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Measuring the Cost Saving in Building Information Modelling (BIM) Implementation: A Systematic Literature Review (SLR)

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Abstract

Building Information Modelling (BIM) has many benefits that could be complex in nature, which call for in-depth examinations into these benefit attributes. While past research often examined these benefits in isolation, this paper looks at how they relate to each other as a strategic step to analyze the quantification technique used by similar measurement metrics. This study examines the measurement process employed in previous studies to measure cost savings from reduced variation and changes using BIM. This paper presents the results of a systematic literature review (SLR) of ten (10) articles. The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and analyzed using meta-ethnography and thematic qualitative analysis. The measurement processes used by past studies were analyzed in terms of detailed measurement techniques, including the steps, measurement units, and sources of data collection. The findings show that the measurement metric, particularly using cost avoidance, provides a robust mechanism for measuring these savings from reduced variations and changes. The basic steps for the cost avoidance approach were proposed based on the reviewed articles. This includes categorizing issues, performing counterfactual assessments, and conducting valuation processes. This paper helps researchers and policymakers to consider an applied measurement technique to improve efficiency in evaluating BIM benefits.

1.0 INTRODUCTION

Building Information Modelling (BIM) has emerged as a transformative technology within the construction industry, reshaping how projects are planned, designed, executed, and maintained. As a system-wide tool, BIM integrates stakeholders and processes across the entire building lifecycle, offering potential benefits ranging from improved collaboration to cost and time savings. Despite its widespread adoption, effectively measuring these benefits remains a critical challenge due to their complex and often interconnected nature.

Over the past decade, numerous studies have examined BIM's benefits, focusing on attributes such as reduced rework, better change management, and enhanced coordination. For instance, Sompolgrunk et al. (2021) reviewed key factors contributing to BIM's return on investment (ROI), including schedule compliance and productivity improvement. Similarly, Mohamed et al. (2023) highlighted 17 distinct BIM benefit attributes and explored various metrics used to measure them. Recently, Gharaibeh et al. (2024) categorized quantifiable factors, including productivity, changes and rework reduction, requests for information reduction, schedule efficiency, safety, environmental sustainability, and operations and facility management. While these studies provide valuable insights, they often treat benefits in isolation, overlooking their interdependencies and the shared metrics used to quantify them. As a result, the measurement process remains fragmented and inconsistent.

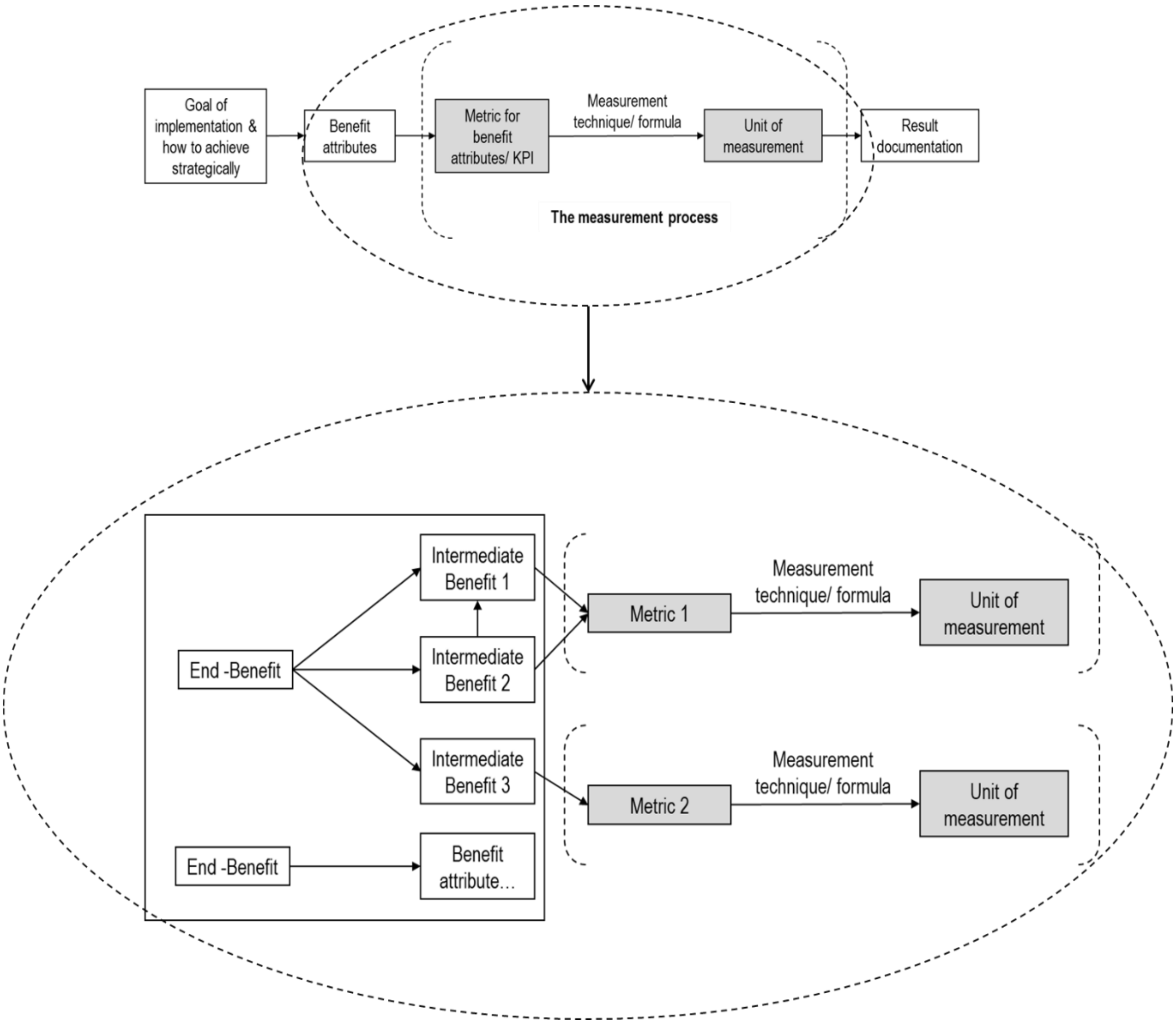

Figure 1. Relationship between benefit attributes and measurement metric influencing the quantification technique (Source: Author)

Recent works, for instance, frameworks like the BIM Value Realization Framework (Love et al., 2014) and the Cost-Benefit Analysis (CBA) model using System Dynamics (SD) developed by Oesterreich & Teuteberg (2018), have attempted to address these complexities. Gurevich & Sacks (2017, 2020) developed the BIM adoption impact map (BIM AIM), which helps visualize the inter-relationship between actions taken with the intermediate outcome and the final value from BIM implementation. Mohamed et al. (2023) proposed an ontology of BIM Benefit Determining Factor, consisting of 4 main dimensions, namely 'project context', stakeholder', 'time', and 'type', to help analysts identify the benefits of BIM to be measured based on several factors outlined by Persaud (2007)'s Benefit Identification Model. These frameworks emphasize the importance of understanding the relationships between benefit attributes to avoid issues such as double-counting and misattribution. However, the discussion has largely focused on identifying benefit factors rather than detailing the measurement techniques required to quantify them accurately.

