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Measuring the Benefits of Building Information Modeling (BIM) Adoption: Trends, Gaps and Future Directions

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Abstract: Building information modelling (BIM) adopters require well-documented, quantitative, and financial simulation studies as solid evidence for the benefits of BIM to implement it and evaluate its success. However, to move towards more practical analyses to be performed by the end-users, more discussions on process to measure BIM benefit should be held, despite the large number of studies related to BIM benefit indicators. Therefore, this study examines the proposed and simulated methods used to measure the benefits of BIM in previous studies. A systematic literature review (SLR) of 21 articles was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and analysed using meta-ethnography and thematic qualitative analysis. The SLR depicted the trends of studies published over the years. The results indicate that out of the 31 BIM benefits identified, only 17 BIM benefits have been measured in simulations. 4 other BIM benefits were suggested to be explored in line with their magnitude of importance. Comparative case studies were used conventionally to collect the data for measuring these benefits. This has since shifted to conducting case studies of single BIM projects along with supplementary data collection for counterfactual assessment. Furthermore, predictive ex-ante studies are currently blooming. At present, ongoing studies are being conducted to demonstrate the detailed technique with which to calculate and measure the benefits of BIM. This paper provides researchers and analysts with initial insights that can be used to move forward with BIM benefit measurements.

Keywords: Systematic Literature Review (SLR), Building Information Modelling (BIM), benefit realization management, measurement, return on investment, cost-benefit analysis

1. Introduction

Many extant studies attempted to provide statistical proof that building information modelling (BIM) could provide adopters with real outcomes and benefits. The five most commonly reported benefits of investing in BIM are schedule reduction and compliance, improved productivity, fewer requests for information (RFI) as well as fewer reworking and change or variation orders (VO) (Sompolgrunk et al., 2021). The use of BIM has been found to decrease the duration of a project by 7% (Azhar & Asce, 2011; Grzyl et al., 2017). A case study by Nur Sholeh et al. (2020) found that the duration of the planning and design phases of a BIM-based project is 50% shorter than that of a conventional project due to the simultaneous working process (Nur Sholeh et al., 2020). Sompolgrunk et al. (2021) reported ROI from previous studies

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on clash detection as one of the returning factors to be 140% to 39,900%. Another case study found that coordinating the mechanical, electrical, and plumbing (MEP) system using BIM as well as virtual design and construction (VDC) decreased RFI and rework by the mechanical subcontractor to less than 0.2% and yielded $9 million in cost savings (Khandoze et al., 2008).

According to Yevu et al. (2020), although many studies have examined the benefits of information technology (IT), not many have attempted to measure its benefits. Similarly, since high capital investment is needed for the adoption of BIM technology, industry players were concerned about the identification and measurement of its benefit and cost as a form of legitimate evidence for their investment (Chahrour et al., 2021; Lu et al., 2014; PwC, 2018a). Therefore, to sustain and increase the BIM adoption rate, quantitative analysis and financial information regarding BIM benefits are needed as key motivators (Becerik-Gerber & Rice, 2010; Ham et al., 2018). Apart from providing empirical evidence, recent literature has highlighted the importance of BIM investment evaluation that could be performed by the adopters to justify, compare, and rank their investment decisions (Ardani et al., 2022).

According to a review study done by Ardani et al. (2022), there are various evaluation methods that have been used by previous studies, such as Return on Investment (ROI), Cost-Benefit Analysis (CBA), Benefit Realization Management (BRM) and Success Level Assessment Model (SLAM BIM). ROI evaluation method examines multiple returning factors that affect the ROI value (Sompolgrunk et al., 2021) while the CBA itemizes different benefit and cost items according to different alternatives and stakeholders (Atkinson et al., 2018; Boardman, 2014; de Rus, 2021; Romijn & Renes, 2013). On the other hand, BIM value realization frameworks, which were adapted from the Benefit Realization Management (BRM) theory (Love et al., 2014; Sanchez & Hampson, 2016) and the SLAM BIM model (Won & Lee, 2016) use a series of processes, which include setting up goals and developing a strategy with which to achieve the goals using different sets of metrics; to measure the benefits of BIM. Specific calculation techniques and the respective resultant units can then be used to measure the benefits of BIM according to the metrics.

Figure 1 provides a summary of the key steps of the above-mentioned methods of evaluating the benefits of BIM. Previous studies have started to evaluate BIM implementation through similar processes (Gurevich & Sacks, 2017, 2020; Huang & Hsieh, 2020; Oesterreich & Teuteberg, 2018; PwC, 2018b, 2018a). However, to move towards more practical analyses to be implemented by the end-users, more discussions on the process to measure BIM benefit should be held, despite the large number of studies related to BIM benefit indicators. In this research, the BIM benefit measurement process refers to the steps that must be taken in response to the BIM benefit indicators set in a certain organisation or project. It consists of metrics, techniques, and units of measurement for each benefit indicator.

