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Seismic building design work process using building information modeling (BIM) technology for Malaysian Government projects

Siti Zati Hanani Mahamood
Malaysia-Japan International Institute of Technology,
Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia and
Public Works Department of Malaysia, Kuala Lumpur, Malaysia, and

Mohamad Syazli Fathi
Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia,
Kuala Lumpur, Malaysia

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Abstract

Purpose – This paper aims to improve the seismic building design (SBD) work process for Malaysian Government projects.

Design/methodology/approach – Semi-structured interviews were virtually conducted to a small sample size of internal and external stakeholders from the Malaysian Government technical agency. There were seven of them, comprising Structural Engineers, an Architect, a Quantity Surveyor and consultants-linked government projects. The respondents have at least five years of experience in building design and construction.

Findings – The paper evaluates the current SBD work process in the government technical agency. There were four main elements that appear to need to be improved, specifically in the design stage: limitations in visualization, variation of works, data management and coordination.

Research limitations/implications – This study was limited to Malaysian Government building projects and covered a small sample size. Therefore, further research is recommended to extend to other government agencies or ministries to obtain better results. Furthermore, the findings and proposal for improvements to the SBD work process can also be replicated for other similar disasters resilience projects.

Practical implications – The findings and proposal for improvements to the SBD work process can also be replicated for other similar disasters resilience projects.

Social implications – This study was limited to government building projects and covered a small sample size. Therefore, further research is recommended to extend to other government agencies or ministries to obtain better results. Furthermore, the findings and proposal for improvements to the SBD work process can also be replicated for other similar disasters resilience projects.

Originality/value – This study provides an initial step to introduce the potential of building information modeling for SBD in implementing Malaysian Government projects. It will be beneficial both pre-and post-disaster and is a significant step toward a resilient infrastructure and community.

Keywords Building information modeling, BIM, Seismic, Disaster, Resilience, Earthquakes, Disaster prevention, Building design, Seismic design

Paper type Case study

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1. Introduction

The frequent occurrence of earthquakes in low seismic zones has prompted researchers worldwide, including Malaysia, to investigate seismic hazards in low seismic zones. Taking Australia as an example, formerly classified as an earthquake-free zone, the region was badly hit by the sudden first earthquake in 1989 with a moderate magnitude of 5.5 that claimed lives, damaged 50,000 buildings and demolished 300 buildings (Ganasan *et al.*, 2020). The 2015 earthquake in Sabah shows some resemblance to the earthquake that occurred in Australia. Although Malaysia is categorized under the low to moderate seismicity region, the possibility of the earthquake should not be ignored because Malaysia is surrounded by highly seismically active bays (Awaludin and Adnan, 2016). The soft soil condition caused the buildings can often be exposed to far-field earthquakes (Ganasan *et al.*, 2020). The communities began to worry for their safety as residents felt tremors from neighboring countries, and local ground shaking, especially those living in the high-rise buildings (Tongkul, 2021). Therefore, the ability of buildings in Malaysia to withstand seismic waves has become the main agenda in the construction industry.

Previously, seismic designs were not practiced because Malaysia has never experienced critical earthquakes (Ismail *et al.*, 2011; Ramli *et al.*, 2017). As a result, most public buildings in Malaysia have been designed as conventional based on British Standard 8110:1997 in which specific seismic provisions may not be available (Ganasan *et al.*, 2020; Loi *et al.*, 2018). Therefore, the case of Ranau, Sabah has been a turning point to strengthen seismic risk reduction in Malaysia. The Malaysian National Annex to Eurocode 8 was then successfully published in late 2017 (Tongkul, 2021). New public buildings in the future are expected to have seismic proof. Figure 1 is the Seismic Hazard Map of Malaysia bound in the Malaysian National Annex to Eurocode 8.