It is essential to measure each benefit attribute in relation to others, considering both direct and indirect benefits. The analyst must identify these attributes and their interconnections to determine appropriate metrics and quantification techniques. Figure 1 illustrates how these relationships can be mapped to show the metrics influencing the measurement techniques. In this light, understanding the non-linear nature of BIM benefit flow is crucial for careful planning of the measurement process.

This study aims to bridge this gap by systematically analyzing the measurement techniques employed in existing research. Through a systematic literature review (SLR) guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, this paper focuses on five key BIM benefit attributes: better change management, less rework, fewer errors, improved coordination, and enhanced data management. By mapping the relationships between these attributes and the metrics used to quantify them, this study seeks to consolidate detailed measurement techniques and propose a standardized framework.

This research contributes to the body of knowledge by offering a unified perspective on measuring BIM benefits. The findings are expected to guide researchers and practitioners in adopting more efficient and accurate methods for evaluating BIM's impact, ultimately enhancing its implementation and value realization across the construction industry.

2.0 METHODOLOGY

2.1 Research Design and Searching Strategy

The Systematic Literature Review (SLR) was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist (Page et al., 2021; Shamseer et al., 2015). First, the systematic literature review protocol was developed based on Kitchenham's (2007) protocol. Then, SPIDER criteria from Cooke et al. (2012) were adopted as the main search strategy on two primary databases, Scopus and Web of Science (WoS), in October 2022. The search strings used are summarised in Table 1. Articles included are those published between 2004 and 2022, as the earliest known publication on the topic appeared in 2004 (Sompolgrunk et al., 2021).

Table 1. Search strings used in the 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" was used in 12 separate searches.

2.2 Eligibility and Quality Appraisal

The automated screening process encompassed only peer-reviewed articles to ensure the reliability and validity of the findings, yielding 61 journal articles. Grey literature, including books, theses, and conference proceedings, was deliberately excluded as any input on detailed measurement techniques was considered only when accompanied by a comprehensive elaboration of the quantification steps and supported by appropriate citations.

Then, the manual screening process was done by two members of the research team using the EndNote database (EndNote version 20.4.1). From 61, only 18 articles were accepted for data extraction after a series of eligibility assessments. Articles were excluded when:

- The research topic did not discuss BIM as the primary cause of the measured benefits
- The research paper only used BIM for simulation purposes
- The contents did not correlate with BIM according to SPIDER criteria
- The research paper did not propose a measuring method for the BIM benefit discussed
- The measuring method presented is too general and does not focus on specific BIM impacts/ benefits.

The reports were assessed further using the quality checklist proposed by Kitchenham (2007). 2 articles were excluded as they did not conduct a simulation to support the proposed process of measuring the benefits of BIM. They also lacked baseline or control variables to prove that the benefit measured was the result of BIM adoption. Subsequently, 5 additional articles were added from cross-referencing during the data extraction stage, resulting in a total of 21 articles for review.

Data from selected journal articles were extracted into the data extraction form. The main data extracted are as follows:

a. Name of the authors
b. Title and year of publication
c. Aim of the study
d. BIM benefit attribute measured
e. Presence of quantification and monetization process
f. Measurement metrics
g. Quantification technique
h. Unit of measurement
i. Data used to perform the measurement
j. Method of data collection

2.3 Data Analysis and Synthesis

Qualitative data analysis, specifically the meta-ethnography method, was used to identify similarities and differences to develop a new interpretation (Noblit & Hare, 1988; Thomas & Harden, 2008). The data extracted were deductively coded using two key themes adopted from two main components in Sanchez & Hampson's (2016) BIM benefit realization framework; namely, the 'benefit dictionary' and 'metric dictionary' (Hudson et al., 2018; Smith, 2021). The result presented in the initial part of the SLR (Mohamed, Yusuwan, et al., 2023) revealed that there are different measurement metrics that could be used to measure certain benefit attributes. Furthermore, it was observed that multiple benefit attributes might share the same measurement metrics.

The analysis highlighted the need to investigate the relationship between benefit attributes and measurement metrics further. This investigation aims to uncover the rationale behind selecting different measurement metrics and their influence on the quantification techniques used in the reviewed articles. Consequently, this study extends to analyzing the quantification techniques associated with each measurement metric. To achieve this, the relationships of benefit attributes using similar or different measurement metrics were mapped based on Sanchez & Hampson's (2016) BIM benefit realization framework. The BIM benefit attributes and their measurement metrics were coded using the qualitative data analysis software, Atlas Ti 8.4.24. Figure 2 shows the graphical representations of benefit flow and metrics explored in previous studies.