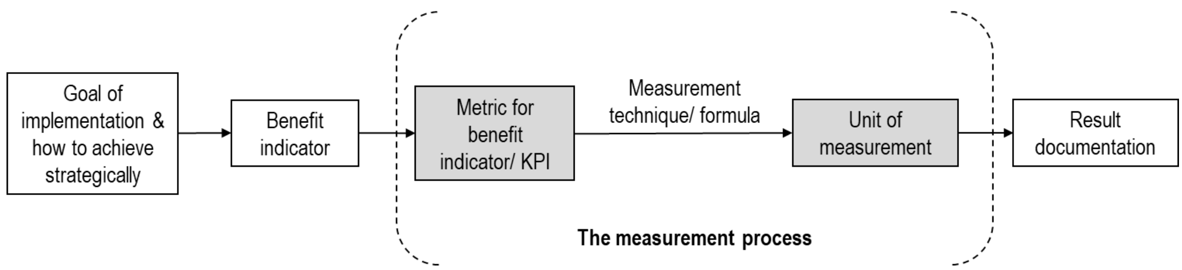

Fig. 1 - Key steps summarized from multiple BIM benefit evaluation methods

Therefore, this present study filled this gap in the knowledge by answering the following research question:

• What is the process used to measure different benefits of BIM investment?

As seen in the research question, this present study aimed to examine the measurement process of BIM benefits that have been proposed and simulated in previous literature. This includes the measurement metrics, the extent of the measurement; whether it is quantified and monetized, the perspective of the measurement; whether it is conducted prior to implementation (*ex-ante*) or after implementation (*ex-post*), and the technique and unit of measurement, as well as the data that adopters must collect for the measurement. This was crucial as it facilitated assessing the applicability of an evaluation method to an end-user.

As such, this present study first provides an overview of the extant literature on the measurement of BIM benefit over the years before classifying these measurement processes according to a BIM benefit realization framework to thematically depict the development of different key processes.

2. Methods

2.1 Research Design

A systematic literature review protocol was first developed and reviewed by the research team. The protocol was adapted from Kitchenham (2007), which was developed based on the needs of researchers in the software engineering industry. This protocol was chosen as it was more applicable to the nature of this present study than other review protocols, such as Campbell Collaboration and Cochrane Collaboration, which were more applicable to the medical industry.

The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Page et al., 2021; Shamseer et al., 2015). According to Shahruddin & Zairul (2020), several BIM studies have used PRISMA.

2.2 Searching Strategy and Configuration

The sample, phenomenon of interest, design, evaluation, research type (SPIDER) tool was used to identify the key elements of the research question. It was chosen as it facilitates a timely and sensitive search process for qualitative exploratory studies (Cooke et al., 2012; Mohamed Shaffril et al., 2021). The SPIDER criteria for this review were as follows:

- Sample: Building Information Modelling (BIM) implementation or project
- Phenomenon of Interest: Benefits
- Design: Measurement and quantification method
- Evaluation: Case study and simulation of measurement method
- Research type: Quantitative and mixed-method studies

Based on the above criteria, a systematic literature search was conducted on two primary databases; namely Scopus and Web of Science (WoS); in October 2022 using the search strings shown in Table 1. These databases were selected as major extant studies on the implementation of BIM had referred to them (Alankarage et al., 2021; Ardani et al., 2022; Z. Liu et al., 2019; Shahruddin & Zairul, 2020; Sompolgrunk et al., 2021; Wan Mohammad, 2022). Furthermore, according to Z. Liu et al. (2019), WoS has a relatively complete data structure and contains major journals that are sufficient for reviewing BIM-related research. Scopus, on the other hand, enables users to execute the four-key searching technique, which could yield better search results (Shahruddin & Zairul, 2020).

Table 1 - Search strings used in two primary databases

Database	Search string
Scopus	TITLE-ABS-KEY ("Building information modelling") OR TITLE-ABS-KEY ("BIM") AND TITLE-ABS-KEY ("benefit") OR TITLE-ABS-KEY ("value") OR TITLE-ABS-KEY ("success") AND TITLE-ABS-KEY ("quantify") OR TITLE-ABS-KEY ("measure")
Web of Science (WoS)	Using the topic of TITLE-ABSTRACT-KEYWORDS, the combination of keywords "Building Information Modelling" OR "BIM" AND "Benefit" OR "Value" OR "Success" AND "Measure" OR "Quantify" were used in 12 separate searches.

2.3 Database Selection and Study Selection Criteria (Inclusion and Exclusion)

While searching the database, automated screening was used to only include articles published between 2004 and 2022, as the first article on BIM was published in 2004 (Z. Liu et al., 2019; Sompolgrunk et al., 2021). Articles that had been published in languages other than English were also excluded at this stage. Grey articles such as books, book chapters, and conference proceedings were also excluded to maintain the reliability and validity of the results.