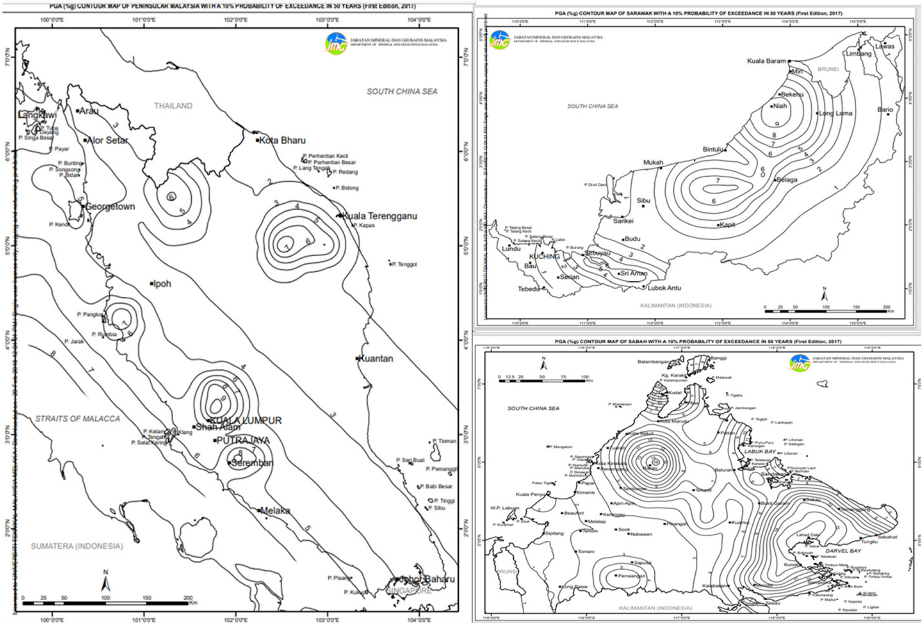

Figure 1.
Malaysian Seismic Hazard Map

However, many studies reveal that even though seismic building codes are already in place, major damage and building failures still occur when an earthquake strikes. Weaknesses in design and construction practices, inadequate analysis, design deficiencies, insufficient research and even low-quality construction are the combined reasons for multiple damages (Agarwal and Shrikhande, 2011; Almarwae, 2017; Khoiry *et al.*, 2018). Because of these problems, many researchers have found that Building Information Technology (IT) (building information modeling [BIM]) technology helps in seismic disaster resilience and is beneficial in many ways. For example, several reports indicate that BIM improves building performance and accelerates building assessment activities following earthquakes.

Seismic building design (SBD) is considered new in the Malaysian construction industry. Based on findings, the existing SBD work process for Malaysian Government projects relies on traditional methods. Drawings and designs provided by paper-based documents often can be a source of errors, misunderstanding and interpretation. Furthermore, the professional tools available in the government technical agency have limitations for certain analytical work, resulting in inaccurate assessments, inappropriate design decisions, the design process becoming complicated and time-consuming. In addition, current work processes have weaknesses in integrating design data and building information, making the assessment of future buildings difficult. For this reason, the current SBD work process needs to be improved to enable faster and more efficient analysis and enhance the quality of seismic building assessments. Therefore, this study aims to improve the SBD work process using BIM technology specifically for Malaysian Government projects.

In achieving the above aim, the primary research objectives that form the background to this paper were to evaluate the current SBD work process and to propose SBD work process using BIM technology for Malaysian Government projects. The study is limited to government building projects in Malaysia. Therefore, the government technical agency was selected as a case study based on their largest role in constructing and maintaining public buildings in Malaysia. Based on findings on the current SBD work process, there were four main elements identified that need to be improved in the design process. The information gathered was then discussed and used to propose improvements to the SBD work process. Thus, this study will improve the efficiency of the current work process and improve the performance of buildings that are resilient to earthquake disasters.

2. Literature review

2.1 Building information modeling technology

Over the past few decades, most industries, including the engineering and construction sector, has undergone various technological developments and innovations to improve performance and productivity. One of them is BIM. BIM has been practically used in the Architecture Engineering Construction (AEC) industry since mid-2000s to transform the way infrastructure is planned, designed, analyzed, built and managed, hence improving project delivery (Azhar *et al.*, 2012; Latiffi *et al.*, 2013).

2.1.1 Definition of building information modeling. There are numerous definitions of BIM available in the literature. However, BIM can be described as a system with a combination of technologies that produces a digital representation of a built asset that enables various parties to exchange physical and functional information (Azhar *et al.*, 2012; Goh *et al.*, 2019; Lu *et al.*, 2019; Welch *et al.*, 2014). The application of BIM as advanced IT in the construction industry can replace traditional work methods to provide better value for work processes, particularly in every construction stage.

