al.*, 2011). 3D visualisation models actively encourage demand amongst members of the project management team for: i) queries to retrieve pertinent data of interest (Tangelder and Veltkamp, 2008); and ii) data-mining algorithms to discover the relationships between them (Han and Kamber, 2006). For example, Gruen and Wang (2000) develop a 3D spatial information system to discover the relationship built up in geometrical information generation and associated information storage and manipulation, while other conceptual models report upon 3D spatial objects and outdoor applications (c.f. Zlatanova and Prosperi, 2005). However, it is expected that 3D models will support spatial analysis and 3D simulation techniques to enhance 3D designs and BIM data federation.

Coordination and Planning of Construction Works

3D objects created at the design stage must link to the construction plan and specific time allowances for constructing these objects must be stated within linked Gantt charts and other planning tools (Eastman *et al.,* 2011). These co-ordination and planning activities assist the project management team to manage construction works more efficiently and effectively on a daily basis and predict potential problems and opportunities for significant improvement (Eastman *et al.*, 2011). Researchers have already augmented BIM's inherent capabilities by developing models to: predict tender prices for construction projects (c.f. Skitmore, 2002; Fitzgerald and Akintoye, 1995); and assist public sector planners to explore the impact of different planned levels of construction workload on tender price changes (c.f. Li *et al.*, 2006). Their research (*ibid*) can be used to assist a planning project for the industry where a demand, capacity and price relationship is applied.

Enhancing Exchange of Information and Knowledge Management

The construction process is renowned as being data and information intensive, particularly in relation to the voluminous drawings, specifications and bills of quantities which accompany a project and are difficult to manage (Sun and Howard, 2004). Information management and knowledge exchange is often accomplished manually between individuals, organisations or members within a project management team (Dawood *et al.*, 2002), or at the project organisation level (Anumba *et al.*, 2008). This process consumes valuable time and inflates cost through loss of data during the exchange of information, inadequacies through rework and uncoordinated exchange of information (Anumba *et al.*, 2008). BIM offers an integrated solution for many ICT systems to support the openness of data and structure for an efficient collaboration among project participants. For example, researchers have established integrated systems for project participants in construction to collaboratively improve the management of information exchange and knowledge management (Chung *et al.*, 2008; Ma *et al.*, 2004). Others, such as Hegazy *et al.*, (2001) and Lee *et al.*, (2008) acknowledge that information models for storing design information, recording design rationale and managing design changes can provide improved design coordination and increase the productivity of the overall design process. Sacks *et al.*,

(2010) identifies the synergies between the principles of BIM implementation and lean construction to manage information exchange and management through lean principles.

Improved Site Layout Planning and Site Safety

Bansal (2011) opines that the geographical and physical characteristic of a facility is dependent upon the layout of temporary site facilities, early construction site works and construction site safety planning. Li *et al.,* (2005) concurr with Bansal (2011) and add that a digital model of construction site terrain could be attained from several approaches including ground surveying, laser scanning, photogrammetry, and light detection and ranging. Moreover, Kamat and Martinez (2005) develop an automated technique to generate 3D terrain databases from digital elevation and imagery data in response to construction operations. Kim and Russel (2003) use digital information on topological and terrain data to explain earthwork operation tasks. Organisational issues consist of a firm's structure, middle management's commitment to safety and the effectiveness of safety trainers in improving the quality of training sessions. According to Jaselskis *et al.,* (1996), and O'Toole (2002), middle management's commitment to site safety training results in low injury occurrences and helps to develop a company's safety culture. In a similar vein Chen *et al.*, (2013) develop a virtual system that comprised of a BIM model to improve safety awareness of hazards and safety issues. In addition, Zhang *et al.*, (2013) propose a rule-checking safety system that applied to fall protection such as guardrails and covers automatically to a BIM. Therefore, BIM facilitates 3D modelling, scheduling and linking them together to visualise safe construction activities.

CONCLUSIONS

Various CSFs for successful BIM implementation have been suggested within extant literature yet there is no review of CSFs for BIM implementation that could summarises a common set of CSFs to provide guidance to both practitioners and academic peers. The current review aimed to identify a common set of CSFs for successful BIM implementation through analysing research articles from 2005 to 2015 (years inclusive). The Scopus search engine was adopted to identify 35 relevant articles that were analysed in this study. The results revealed an increasing trend of CSFs for implementing BIM during the studied period. Developed countries such as the USA, UK and South Korea made the most contribution by publishing the majority of CSFs for successful BIM implementation, albeit developing countries such as India, China, and Malaysia are expected to increase their efforts for successful BIM implementation given the rapid rate of urbanisation in the developing world. Moreover, the majority of target project applications in implementing BIM focused on building construction projects, as evident in 27 articles during the studied period. Furthermore, the research method adopted by most researchers in CSFs for implementing BIM was the case study approach. The key findings proposed five major common set of CSFs for successfully implementing BIM, namely: i) collaboration in design, engineering, and construction stakeholders; ii) earlier and accurate 3D visualisation of design; iii) coordination and planning of construction works; iv) enhancing exchange of information and knowledge management; and v) improved site layout planning and site safety. The findings of this study are expected to provide a useful reference for researchers and practitioners to appreciate research trends and development of CSFs for BIM implementation, and to further deepen their understanding of CSFs in BIM project applications. As such, the developed checklist of CSFs for BIM implementation could be used by researchers to conduct further empirical studies on the studied area and has general applicability for enhancing project-based BIM implementation. Although building construction projects was identified as the greatest target application with CSFs for implementing BIM, researchers and practitioners could conduct more studies based on the checklist of CSFs for BIM implementation in other application such as nuclear power and rail station projects. In addition, the research methods adopted in CSFs for BIM implementation could be used by researchers and practitioners in developed and developing countries to better understand the key approaches that are worth considering when enhancing BIM implementation according to their unique situations, with the help of a common set of CSFs for successful BIM in this review study. By identifying a common set of CSFs for successful BIM implementation, practitioners may better predict the probability of successful BIM implementation and take necessary steps to avoid project-based BIM failure. Moreover, practitioners that could successfully implement the common set of CSFs in their projects may gain a competitive advantage to help win contract bids in the future market. Like other reviews, the current review has some limitations. Firstly, although a comprehensive search strategy was used in the current review, some relevant studies may have been missed. As such, future review studies should consider adding conference proceedings and more recent BIM-related articles to broaden the scope of the study. Secondly, this review was limited to six top tier construction management academic journals and journals that published at least three articles during the period covered by the study (according to the search results). As such the findings cannot be generalised to other industries. Future review may be required to increase the sample size by focusing on BIM implementation in other industries to provide a holistic view of what has been reported in this study.

Acknowledgement

The work described in this study forms part of a PhD research project fully supported by the Department of Building and Real Estate, The Hong Kong Polytechnic University and Research Grants Council of the Hong Kong Special Administrative Region.

REFERENCES

Acharya, N. K., Lee, Y. D. and Im, H. M. (2006) Design Errors: Tragic for Clients, Journal of Construction Research, Vol. 7, No. 1/2, pp. 117–190. DOI: 10.1142/S1609945106000505.

AGC (2006) The Contractors' Guide to BIM-Edition 1, Associated General Contractors of America, (AGC).

AIA (American Institute of Architects) (2007) Integrated Project Delivery: A Guide, Washington, DC. ISBN: 9780470251669.