The references obtained by searching both databases were exported to the Endnote database (Endnote version 20.4.1), and duplicates were removed. This yielded 308 articles. The titles and abstracts of the articles were then manually screened. Articles were excluded if the research topic did not discuss BIM as the primary cause of the measured benefits or only used BIM for simulation purposes. For example, articles that discussed the environmental benefits of other non-BIM-related activities but used BIM to conduct simulations were excluded. This yielded 61 articles.

2.4 Study Selection Procedure (Eligibility)

The eligibility of the remaining 61 articles was assessed. Two members of the research team manually and independently reassessed the title, abstract, findings, and conclusions of the articles. Articles were excluded if: (1) their contents did not correlate with BIM according to the SPIDER criteria; (2) they did not propose a method of measuring the benefits of BIM; or (3) they were measurement method studies such as whole CBA or ROI studies that measured the benefits of BIM but only in general. This yielded 18 articles for quality appraisal with consensus.

2.5 Quality Appraisal

The quality checklist that Kitchenham's (2007) proposed was used to assess the quality of the remaining 18 articles. Kitchenham's (2007) checklist is normally used to examine software engineering experiments qualitatively and quantitatively as opposed to the 'subject blinding' protocols of medical research. The adapted checklist for this present study focused on several issues, including:

1. Is the research design appropriate?
    - Is the aim of the research clearly stated?
    - Does the research have a control group?
    - If it does have a control group, are the outcome-affecting variables that these participants encounter similar to those of the treatment group?
    - Does the scope of the research, namely its size and duration, sufficiently allow for changes in the outcomes of interest to be identified?
2. Are the methodology and analysis methods of the research appropriate?
    - Are the data collection methods of the research adequately described?
    - Are the types of data clearly explained?
    - Are the participants or observational units of the research adequately described?
    - Are the scoring systems of the research described?

A two-point scale, with 1 for Yes and 0 for No, was used to assess the quality of studies according to the items on the checklist and rate them as either high, medium, or low (Mohamed Shaffril et al., 2021). Two articles were discarded as they did not conduct a simulation to prove the proposed process of measuring the benefits of BIM. They also failed to provide baseline or control variables to depict that the benefit measured was the result of BIM adoption.

2.6 Data Extraction

A total of 16 articles were included for data extraction. Five additional articles were included at this stage as a result of cross referencing during the data extraction process. Figure 2 illustrates the process that was used to exclude, include, and evaluate the records in a PRISMA 2020 flow diagram (Page et al., 2021).

A data extraction form, that had been validated by two members of the research team, was used to extract the data. Key variables; namely the (i) name of the authors, (ii) the title and year of publication, (iii) the aim of study, (v) the BIM benefit measured, (vi) the presence of quantification and monetization process, (vii) measurement metrics and formula, (viii) the units of the benefit measurement, (ix) the data used to perform the measurement, and (x) its method and data collection method; were extracted into the data extraction form.