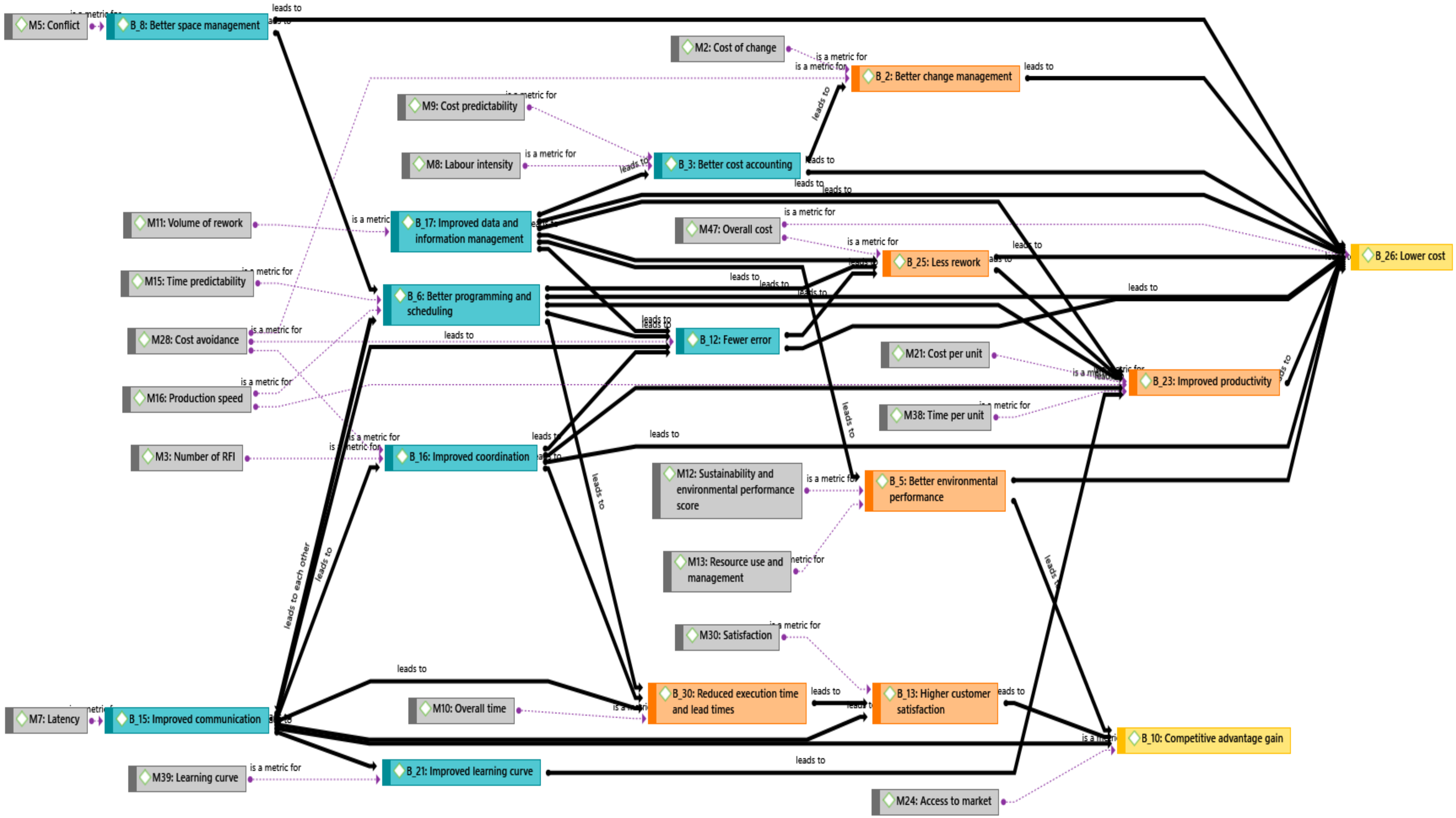

Figure 2. Benefit flow and measurement metric used in reviewed studies (Yellow: End benefit, Orange and Blue: Intermediate benefit, Grey: Measurement metric) (Source: author)

For improved clarity and coherence, this study organizes the benefit attributes into categories based on shared measurement metrics and interconnected measurement techniques. This structured approach enables a detailed analysis of the similarities, differences, and potential gaps in the quantification techniques proposed in prior research. The benefit attributes are categorized as follows:

1. 'Cost Saving from Reduced Variations and Changes'
2. 'Cost Saving from Improved Cost Accounting'
3. 'Cost and Time Saving through Enhanced Communication'
4. 'Increased Reputation from Environmental Strategies'
5. 'Increased Reputation from Client Satisfaction.'

Out of these attributes, this study focuses specifically on the quantification techniques for the 'Cost Saving from Reduced Variations and Changes' category, aiming to provide a comprehensive synthesis. Hence, from 21 articles in the main SLR, only ten (10) were retained for further review, scoping down the reports related to the measurement of BIM cost saving due to reduced changes and variations. There were five (5) intermediate BIM benefit attributes involved: B_25: Less Rework, B_12: Fewer Errors, B_17: Improved Data and Information Management, B_16: Improved Coordination, and B_2: Better Change Management that leads to 1 end-benefit, which is B_26: Lower Cost. This study will discuss the quantification technique of 5 types of measurement metrics, specifically, M28: Cost Avoidance, M47: Overall Cost, M3: Number of RFI, M11: Volume of Rework, and M2: Cost of Change Orders/ Variation. Figure 3 illustrates the process used to evaluate records according to the PRISMA 2020 flow diagram (Page et al., 2021).

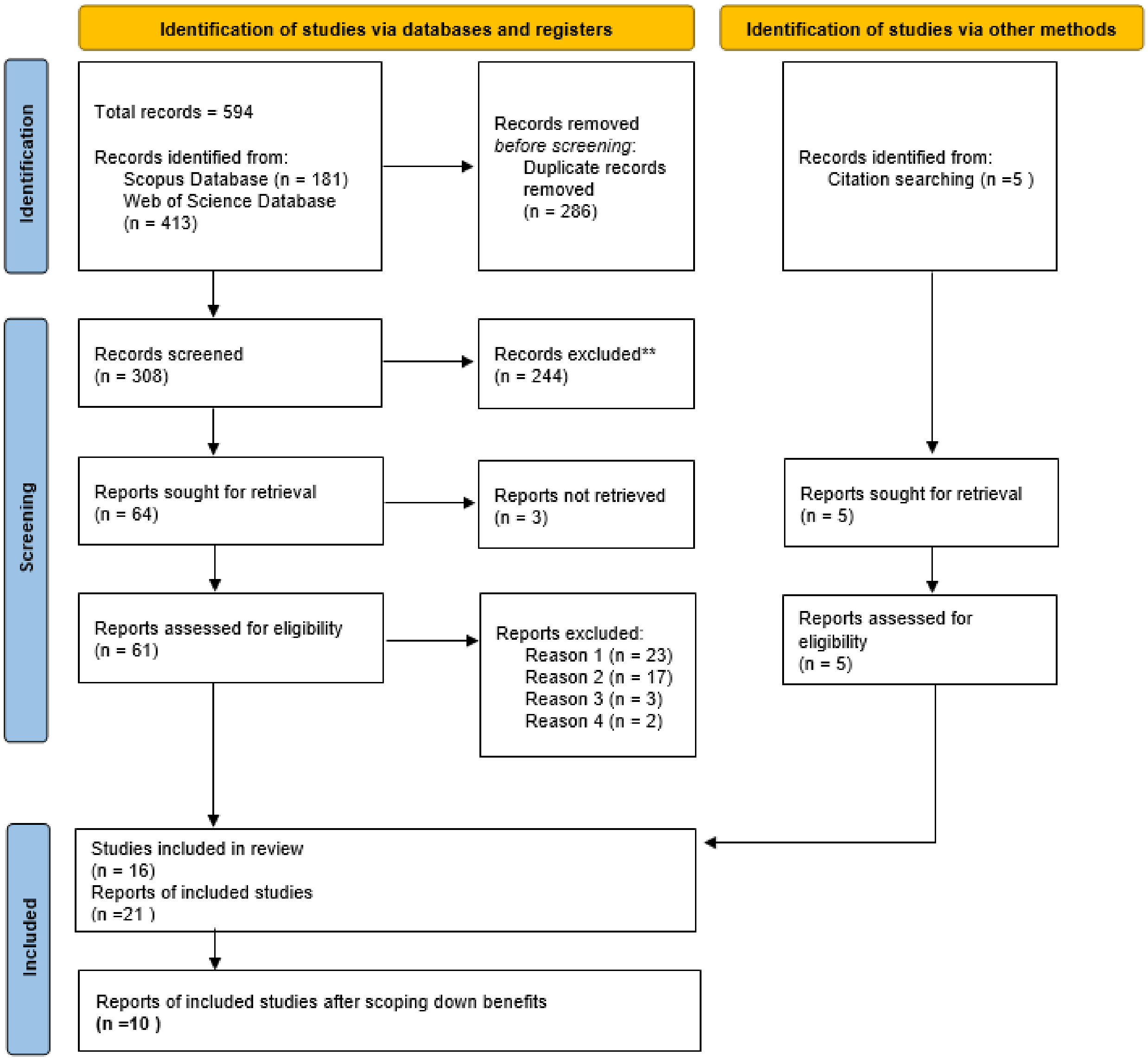

Figure 3. PRISMA flow diagram.

