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Potentials of Building Information Modelling (BIM) in Managing Variations

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ABSTRACT

As property development and information technologies are going rapid in these few decades, information construction becomes necessarily as a management tool. Changes and variations in construction projects are common and inevitable. This paper aims to study potentials of Building Information Modelling (BIM) in managing variations. The research objective is to identify the potentials of BIM in managing variations. Qualitative method was adopted for this research. Semi-structured interviews were conducted with the respondents to collect data. Twelve respondents were chosen based on the following criteria: (a) involved in BIM projects and (b) experts with BIM knowledge. The respondents involved in the interviews are BIM software providers, BIM software resellers, BIM consultants, main contractors and government personnel in Malaysia. From the interview findings, the potentials of BIM in managing variations are to reduce the variations due to design-related changes, material-related changes, information discrepancies and construction method. Resolving design-related changes includes better visualisation, design coordination, clash detection, better decision making and minimised uncertainties. Managing material-related changes involves automated quantity taking-off, detailed plan for visualisation and material purchase plan. Reducing information discrepancies involves data digitalisation, communication and collaboration, real-time tracking changes as well as improved on request for information (RFI) process. Minimising variations due to construction method includes simulation, better site management and prefabrication with BIM. This research proves that it is necessary to promote BIM management approach in managing variations.

1. Introduction

Building Information Modelling (BIM) is adopted widely in the United State of America (USA), United Kingdom (UK), Hong Kong, Australia and Singapore [1] but is relatively new to the Malaysia [2]. Public Works Department (PWD) introduced BIM in Malaysia in 2007 [3]. BIM is adopted in Malaysian architecture, engineering and construction (AEC) industry. Government institutions, which include PWD, Construction Industry Development Board (CIDB) and Construction Research

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Institute of Malaysia (CREAM), made some initiatives to encourage BIM in Malaysian construction projects [4].

The Malaysian government is proactive in promoting the successful implementation of BIM. Several government projects adopted BIM for construction. National Cancer Institute of Malaysia was the first BIM project in Malaysia. Healthcare Centre Pahang and Administration Complex of Suruhanjaya Pencegah Rasuah Shah Alam under BIM Pilot program [5]. BIM was utilized in these pilot projects for site modelling, visualization, design review, clash detection, scheduling simulation and record modelling [6].

Changes in construction projects are common and inevitable [7]. Variation orders involved alteration, addition, omission, and substitution in terms of quality, quantity and schedule of work. Sources of variations include the stakeholders' performance, other parties' involvement, availability of resources, contractual relation and, environmental conditions [8]. Imperfections of the initial plans are due to project complexities and uncertainties, realization process and limited time of planning phase [9]. Frequent changes usually cause time overuns, overbudget, defects in quality and other negative consequences. BIM tools are more capable in preparing construction documents with better information for downstream use which is higher quality compared to 2D CAD software and are suitable for [10]. BIM solved issues due to design-related changes.

It is essential to measure project performance because BIM is adopted to improve project performance [11]. Variety of methods to measure BIM implementation have been used for various reasons in the research. For instances, assessment on BIM impacts was done on project outcomes by comparing BIM project vs. conventional project and evaluation of BIM financial advantages and Return of Investment (ROI) [12]. Pidgeon overviewed the measurements for BIM implementation in terms of BIM inputs and BIM outputs [13]. However, those methods are too complicated to showcase the impacts of BIM implementation to the practitioners thus this make it difficult to become the solid evidence for the benefits of BIM. Hence, this study focuses on managing variations which clearly reflect the potentials of BIM to fill the research gap of BIM in managing variations.

The studies show that most of the benefits of BIM emphasized in terms of cost, time and quality rather than discussing the potentials of BIM deal with variation orders. Variation order is important to keep track the variations made to the projects and the cost change incurred due the variations. The variation orders often lead to disputes if it is not handled carefully. One of the general assumptions about BIM utilization reduces design error thus design changes will be reduced to stimulate reduction in variation orders towards a zero variation order in project [14].

This research contributes to body knowledge by providing further applications of BIM in managing variations. This research also benefits the construction industry with giving reference on how to utilise BIM to manage variations in construction projects. BIM adoption in effectively reduces variations due to design changes and discrepancies between contractual documents.