Anumba, C. J., Issa, R. R. A., Pan, J. and Mutis, I. (2008) Ontology-Based Information and Knowledge Management in Construction, Construction Innovation: Information, Process, Management, Vol. 8, No. 3, pp. 218–239. DOI: 10.1108/14714170810888976.

Aranda-Mena, G., Crawford, J., Chevez, A. and Froese, T. (2009) Building Information Modelling Demystified: Does it Make Business Sense to Adopt BIM? International Journal of Management Projects in Business, Vol. 2, No. 3, pp. 419–434. DOI: 10.1108/17538370910971063.

Arayici, Y. (2008) Towards Building Information Modelling for Existing Structures, Structural Survey, Vol. 26, No. 3, pp. 210-222. DOI: 10.1108/02630800810887108.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. and O'Reilly, K. (2011) BIM Adoption and Implementation for Architectural Practices, Structural Survey, Vol. 29, No. 1, pp. 7–25. DOI: 10.1108/02630801111118377.

Azhar, S. (2011) Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry, Leadership and Management in Engineering, Vol. 11, No. 3, pp. 241–252. DOI: https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127.

Azhar, S., Carlton, W. A., Olsen, D. and Ahmad, I. (2011) Building Information Modelling for Sustainable Design and LEED Rating Analysis, Automation in Construction, Vol. 20, No. 2, pp. 217–224. DOI: https://doi.org/10.1016/j.autcon.2010.09.019.

Azhar, S., Hein, M. and Sketo, B. (2008) Building Information Modeling (BIM): Benefits, Risks and Challenges. Available via: http://ascpro. ascweb. Org/chair/paper/CPGT182002008. pdf (Accessed: November, 2017).

Bansal, V. K. (2011) Application of Geographic Information Systems in Construction Safety Planning, International Journal of Project Management, Vol. 29, No. 1, pp. 66–77. DOI: https://doi.org/10.1016/j.ijproman.2010.01.007.

Barlish, K. and Sullivan, K. (2012) How to Measure the Benefits of BIM-A Case Study Approach, Automation in Construction, Vol. 24, pp. 149–159. DOI: https://doi.org/10.1016/j.autcon.2012.02.008.

Becerik-Gerber, B., Jazizadeh, F., Li, N. and Calis, G. (2011) Application Areas and Data Requirements for BIM-Enabled Facilities Management, Journal of construction engineering and management, Vol. 138, No. 3, pp. 431-442. DOI: 10.1061/ (ASCE) CO.1943-7862.0000433.

Becerik-Gerber, B. and Kensak, K. (2010) Building Information Modeling in Architecture, Engineering, and Construction: Emerging Research Directions and Trends, Journal of Professional Issues in Engineering, Education and Practice, Vol. 136, No. 3, pp. 139–147. DOI: 10.1061/ (ASCE) EI.1943-5541.0000023.

Boktor, J., Hanna, A. and Menassa, C. C. (2014) State of Practice of Building Information Modeling in the Mechanical Construction Industry, Journal of Management in

Engineering, Vol. 30, No. 1, pp. 78–85. DOI: https://doi.org/10.1061/(ASCE)ME.1943-5479.0000176.
Bryde, D., Broquetas, M. and Volm, J. M. (2013) The Project Benefits of Building Information Modelling (BIM), International Journal of Project Management, Vol. 31, No. 7, pp. 971–980. DOI: https://doi.org/10.1016/j.ijproman.2012.12.001.
Bynum, P., Issa, R. R.A. and Olbina, S. (2013) Building Information Modeling in Support of Sustainable Design and Construction, Journal of Construction Engineering and Management, Vol. 139, No. 1, pp. 24–34. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000560.
Cerovsek, T. (2011) A Review and Outlook for a Building Information Model (BIM): A Multi-Standpoint Framework for Technological Development, Advanced Engineering Informatics, Vol. 25, No. 2, pp. 224–244. DOI: https://doi.org/10.1016/j.aei.2010.06.003.
Chan, A. P. C., Chan, D. W. M. and Ho, K. S. K. (2003) An Empirical Study of the Benefits of Construction Partnering in Hong Kong, Construction Management and Economics, Vol. 21, No. 5, pp. 523–533. DOI: 10.1080/0144619032000056162.
Chau, K.W. (1997) The Ranking of Construction Management Journals, Construction Management and Economics, Vol. 15, No. 4, pp. 387–398. DOI: 10.1080/014461997372953.
Chen, A., Golparvar-Fard, M. and Kleiner, B. (2013) Design and Development of SAVES: A Construction Safety Training Augmented Virtually Environment for Hazard Recognition and Severity Identification, Proceedings of International Conference on Computing in Civil Engineering. ASCE, Los Angeles, CA, pp. 841–848. DOI: https://doi.org/10.1061/9780784413029.105.
Cheung, S., Yiu, T. and Lam, M. (2013) Interweaving Trust and Communication with Project Performance, Journal of Construction Engineering and Management, Vol. 139, No. 8, pp. 941–950. DOI: 10.1061/ (ASCE) CO.1943-7862.0000681.
Chiu, M. L. and Lan, J. H. (2005) Information and IN-formation: Information Mining for Supporting Collaborative Design, Automation in Construction, Vol. 14, No. 2, pp. 197–205. DOI: https://doi.org/10.1016/j.autcon.2004.07.011.
Choi, B, Lee, H., Park, M., Cho, Y. K. and Kim, H. (2014) Framework for Work-Space Planning Using Four-Dimensional BIM in Construction Projects, Journal of Construction Engineering and Management, Vol. 140, No. 9, pp. 04014041(13). DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000885.
Chung, B. Y., Skibniewski, M. J., Lucas, H. C. Jr. and Kwak, Y. H. (2008) Analyzing Enterprise Resource Planning System Implementation Success Factors in the Engineering–Construction Industry, Journal of Computing in Civil Engineering, Vol. 22, No. 6, pp. 373–382. DOI: https://doi.org/10.1061/(ASCE)0887-3801(2008)22:6(373).
CII (Construction Industry Institute) (1999a) Exceptional projects and methods of improving project performance. RT 124-1, Austin, TX. Available via: https://www.construction-institute.org/resources/knowledgebase/more-filter-options/result/topics/rt-124/pubs/rs124-1 (Accessed: November, 2017).
Collin, J. (2002) Measuring The Success of Building Projects–Improved Project Delivery Initiatives, An International Journal, Vol. 11, No. 2, pp. 203-221. ISSN: 0090-4600.

CURT (Construction Users Roundtable), (2010) BIM Implementation: An Owner's Guide to Getting Started. Cincinnati. Available via: http://www. aia. Org/aiaucmp/groups/aia/documents/pdf/aiab085571. Pdf, (Accessed: November, 2017).

Darko, A. and Chan, A. P. (2016) Critical Analysis of Green Building Research Trend in Construction Journals, Habitat International, Vol. 57, pp. 53-63. DOI: https://doi.org/10.1016/j.habitatint.2016.07.001.

Dawood, N., Akinsola, A. and Hobbs, B. (2002) Development of Automated Communication of System for Managing Site Information Using Internet Technology, Automation in Construction, Vol. 11, No. 5, pp. 557–572. DOI: https://doi.org/10.1016/S0926-5805(01)00066-8.