3.0 RESULTS

Figure 4 illustrates the significant role of various benefit attributes in achieving the end-benefit of BIM implementation. In this case, to lower the cost, two main benefit attributes, B_25: Less Rework, and B_2: Better Change Management, could act as an indicator. Measurement of 'B_25: Less Rework' was done more extensively due to the multiple flow-on benefits that needed to be consolidated to provide a more comprehensive and standardized measurement process. The benefit 'B_25: Less Rework' could be realized from 'B_12: Fewer Errors' or attributed to 'B_16: Improved Coordination' and 'B_17: Improved Data and Information Management'.

As tabulated in Table 2, Lee et al. (2012) pioneered the simulation of measurement using the cost avoidance concept without a comparable case study method to measure 'B_12: Fewer Errors'. The direct cost saving from rework due to design errors was calculated by factoring the probability of detecting the errors using a conventional method into the direct cost of errors expected. Earlier in 2011, Azhar & Asce (2011) mentioned the concept of using counterfactual scenarios to isolate and measure the net impact of BIM in case studies, without presenting a detail calculation process. This presents a great mechanism as a result of the total ROI from the studies calculated with and without using the probability approach, as counterfactual assessment has signaled the causes behind the extreme value of ROI measured in other studies (Sompolgrunk et al., 2021). Lee et al. (2012) reported an ROI result of 63% on average based on rework cost due to design errors. Similarly, other studies have attempted to improve the calculation steps for more accurate cost-saving results (Ham et al., 2018; Myungdo & Ung-Kyun, 2020; Won et al., 2016).

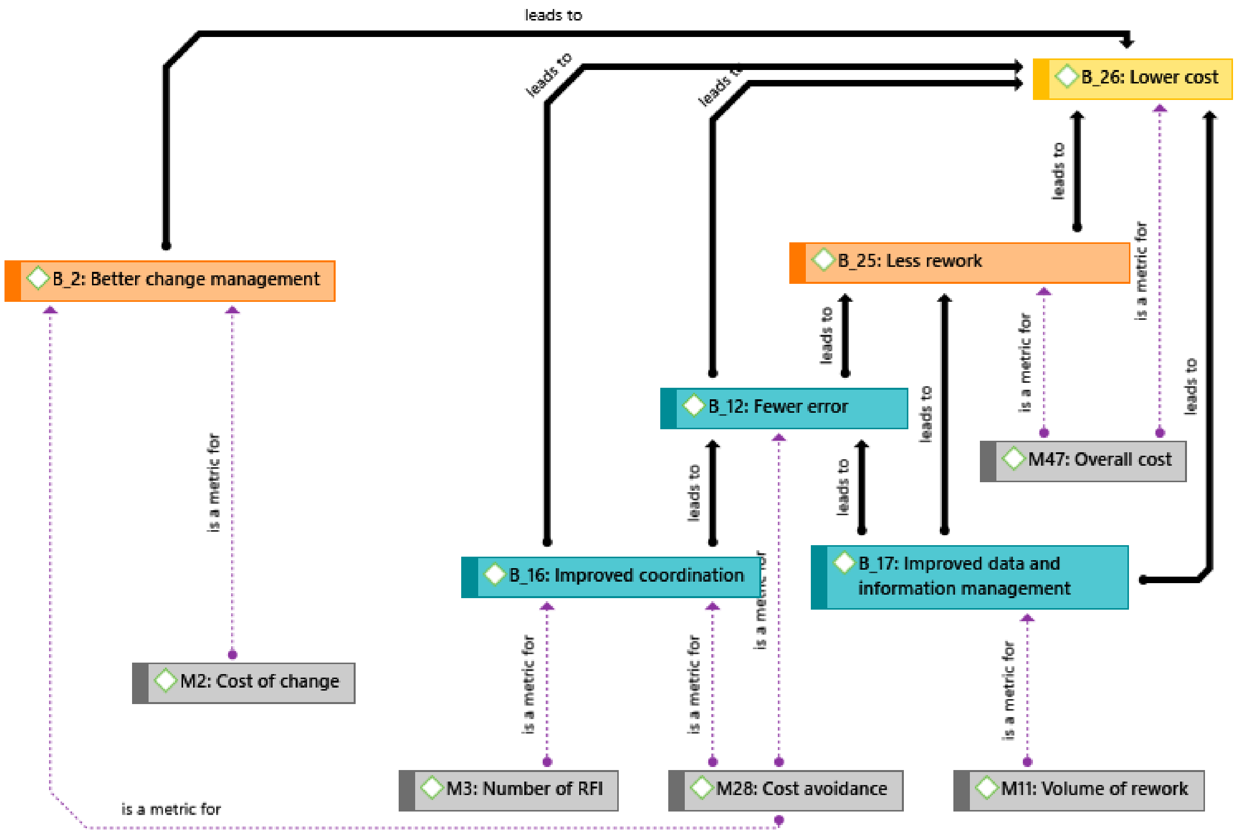

Figure 4. Benefit attributes related to cost saving from reduced variations and changes with its respective measurement metric (Yellow: End benefit, Orange and Blue: Intermediate benefit, Grey: Measurement metric) (Source: author)

Kim et al. (2017) conducted a measurement process simulation to study cost savings for 'B_16: Improved Coordination' using a similar cost avoidance approach. The study addressed a broad range of issues, including clashes, design errors, constructability problems, and design options. It detailed the valuation steps using the Cost Budget to minimize subjective judgment and incorporated qualitative data collection to triangulate the results. The result indicates that BIM contributed to identifying and resolving issues equivalent to 15.92% of the total direct cost. The measurement technique used is reported in Table 3.