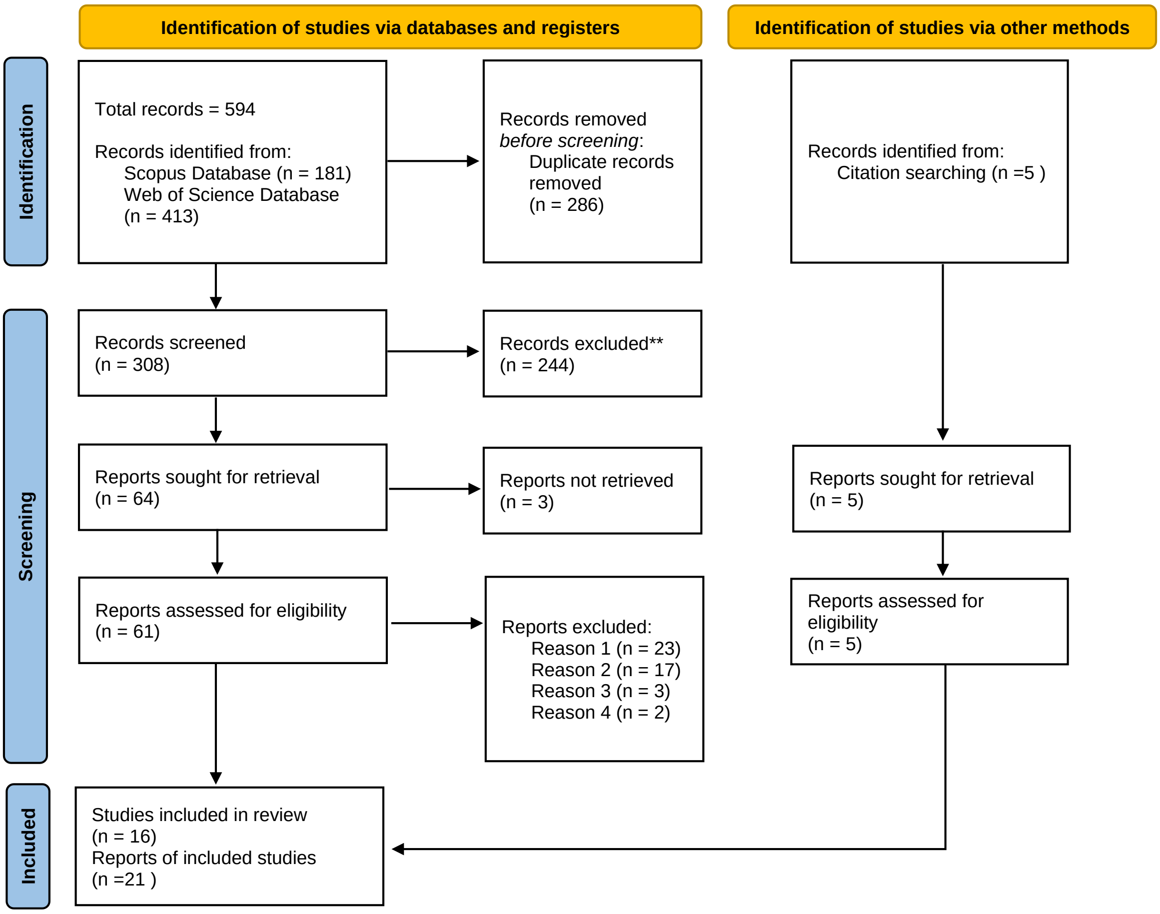

Fig. 2 - PRISMA flow diagram

2.7 Data Synthesis

The 21 articles were qualitative synthesised according to the recommendations of Noblit and Hare (1988) as 'lines of argument' using the meta-ethnography method. Kitchenham (2007) describes this method as creating an inference of a topic based on the studies examined. The individual articles were analysed to identify similarities or dissimilarities to develop a new interpretation (Noblit & Hare, 1988; Thomas & Harden, 2008). A thematic analysis was conducted as part of the meta-ethnography synthesis, where the key concepts of the studies were identified then translated into another using the theme (Thomas & Harden, 2008).

The data that was tabulated in the data extraction form was initially open coded to identify the themes. This was then compared to similar themes found in existing literature. The themes present in the data were identified using previous studies, mostly in the form of a 'metric' for the different indicators of BIM benefits (Figure 1). The measurement processes identified in each paper were deductively coded by basing the analysis on two of the components in Sanchez & Hampson's (2016) BIM benefit realisation framework; namely, the benefit dictionary and metric dictionary (Hudson et al., 2018; Smith, 2021). These two components were chosen as they comprehensively link different measurement metrics to their respective BIM benefits. Furthermore, Sanchez & Hampson's (2016) benefit dictionary was compiled in different perspectives of project phases and construction stakeholders. Oesterreich & Teuteberg's (2018), similarly, successfully adapted Sanchez & Hampson (2016)'s framework and dictionaries to measure BIM benefits. The data of this present study was primarily analysed by coding it according to the 54 types of measurement metrics and later mapping them to their respective benefit indicators (Figure 3).