The aim of this research is to explore in depth the potentials of BIM in managing variations. To achieve the research aim, the research objective is to identify the potentials of BIM in managing variations.

2. Literature Review

2.1 Variations

Variations is defined as any deviation such as alteration, addition, omission or substitution in terms of design, quality, quantity and scope of work as agreed in the contract drawings, specifications, and bills of quantities, whether they affect the project cost or schedule or caused by modifications of pre-existing conditions, assumptions, or requirements [15]. According to Abdullah, the characteristics of variation order were described as: i) a written document that contains authorization of the requested alteration, ii) the variation is not fault of contractor, iii) the variation is not included in the original contract hence it is not included in the contract price.

The most common aspects that is the causes of variations is based on the origin agents such as owner-related, consultant-related, contractor-related and others [16]. For example, impediment in prompt decision-making process was interrelated with obstinate nature of owner. An obstinate owner was less likely open to beneficial ideas hence this caused delay in decision making which leads to major variations and thus delay in project. In some cases, design errors and omissions would initiate the consultant to change the design frequently. Besides, changes in specifications by owner were strongly correlated with defective workmanship. Occasionally, consultant who was lack of judgement and experience, was also lack of knowledge of available materials and equipment. In some circumstances, due to consultant's lack of judgement and experience, there were the conflicts between contract documents and inadequate work scope for contractor. The conflicts between contract documents, inadequate working drawing details and unclear work scope for contractor may cause the project actual requirement be misinterpreted. When the design complexity was high and there were inadequate working drawing details, hence this would contribute to variations.

2.2 Building Information Modelling (BIM)

Various BIM software are used by the designers and users as BIM tools to generate and exchange information as BIM process involves creating managing, analysing and using digital information throughout lifecycle of project [17]. Table 1 tabulates information on different stakeholders can utilise BIM tools for different BIM uses to achieve purpose of BIM activities and deliverables [18].

Stanford University Center for Integrated Facilities Engineering (CIFE) proved quantified benefits of BIM adoption from 32 major BIM projects. This included up to 80% reduction in time taken to generate a cost estimate, cost estimation accuracy within 3%, savings of up to 10% of the contract value through clash detections, up to 40% elimination of unbudgeted change, up to 7% reduction in project time [19].

Keskin revealed that the comprehension of BIM concept among the construction stakeholders is restricted to BIM as a process and technology. Poor understanding on BIM overall process such as lack of realization on the advantages of BIM in design and construction by the industry, lack of focused purpose in BIM adoption by BIM adopters, this discourages the implementation of BIM [20]. Table 2 summarises barriers to BIM adoption in different literatures.

Table 1
BIM Uses, Purpose of BIM Activities and Deliverables

BIM Uses	Purpose of BIM activities	Deliverables
Existing Conditions Modelling	To model an accurate representation of the existing conditions for a site, building, adjacent facilities or services.	• Geographical Information • Site Investigation Report • Site Condition Planning • Utilities Model • Preliminary Development Brief • Feasibility Study Report • Land valuation report • Risk analysis report
Site Analysis	To develop a general outline for design development.	• Input for authority information • Solar Analysis • Terrain Analysis • Environmental Impact Assessment
Cost Management	To provide a cost exercises throughout the project lifecycle	• Preliminary Cost Estimates • Cost Planning • Cost Estimate • Bill of Quantities • Procurement Contracts • Cash Flow Analysis • Value Management • Life-Cycle Costing
Design Model	To transform the building's design into a workable model	• Architectural Model • Structure Model • MEP Model • Submission Model to Local Authority (e-submission)
Design Analysis	To execute the analysis of model to increase the performance, suitability and productivity throughout the project lifecycle.	• Sun (shading, orientation) • Building orientation • Natural ventilation • Structural Analysis • Energy Analysis • Life Cycle Cost Modelling • Sustainability Analysis • Lighting Analysis
3D Coordination	To streamline the coordination of BIM models to resolve conflicts before and during construction.	• Design Coordination Report • Clash Analysis Report • Constructability Report
Digital Fabrication	To produce detailing model that is ready for pre-fabrication activities.	• Modular Pre-fabrication Model • Manufacturer Specific Content Libraries
As-Built Modelling	To capture completed as-built parametric and geometric information of project in model.	Project close-out report
FM System	To deliver a model for operation and maintenance decision-making throughout a building's lifecycle	• Operation and Maintenance Manual • Operation Schedule • Building Operation Data