Table 2. Measurement technique for B_12: Fewer Errors

Benefit attribute	Measurement metric	Source	Beneficiary	Unit of measurement	Method of data collection and Data to be collected
			Measurement technique		
B_12	**M28: Cost avoidance** (Cost of rework from design error)	(Lee et al., 2012)	Contractor	$ of cost savings	-Case study (BIM project) -Design error report, expert's judgement
			1. Categorize design errors into 3 causes. 2. Assign each design error case to the likelihood of identifying error without BIM (25%, 50% and 75%) 3. **Direct cost of rework (cost saving, $)** = ∑ (cost of design error × probability of error detection)		
		(Ham et al., 2018)	Contractor	$ of cost savings	-Case study (BIM project) -Design error report, expert's judgement, BIM model, unit cost data
			1. Categorize design errors into 3 types of impact 2. Assign % of BIM impact (60%, 80%, 100%) to each design error cases 3. Valuation based on 3 types of impact: a. **Type 1 -Total labour cost ($)** = *x* + technical fee (110% *x*) + indirect labour cost (20% *x*) *Direct labour cost, x = (number of cases × productivity) × daily labour cost × number of staff* **productivity/ processing time set is 2 hours/ case = 0.25 day/ case (if the total working hours is 8)* b. **Type 2 - Total rework cost ($)** = *y* + waste cost (0.3% *y*) *Direct demolition and rework cost, y = (Volume of Material related to demolition × unit cost) + (Volume of Material related to rework × unit cost)* c. **Type 3 - Total schedule overrun cost ($)** = *z* x 0.1% total construction cost *Schedule delay due to demolition, z1 = Volume of Material related to demolition × productivity* *Schedule delay due to rework, z2 = Volume of Material related to rework × productivity* **productivity / overrun due to rework set is 1 hour / 6m3 material volume = 1 day/ 48m3 (if total working hour is 8* **Total cost saving (%)** = Total economic loss *(BIM impact not reflected)* - Total economic loss *(BIM impact reflected)* *%Total economic loss (BIM impact not reflected)* = $\frac{\sum Type\ 1\ cost + \sum Type\ 2\ cost + \sum Type\ 3\ cost}{\sum construction\ cost} \times 100$ *%Total economic loss (BIM impact reflected)* = $\frac{\sum Type\ 1\ cost + \sum(Type\ 2\ cost \times \%\ of\ BIM\ Impact) + \sum (Type\ 3\ cost \times \%\ of\ BIM}{\sum construction\ cost}$ 100		

		(Myung do & Ung-Kyun, 2020)	Contractor	$ of cost savings	-Case study (BIM project) -Design error report, expert's judgement, and cost estimation sheet
			1. Categorize design errors into 3 different disciplines 2. Assign each design error case to the likelihood of identifying errors without BIM using a 5-point Likert scale, and convert the average scale to BIM contribution value (0%, 25%, 50%, 75% and 100%) a. **Cost of rework (avoided) for each error ($)** = cost of initial construction + cost of demolition: *Cost of initial construction = material cost + labour cost +overhead cost* *Cost of demolition, y = material cost + labour cost +overhead cost* b. **Direct cost of rework (cost saving, $)** = ∑ (cost of rework X contribution value)		
	M47: Overall Cost (Less rework cost)	(Poirier et al., 2015b)	Contractor	% of rework	-Longitudinal comparative case study: conventional versus BIM project
			Project quality (less rework) = = (∑cost of rework)/(total project cost) ×100		

On the other hand, Chahrour et al. (2021) developed a schema to estimate cost saving specifically from BIM-enabled clash detection and reported cost savings of around 20%. The study used M28: Cost avoidance, where the clash cases are considered similar to VDC-RFI, as termed by Giel & Issa (2013). Whereby, the field-RFI measured by Barlish & Sullivan (2012) can only be used for ex-post comparative case study analysis. However, using the 'M3: Number of RFI' as a metric on its own is not suitable because the number of RFI itself differs based on several factors, including the project characteristics, project participants, and the cultural context of the project implemented (Lee et al., 2012). Using this logic, the VDC RFI or clash cases also must be selected or filtered properly based on a proper counterfactual assessment.

Demian & Walters (2014) attempted to measure less rework from different perspectives. The study focused on quantifying information redundancy through comparable BIM-based and conventional information systems. The case study using BIM was able to centralize, streamline, and accurately manage information, evidenced by the lower revision rates and information iteration rate. However, the author did not proceed to quantify the reduced in revisions and information iteration volume monetarily as indicated in Table 3.

Table 3. Measurement technique for B_16: Improved Coordination

Benefit attribute	Measurement metric	Source	Beneficiary	Unit of measurement	Method of data collection and Data to be collected
			Measurement technique		
B_16	M3: Number of RFI	(Barlish & Sullivan, 2012)	Owner	RFI quantity (qty)	- Comparative case study -The type of data collected was not disclosed. Need baseline data (BIM versus non-BIM)
			Differential unit of RFI = Number of RFI in BIM – Number of RFI in nonBIM		
	M28: Cost avoidance (Cost saving from	(Chahrour et al., 2021)	Contractor, designer, and client	$ of cost savings	-Case study (BIM project) & Workshop -Clash report, Bill of Quantities (BQ), expert's judgement

<table>
<tr><td rowspan="3"></td><td>automated clash detection)</td><td></td><td colspan="3">1. Filter clashes and categorize them into 3 based on clash classification criteria.
2. Develop the average value of the cost implication for each type
a. Minor clash: $0- $150,000 (Average: $75,000)
b. Medium clash: $150,000 - $550,000 (Average: $350,000)
c. Major clash: $550,000 - $1,500,000 (Average: $1,025,000)
3. Cost impact of clashes (cost saving, $) = ∑ (Average value of clash category × number of clashes)</td></tr>
<tr><td rowspan="2">M28: Cost avoidance (Cost saving from early issue identification and resolving)</td><td rowspan="2">(Kim et al., 2017)</td><td>Contractor, designer, and client</td><td>$ of cost savings</td><td>-Case study (BIM P</td></tr>
<tr><td colspan="3">1. Categorize issues based on the cause of the issue and then by discipline & trade:
a. Eg. Architecture
2. -metal works, steel structure, RC, etc
3. Assign DI & DC for each issue to calculate the CR:
4. Contribution rate (CR) = DI X DC
5. Degree of identification (DI) = 0, 0.1, 0.2, 0.3, 0.4, 0.5
6. Degree of cost impact (DC) = 0, 0.1, 0.2, 0.3, 0.4, 0.5
7. BIM Utilization Value (BUV, $) $= \frac{area\ affected,\ m^2}{total\ area\ of\ trade} \times cost\ item$
8. *BUV-B (%) $= \frac{BUV}{budget} \times 100$
9. *BUV-D (%) $= \frac{BUV}{total\ direct\ cost} \times 100$
10. Empirical measurement:
11. BIM Contribution Value (BCV, $) = ∑ (BUV x CR)
12. *BCV-B (%) $= \frac{BCV}{budget} \times 100$
13. *BCV-D (%) $= \frac{BCV}{total\ direct\ cost} \times 100$
14. Qualitative measurement:
15. BIM Sensible Value Value (BSV) = % of schedule overrun and % cost overrun</td></tr>
<tr><td rowspan="2">B_17</td><td rowspan="2">M11: Volume of rework: Revision rate and Information iteration rate</td><td rowspan="2">(Demian & Walters, 2014)</td><td>Contractor (fabricator)</td><td>- Revision rate (qty)
- % of Information Iteration</td><td>-Case study
-Info flow logs from primary info system:
• email
• central repository of project documents and project workflow forms
• transfer and storage tool for commercial info
• BIM-based information management and coordination tool</td></tr>
<tr><td colspan="3">1. Revision rate
2. = cumulative number of revised information packages transferred in a period of time:
= (total number of revision package (in duration))/duration
3. Info iteration = quantity of revised information in relation to the total number of information packages
= (total number of revision package (in duration)) / (total number of information package (in duration)) × 100</td></tr>
</table>

To measure ‘B_2: Better Change Management’, there are two main measurement metrics used, which are ‘M2: Cost of change orders/ variation’ and ‘M28: Cost avoidance - Cost saving from preventable change order’. Table 4 summarizes how ‘better change management’ was measured using these different metrics.