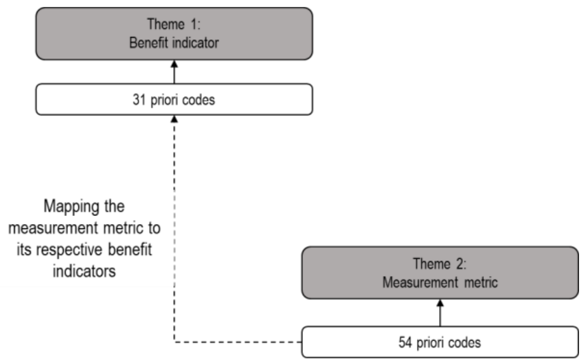

Fig. 3 - Thematic analysis via deductive coding

3. Results and Discussion

3.1 Trends of Measurement of BIM Benefits Across the Years

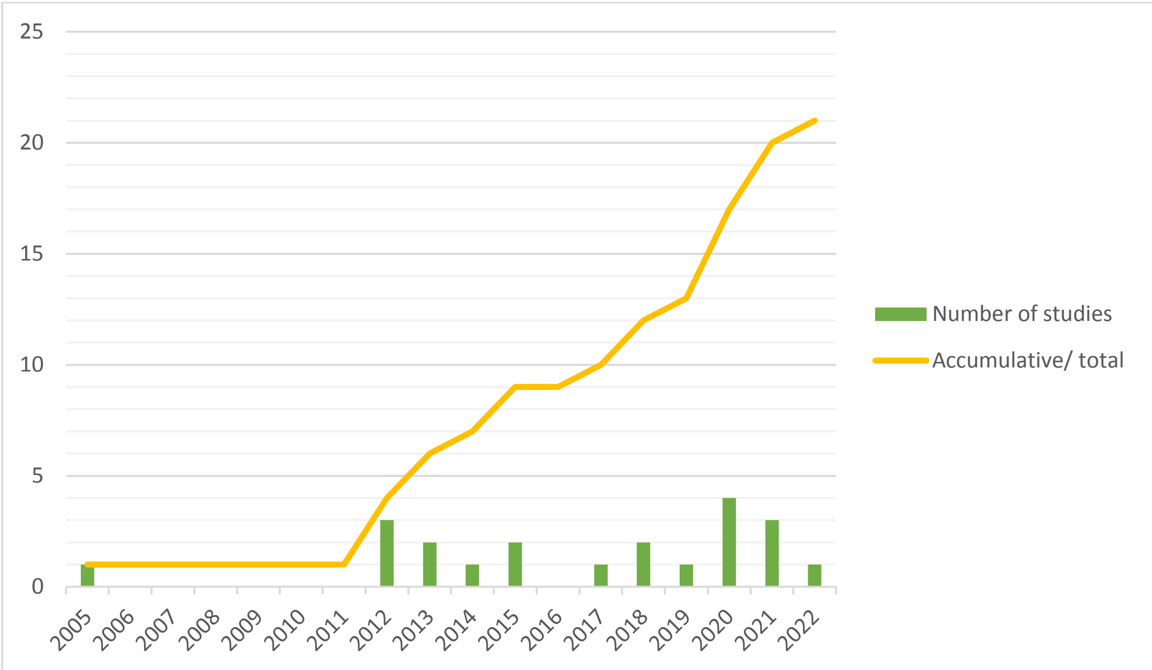

Fig. 4 - Overview of previous related studies published between 2005 to 2022

Figure 4 provides the distribution of past studies published according to year. Although the first study on BIM benefit measurements was first simulated and scientifically published in 2005, most of the studies were conducted only after 2012. Since then, two to three BIM benefit measurement studies have been published annually on average. This indicates that this area of research is new and gaining more and more attention.

The results of the review were further examined using Sanchez & Hampson's (2016) BIM benefit realization framework to determine the comprehensiveness of selected studies in capturing BIM benefit measurement. The studies were coded and mapped according to 31 BIM benefit indicators and 54 measurement metrics (Sanchez & Hampson, 2016).

3.2 Benefits Indicators

As seen in Table 2, out of the 31 BIM benefits, the reviewed studies have only examined methods of measuring 17 of them, namely ‘better change management’, ‘better cost estimation’, ‘better environmental performance’, ‘better programming and scheduling’, ‘better space management’, ‘gaining competitive advantage’, ‘fewer errors’, ‘higher customer satisfaction’, ‘improved communication’, ‘improved coordination’, ‘improved data and information management’, ‘improved learning curve’, ‘improved productivity’, ‘less reworking’, ‘lower cost', 'more accurate quantity take-offs’, and lastly, ‘shorter execution and lead times’.

Some of the existing studies simulated measuring more than one benefit in their case study, while others measured the same benefits using the same or different metrics. Table 3 lists the metrics used for different BIM benefits.

Table 2 - Mapping of reviewed studies to BIM benefit indicators

ID	Benefit Indicator	Literatures
B1	Asset management labour utilisation saving	-
B2	Better change management	(Barlish & Sullivan, 2012; Giel & Issa, 2013; Poirier et al., 2015a)
B3	Better cost accounting	(Giel & Issa, 2013; Nassar, 2012; Poirier et al., 2015a)
B4	Better data/ information capturing	-
B5	Better environmental performance	(Maskil-Leitan et al., 2020; Poirier et al., 2015a; Zoghi & Kim, 2020)
B6	Better programming and scheduling	(Maraqa et al., 2021)
B7	Better scenario and alternative analysis	-
B8	Better space management	(Mirzaei et al., 2018)
B9	Better use of supply chain knowledge	-
B10	Competitive advantage gain	(Majzoub & Eweda, 2021)
B11	Faster regulation and requirement compliance	-
B12	Fewer error	(Ham et al., 2018; Lee et al., 2012; Myungdo & Ung-Kyun, 2020)
B13	Higher customer satisfaction	(H. Liu et al., 2020)
B14	Higher process automation	-
B15	Improved communication	(Demian & Walters, 2014)
B16	Improved coordination	(Barlish & Sullivan, 2012; Chahrour et al., 2021)
B17	Improved data and information management	(Demian & Walters, 2014)
B18	Improved documentation quality and process	-
B19	Improved efficiency	-
B20	Improved information exchange	-
B21	Improved learning curve	(Lu et al., 2013)
B22	Improved output quality	-
B23	Improved productivity	(Poirier et al., 2015a; Sacks et al., 2005)
B24	Improved safety	-
B25	Less rework	(Poirier et al., 2015b, 2015a)
B26	Lower cost	(Kim et al., 2017; Nguyen & Akhavian, 2019)
B27	More accurate quantity take-off	-
B28	More effective emergency management	-
B29	Optimization of construction sequence	-
B30	Reduced execution time and lead times	(Barlish & Sullivan, 2012; Nguyen & Akhavian, 2019)
B31	Reduced risks	-

A shift in the trend of the types of benefits measured was observed. Earlier studies mostly measured benefits such as 'better change management', 'improved coordination', 'better cost estimation', and 'improved productivity'. Furthermore, they also, largely, used easily quantifiable metrics, such as 'cost of change orders', 'shorter durations', and 'overall schedule and cost performance' (Barlish & Sullivan, 2012; Giel & Issa, 2013; Lu & Peng et al., 2013; Poirier et al., 2015a, 2015b; Sacks et al., 2005); to measure benefits.

