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Review

Critical success factors for implementing building information modelling (BIM): A longitudinal review

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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.

1. Introduction

Building information modelling (BIM) has revolutionised building and infrastructure development within the construction and civil engineering industries over the last decade [1]. A plethora of studies expound the virtues of BIM implementation throughout a development's whole life cycle (c.f. [1–4]). However, BIM implementation has been slow particularly among small-to-medium enterprises [1,5,6]. 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) [2,7–11]. However, resolving these issues requires a deeper and richer knowledge of critical success factors (CSFs) used for measuring the successful implementation of BIM. From Hornby et al. [12], implementation is the process of putting a decision or plan into effect. According to Rockart [13], 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 [14] 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 [15]. 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 [16].

Extant literature reports upon a plethora of BIM studies that utilise CSFs for measuring successful BIM implementation. For example, Eastman et al. [1] identify that an evaluation of energy analyses during the design stage provides insight as a CSF for a successful BIM implementation. Popov et al. [17] asserts that BIM implementation facilitates the creation, communication and sharing of information throughout a building's entire life-cycle, while Kymmell [18] 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 [8]. Yet despite increased academic attention, a longitudinal analysis of CSFs within existing literature is

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Table 1
Summary of related literature on CSFs for implementing BIM.

Item	CSFs	References
1.	Earlier and accurate 3D visualisation of design	Fox and Hietanen [37], Olatunji and Sher [38]
2.	Enhancing exchange of information and knowledge management	Pektas and Pultar [39], Chiu and Lan [40], Ozkaya and Akin [41]
3.	Collaboration of simultaneous access of construction work	Ohsuga [42], Dean and McClendon [43]
4.	Better design/multi-dimensional design alternatives/applications	Aranda-Mena et al. [44], Sacks et al. [35,45]
5.	Design coordination on various elements/components	Eastman et al. [1]
6.	Predictive analysis of performance (energy analysis, e.g. CO_2)	Lee et al. [46], Taylor and Bernstein [28], Bynum et al. [47], Li et al. [48]
7.	Thermal energy analysis and simulation	Azhar [2], Sebastian and Van Berlo [49], AGC BIM Guide [23]
8.	MEP analysis and simulation (HVAC)	Eastman et al. [1], Azhar [2], NIBS NBIM Standard [50]
9.	Structural analysis and design	AGC BIM Guide [23], Hartmann et al. [51], Arayici et al. [8]
10.	Predicting environmental analysis and simulation (airflow, weather)	Eastman et al. [1], Azhar [2], NIBS NBIM Standard [50], Sebastian and Van Berlo [49]
11.	Acoustical analysis and simulation (sound)	Eastman et al. [1], Azhar [2], NIBS NBIM Standard [50], Sebastian and Van Berlo [49]
12.	Verification of consistency to the design intent	Eastman et al. [1]
13.	Ensuring effective communication among project participants	Acharya et al. [25]
14.	Collaboration in design, construction, engineering and facility management stakeholders	Lu et al. [52], Wu and Issa [53]
15.	Providing BIM models for shop drawings	Eastman et al. [1], AGC BIM Guide [23], Hartmann et al. [51], Arayici et al. [8]
16.	Providing BIM models for offsite prefabrication	Eastman et al. [1], Azhar [2], NIBS NBIM Standard [50], Sebastian and Van Berlo [49]
17.	Providing better implementation of lean construction, green sustainability and integrated project delivery	Eastman et al. [1], NIBS NBIM Standard [50], Hartmann et al. [51], Arayici et al. [8]
18.	Reducing construction project duration	Bynum et al. [47], CURT [54], Khanzode et al. [55]
19.	Reducing construction project cost	McGraw-Hill Construction [56]
20.	Model checking and validation (reviewing code)	Azhar [2], NIBS BIM Standard [50,120], AGC BIM Guide [23], Hartmann et al. [51]
21.	Improved construction project performance and quality	Khanzode et al. [55], Suermann and Issa [57]
22.	Accuracy and reliability of data (less reworking and fewer document errors and omissions)	Barlish and Sullivan [3], Boktor et al. [58], Hanna et al. [59]
23.	Improved site layout, planning and site safety	Li et al. [60], Vacharapoom and Sdhabhon [61]
24.	Reduced claims or litigation (risks)	Aranda-Mena et al. [44], CURT [54]
25.	Improved operations and maintenance (facility management)	Azhar [2], Eastman et al. [1]
26.	4D construction scheduling and sequencing (3D + time)	Eastman et al. [1], NIBS NBIM Standard [50], Sebastian and Van Berlo [49]
27.	5D cost estimation and scheduling (3D + time + cost)	AGC BIM Guide [23], Hartmann et al. [51]
28.	Coordination and planning of construction works	Eastman et al. [1], Azhar [2], Arayici et al. [8]
29.	Integrating project documentation/bid preparation	Olatunji and Sher [38]
30.	Synchronization of procurement with design and construction	Eastman et al. [1], NIBS NBIM Standard [50], Sebastian and Van Berlo [49]
31.	Integrating design validation (clash detection)	Eastman et al. [1]
32.	Extracting cost estimation and quantity take off	Azhar [2], Gallello et al. [62]
33.	Remodeling and renovation	Azhar [2], Hartmann et al. [51], Arayici et al. [8]
34.	Photorealistic rendering for marketing purposes	NIBS NBIM Standard [50], Sebastian and Van Berlo [49], Hartmann et al. [51]

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.

2. Research background

2.1. 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 [1,18]. According to Smith [19], 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 [20]. Although BIM definitions are myriad (c.f. [21,22]), 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.*"
>
> ([23], 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' [7]) is integral to current industry trends toward fully automating project processes [24]. While several contextual definitions of BIM have been established (c.f. [2,7,21,23]), for this study BIM is defined as a modelling technology and associated set of processes to produce, communicate and analyse building models [1].

2.2. 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 [1,2,8,25]. Azhar et al.