Table 2
Summary of Barriers to BIM Adoption in Different Literatures

Barriers to BIM adoption	
Company innovation	Cost of investment
	Learning curve for BIM technologies
	Lack of executive buy-in
Interorganizational innovation	Shift of liability among project participants
	Poor collaboration among participants
	Poor interoperability among BIM software
	Reluctance to openly share information
	Management problems with BIM master model
	Lack of collaboration management tools
	Organizational structure that does not support BIM
	Lack of subcontractors who can use BIM technology
	Security risk
Both company-specific and interorganizational innovation issues	Lack of expertise
	Limitation of current BIM applications
	Lack of industry standards
	Shortage of BIM implementation data in construction phase
	Difficulties in measuring impacts of BIM

Source: Ibrahim [17]; Del Savio [18]; Keskin [19]

2.3 Application of BIM in Managing Variations

Variations in the project are too many to be picked up and all registered. Often, variations were not identified because the design consultant made changes on 2D drawings and no one is informed about it. Then clashes happened and variation orders are needed to resolve the clashes which incur cost. Variation orders is one of the main reasons of delays in project [21]. The direct cost of design changes during post contract is 5.1%-7.6% of the total project cost.

Understanding the BIM impacts on the variation order system will lead to creation of variation order management and prevention strategy. Design changes can be updated in real time and shown visually in the BIM model. BIM can keep track and register each design change on the model. Two or more revisions of the model in IFC format is compared to mark the changes made to the components in the model. Single design change on one element might affect other components such as architectural, structural, electrical or mechanical (HVAC, piping and plumbing) systems. The change sequence is tracked and list of components affected by main source of change will be provided [22].

The design phase induced 75% of problems or reworks. Greater influence on cost could be achieved with earlier BIM deployment in the design process. BIM is the alternative approach to design since it can present design digitally and it is embedded with necessary information before construction [23]. BIM is typically used to coordinate data from design process and compile into 3D parametric model which facilitates design consultants to visualise project and reduces design errors. BIM simulation reduces variations due to structural or work program clashes and thus this reduces rework and unprecedented cost [24].

Data visualisation, reliable database and data coordination though BIM makes information improved. BIM implementation improves information in project early stage through better quality of data production, better understanding through visualisation and access to information for documentation. BIM reduces uncertainties which leads to project successful completion [25]. BIM serves as communication and collaboration platform with common referent for different stakeholders to interact and align their work. Good relationship and communication between client and design consultant will reduce rework due to design significantly [26].

3. Methodology

The research process started with the determination of research topic, aim and objectives. Then the research process continued by conducting literature review and then research design. The research method used for this research is qualitative method which involves semi-structured interview. Data collected is then analyzed to answer the research objectives and questions.

Qualitative research method is adopted when the concept is immature due to inadequate previous research; theory available is inaccurate, inappropriate, incorrect, or biased; the phenomena is needed to be explored and described; or quantitative method is not suitable to be adopted. Hence, for this study, qualitative methods are adopted for the research. This is because BIM is still at infancy stage in Malaysia, people are still trying to figure out how to integrate BIM in the existing Malaysian construction practice. Thus, the population of BIM expertise in Malaysia who have the insights for BIM in managing variations is small and most of them are based in Kuala Lumpur. The small population of BIM expertise causes qualitative method is more suitable in this research. Although there are abundant BIM-related researches, lack of actual outcomes to sum up the value of BIM in managing variations. There is need for deep and detailed information to be explored from face-to-face interview with the target respondents which the information obtained will be analyzed and interpreted to generate meaningful findings.