Barlish & Sullivan (2012) measured the difference in the percentage of cost of change reduction (%) between a BIM-based project and a conventional project using differential computations from case studies. The reduced cost of change from BIM implementation reported ranges from 42% to 70% compared to non-BIM projects.

Table 4. Measurement technique for B_2: Better Change Management.

<table>
<tr><th>Benefit attribute</th><th>Measurement metric</th><th>Source</th><th>Beneficiary</th><th>Unit of measurement</th><th>Data to be collected</th></tr>
<tr><td rowspan="6">B_2</td><td rowspan="4">M2: Cost of change orders/ variation</td><td rowspan="2">(Barlish & Sullivan, 2012)</td><td>Owner</td><td>% of different in the cost of change BIM vs non-BIM</td><td>- Comparative case study
-The type of data collected was not disclosed. Need baseline data (BIM versus non-BIM)</td></tr>
<tr><td colspan="3">1. $Percentage\ of\ cost\ of\ change\ (\%) = \frac{cost\ of\ change}{total\ cost\ of\ project} \times 100$
2. $Percentage\ of\ standard\ of\ project\ cost\ (\%) = (\frac{\%\ cost\ of\ change\ for\ BIM}{\%\ cost\ of\ change\ for\ non-BIM} \times 100) - 100$</td></tr>
<tr><td rowspan="2">(Poirier et al., 2015a)</td><td>Mechanical Contractor</td><td>% of the cost of change</td><td>- Longitudinal comparative case study
-Project estimates, cost reports, schedules, RFI logs, CO logs, employee timesheet (collected from centralized project management and ERP software)</td></tr>
<tr><td colspan="3">1. Percentage of cost of change order (%) = $\frac{(total\ cost\ of\ change\ orders)}{(total\ cost\ of\ work)} \times 100$</td></tr>
<tr><td rowspan="2">M28: Cost avoidance (Cost saving from a preventable change order)</td><td rowspan="2">(Giel & Issa, 2013)</td><td>Contractor</td><td>$ of cost savings from preventable change orders</td><td>- Comparative case study
-RFI, Change Order Logs for BIM and non-BIM projects</td></tr>
<tr><td colspan="3">1. Categorize issues into 5 types (RFI issues)
2. Filter RFI related to BIM-discoverable issues and trace it to the corresponding Change Orders.
3. Direct cost saving = ∑ preventable cost of change orders
4. Indirect cost saving = the sum of preventable schedule overrun
= ∑ (number of days delayed × daily cost)
5. Daily cost includes contractor’s general conditions, developer’s admin fee, architect contract’s admin fee, interest on owner’s construction loan
6. Total cost of change (cost saving) = Direct cost saving + Indirect cost saving</td></tr>
</table>

Poirier et al. (2015a) also studied on impact of BIM using the cost of change metric. However, instead of comparing BIM-based projects to conventional ones as the baseline data, the study used multiple BIM case studies conducted by a single contracting firm to uncover any pattern related to the reduced number of Change Orders and their percentage of the total cost of work. The result shows that there is no clear relationship between the reduced number of Change Orders (assumed to be the impact of BIM implementation) in relation to the percentage of cost of change to the total cost of work. It was presumed that the results may be rooted in the lack of integration between the project and the organizational environment.

On the contrary, Giel & Issa (2013) measured the benefit of 'better change management' through the cost avoidance concept in a conventional project. The change orders that could be avoided by using BIM were quantified to measure the cost savings. The study has developed an estimating model and simulated it through three sets of comparable case studies from the same contracting firm. It has measured direct and indirect cost savings in both comparable case studies. However, it is noteworthy to mention that the value used to compare between BIM and non-BIM projects is the RFI unit, and also the number of change orders preventable by BIM, whereas the monetary comparison for direct cost saving is questionable since the data was deemed insufficient by the author.

The results indicate that the cost avoidance metric has been widely adopted and refined through detailed methodologies. Other metrics, such as the cost of change orders/variations and the number of RFIs, function as simplified metrics that are ultimately integrated into the cost avoidance measurement framework. For instance, M2: Cost of Change, as utilized by Poirier et al. (2015a) and Barlish & Sullivan (2012), is incorporated into the calculations performed by Giel & Issa (2013) using the M28: Cost Avoidance metric. This supports the argument by Lee et al. (2012), who emphasized that certain metrics, such as the number of RFIs and shortened project duration, are insufficient when used independently. These metrics require contextual information to ensure accurate justification and interpretation of results.

This suggests that the M28: Cost Avoidance metric is robust and comprehensive enough to serve as the primary measurement metric for benefits associated with cost savings from reduced variations and changes. To gain deeper insights, further analysis is necessary to identify patterns and assess the strengths and weaknesses of these metrics across different applications. The following section delves into the cost avoidance metric in greater detail, examining its implementation and effectiveness.

4.0 DISCUSSION: MEASUREMENT TECHNIQUE USING COST AVOIDANCE

Metric M28: Cost avoidance is defined as the cost incurred if BIM had not been implemented (Sanchez & Hampson, 2016). The avoidance cost is calculated by assigning the estimated value of impact that could be avoided from BIM implementation, particularly design review and automated clash detection. Based on the results presented in Table 2-4, several benefit attributes can be measured using a similar measurement metric M28: Cost avoidance. This includes B_12: Fewer Errors, B_16: Improved Coordination, and B_2: Better Change Management. Hence, the different goals of measurement necessitates different quantification techniques based on the cost avoidance approach. For example, the value of cost avoidance can be measured using the total cost of rework that can be avoided from fewer design errors (Ham et al., 2018; Lee et al., 2012; Myungdo & Ung-Kyun, 2020). Using a similar concept, the value also could be quantified from the cost impact of clashes that have been detected using BIM (Chahrour et al., 2021; Kim et al., 2017).

This quantification technique represents a distinct paradigm for evaluating BIM value. Traditionally, past studies have employed comparative case studies between BIM-based projects and conventional ones for ex-post analyses (Barlish & Sullivan, 2012; Giel & Issa, 2013; Lu et al., 2014; Poirier et al., 2015a, 2015b). Typically, the ROI or CBA processes are conducted ex-post, after the project's completion, to facilitate learning and reflection (Boardman, 2014).