However, newer studies examined methods of measuring the other secondary uses of BIM, which are harder to quantify. The benefits measured were 'fewer design errors' from design review activities, 'better space management, programming, and scheduling' from four-dimensional (4D) BIM implementation, and 'better environmental performance'. Different measurement metrics have been developed to quantify and monetise these benefits; such as the 'cost of reworking' from different types of error prevention (Ham et al., 2018; Kim et al., 2017; Lee et al., 2012), 'fewer time-space conflicts' that leads to improved productivity (Mirzaei et al., 2018), 'Construction Flow Index (CFI)' (Maraqa et al., 2021), 'green indices' (Maskil-Leitan et al., 2020), and also the 'direct cost savings' of using BIM for waste management activities (Kang et al., 2022; Zoghi & Kim, 2020).

To date, only Demian and Walters (2014) have attempted to measure improvements in communications and information management as a result of increased collaboration due to BIM adoption. A good collaboration not only facilitates better information transfer, knowledge creation, technological coordination, and resource allocation but also alters relationship dynamics between project parties (Y. Liu et al., 2017). Although collaboration in BIM adoption reflects a higher implementation maturity level, the essence of BIM adoption itself is the collaborative working process (Lu, Zhang, et al., 2013). Therefore, measurement of the BIM benefit resulting from increased collaborative design is needed to encourage more users to perform collaborative activities and evaluate its benefit afterwards.

Based on the trends of the studies discussed, academic and industrial researchers could visualize certain gaps that could be further filled. Other benefits that are relatively important and whose measurement process warrants closer examination include improvements in the quality of documentation, efficiency, information exchange, and the accuracy of quantity take-off.

3.3 BIM Benefits Measuring Processes

The details of the measurement processes used to measure BIM benefits were tabulated to refine the trends of the studies. Table 3 lists key items in the process of measuring BIM benefits, namely the measurement metrics used, the quantification (q) and monetization (m) performed, the perspective (p), as well as the data collection methods and general measurement techniques used. This present study does not discuss the measurement technique used, as an exhaustive discussion is required to analyze the calculations that each study has developed. The perspective of the studies indicates whether the proposed measurement methods can be used *ex-ante* or *ex-post*. An *ex-post* evaluation is conducted after a project has been completed, while an *ex-ante* evaluation is performed before a project begins. An *ex-ante* evaluation attempts to identify the best and most strategic investment management decisions; therefore, it is required prior to investing in BIM (Oesterreich & Teuteberg, 2018).

The measurement metrics seen in Table 3 were based on the 17 benefit indicators that existing studies have examined. Most studies used different measurement metrics to measure the benefits of BIM, with the exception of B2 (lower cost of change) and B12 (cost of reworking). For B2, Poirier et al. (2015a) proposed monetization in the measurement technique, while Barlish & Sullivan (2012) only quantified the value. On the other hand, both Lee et al. (2012) and Myungdo & Ung-Kyun (2020) have provided evidence for B12 using the same metric in monetized form but proposed different measurement techniques. Poirier et al. (2015b) also suggested using the same metric to measure B25. It is noteworthy that the same metrics are commonly used to measure different benefit indicators. This may be due to the interrelated nature of BIM benefits (Oesterreich & Teuteberg, 2018; Sanchez & Hampson, 2016).

The use of different metrics to measure the indicators of BIM benefits closely correlates with the methods and perspectives of data collection. Sacks et al. (2005) were the first to measure BIM benefits. The study measured productivity improvements in early BIM adoption following simple BIM uses, such as BIM authoring and modelling activities, in the precast concrete industry. Although the study attempted to monetise BIM benefits, simulations conducted using real data were limited as more focus was placed on relative predictions and hypothetical figures based on the percentage of productivity improvement calculated.

However, the number of studies on measuring BIM benefits significantly increased in 2012, when Barlish & Sullivan (2012) recognized the importance of empirically measuring it. This was accomplished by comparing BIM projects with conventional methods, as the methodology to calculate and analyze BIM returns did not exist at that time. The study was developed by first establishing certain metrics with which to quantify the benefits of BIM, such as lower cost of change, fewer RFIs, and fewer schedule delays. These metrics were further tested using comparative case studies. However, due to data confidentiality, the results were in the form of percentages and not monetary. Past studies used many other metrics to conduct comparative case studies and produce monetary values (Giel & Issa, 2013; Lu, Peng, et al., 2013; Maraqa et al., 2021; Nguyen & Akhavian, 2019; Zoghi & Kim, 2020).