Semi structured interviews were set up for this research. There are topics around to construct the interview and this is more formal if compared to unstructured interview [27]. List of questions were prepared as interview guide prior the interview session with the respondents. The questions were not asked in specific sequence but were accordingly modified based on the situation and interaction with the respondent during interview session. The focus of the interview was on the discovery as much as possible on the issues specified in the research objective. Interview guideline questions are basically divided into 2 sections: Part A respondent’s profile, Part B Potentials of BIM in Managing Variations.

Twelve respondents are refined based on the criteria developed by the researcher to fulfil the aim of this research. The criteria employed to determine the suitability of respondents in this research are: (a) involved in BIM projects; (b) experts with BIM knowledge. The respondents involved for the interviews are BIM software providers, BIM software resellers, BIM consultants, contractors and government personnel in Malaysia.

Thematic analysis is used as the technique to analyze the data obtained [28]. The seven stages of thematic analysis are transcription, reading & familiarization, coding, searching for themes, reviewing themes, defining & naming themes and writing the report. Table 3 lists the description for each stage in thematic analysis.

Table 3
Braun and Clarke's Seven Stage of Thematic

Stage	Thematic Analysis	Description
1	Transcription	• Transcribe audio data into written text so that data can be systematically coded and analysed.
2	Reading & Familiarization	• Reading and re-reading the data to become intimately familiar with the content • Analysis begins by noticing things of interest that might be relevant to the research questions.
3	Coding (Selective & Complete)	• Identify aspects of the data that relate to the research questions • Involve selective coding where only material of interest is coded or complete coding where the entire dataset is coded
4	Searching for Themes	• Identify salient features that capture something important data in relation to the research question
5	Reviewing Themes	• Determine whether candidate themes fit well with the coded data • Quality control in relation to the analysis
6	Defining & Naming Themes	• Define themes by stating what is unique and specific about each one • Define the focus and boundaries of the themes
7	Writing the Report	• Write the report by selecting compelling, vivid examples of data extracts, and relating them back to the research question and literature.

4. Results and Discussion

4.1 Respondents' Background Overview

Total twelve respondents who are constructions professional with BIM expertise were interviewed to obtain insights on the potentials of BIM in managing implications. Different perspectives were gained from the respondents with different backgrounds from variety of organizations. The interviews were involved with BIM consultancy firms, BIM software provider company, BIM software reseller company, main contractor company and government agency. Table 4 shows the respondents' profile on their job designation, type of organization, education qualification, as well as their experience in construction industry and practicing BIM.

Table 4
Respondents' Profile

ID	Job Designation	Type of Organization	Education Qualification	Years of Experience in		Experience, Roles and Responsibilities
				Construction industry	Practicing BIM	
R1	BIM Manager	BIM Consultancy Firm	Architecture, Industrial Engineering, M&E Engineering	12	9	• Manage processes and procedures for BIM model exchange. • Create, maintain and analyse federated model for coordination. • Coordinate hand over of BIM model and data to clients. • Manage the implementation of supporting software for BIM. • Responsible for BIM standards development, implementation and enforcement of BIM documentation and workflow process. • Train and oversee the day-to-day activities to ensure BIM standards are maintained in the creation of the BIM model. • Evaluate the workflow, strategies, projects, staffing, etc.
R2	Application Engineer	BIM Software Provider Company	Architecture	12	12	• Responsible in all Architecture, Engineering and Construction (AEC) technical sales aspects for ASEAN region. • Partner with sales teams and authorized resellers to assist in the development, management and execution on strategies for business. • Meet with individuals at all levels to understand their issues and position solutions while discovering business opportunities.
R3	BIM Section Lead	Main Contractor Company	Mechanical Engineering	4	4	• Visualize organizational procedure into BIM format which is compactable to market's BIM requirements. • Create a sustainable system for BIM implementation within the organisation. • Train and coach company staffs on their roles with BIM.
R4	BIM Steering Committee	Developer Company	Architecture	22	10	• Spearheaded the planning and implementation of innovative projects. • Led a team that introduced innovative ways of improving process, cost and technology. • Headed a team that developed SEA's first carbon neutral house, first residential building to be certified Platinum by the BCA (Singapore). • Oversee a team of Design Managers that manages the detailed product development. • Aimed to speed up design process and reduce variations on site with BIM.