Dainty, A. R. J., Roine, L., Fernie, S. and Harty, C. F. (2017) BIM and the Small Construction Firm: A Critical Perspective, Building Research and Information, Vol. 45, No. 6, pp. 696–709. DOI: http://dx.doi.org/10.1080/09613218.2017.1293940.

Dean, R. P. and McClendon, S. (2007) Specifying and Cost Estimating with BIM. Available via: www.architechmag.com/articles/detail.aspx? (Accessed: November, 2017).

Dossick, C. S. and Neff, G. (2010) Organization Divisions in BIM-Enabled Commercial Construction, Journal of Construction Engineering and Management, Vol. 136, No. 4, pp. 459–467. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000109.

Eastman, C. M., Eastman, C., Teicholz, P. and Sacks, R. (2011) BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractor. Hoboken, NJ: Wiley. ISBN: 9780470541371.

Elbeltagi, E. and Dawood, M. (2011) Integrated Visualized Time Control System for Repetitive Construction Projects, Automation in Construction, Vol. 20, No. 7, pp. 940–953. DOI: https://doi.org/10.1016/j.autcon.2011.03.012.

Eriksson, E., Nilsson, T. and Atkin, B. (2008) Client Perceptions of Barriers to Partnering, Engineering Construction and Architectural Management, Vol. 15, No. 6, pp. 527–539. DOI: 10.1108/09699980810916979.

Falagas, M. E., Pitsouni, E. I., Malietzis, G. A. and Pappas, G. (2008) Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and Weaknesses, FASEB Journal, Vol. 22, No. 2, pp. 338–342. DOI: 10.1096/fj.07-9492LSF.

Fitzgerald, E. and Akintoye, A. (1995) The Accuracy and Optimal Linear Correction of UK Construction Tender Price Index Forecasts, Construction Management and Economics Vol. 13, No. 6, pp. 493–500. DOI: 10.1080/01446199500000057.

Fox, S. and Hietanen, J. (2007) Interorganizational Use of Building Information Models: Potential for Automational, Informational and Transformational Effects, Construction Management and Economics, Vol. 25, No. 3, pp. 289–296. DOI: http://dx.doi.org/10.1080/01446190600892995.

Gallello, D., Broekmaat, M. and Freeman, C. (2009) Virtual Construction Benefits. Available via: http://www.vicosoftware.com/virtual-construction-benefits-/tabid/54073/Default.aspx, (Accessed: November, 2017).

Gecevska, V., Chiabert, P., Anisic, Z., Lombardi, F. and Cus, F. (2010) Product Lifecycle Management through Innovative and Competitive Business Environment, Journal of Industrial Engineering and Management, Vol. 3, No. 2, pp. 323–336. DOI: http://dx.doi.org/10.3926/jiem..v3n2.p323-336.

Gruen, A. and Wang, X. (2000) A Hybrid GIS for 3D City Models, International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. 33, No. 4/3, pp. 1165–1172. DOI: https://doi.org/10.3929/ethz-a-005717578.

Gu, N. and London, K. (2010) Understanding and Facilitating BIM Adoption in the AEC Industry, Automation in Construction, Vol. 19, No. 8, pp. 988–999. DOI: https://doi.org/10.1016/j.autcon.2010.09.002.

Han, J., Kamber, M. (2006) Data Mining – Concepts and Techniques, 2nd Edition, Morgan Kaufmann, San Francisco, CA. ISBN: 9781558609013.

Hanna, A., Boodai, F. and Asmar, M. E. (2013) State of Practice of Building Information Modeling (BIM) in Mechanical and Electrical Construction Industries, Journal of Construction Engineering and Management, Vol. 139, No. 10, pp. 04013009. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000747.

Hartmann, T., Meerveld, H. V., Vossebeld, N. and Adriaanse, A. (2012) Aligning Building Information Model Tools and Construction Management Methods, Automation in Construction, Vol. 22, No. 3, pp. 605–613. DOI: https://doi.org/10.1016/j.autcon.2011.12.011.

Hegazy, T., Zaneldin, E. and Grierson, D. (2001) Improving Design Coordination for Building Projects. In: Information Model, Journal of Construction Engineering and Management, Vol. 127, No. 4, pp. 322–329. DOI: https://doi.org/10.1061/(ASCE)0733-9364(2001)127:4(322).

Holt, G. (2010) Contractor Selection Innovation: Examination of Two Decades' Published Research, Construction Innovation, Vol. 10, No. 3, pp. 304-328. DOI: https://doi.org/10.1108/14714171011060097.

Hong, Y. and Chan, D. W. M. (2014) Research Trend of Joint Ventures in Construction: A Two-Decade Taxonomic Review, Journal of Facility Management, Vol. 12, No. 2, pp. 118–141. DOI: 10.1108/JFM-04-2013-0022.

Hong, Y., Chan, D. W. M., Chan, A. P. C. and Yeung, J. F. Y. (2011) Critical Analysis of Partnering Research Trend in Construction Journals, Journal of Management in Engineering, Vol. 28, No. 2, pp. 82–95. DOI: 10.1061/ (ASCE) ME.1943-5479.0000084.

Hornby, A. S., Turnbull, J., Wehmeier, S. and Mclntosh, C. (2005) Oxford Advanced Learner's Dictionary of Current English, 7th Ed., Oxford University Press, Oxford. ISBN: 0194316580.

Howard, G. S., Cole, D. A. and Scott, M. E. (1987) Research Productivity in Psychology Based on Publication in the Journals of the American Psychological Association, American Psychologist, Vol. 42, No. 11, pp. 975–986. DOI: http://dx.doi.org/10.1037/0003-066X.42.11.975.

Huang, T., Li, H., Guo, H., Chan, N., Kong, S., Chan, G. and Skitmore, M. (2009) Construction Virtual Prototyping: A Survey of Use, Construction Innovation, Vol. 9, No. 4, pp. 420–433. DOI: 10.1108/14714170910995958.

Jaselskis, E. J., Anderson, S. D. and Russell, J. S. (1996) Strategies for Achieving Excellence in Construction Safety Performance, Journal of Construction Engineering and Management, Vol. 122, No. 1, pp. 61–70. DOI: https://doi.org/10.1061/(ASCE)0733-9364(1996)122:1(61).

Jung, Y. and Joo, M. (2011) Building information modelling (BIM) Framework for Practical Implementation, Automation in Construction, Vol. 20, No. 2, pp. 126–133. DOI: https://doi.org/10.1016/j.autcon.2010.09.010.

Kamat, V. R. and Martinez, J. C. (2005) Large-Scale Dynamic Terrain in Three-Dimensional Construction Process Visualizations, Journal of Computing in Civil Engineering, Vol. 19, No. 2, pp. 160–171. DOI: 10.1061/ (ASCE) 0887-3801(2005)19:2(160).

Ke, Y., Wang, S., Chan, A. P. and Cheung, E. (2009) Research Trend of Public– Private Partnership in Construction Journals, Journal of Construction Engineering and Management, Vol. 135, No. 10, pp. 1076–1086. DOI: https://doi.org/10.1061/(ASCE)0733-9364(2009)135:10(1076).

Kent, D. C. and Becerik-Gerber, B. (2010) Understanding Construction Industry Experience and Attitudes toward Integrated Project Delivery, Journal of Construction Engineering and Management, Vol. 136, No. 8, pp. 815–825. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000188.