2.1.2 Application of building information modeling in construction industry. BIM is a promising advancement in the fields of design, engineering and construction. BIM offers a platform for fostering collaboration across multiple disciplines (Goh *et al.*, 2019; Kubba, 2014) and has led to a significant rise in the use of BIM in the construction industry internationally (Othman *et al.*, 2021). BIM was introduced in Malaysia in 2007 to improve project performance (Ibrahim *et al.*, 2019). Although BIM adoption in Malaysia is still low (Othman *et al.*, 2021), BIM technology has recently become part of Malaysia's national agenda toward digital construction through the Malaysia Construction 4.0 Strategic Plan 2021–2025 (CIDB, 2021). It is one of the government initiatives to encourage construction industry players in Malaysia to use BIM technology in the era of technological revolution.

The application of BIM in construction projects encompasses all project phases, including planning, design, construction and post-construction for operation and maintenance of a building (Azhar *et al.*, 2012; Fadeyi, 2017; Latiffi *et al.*, 2013). It integrates all processes and parties from different disciplines in a virtual environment, which improves the productivity of a project team. The information stored in the BIM repository during the planning stage can drive design stage activities more efficiently. Digital BIM models with cloud-based tools allow teams to share project models and coordinate project planning, ensuring all design stakeholders have insight into the project. Cloud access enables project teams to review drawings and models at any time, even remotely. The ability of BIM to have a greater overview from the beginning offers the building owners to make changes before construction begins. In addition, BIM provides an opportunity to avoid clashes between building elements and unforeseen issues by enabling easy commenting and reviewing across multiple disciplines (Azhar, 2011). BIM also allows for quantity extractions based on visualization and information stored in the model. BIM enables automatic quantification as design data is interrelated. Any changes on the model, all data instantly updates (Goucher and Thurairajah, 2009). Thus, human error can be eliminated.

BIM data can be used to generate construction and fabrication drawings instantly because of its capability to provide accurate information and complete component details, such as 3D geometry, material specifications, finishing requirements, delivery sequence and time (Fadeyi, 2017; Hunt, 2013). Accurate and continuous digital records of building information are invaluable for facilities management (Eastman *et al.*, 2008). The emergence of BIM technology as a digital platform has changed the work process in many ways. The capabilities of BIM have been proven in project management and provide numerous benefits over the traditional method.

2.1.3 Benefits of building information modeling technology. BIM has become an invaluable tool with abundant benefits for the construction industry and discussed for many years. BIM creates work more efficiently through intelligent models and efficient data management. As a result, BIM enables projects to have a better chance of success and maximize project effectiveness throughout their lifecycle and beyond.

Optimal cost in a project is often seen as a result of the use of BIM. According to Bryde *et al.* (2014) and Mesaros and Mandicak (2017), the most significant benefit of BIM application in the construction industry is cost reduction or cost control. BIM could also lessen construction time when it is used ultimately and effectively (Bryde *et al.*, 2014; Doumbouya *et al.*, 2016). BIM benefits designers by eliminating manual checking work and assisting in the quick decision-making in various project tasks (Doumbouya *et al.*, 2016). BIM allows the entire model to be automatically updated based on the changes made (Garavaglia *et al.*, 2020), which indirectly reduces the time required to produce the drawings and other construction processes. The virtual 3D, 4D and 5D knowledge repository provided by BIM could aid quick modifications if design changes are required to meet project specifications (Fadeyi, 2017).

The BIM repository enables automatic coordination through virtual modeling 3D viewing sessions, which improves communications and trust between stakeholders and eliminates the need for traditional coordination sessions (Azhar, 2011; Bryde *et al.*, 2014). Better coordination and collaboration can also help in the early detection of conflicts, minimize errors and possible rework, faster decision-making and reduce the risk of budget overruns (Azhar, 2011; Chou and Chen, 2017; Garavaglia *et al.*, 2020). Design accuracy and documentation improvement are two key elements related to quality compliance due to the BIM approach (Bryde *et al.*, 2014). BIM also enables construction verification before construction begins, which directly increases the accuracy of construction work on-site and reduces the possibility of rework. As a result, it will improve overall construction efficiency and quality (Chou and Chen, 2017). Furthermore, BIM contains the most up-to-date information as all project teams need to update the BIM model throughout the project lifecycle continuously. Therefore, BIM is considered a lifecycle data that can facilitate facility managers to operate and maintain buildings more efficiently (Azhar, 2011; Azhar *et al.*, 2012). Based on the stated benefits, BIM improves the construction process to be smoother, less complicated and successful and serves buildings efficiently throughout their lifespan.