Table 3 - Detailed measurement process used to measure BIM benefits

ID	Benefit indicators measured	Source	Measurement metric	q	m	Measurement technique	p	Method of data collection
B2	Better change management	(Barlish & Sullivan, 2012)	Reduced cost of change	x		Formulated calculation	Ex-post	Comparative case study conventional versus BIM project
		(Giel & Issa, 2013)	Cost saving from preventable change order	x	x			Comparative case study conventional versus BIM project
		(Poirier et al., 2015a)	Reduced cost of change	x	x			Longitudinal comparative case study conventional versus BIM project
B3	Better cost accounting	(Nassar, 2012)	Cost reduction (labor intensity) to prepare cost estimate	x		Formulated calculation	Ex-post	Experiments using various cost estimating techniques
		(Giel & Issa, 2013)	Cost saving from preventable change order	x	x			Comparative case study conventional versus BIM project

		(Poirier et al., 2015a)	Improved project budget predictability	x	x			Longitudinal comparative case study conventional versus BIM project
B5	Better environmental performance	(Maskil-Leitan et al., 2020)	Sustainability green BIM index	x		CSR-based SNA (social network analysis)	Ex-post	Survey questionnaire per case study
		(Zoghi & Kim, 2020)	BIM-based waste collection, sorting and selling profit	x	x	System dynamic (SD) modelling		Comparative case study conventional versus BIM project
		(Kang et al., 2022)	Saving from demilition waste scrap selling, collection, transportation, and landfill charge	x	x	Formulated calculation	Ex-ante	Case study BIM project
B6	Better programming and scheduling	(Poirier et al., 2015a)	Improved project schedule predictability	x	x	Formulated calculation	Ex-post	Longitudinal comparative case study conventional versus BIM project
		(Maraqa et al., 2021)	Construction flow index (CFI)	x				Comparative case study LPS, BIM, VDC, 5S
B8	Better space management	(Mirzaei et al., 2018)	•Reduction of time space conflicts •Percentage of productivity loss predictability	x		Formulated calculation	Ex-ante	Case study BIM project
B10	Competitive advantage gain	(Majzoub & Eweda, 2021)	Winning tender probability	x		Analytical Hierarchy Process (AHP)	Ex-ante	Survey questionnaire
B12	Fewer error	(Lee et al., 2012)	Cost of rework	x	x	Formulated calculation	Ex-ante	Case study BIM project and discussion with project team
		(Ham et al., 2018)	Reduced cost from design error prevention	x	x			Case study BIM project and survey with experts
		(Myungdo & Ung-Kyun, 2020)	Cost of rework	x	x			BIM project and interview and discussion with experts
B13	Higher customer satisfaction	(H. Liu et al., 2020)	Score of satisfaction	x		Entropy method and Fuzzy set theory	Ex-post	Survey questionnaire
B15	Improved communication	(Demian & Walters, 2014)	Information inventory rate	x		Formulated calculation	Ex-post	Case study using various information management system
B16	Improved coordination	(Barlish & Sullivan, 2012)	Reduced number of RFI	x		Formulated calculation	Ex-post	Comparative case study conventional versus BIM project
		(Chahrour et al., 2021)	Cost saving from clash detection	x	x		Ex-ante	Case study BIM project and interview workshop
B17	Improved data and information management	(Demian & Walters, 2014)	Revision rate/ Information iteration rate	x		Formulated calculation	Ex-post	Case study using various information management system
B21	Improved learning curve	(Lu et al., 2013)	Productivity improvement from learning curve	x	x	Best-fit learning curve	Ex-post	Comparative case study conventional versus BIM project
B23	Improved productivity	(Sacks et al., 2005)	Reduced time to produce drawing	x	x	Formulated calculation	Ex-post	Comparative case study conventional versus BIM project
		(Poirier et al., 2015a)	Improved labor productivity cost per unit	x	x			Longitudinal comparative case study conventional versus BIM project

		(Poirier et al., 2015b)	Improved labor productivity unit per time					
B25	Less rework	(Poirier et al., 2015b)	Less rework cost	x	x	Formulated calculation	Ex-post	Longitudinal comparative case study conventional versus BIM project
B26	Lower cost	(Kim et al., 2017)	Cost saving from early issue identification and resolving	x	x	Formulated calculation	Ex-ante	Case study BIM project and Delphi survey
		(Nguyen & Akhavian, 2019)	Cost performance	x			Ex-post	Comparative case study IPD, lean principles, BIM project
B30	Reduced execution time and lead times	(Barlish & Sullivan, 2012)	Reduced schedule delay	x		Formulated calculation	Ex-post	Comparative case study conventional versus BIM project
		(Nguyen & Akhavian, 2019)	Schedule performance	x				Comparative case study IPD, lean principles, BIM project

That same year, Lee et al. (2012) examined measuring reduction in error through reduced cost of rework using solely BIM projects to collect the data instead of using the aforementioned comparable technique. This method of data collection was used for *ex-ante* or predicted value of cost avoidance that could be attained with BIM implementation through different BIM uses such as BIM-based design review and automated clash detection (Chahrour et al., 2021; Ham et al., 2018; Kim et al., 2017; Lee et al., 2012; Myungdo & Ung-Kyun, 2020). However, it was revealed that this data collection method is usually performed alongside other qualitative data collection methods, such as discussions, interviews, Delphi surveys, and even workshops with the members of the project team or BIM experts, to formulate certain rules for the calculation.