Khanzode, A., Fischer, M. and Reed, D. (2008) Virtual Design and Construction (VDC) Technologies for Coordination of Mechanical, Electrical, and Plumbing (MEP) Systems on a Large Healthcare Project, Journal of Information Technology in Construction, Vol. 13, pp. 324–342. DOI: http://www.itcon.org/2008/22.

Kim, S. K. and Russell, J. S. (2003) Framework for an Intelligent Earthwork System: Part I. System Architecture, Automation in Construction, Vol. 12, No. 1, pp. 1–13. DOI: https://doi.org/10.1016/S0926-5805(02)00034-1.

Koo, B. and Fischer, M. (2000) Feasibility Study of 4D in Commercial Construction, Journal of Construction Engineering and Management, Vol. 126, No. 4, pp. 251–260. DOI: https://doi.org/10.1061/(ASCE)0733-9364(2000)126:4(251).

Kymmell, W. (2008) Building Information Modelling: Planning and Managing Construction Projects with 4D CAD and Simulations, McGraw Hill Construction, New York, USA. ISBN: 9780071494533.

Laan, A., Voordijk, H., Noorderhaven, N. and Dewulf, G. (2012) Levels of Inter Organizational Trust in Construction Projects: Empirical Evidence, Journal of Construction Engineering and Management, Vol. 138, No. 7, pp. 821–831. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000495.

Lee, H. K., Lee, Y. S. and Kim, J. J. (2008) A Cost-Based Interior Design Decision Support System for Large-Scale Housing Projects, Journal of Information Technology in Construction, Vol. 13, pp. 20–38. DOI: http://www.itcon.org/2008/2.

Lee, S., Yu, J. and Jeong, D. (2015) BIM Acceptance Model in Construction Organizations, Journal of Management in Engineering, Vol. 31, No. 3, pp. 04014048(13). DOI: https://doi.org/10.1061/(ASCE)ME.1943-5479.0000252.

Li, B., Fu, F. F., Zhong, H. and Luo, H. B. (2012) Research on the Computational Model for Carbon Emissions in Building Construction Stage Based on BIM, Structural Survey, Vol. 30, No. 5, pp. 411– 425. DOI: 10.1108/02630801211288198.

Li, H., Chan, N., Huang, T., Guo, H. L., Lu, W. and Skitmore, M. (2009) Optimizing Construction Planning Schedules by Virtual Prototyping Enabled Resource Analysis, Automation in Construction, Vol. 18, No. 7, pp. 912–918. DOI: https://doi.org/10.1016/j.autcon.2009.04.002.

Li., H., Lu, W. and Huang, T. (2009) Rethinking Project Management and Exploring Virtual Design and Construction as a Potential Solution, Construction Management and Economics, Vol. 27, No. 4, pp. 363–371. DOI: 10.1080/01446190902838217.

Li, X., Ogier, J. and Cullen, J. (2006) An Economic Modelling Approach for Public Sector Construction Workload Planning, Construction Management and Economics, Vol. 24, No. 11, pp. 1137–1147. DOI: 10.1080/01446190600798960.

Li, Z., Zhu, Q. and Gold, C. (2005) Digital Terrain Modeling: Principles and Methodology, CRC Press, New York. ISBN: 9780203486740.

Love, P. E. D., Mistry, D. and Davis, P. R. (2010) Price Competitive Alliance Projects: Identification of Success Factors for Public Clients, Journal of Construction Engineering and Management, Vol. 136, No. 9, pp. 947–956. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000208.

Lu, Y., Li, Y., Skibniewski, M., Wu, Z., Wang, R. and Le, Y. (2015) Information and Communication Technology Applications in Architecture, Engineering, and Construction Organizations: A 15–Year Review, Journal of Management in Engineering, Vol. 31, No. 1, pp. A4014010 (19). DOI: https://doi.org/10.1061/(ASCE)ME.1943-5479.0000319.

Luth, G. P., Schorer, A. and Turkan, Y. (2014) Lessons from Using BIM to Increase Design-Construction Integration, Practice Periodical on Structural Design and Construction, Vol. 19, No. 1, pp. 103–110. DOI: 10.1061/ (ASCE) SC.1943-5576.0000200.

Ma, Z., Li, H., Shen, Q. P. and Yang, J. (2004) Using XML to Support Information Exchange in Construction Projects, Automation in Construction, Vol. 13, No. 5, pp. 629–637. DOI: https://doi.org/10.1016/j.autcon.2004.04.010.

Manning, R. and Messner, J. I. (2008) Case Studies in BIM Implementation for Programming of Healthcare Facilities, Information Technology in Construction, Vol. 13, No. 18, pp. 446–457. DOI: http://www.itcon.org/2008/18.

Martin, E. W. (1982) Critical Success Factors of Chief MIS/DP Executives, MIS Quarterly, Vol. 6, No. 2, pp. 1-9. DOI: http://www.jstor.org/stable/249279.

McCutcheon, D. M. and Meredith, J. R. (1993) Conducting Case Study Research in Operation Management, Journal of Operations Management, Vol. 11, No. 3, pp. 239–256. DOI: https://doi.org/10.1016/0272-6963(93)90002-7.

McGraw Hill Construction (2012) Smart Market Report: The Business Value of BIM in North America. Bedford, MA, United States. ISBN: 1-800-591-4462.

National Institute of Building Science (NIBS) (2007) National Building Information Modeling Standard (NBIMS), Washington, DC.. Available via: http://www.wbdg.org/pdfs/NBIMSv1_p1.pdf (Accessed: November 2017).

Nitithamyong, P. and Skibniewski, M. J. (2007) Key Success/Failure Factors and Their Impacts on System Performance of Web-Based Project Management Systems in Construction, Journal of Information Technology in Construction. Vol. 12, pp. 39–59. DOI: http://www.itcon.org/2007/3.

Ohsuga, S. (1989). Toward Intelligent CAD Systems, Computer-Aided Design, Vol. 21, No. 5, pp. 315–337. DOI: 10.1016/0010-4485(89)90039-0.

Olatunji, O. A., Sher, W. D. (2009b) Chapter IX: The Applications of Building Information Modelling in Facilities Management. In: Handbook of Research on Building Information Modeling and Construction Informatics: Concepts and Technologies, J. Underwood and U. E. Isikdag, eds., IGI Global. ISBN: 9781605669298.

Osei-Kyei, R. and Chan, A. P. (2015) Review of Studies on the Critical Success Factors for Public–Private Partnership (PPP) Projects from 1990 to 2013, International Journal of Project Management, Vol. 33, No.6, pp. 1335-1346. DOI: https://doi.org/10.1016/j.ijproman.2015.02.008.

O'Toole, M. (2002) The Relationship between Employees' Perceptions of Safety and Organizational Culture, Journal of Safety Research, Vol. 33, No. 2, pp. 231–243. DOI: https://doi.org/10.1016/S0022-4375(02)00014-2.

Ozkaya, I. and Akin, Ö. (2006) Requirement-Driven Design: Assistance for Information Traceability in Design Computing, Design Studies, Vol. 27, No. 3, pp. 381–398. DOI: https://doi.org/10.1016/j.destud.2005.11.005.

Pärn, E. A. and Edwards, D. J. (2017) Conceptualizing the FINDD Toolkit: A Case Study of BIM/ FM Integration, Automation in Construction, Vol. 80, pp. 11–21. DOI: http://dx.doi.org/10.1016/j.autcon.2017.03.015.