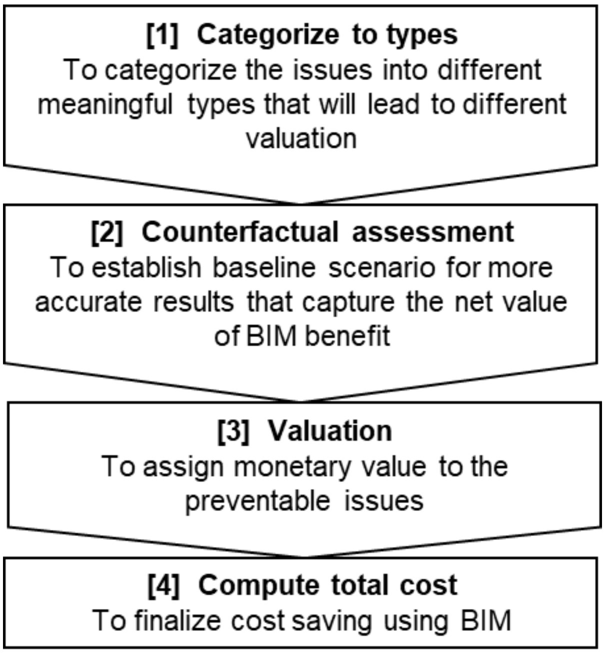

Figure 5. Proposed steps for measuring using M28: Cost avoidance.

The differential computations method, using comparative case studies, used by Barlish & Sullivan (2012) required the analyst to find two similar case studies according to certain criteria. (Barlish & Sullivan, 2012) mentioned that comparative case studies would be ideal if both studies were carried out under the same owner and the same contractor with a similar scope of work. However, no two construction projects will ever be exactly similar. By adopting the cost avoidance concept, and with sufficient project information, the reliance on comparative case study methods can be significantly reduced (Giel & Issa, 2013). Alternatively, if the goal of measurement is not to compare BIM implementation versus conventional, the measurement method by Poirier et al. (2015a) can be used when the alternative (status quo) of the CBA is not using conventional projects, rather, to assess the performance of BIM implementation by tracking its progress through time.

Based on the detailed quantification technique analyzed, there is a unified sequence that has been performed by previous authors using the cost avoidance approach. Figure 5 summarizes the steps proposed in using M28, as highlighted in the articles reviewed.

4.1 Categorize Issues

In all studies, the first step was to categorize the issues gathered from design review and coordination activities. The categorization step considered several factors, including the sources of issues, the nature of issues, and the implications of issues detected using BIM. As asserted in Dosumu et al. (2023), construction errors can be categorized based on sources of errors from the construction documents, which include the construction drawings, Bill of Quantities (BQ), specifications, and conflicting information from the contract documents (coordination). In the context of this study, the sources of issues can be extracted from the design review report and clash analysis report.

The studies that demonstrate a clear process of measurement often categorize the issues based on their implications. Ham et al. (2018) divided the design errors into simple errors, errors that require rework, and, lastly, errors that result in delay. In terms of issues detected specifically from clash analysis, Chahrour et al. (2021) classified them into minor, medium, and major types of clashes, where the different categories will have different valuation formulas based on impact. The clashes were categorized based on the stakeholder involved and the criticality of the issues identified (Chahrour et al., 2021; Daszczyński et al., 2022; Elyano & Yuliastuti, 2021).

It was also found that some studies have grouped issues from design review and clash analysis together. For example, Kim et al. (2025) categorized both errors and clashes by discipline and trade, enabling the quantification of cost savings for each issue based on the affected area, as derived from the cost budget document. Similarly, Elyano and Yuliastuti (2021) identified *design errors*, *design inconsistencies*, and *design discrepancies* as primary causes of clashes. Their study further classified each clash using a predefined "resolve option" category that highlighted the impacted stakeholders, components, and resulting changes in terms of time, cost, scope, and quality. Based on this perspective, design errors were considered a subset of clashes, representing the primary issues detected from BIM implementation.

Table 5. Categories based on the nature of the issue in past studies

(Giel & Issa, 2013)	(Lee et al., 2012)	(Kim et al., 2017)
Dimensional inconsistencies	Illogical design	Design error
Document discrepancies	Discrepancy between drawing	Decision support
2D errors and omissions	Missing item	Documentation support
Grid and column alignment issues		
Direct clashes		

The issues can be categorized into different types or the nature of issues, as shown in Table 5. However, the types of issues were presented based on their individual case study and are varied across different types of projects and the extent of BIM implementation (Giel & Issa, 2013).

The categorization step is crucial as it influences the valuation process, going beyond merely providing insights and descriptive analysis of issues. Categorizing construction issues using a structured approach—considering the source, nature/type, criticality, and impact—helps ensure more accurate cost-saving measurements by preventing the double counting of similar issues classified under different categories.

4.2 Counterfactual assessment

The second step is to perform a counterfactual assessment by providing a scenario as a baseline to compare the outcomes that will be achieved without BIM implementation. This is to attribute the benefits more accurately to the use of BIM (PwC, 2018). Based on the reviewed studies, there are various ways documented as a counterfactual assessment. Only Chahrour et al. (2021) have not disclosed whether the assessment was done or not during the development of the average cost implication of each clash category.

Both Lee et al. (2012) and Giel & Issa (2013) used the expert judgement to provide the baseline. However, instead of dividing the issues into BIM-discoverable or not, Lee et al. (2012) used the 'probability of error detection without BIM' (%) as a counterfactual assessment method. The percentage was converted into weightage form. For example, design errors with a 25% likelihood to be identified without using BIM will have 0.25 weightage, which will be multiplied by the cost of design error to get the real cost saving from BIM. The probability options given were 25%, 50% and 75%. This type of assessment was adapted by Myungdo & Ung-Kyun (2020) with several changes made to it. Myungdo & Ung-Kyun (2020) survey involved experts from the project team to set the 'BIM contribution value' (%) using the average scale from a 5-point Likert scale. The 'BIM contribution value' is classified in 5 options, which are 0%, 25%, 50%, 75% and 100%. He considered 0% and 100% based on cases with no contribution of BIM for more accurate results. In this method, the cost saving is directly proportional to the BIM contribution 'value' (%).

Ham et al. (2018) used 'BIM impact reflected' (%), which is defined by the reduction in cost due to BIM's ability to prevent errors. 3 options were presented, which are Low Impact (60%), Medium Impact (80%), and High Impact (100%). To make it clearer, errors with a 40% probability of detection without BIM were considered to have a low impact (BIM has 60% influence), while errors with 0% probability of detection without BIM have a high impact (BIM has 100% influence). The 'BIM impact' (%) will be multiplied by the cost of reworking to get the economic loss. This explains why the author must subtract the economic loss (without BIM) from the economic loss (with BIM) in the last step of the calculation. The difference between these two values represented the cost savings due to BIM implementation. Hence, the cost saving is inversely proportional to the 'BIM impact reflected' (%).

From another perspective, Kim et al. (2017) attempted to improve the counterfactual assessment method using the BIM Contribution Rate (CR), which takes account of the Degree of Identification (DI) and Degree of Cost Impact (DC) based on an expert's opinion. The DI and DC were each capped at a maximum of 0.5 to form the total CR with a maximum value of 1.0. By dividing the CR into equal maximum values of 0.5, the authors aimed to give balanced importance to both the identification and cost impact aspects of BIM's contributions. Kim et al. (2017) must include DC in their calculation as the valuation process was done using the item's cost budget instead of 'impact' based. However, by incorporating more subjective evaluations for DC, the value is susceptible to underestimation as the DC is always capped at 0.5 using the capped summation approach.