Among the rules that must be developed are counterfactual assessments, which determine the extent to which BIM adoption has affected any activity in a project. This is crucial, as it will serve as a baseline and replace the control variable used in comparative studies. Lee et al. (2012), as well as Myungdo and Ung-Kyun (2020), proposed developing a BIM contribution rate using surveys and discussions with project members. However, this depends on the judgement and experience of an expert to provide reliable values that can be used in the calculation. Another potential method is regression analysis (PwC, 2018b). However, none of the reviewed studies have used it. Therefore, it is important to develop counterfactual assessments as part of the calculation process for BIM benefit measurement studies.

Furthermore, additional qualitative data collection for the classification and categorization of the measurement metrics should be conducted to complement the findings of this case study method of data collection. For example, Ham et al. (2018) used the ‘lower cost of design errors via prevention’ metric to further classify design errors as either simple design errors, design errors that require reworking, or design errors that cause delays. The classification of errors will significantly impact the final measurement outcome, as different categories will result in different calculation methods. Conversely, Chahrour et al. (2021) developed different categories of clash severity with the involvement of stakeholders and required action to measure the costs avoided by automated clash detection. This categorization was created through discussions with industry experts.

In terms of the methods of measuring the benefits of BIM adoption, most existing studies have used formulated calculations that future studies can adopt. Meanwhile, others used specified methodological analyses, such as the analytical hierarchy process (AHP) or system dynamics (SD), that are too complex to be incorporated into a whole BIM ROI or CBA calculation tool. This present study does not discuss the calculations that the reviewed studies have proposed, as they warrant a separate study to be examined more rigorously and robustly.

4. Future Research Direction

Future studies should prioritize investigating and simulating the measurement of BIM benefits relative to the plethora of BIM benefits for the construction industry. The following suggestions for future studies were made based on the trends and characteristics of existing studies:

1. *Fill gaps in the research trend:*

   The research trends enable researchers to identify BIM benefits that have not been sufficiently explored and whose measurement processes warrant closer scrutiny. Future BIM studies may examine the benefits of the quality of documentation, efficiency, information exchange, and accuracy of quantity take-offs, such as B18, B19, B20, and B27. The types of benefits measured should be in line with their magnitude of importance relative to the total BIM benefits that can be attained by different beneficiaries.

2. *Adapt in response to measurement challenges:*

   The measurement perspective has evolved from *ex-post* to *ex-ante* as researchers and analysts are predicting BIM benefits for value assessment purposes instead of post-implementation evaluation purposes. To date, eight studies have proposed simulations that can be performed *ex-ante* by only using six benefit indicators, namely, B5, 8, 10, 12, 16, and 26. Researchers could overcome the issue of having to choose BIM and non-BIM projects that have the closest characteristics by using an *ex-ante* data collection perspective since all projects are different. Ardani et al. (2022), similarly, stated that more and more artificial intelligence (AI)-based predictive studies are being proposed to overcome the time, cost, and confidentiality constraints faced when collecting data to measure the benefits of BIM.

3. *Tabulate and analyze the formulated calculations*:

   The details and simulations of the 'formulated calculation' technique that the reviewed studies proposed and used (Table 3) warrant further analysis. Researchers and analysts that are interested in performing more BIM ROI or CBA analyses may benefit from using these calculation formulas. Furthermore, the lessons learned should be documented so that they may be improved upon by future studies.

5. Conclusion

This present study examines the process of measuring the benefits of BIM adoption by identifying the trends and characteristics of previous studies on the methods of measuring BIM benefits. An SLR was conducted according to the PRISMA guideline by examining 21 articles obtained by searching on two primary databases as well as cross referencing articles published between 2004 and 2022.

The SLR provided a qualitative thematic understanding of which BIM benefit measurement processes had been explored and how they were measured. The study has analyzed the BIM benefit indicators that have been explored and suggested several benefit indicators that could be taken into consideration for further measurement. Furthermore, different measurement metrics have been presented according to respective benefit indicators, supplemented with the methods to collect the data needed to perform the measurements. The findings of this present study provide researchers and analysts with initial insights that can be used to move forward with BIM benefit measurements. As the analysis of the details of the calculation processes of these existing studies is ongoing, it will be discussed in greater detail in the second part of the data synthesis of this SLR.

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