Pärn, E. A., Edwards, D. J. and Sing. M. C. P. (2017) The Building Information Modelling Trajectory in Facilities Management: A Review, Automation in Construction, Vol. 75, pp. 45–55. DOI: 10.1016/j.autcon.2016.12.003.

Pektas, S. T. and Pultar, M. (2006) Modelling Detailed Information Flows in Building Design with the Parameter-Based Design Structure Matrix, Design Studies, Vol. 27, No. 1, pp. 99–122. DOI: https://doi.org/10.1016/j.destud.2005.07.004.

Popov, V., Juocevicius, V., Migilimskas, D., Ustinovichius, L. and Mikakauskas, S. (2010) The Use of a Virtual Building Design and Construction Model for Developing an Effective Project Concept in 5D Environment, Automation in Construction, Vol. 19, No. 3, pp. 357–367. DOI: https://doi.org/10.1016/j.autcon.2009.12.005.

Quesada, H. and Gazo, R. (2007) Methodology for Determining Key Internal Business Processes Based on Critical Success Factors: A Case Study in Furniture Industry, Business Process Management Journal, Vol. 13, No. 1, pp. 5–20. DOI: 10.1108/14637150710721104.

Rockart, J. F. (1982) The Changing Role of the Information Systems Executive: A Critical Success Factors Perspective, Sloan Management Review, Vol. 24, No. 1, pp. 3–13. DOI: http://hdl.handle.net/1721.1/2010.

Russell, J. S. (2000) Trends in Our Industry, Journal of Management in Engineering, Vol. 16, No. 1, pp. 3-3. DOI: 10.1061/ (ASCE) 0742-597X (2000).

Sacks, R., Kaner, I., Eastman, C. M. and Jeong, Y. S. (2010) The Rosewood Experiment-Building Information Modeling and Interoperability for Architecture Precast Facades, Automation in Construction, Vol. 19, No. 4, pp. 419–432. DOI: https://doi.org/10.1016/j.autcon.2009.11.012.

Sacks, R., Koskela, L., Dave, B. A. and Owen, R. (2010) Interaction of Lean and Building Information Modeling in Construction, Journal of Construction Engineering and Management, Vol. 136, No. 9, pp. 968–980. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000203.

Sebastian, R. and Van Berlo, L. (2010) Tool for Benchmarking BIM Performance of Design, Engineering and Construction Firms in the Netherlands, Architectural Engineering and Design Management, Vol. 6, No. 4, pp. 254–263. DOI: http://dx.doi.org/10.3763/aedm.2010.IDDS3.

Shiratuddin, M. F. and Thabet, W. (2011) Utilizing A 3D Game Engine to Develop A Virtual Design Review System, Journal of Information Technology in Construction, Vol. 16, pp. 39–68. DOI: http://www.itcon.org/2011/4.

Skitmore, M. (2002) Raftery Curve Construction for Tender Price Forecasts, Construction Management and Economics, Vol. 20, No. 1, pp. 83–89. DOI: 10.1080/01446190110093551.

Smith, D. K., and Tardif, M. (2009) Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers. John Wiley & Sons. ISBN: 9780470250037.

Smith, S. (2007) Using BIM for Sustainable Design, AEC Cafe Weekly, Available via: http://www10.aeccafe.com/nbc/articles/view_weekly.php?section=Magazine&articleid=3 8 6029&printerfriendly=1 (Accessed: November, 2017).

Succar, B. (2009) Building Information Modelling Framework: A Research and Delivery Foundation for Industry Stakeholders, Automation in Construction, Vol. 18, No. 3, pp. 357–375. DOI: https://doi.org/10.1016/j.autcon.2008.10.003.

Suermann, P. C. and Issa, R. R. A. (2009) Evaluation Industry Perceptions of Building Information Modeling (BIM) Impact on Construction, Journal of Information Technology in Construction, Vol. 14, pp. 574–594. DOI: http://www.itcon.org/2009/37.

Sun, M. and Howard, R. (2004) Understanding IT in Construction, Routledge. ISBN: 9781134574032.

Tangelder, J. W. H. and Veltkamp, R. C. (2008) A Survey of Content Based 3D Shape Retrieval Methods, Multimedia Tools and Applications, Vol. 39, No. 3, pp. 441–471. DOI: 10.1007/s11042-007-0181-0.

Tarja, M. and Hannele, K. (2015) Site Managers' Daily Work and the Uses of Building Information Modelling in Construction Site Management, Construction Management and Economics, Vol. 33, No. 3, pp. 163–175. DOI: 10.1080/01446193.2015.1028953.

Taylor, J. E. and Bernstein, P. G. (2009) Paradigm Trajectories of Building Information Modeling Practice in Project Networks, Journal of Management in Engineering, Vol. 25, No. 2, pp. 69–76. DOI: 10.1061/ (ASCE) 0742-597X (2009)25:2(69).

Ting, H. A., Kong, C. W., Guo, H. L., Baldwin, A. and Li, H. (2007) A Virtual Prototyping System for Simulating Construction Processes, Automation in Construction, Vol. 16, No. 5, pp. 576–585. DOI: https://doi.org/10.1016/j.autcon.2006.09.007.

Tsai, C. C. and Wen, M. L. (2005) Research and Trends in Science Education from 1998 to 2002: A Content Analysis of Publication in Selected Journals, International Journal of Science Education, Vol. 27, No. 1, pp. 3–14. DOI: http://dx.doi.org/10.1080/0950069042000243727.

Tse, T. C. K., Wong, K. D. A. and Wong, K. W. F. (2005) The Utilization of Building Information Models in nD modelling: A Study of Data Interfacing and Adoption Barriers, Journal of Information Technology in Construction, Vol. 10, No. 8, pp. 85–110. DOI: http://hdl.handle.net/10397/25423.

US-GSA (U.S. General Services Administration) (2008) 3D-4D Building Information Modelling, Available via: http://www.gsa.gov. (Accessed: November, 2017).

Vacharapoom, B. and Sdhabhon, B. (2010) An Integrated Safety Management with Construction Management Using 4D CAD Model, Safety Science, Vol. 48, No. 3, pp. 395–403. DOI: https://doi.org/10.1016/j.ssci.2009.09.009.

Won, J., Lee, G., Dossick, C. and Messner, J. (2013) Where to Focus for Successful Adoption of Building Information Modeling within Organization, Journal of Construction Engineering and Management, Vol. 139, No. 11, pp. 04013014. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000731.

Wright, E. R., Cho, K. and Hastak, M. (2014) Assessment of Critical Construction Engineering and Management Aspects of Nuclear Power Projects, Journal of Management in Engineering, Vol. 30, No. 4, pp. 04014016(11). DOI: https://doi.org/10.1061/(ASCE)ME.1943-5479.0000286.

Wu, W., and Issa, R. R. A. (2015) BIM Execution Planning in Green Building Projects: LEED as A Use Case, Journal of Management in Engineering, Vol. 31, No. 1, pp. A4014007 (18). DOI: https://doi.org/10.1061/(ASCE)ME.1943-5479.0000314.

Yi, W. and Chan, A. P. (2013) Critical Review of Labor Productivity Research in Construction Journals, Journal of Management in Engineering, Vol. 30, No. 2, pp. 214-225. DOI: https://doi.org/10.1061/(ASCE)ME.1943-5479.0000194.