The counterfactual assessment can also be conducted on a broader scope to estimate BIM benefits. This concept has been applied in a recent study that simulates the value of BIM using a predefined counterfactual assessment (Gharaibeh et al., 2024). Their framework employs specific percentage (%) reductions derived from expert valuations and historical project data to quantify benefits across the design, construction, and operational phases.

This baseline estimation method is particularly essential when the analysis does not involve a comparative case study approach, which directly compares a BIM project to a conventional project. In such cases, establishing a robust counterfactual scenario ensures that the reported benefits represent the net value attributable to BIM. Similar approaches have been used in other studies to quantify BIM benefits when direct comparisons are not feasible (Barlish & Sullivan, 2012; Love et al., 2013; Won & Lee, 2016).

Careful consideration must be given to the selection of case studies to ensure comparability and validity. For example, Das et al. (2025) emphasize that comparative case studies should account for projects with similar characteristics, such as building type, scale, and complexity, while differing in the level of BIM implementation. This approach allows researchers to isolate the specific benefits of BIM by controlling external variables that might otherwise influence project outcomes. Similarly, Giel and Issa (2013) highlight the importance of using historical project data to establish realistic counterfactual baselines, ensuring that estimated savings are grounded in practical experience rather than theoretical assumptions.

In summary, the counterfactual assessment and comparative case study methods are both valuable tools for quantifying BIM benefits. The choice of method should depend on the availability of comparable projects and the scope of the analysis, with the counterfactual approach offering a robust alternative when direct comparisons are not feasible.

4.3 Valuation

The third step in performing the cost avoidance approach is the valuation process. This step is highly dependent on the decision made in previous stages. The key challenge in performing this step is data availability. Since this paper revolves only around cost saving generated from variations and changes, an integral part of the data needed to be collected is the BIM issue reports, ranging from design review reports and automated clash detection reports pre-construction, which can also be called as VDC-RFI. This is to compile all issues that potentially result in unwanted variations and changes. In certain cases, the field-RFI was used and mapped to the respective Change Order report to detect the preventable cost of change orders if the analysis is done Ex-post in conventional projects to estimate the economic losses for not implementing BIM (Giel & Issa, 2013).

Besides that, other supplementary data needed to be collected depending on the calculation technique. Most of the reviewed studies have included or at least attempted to measure both direct and indirect cost savings generated from preventable issues. Lee et al. (2012) did not elaborate on the valuation step. However, Ham et al. (2018) and Myungdo & Ung-Kyun (2020) detailed the formula used to measure cost savings based on reduced rework from design errors.

Ham et al. (2018) valuation was done following an earlier detailed categorisation step. Each category, signifying a different impact of design errors, results in a different calculation process. The valuation step was done using the project data and the standard agreed-upon value of unit cost and productivity to calculate the cost savings. This reduced the subjective valuation and could increase the accuracy of the result eventually. However, the evaluator must be prepared with all the agreed values based on the project types and settings, such as the rate of labour cost, the rate of productivity of the workers for the projects, and the unit cost standard used for the project.

Meanwhile, Myungdo & Ung-Kyun (2020) relied more on experts' evaluation on each case to determine the cost associated with each case, encompassing material cost, labour cost, and overhead cost for both initial construction and demolition. The data collected from the project and the estimation experts were compiled in a 'rework cost estimation sheet' developed. The rework cost estimation sheet developed could be used as a standard template for future projects to record the accurate VDC logs that document the issue and its corresponding solutions with the cost implications, ensuring the availability of data for the analysis as recommended by Giel & Issa (2013).

Chahrour et al. (2021) performed case study workshops to assess implications of clashes in the form of scenarios with which the Cost Management Consultant (CMC) involved had to assign to it the BQ codes and unit rates. The detailed calculation of it was not discussed. However, the authors reported the average value of cost impact for each clash category, but the value is highly contextual since the unit rate of materials is not the same. This method can be used as a starting point for an organisation to develop a personalized calculation tool by developing the average value of each clash category based on selected case studies in the organisation, using the local BQ rates and customary construction solutions.

To avoid using estimated impact costs as the valuation basis, Kim et al. (2017) applied the contract budget (CB) to value cost savings from various issues, including errors, clashes, and design options. Each BIM issue was mapped to the most detailed level of the related CB item. The value of each issue was calculated based on the proportion of the issue's dimension (e.g., area, volume) to the total dimension of the corresponding CB item. Rework was not measured in this study, as the CB was considered the most appropriate basis for estimating value in lump sum contracts. Otherwise, conflicts could arise among stakeholders over who benefit from the cost savings due to BIM, given the unclear costs attributable to demolition and reconstruction, or just design changes.

In summary, out of the outlined steps, the Counterfactual Assessment step plays the most pivotal role in accurately attributing benefits to BIM and ensuring the reliability of cost avoidance calculations. By establishing a baseline scenario to compare outcomes without BIM implementation, this step enhances the precision of cost avoidance calculations, making it a cornerstone of the overall process.

Effective implementation requires a comprehensive data collection system integrated into review and coordination activities. Key data points, such as BIM contribution levels and cost implications, often rely on subjective assessments and require significant input from experts. This involves gathering detailed project information, conducting expert evaluations, and using standardized templates to ensure consistency and accuracy in data collection and analysis. By adopting this structured approach and integrating necessary data, reliance on comparative case studies is minimized, enabling a more precise measurement of BIM benefits.

5.0 CONCLUSIONS

This systematic literature review has provided a comprehensive analysis of the measurement methods used to quantify cost savings from BIM implementation. By reviewing 10 articles in-depth, five key BIM benefit attributes were analyzed in terms of their measurement metrics and detailed measurement techniques. The findings indicate that different benefit attributes often utilize similar measurement metrics, highlighting the interconnected nature of BIM benefits. The relationships between these benefits and their metrics were mapped, and detailed measurement techniques were consolidated to aid future research. This study underscores the importance of a standardized measurement technique to enhance the accuracy and efficiency of evaluating BIM benefits.

The analysis revealed that the quantification techniques, particularly those based on cost avoidance, provide a robust mechanism for measuring these savings. The paper has proposed basic steps for the cost avoidance approach, which include categorizing issues, performing counterfactual assessments, and conducting valuation processes. However, the variability in measurement methods and the need for context-specific adjustments suggest that further research is necessary to refine these techniques and develop more universally applicable standards.

In conclusion, this paper contributes to the body of knowledge by offering a detailed examination of the measurement processes for BIM benefits, emphasizing the need for standardized metrics and techniques. Future research should focus on expanding the scope of benefit attributes to be measured. To extend this study further, the proposed steps for measuring cost avoidance could be adopted and tested on multiple case studies for developing a practical tool based on the availability and reliability of data and input. Moreover, it is recommended to explore the integration of these measurement methods into practical BIM applications in different organizational contexts to maximize their impact on cost savings in the construction industry.

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