R5	Assistant Commercial Manager	Main Contractor Company	Quantity Surveying	9	6	• Oversee all quantity surveying works for sections of underground and tunnel works. • Procurement strategy for package of work. • Cash flow projection & budget monitoring. • Part of tendering team leading all aspects of tender for underground architectural packages. • BIM initiation with 5D aspect related to cost.
R6	Managing Director	BIM Consultancy Firm	Architecture	12	12	• Part of Building SMART community. • Practice Open BIM - a universal approach to the collaborative design, realization and operation of buildings based on open standards and workflows that allow collaboration regardless of the software tools used. • Provide an integrated BIM services - Consulting, Training, Technology and Production for complete project lifecycle for Infrastructure, Building and Oil & Gas industries. • Utilise a Common Data Environment (CDE), a cloud-based collaboration tool to create, manage and share information throughout project lifecycle which is BS1192 compliant. • Provide technology, cost advantage and value add services to clients. • Provide personalised professional services, innovative process flows and intelligent delivery solutions.
R7	BIM Coordinator	Main Contractor Company	Architecture	6	6	• Responsible for BIM modelling updates & coordination for design, construction and as-built purposes. • Liaise with consultant and sub-contractors to perform BIM workshops & coordination on daily basis. • Involve for any related BIM meeting and coordination. • Expertise in Autodesk Revit for architectural & structure discipline.
R8	Managing Director	BIM Software Reseller Company	Architecture	18	14	• BIM consultant with technical knowledge in BIM and professional trainer with proven track record for high level trainings for BIM tools and process. • Innovate software & IT solutions make customer core business more effective. • Deliver a workable and practical solution to ensure full adoption of BIM. • Provide BIM solutions, engineering services consultancy, training, certification, BIM project implementation and IT infrastructure and maintenance services.

R9	General Manager	CIDB-myBIM Centre	Bussiness Management	30	12	• Acting HOD for Training Unit & Marketing Unit. • Responsible for the administration and management of the company, planning and development of resources, overall management of the projects and programs awarded to the company, according to the directions and planning with the stakeholders.
R10	Director	Architectural Firm	Architecture	12	9	• Provide architectural services with BIM. • Advise CIDB and JKR in term of BIM practical implementation. • Create standard models for JKR for repetitive use.
R11	Civil Engineer	Main Contractor Company	Civil Engineering	8	3	• Produce 2D drawings (layout plans, details, etc.) and BIM models in accordance with company's BIM standards. • Develop and maintain BIM Guide and other BIM documents such as Employer Information Requirements (EIR) and BIM Execution Plan (BEP). • Develop BIM model auditing checklist in compliance to company's BIM standards. • Audit consultants' BIM models (architecture, C&S) in compliance to company's BIM standards and prepare audit reports. • Assist construction team in as-built BIM models production. • Monitor the progress and ensure the delivery of BIM models according to the planned delivery schedule. • Attend project meetings including BIM model review sessions and BIM coordination meetings.
R12	Site Engineer	Main Contractor Company	Civil Engineering	4	3	• Assist the Project Manager/Construction Manager in site supervision and monitoring for structural and architectural works. • Prepare and compile the as-built drawing and 3D Revit BIM modelling for structural, architectural and civil works. • Liaise with the quantity surveyor regarding to the procurement and progress claim. • Ensure the responsibility for planning, scheduling, conducting and coordinating the technical and management aspects of projects. • Resolve any unexpected technical difficulties and problems that may arise.

4.2 Potentials BIM in Managing Variations

From the interview findings, potentials of BIM to manage variations can be categorised according to the elements contributing to variations. The causes of variations are divided into four elements: design-related changes, material-related, information discrepancies and construction method.

4.2.1 Design-related Changes

To manage variations, BIM solved issues caused by design-related changes [29]. From the interview findings, design-related changes can be overcome using BIM through a better design visualisation, design coordination and clash detection, together with minimised uncertainties and better decision making. Table 5 tabulates the opinions from respondents on the potential of BIM for managing design-related variations.