Yi, H. and Wang, Y. (2013) Trend of the Research on Public Funded Projects, Open Construction Building Technology Journal, Vol. 7, No. 1, pp. 51–62. DOI: 10.2174/1874836820130716002.

Yin, R. K. (2003) Case Study Research: Design and Methods, 3rd Edition, Thousand Oaks, California: Sage Publications. ISBN: 9780761925521.

Zhang, S., Teizer, J., Lee, J. K., Eastman, C. M. and Venugopal, M. (2013) Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules, Automation in Construction, Vol. 29, pp. 183–195. DOI: https://doi.org/10.1016/j.autcon.2012.05.006.

Zhou, W., Whyte, J. and Sacks, R. (2012) Construction Safety and Digital Design: A Review, Automation in Construction, Vol. 22, pp. 102–111. DOI: https://doi.org/10.1016/j.autcon.2011.07.005.

Zlatanova, S. and Prosperi, D. (2005) Large-scale 3D Data Integration: Challenges and Opportunities, CRC Press, Boca Raton, FL. 33487-2742. ISBN: 13: 978-1-4200-3628-2.

Table 1 - Summary of Related Literature on CSFs for Implementing BIM

Item	CSFs	References
1.	Earlier and accurate 3D visualization of design	Fox and Hietanen (2007), Olatunji and Sher (2009b)
2.	Enhancing exchange of information and knowledge management	Pektas and Pultar (2006), Chiu and Lan (2005), Ozkaya and Akin (2006),
3.	Collaboration of simultaneous access of construction work	Ohsuga (1989), Dean and McClendon (2007)
4.	Better design/multi-dimensional design alternatives/applications	Aranda-Mena et al. (2009), Sacks et al. (2010)
5.	Design coordination on various elements/components	Eastman et al. (2011)
6.	Predictive analysis of performance (energy analysis, e.g. CO_2)	Lee et al. (2015), Taylor and Bernstein (2009), Bynum et al. (2013), Li et al. (2012)
7.	Thermal energy analysis and simulation	Azhar (2011), Sebastian and Van Berlo (2010), AGC BIM Guide (2006)
8.	MEP analysis and simulation (HVAC)	Eastman et al. (2011), Azhar (2011), NIBS NBIM Standard (2007)
9.	Structural analysis and design	AGC BIM Guide (2006), Hartmann et al (2012), Arayici et al. (2011)
10.	Predicting environmental analysis and simulation (airflow, weather)	Eastman et al. (2011), Azhar (2011), NIBS NBIM Standard (2007), Sebastian and Van Berlo (2010)
11.	Acoustical analysis and simulation (sound)	Eastman et al. (2011), Azhar (2011), NIBS NBIM Standard (2007), Sebastian and Van Berlo (2010)
12.	Verification of consistency to the design intent	Eastman et al. (2011)
13.	Ensuring effective communication among project participants	Acharya et al (2006)
14.	Collaboration in design, construction, engineering and facility management stakeholders	Lu et al. (2015), Wu and Issa (2015)
15.	Providing BIM models for shop drawings	Eastman et al. (2011), AGC BIM Guide (2006), Hartmann et al (2012), Arayici et al. (2011)
16.	Providing BIM models for offsite prefabrication	Eastman et al. (2011), Azhar (2011), NIBS NBIM Standard (2007), Sebastian and Van Berlo (2010),
17.	Providing better implementation of lean construction, green sustainability and integrated project delivery	Eastman et al. (2011), NIBS NBIM Standard (2007) Hartmann et al (2012), Arayici et al. (2011)
18.	Reducing construction project duration	Bynum et al. (2013), CURT (2010), Khanzode et al. (2008)
19.	Reducing construction project cost	McGraw-Hill Construction (2012)
20.	Model checking and validation (reviewing code)	Azhar (2011), NIBS BIM Standard (2007, 2012), AGC BIM Guide (2006), Hartmann et al (2012)
21.	Improved construction project performance and quality	Khanzode et al. (2008), Suermann and Issa (2009)
22.	Accuracy and reliability of data (less reworking and fewer document errors and omissions)	Barlish and Sullivan (2012), Boktor et al. (2014), Hanna et al. (2013)
23.	Improved site layout, planning and site safety	Li et al. (2009), Vacharapoom and Sdhabhon (2010)
24.	Reduced claims or litigation (risks)	Aranda-Mena et al. (2009), CURT (2010),
25.	Improved operations and maintenance (facility management)	Azhar (2011), Eastman et al. (2011)
26.	4D construction scheduling and sequencing (3D + Time)	Eastman et al. (2011), NIBS NBIM Standard (2007), Sebastian and Van Berlo (2010)
27.	5D cost estimation and scheduling (3D + Time + Cost)	AGC BIM Guide (2006), Hartmann et al (2012)
28.	Coordination and planning of construction works	Eastman et al. (2011), Azhar (2011),Arayici et al. (2011)
29.	Integrating project documentation/bid preparation	Olatuji and Sher (2009b)
30.	Synchronization of procurement with design and construction	Eastman et al. (2011), NIBS NBIM Standard (2007), Sebastian and Van Berlo (2010)
31.	Integrating design validation (clash detection)	Eastman et al. (2011)
32.	Extracting cost estimation and quantity take off	Azhar (2011), Gallello et al (2009),
33.	Remodeling and renovation	Azhar (2011), Hartmann et al (2012), Arayici et al. (2011)
34.	Photorealistic rendering for marketing purposes	NIBS NBIM Standard (2007), Sebastian and Van Berlo (2010), Hartmann et al (2012)

Table 2 - Relevant Publications for this Study

Journal Name	Number of Papers Retrieved from Search Engine	Number of Relevant Publications
Journal of Construction Engineering and Management	13	10
Construction Management and Economics	10	8
Journal of Management in Engineering	11	6
Building Research and Information	4	4
International Journal of Project Management	6	4
Engineering, Construction and Architectural Management	6	3
Total	50	35

Table 3 - Score Matrix for Multi Authored Papers

No. of Authors	Order of Authors					
	1	2	3	4	5	6
1	1					
2	0.6	0.4				
3	0.47	0.32	0.21			
4	0.42	0.28	0.18	0.12		
5	0.38	0.26	0.17	0.11	0.08	
6	0.37	0.24	0.16	0.11	0.07	0.05

Source: Howard *et al.*, (1987), Tsai and Wen (2005), Ke *et al.*, (2009) and Yi and Wang (2013)

Figure 1 - Annual Distribution of Selected Papers Over the Period 2005 to 2015

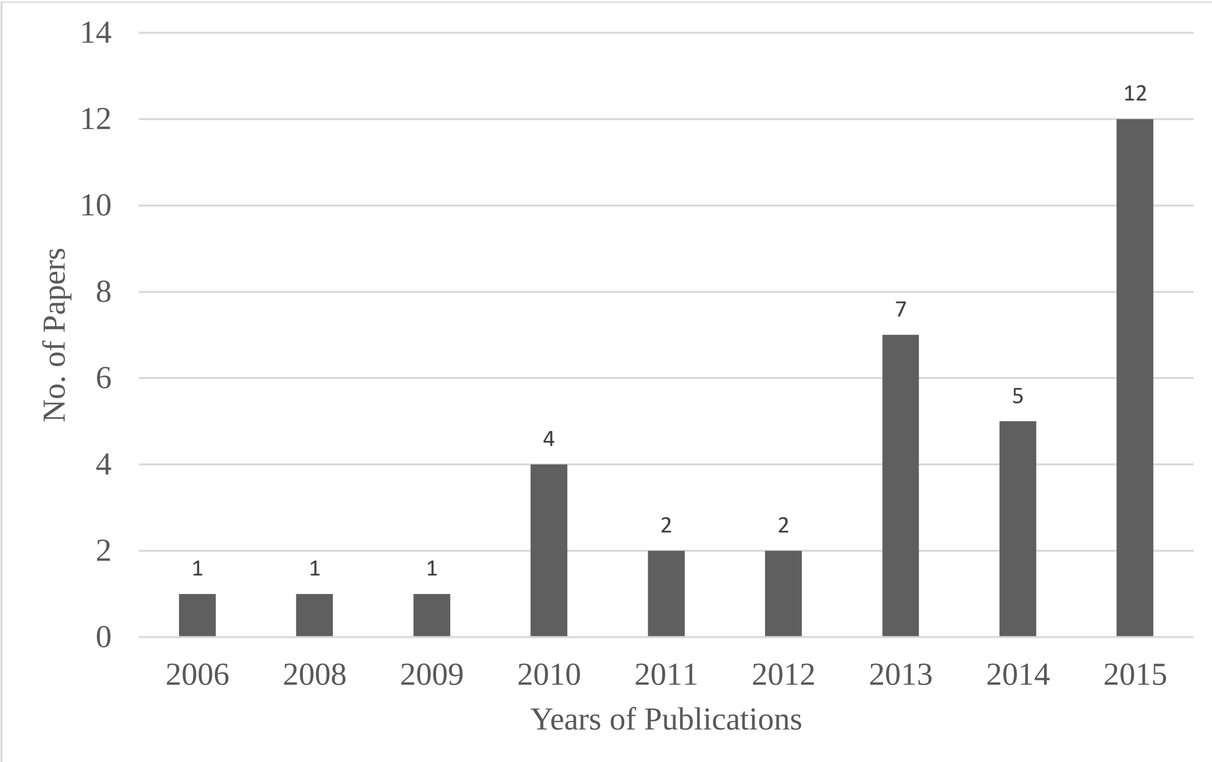

Table 4 - Authors' Origin/ Country Contribution on CSFs for Implementing BIM Over the Period 2005 to 2015

Country	Research Centres	No. of Researchers	Publications (Papers)	Score
USA	15	31	17	9.79
UK	10	17	8	7.74
South Korea	4	10	6	3.85
Finland	1	6	2	2.00
Australia	2	3	2	1.79
India	3	3	2	1.79
Israel	1	3	1	1.00
Netherland	1	1	1	1.00
Norway	1	4	1	1.00
Germany	3	4	3	0.96
Switzerland	2	2	1	0.79
Turkey	1	1	1	0.60
Singapore	2	2	2	0.58
China	1	4	1	0.47
Spain	1	1	1	0.32
Malaysia	1	1	1	0.21
Brazil	1	1	1	0.11