33% of the respondents stated the potential of BIM in a better design visualisation. Respondent 3, 6, 10 and 12 mentioned that "*BIM assists architects in explaining their design to clients through visualisation. Clients will be more certain of the design outcomes."* The BIM provides clients with a better design visualization and a greater certainty on the final products, thus reducing the design changes requested by clients during the construction stage [30]. An earlier and more accurate design visualisation provides a better understanding of proposals. Statements of BIM give a better design visualisation, which is supported by most of the respondents. 25% of the respondents stated that BIM had the potential for clash detection. Respondent 1, 5 and 9 mentioned that *"Clashes are detected and solved before construction. Major architectural and structural clashes can be avoided to reduce reworking during construction."* Through clash detection, design changes caused by clashes are reduced, which has been proved in many studies [31]. Most of the respondents agreed that BIM helped in avoiding major clashes that led to structural failure. Hence, this avoids design changes during the construction stage to fix the design errors for clashes. 17% of the respondents mentioned the potential of BIM for design coordination. Respondent 3 and 10 mentioned that *"Design coordination at the project beginning can reduce variations. Design coordination ensures correct information to go to sites during construction."* Massimo-Kaiser *et al*., [32] mentioned that BIM led to a streamlined design process across disciplines. BIM is typically used to coordinate data from design process and compile it into a 3D parametric model, which facilitates design consultants to visualise projects with reduced design errors [33]. Most of the respondents carried out a design coordination by integrating an architectural model with a structural model to eliminate design discrepancies and avoid clashes. 17% of the respondents mentioned the potential of BIM for better decision making. Respondent 3 and 10 mentioned that *"BIM allows more data to be collected for better decisions in the next project, which reduces variations."* BIM is an alternative approach to design since it can present design digitally, which is embedded with necessary information before construction [34]. BIM facilitates decision making in relation to design [35]. A better visualisation of BIM helps clients to make wiser decisions when requesting for design changes. Another 8% of the respondents mentioned the potential of minimised uncertainties. Respondent 4 mentioned that *"The building design is visualised and revised using BIM in a virtual model. This is to ensure that there is no design error before construction."* Soust-Verdaguer *et al*., [36] explained that greater influence on cost could be achieved with an earlier BIM deployment in the design process. BIM reduces uncertainties, which leads to a successful project completion [37]. Respondent 4 emphasized that BIM provided certainty at an early stage where the risk for cost of changes was low. The Sinenko *et* *al*., [38] showed that BIM adoption causes the work efforts to shift to the earlier stage of the project, when the cost of making design changes is low while the impact on cost and performance is high.

Table 5
Potentials of BIM in managing design-related variations

Potentials of BIM in Managing Variations		Respondents	Proposed Frequency
Design-Related Changes	Better Design Visualisation	R3, R6, R10, R12	33%
	Clash Detection	R1, R5, R9	25%
	Design Coordination	R3, R10	17%
	Better Decision Making	R3, R10	17%
	Minimised Uncertainties	R4	8%

4.2.2 Material-related Changes

Most of the respondents did agree that BIM could be used to improve accuracy in quantities of materials to avoid variations caused by inadequate materials. However, a few respondents think that BIM has a limited control over material availability. R8 stated that it was difficult to predict the availability of materials upfront for few years later during construction. According to the findings from interviews, material-related changes could be managed using BIM through an automated quantity taking-off, a detailed visualisation plan and material purchase planning. Table 6 tabulates the opinions from respondents on the potential of BIM in managing material-related variations.