Figure 2 - Distribution of Target Project Applications of BIM Implementation

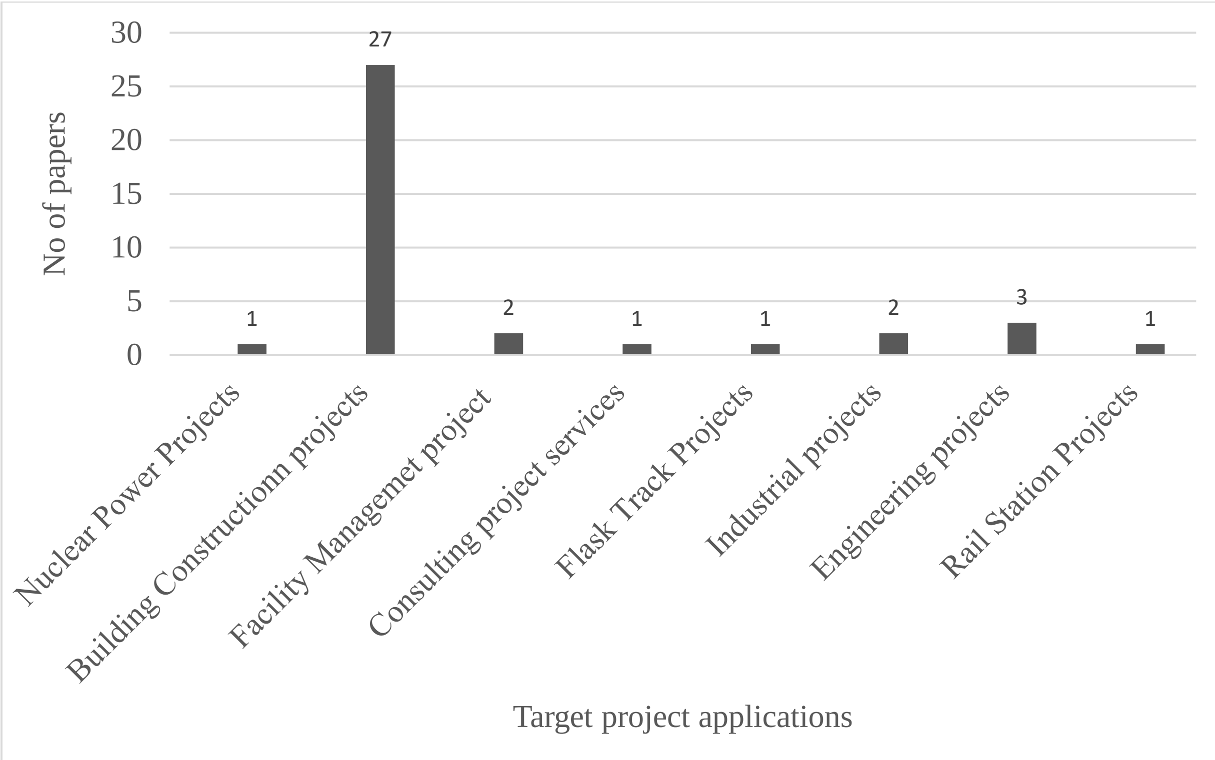

Figure 3 - Distribution of Research Methods Used in Selected Journal Papers

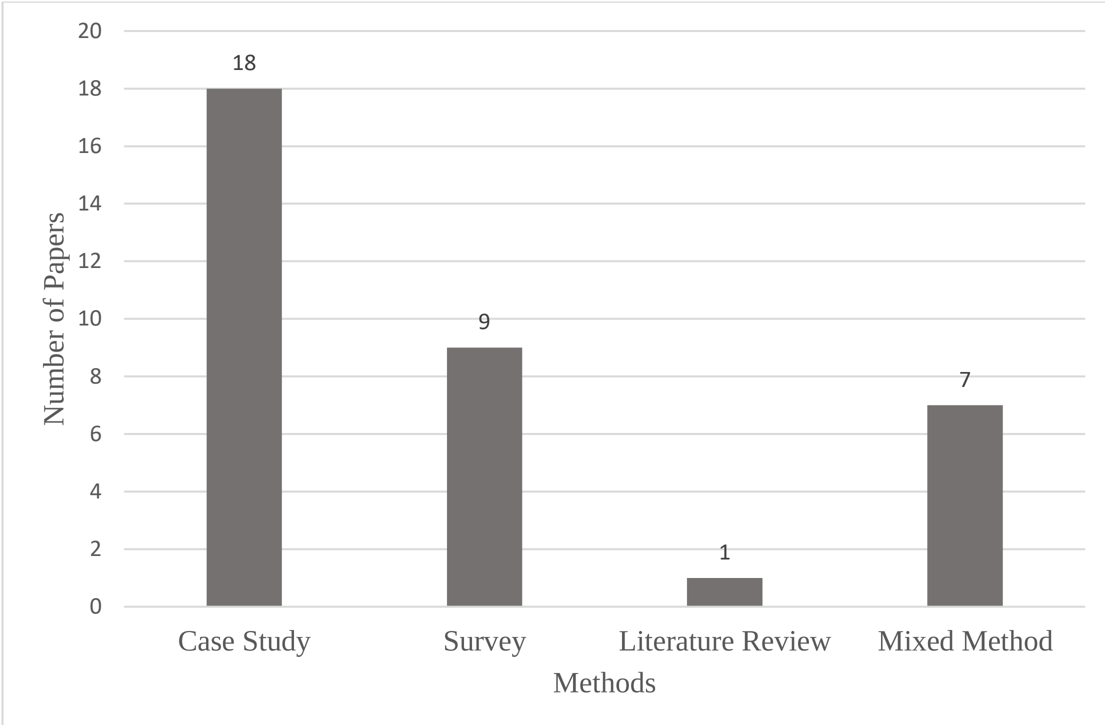

Table 5 - Findings from Studies on CSFs for Implementing BIM Over the Period 2005 to 2015

S/N	Publications									Total	Rank
	2006	2008	2009	2010	2011	2012	2013	2014	2015		
1.			*	*			**	*	****	**9**	**2**
2.			*	*			***	***		**8**	**4**
3.			*	*			*	*	*	5	6
4.								*	*	2	19
5.				*			**	*	*	5	6
6.								*		1	25
7.				*						1	25
8.				*	*				*	3	17
9.				*						1	25
10.				*		*	*			3	17
11.				*						1	25
12.							*	*		2	19
13.				*			*	*	**	5	6
14.				**			***	*	*****	**11**	**1**
15.								*	*	2	19
16.				*		*		*	**	5	6
17.							*	**	*	4	11
18.							*	**	*	4	11
19.							*	**	*	4	11
20.			*	*						2	19
21.							***	*	*	5	6
22.				**				*	*	4	11
23.					*		*	**	**	**6**	**5**
24.							*		*	2	19
25.				*				*	**	4	11
26.								*		1	25
27.								*		1	25
28.	*						****	*	***	**9**	**2**
29.								*		1	25
30.								*		1	25
31.				*			*	*	*	4	11
32.							*	*		2	19
33.		*								1	25
34.								*		1	25

Table 6 - Findings from Studies on Identified CSFs for Implementing BIM with their Respective Publications

S/N	Publications																																			Total	Rank
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
1.		*							*			*		*				*	*			*				*					*			*		10	2
2.		*										*	*		*			*		*		*													*	8	3
3.		*										*		*	*			*																		5	7
4.														*				*																		2	19
5.												*		*				*				*												*		5	7
6.																		*																		1	24
7.																																		*		1	24
8.						*																				*								*		3	14
9.																																		*		1	24
10.				*																		*												*		3	14
11.																																		*		1	24
12.																		*				*														2	19
13.										*					*			*				*				*										5	7
14.										*		*		*	*			*				*				*	*	*					*		*	11	1
15.																													*	*						2	19
16.																										*			*	*		*		*		5	7
17.																				*		*					*									3	14
18.														*		*		*				*														4	11
19.														*		*		*				*														4	11
20.		*																																		1	24
21.					*					*							*	*				*												*		6	6
22.			*							*								*																		3	14
23.							*			*					*	*		*						*	*											7	5
24.																						*	*													2	19
25.											*										*													*		3	14
26.																		*																		1	24
27.																		*																		1	24
28.								*		*		*						*				*					*	*			*					8	3
29.																		*																		1	24
30.																		*																		1	24
31.														*				*				*												*		4	11
32.							*											*																		2	19
33.	*																																			1	24
34.																		*																		1	24

Table 7 -Papers on CSFs for BIM Implementation in Selected Journals

S/N	Journal	Year	Authors
1.	BRI	2008	Igor Sartoti, Havard Bergsdal, Daniel B. Muller and Helge BrattebØ
2.		2009	Armin Gruen, Martin Behnisch and Niklaus Kohler
3.		2010	T.J. Williamson
4.		2012	Carlos Calderon and James Keirstead
5.	CME	2013	Richard Davies and Chris Harty
6.		2011	Irina Brodetskaia, Rafael Sacks, and Aviad Shapira
7.		2013	Jürgen Melzner, Sijie Zhang, Jochen Teizer and Hans-Joachim Bargstädt
8.		2006	Xiaohong Li, John Ogier and John Cullen
9.		2015	Amma Shibeika and Chris Harty
10.		2015	Tarja Mäki and Hannele Kerosuo
11.		2015	Jenni Korpela, Reijo Miettinen, Teppo Salmikivi and Jaana Ihalainen
12.		2013	Peter Demian and David Walters
13.	ECAM	2014	Abdou Karim Jallow, Peter Demian, Andrew N. Baldwin and Chimay Anumba
14.		2015	John Rogers, Heap-Yih Chong and Christopher Preece
15.		2010	Rizal Sebastian
16.	JME	2014	Erik R. Wright, Kyuman Cho and Makarand Hastak
17.		2013	Seulki Lee, Jungho Yu and David Jeong
18.		2014	Yujie Lu, Yongkui Li, Miroslaw Skibniewski, Zhilei Wu, Runshi and Yun Le
19.		2015	Algan Tezel, Lauri Koskela, Patricia Tzortzopoulos, Carlos Torres Formoso and Thais Alves
20.		2014	Nida Azhar, Youngcheol Kang and Irtishad Ahmad
21.		2015	Brittany Giel and Raja R A. Issa
22.	IJPM	2013	David Bryde, Martí Broquetas and Jürgen Marc Volm
23.		2015	Chen-Yu Chang
24.		2011	V.K. Bansal
25.		2015	Sevilay Demirkesen and David Arditi
26.	JCEM	2015	Hisham Said
27.		2015	Ashwin Mahalingam, Amit Kumar Yadav and Jarjana Varaprasad
28.		2015	Robert B. Austin P.E., Pardis Pishdad-Bozorgi and Jesus M. de la Garza
29.		2015	James T. O'Connor, William J. O'Brien and Jin Ouk Choi
30.		2014	James T. O'Connor, William J. O'Brien and Jin Ouk Choi
31.		2013	Ebrahim P. Karan, Ramachandra Sivakumar, Javier Irizarry and Subhro Guhathakurta
32.		2012	Ghang Lee and Seonwoo Kim
33.		2010	Heedae Park, Seung H. Han, Eddy M. Rojas, JeongWook Son and Wooyong Jung
34.		2010	David C. Kent and Burcin Becerik-Gerber
35.		2013	Jongsung Won, Ghang Lee, Carrie Dossick and John Messner