25% of the respondents stated the potential of BIM in automated quantity taking-off. Respondent 1, 6 and 8 mentioned that *"Quantities are generated automatically based on building components through the BIM model. This allows a faster quantity take-off for materials. Any change will be kept tracked without re-measurement. Hence, contractors earned more by reducing material wastage using BIM."* The BIM model provides more accurate quantities, thus reducing variations caused by inadequate materials. As is mentioned by Wright *et al*., [39] quantities of materials will be continuously updated with changes made to the model during the design phase. 17% of the respondents stated that BIM had the potential of making detailed plans for visualisation. Respondent 1 and 5 mentioned that *"BIM provided a better visualisation of design through detailed plans with sections and elevations from different perspectives. A better visualisation facilitates the identification of materials needed for every building component in detail. This reduces the probability of missing out materials and improves the accuracy of material quantification."* BIM providing a comprehensive design of 3D models improves the visualisation of the elements or items for measurement. The improved visualisation facilitates the minimisation of omissions due to difficulties in understanding the design through 2D drawings. Another 8% of the respondents mentioned the potential of BIM for material purchase planning. Respondent 2 mentioned that *"It is useful to control inventory, sales, marketing and finance. An ERP system can be linked to the progress payment to subcontractors. BIM data such as measurements of material quantities and project scheduling is linked to the ERP system, which helps to schedule and manage the material purchasing, so as to avoid delay and variation order caused by material issues."* The BIM model provides more accurate quantities, thus reducing variations caused by inadequate materials [40]. Quantities of materials will be continuously updated with changes made to the model during the design phase. An enterprise resource planning system (ERP) can be linked with BIM data, which controls inventory, sales and finance using a common database. The combination of BIM data with the ERP system is useful for material purchasing and progress payment to suppliers or subcontractors.

Table 6
Potentials of BIM in managing material-related variations

Potentials of BIM in Managing Variations		Respondents	Proposed Frequency
Material-Related Changes	Automated quantity taking-off	R1, R6, R8	25%
	Detailed plan for visualisation	R1, R5	17%
	Material purchase planning	R2	8%

4.2.3 Information Discrepancies

BIM tools are more capable in preparing construction documents with better information for downstream use, which are of a higher quality compared to 2D CAD software and are suitable for [41]. Table 7 tabulates the opinions from respondents on the potential of BIM for managing information discrepancy variations. According to the respondents, information discrepancies could be reduced using BIM through data digitalization, communication and collaboration, as well as real-time tracking changes and an improved request for information (RFI).

33% of the respondents stated the potential of BIM for data digitalisation. There are always discrepancies between contractual documents and sources of information. *"Arguments on variation orders are usually due to discrepancies in the sources of information",* stated by Respondent 1, 2 and 3. *"Contractual documents are supposed to speak to each other in a unified manner, but unfortunately there is plenty of room for human errors. There are discrepancies. It is the nature of information when they are produced independently. BIM unifies information on contractual documents and make sure that all of them speak to each other. BIM acts as the tools to ensure that the sources of information are consistent. BIM digitalises information where the hardcopies are managed in a digital format. BIM increases information accuracy with more organised information."* Respondent 9 mentioned that *"The EDMS system handles digital documents or digitally-scanned versions of original paper documents such as drawings, which is important to the operation of a common data environment (CDE) in BIM, enabling a secure, timely and reliable access to current, validated and relevant information."* Ismail *et al*., [42] stated that data visualisation, reliable databases and data coordination through BIM make information improved. Gomes *et al*., [43] also mentioned the ability of BIM to check the consistency and accuracy of drawings. 25% of the respondents stated that BIM had the potential for improved requests for information process. Erri Pradeep *et al*., [44] mentioned the potential of BIM for improving the ability to solve requests for information (RFI) in real time. This statement is supported by some of the respondents agreeing that the RFI process is faster through BIM. Respondent 2, 8 and 10 mentioned that *"RFI is to get clarification for things that are unsure or unclear. BIM makes the visualisation of problems better either it is design issues or construction issues. RFI is usually requested by subcontractors when something is unclear or happens on site. Subcontractors can mark the exact location through the BIM model rather than sending drawing attachments or photos. The conversations between subcontractors and main contractors will be kept track in the BIM model, which reduces disputes since every single piece of information is recorded. BIM makes the RFI process faster and better."* 25% of the respondents stated that BIM had the potential for real-time tracking changes. BIM can keep track and register each design change through the model, in which design changes are shown visually and updated in real time

[45]. Respondent 5 recalled that repetitive work had to be done at each time for the revision of drawings in conventional practice, *"Changes had to be picked up manually with a comparison between old and new drawings through flipping pages of the drawings. Can you imagine the checking repetition through flipping hundreds or thousands of drawing pages of and the repetition of BQ updating?"* According to Chang *et al*., [46] a fast reaction to design changes facilitates the process of variation orders. Respondent 10 and 12 mentioned that *"Changes are highlighted faster and more easily by comparing the revised and original BIM model."* Another 8% of the respondents mentioned the potential of BIM for communication and collaboration. Gaur *et al*., [47] mentioned that BIM served as a communication and collaboration platform with common reference for different stakeholders to interact and align with their work. Most respondents communicate and collaborate in BIM through a common data environment (CDE). Respondent 12 mentioned that *"BIM is used as the central location for all relevant project information, making it much easier to manage said information and re-access them anytime, including during the operation and maintenance stages. It is much easier to convey to other stakeholders, especially when a project and its associated systems are complex, and when not all stakeholders have the technical knowledge to understand certain elements of a project. BIM cannot progress more without CDE. It is like having amazing hardware but it is of a low battery, or having a sun but it is shaded by the clouds."*

Table 7
Potentials of BIM in managing information discrepancies variations

Potentials of BIM in Managing Variations		Respondents	Proposed Frequency
Information Discrepancies	Data digitalisation	R1, R2, R3, R9	33%
	Improved request for information (RFI) process	R2, R8, R10	25%
	Real-time tracking changes	R5, R10, R12	25%
	Communication and collaboration	R12	8%

4.2.4 Construction Method

According to Respondent R9, variations happen when consultant-specified construction methods are not possible to be built or contractors propose better construction alternatives. Constructability issues can be solved using BIM through simulation, better site management and prefabrication [48]. Table 8 tabulates the opinions from respondents on the potential of BIM for managing construction method variations.

42% of the respondents stated the potential of BIM for simulation. Variations caused by structural or work program clashes are reduced through BIM simulation, which thus reduces reworking and unprecedented costs [49]. Respondent 1, 5, 7, 8 and 12 mentioned that *"BIM can simulate the progress of work with the schedule and cost projection. The planned model and the actual progress model can be superimposed to monitor the progress of work. The schedule was planned with simulation. Delay will be highlighted to site management officers."* 33% of the respondents stated that BIM had the potential for better site management. Respondent 2, 6, 8 and 9 mentioned that *"BIM assists in site planning during construction, helping in monitoring what is happening on site. Variations can be reduced through effective site planning."* BIM provides a holistic view on site management to improve the constructability. 2D drawings are hard to be visualised for site planning compared to 3D models. Another 25% of the respondents mentioned the potential for prefabrication with BIM. Respondent 10 emphasized the difficulties in completely eliminating changes for on-site work, *"Ideally, you want everything to be settled before the real* *construction. You wish nothing to be changed on site. This would not happen unless everything is prefabricated."* Respondent 2 and 4 mentioned that *"Design for manufacturing & assembly (DfMA) is the combination of two methodologies, which are design for manufacturing and design for assembly. In DfMA, BIM is used to design components that are manufactured in factories and transported to sites for assembly. Modular construction with BIM brings the certainty of design and cost, so that there will be fewer variations."*

Table 8
Potentials of BIM in managing construction method variations

Potentials of BIM in Managing Variations		Respondents	Proposed Frequency
Construction Method	Simulation	R1, R5, R7, R8, R12	42%
	Better site management	R2, R6, R8, R9	33%
	Prefabrication with BIM	R2, R4, R10	25%

5. Conclusions

This research aimed to explore the potentials of BIM in managing variations. The research objective has been achieved in this research. From the literature review, the causes of variations identified are design-related changes, material-related changes, information discrepancies and construction method.

The potentials of BIM in managing variations are to reduce the variations due to design-related changes, material-related changes, information discrepancies and construction method. To resolve design-related changes, potentials of BIM include better visualisation, design coordination, clash detection, better decision making and minimised uncertainties. To manage material-related changes, potentials of BIM involved automated quantity taking-off, detailed plan for visualisation and material purchase plan. To reduce information discrepancies, potentials of BIM are utilised in data digitalisation, communication and collaboration, real-time tracking changes as well as improved Request for Information (RFI) process. To minimise variations due to construction method includes simulation, better site management and prefabrication with BIM.

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