Recently, several studies have shown that the BIM platform can also be used in performance evaluation against destructive events such as earthquakes (Angulo *et al.*, 2020). Therefore, Section 2.4 will evaluate the potential of BIM technology in reducing seismic risk.

2.2 Earthquake hazards

Hazards exist in our daily lives. United Nations Office for Disaster Risk Reduction defines hazards as a process, phenomenon or human activity that may cause loss of life, injury or other adverse health consequences, property damage, social and economic disturbance or environmental degradation. Hazardous events at any scale that can cause damage to infrastructure, economic losses and endanger human life are called disasters.

One example of a natural hazard is a geophysical hazard that originates from internal earth processes. According to CRED (2019), earthquakes are part of geophysical events and are considered mega-disaster because of the highest numbers of deaths in the world causing, more than 100,000 deaths per incident. In addition, the earthquake also has caused massive damage to the infrastructure system, loss of livelihoods and disrupted supply chains. These incidents show the importance of proper land use and appropriate application building codes in seismic zones.

2.3 Seismic building design

Human interventions can generally reduce seismic risk. Vulnerability can be minimized by applying advanced design and construction that is resistant to earthquakes (Tolis, 2014). Therefore, engineers play a critical role in reducing seismic vulnerabilities by providing sophisticated engineering solutions. The essence of the seismic design philosophy of buildings is to design the buildings to have sufficient energy dissipation characteristics without experiencing collapse and survive future earthquakes. As stated by Bilham (2014), the responsibility of engineers is to construct buildings that do not collapse during earthquakes, reduce the number of injuries, allow the occupants to escape and the building is expected to function immediately after the quake stops.

2.3.1 Seismic building design requirement. Seismic design offers structures with adequate stiffness, strength, configuration and ductility (Haseeb *et al.*, 2011). The design of a building requires consideration of many factors that can significantly impact seismic performance (FEMA, 2018). Therefore, the basic requirements of seismic design vary depending on the type of structure, location and application of the seismic design and criteria (Haseeb *et al.*, 2011). Figure 2 is the seismic design requirements.

In most building codes, including Malaysia building code MS EN 1998–1:2015 (National Annex, 2017), the fundamental design requirement is the structure should be designed and constructed with 10% probability of exceedance (P_{NCR}) in 50 years. The level of seismic action depends on the importance class of the building where it is based on the functional use of the buildings for optimal seismic design (Dhir *et al.*, 2020). It is recommended in the seismic design as a multiplier to increase or decrease the design base shear. According to Malaysia National Annex 2017, the building importance class for Malaysia is categorized under four categories. The higher importance class category refers to the critical and safety level of the buildings for SBD considerations.

Construction location is a fundamental criterion in SBD. The seismic hazard map is a step toward disaster mitigation, as it is a guideline for providing adequate seismic resistance in a construction project (Agarwal and Shrikhande, 2011). Clause 3.2.1 MS EN 1998–1 states that three categories can distinguish seismic zones according to the level of seismic hazard very low seismicity, low seismicity and considerable seismicity zones. Each seismic zone is defined with a different level of code design requirement.

Soil condition at the construction site is important in determining the seismic design category (FEMA, 2010). This is because the effects of the earthquake largely depend on the type of soil. According to Matinmanesh and Asheghabadi (2011), there are numerous studies and example cases related to soil conditions and building damage. Therefore, MS EN 1998–1:2015 (National Annex, 2017) provides five ground profiles, denoted Ground Types A, B, C, D and E. The average properties of soil within 100 feet (30 meters) of the ground surface are used to determine the ground type.

Building configuration is also an important aspect of seismic design considerations. The building configuration determines the distribution of seismic forces within a structure, their relative magnitude and design issues (Taranath, 2004). In addition, several studies indicate that irregular structural configurations are responsible for most damage and subsequent building collapses (Mezzi *et al.*, 2004). Therefore, building configuration is a fundamental requirement in seismic design to control the response of buildings under seismic attack and determine the most appropriate seismic design devices and mitigation strategies to use.

Figure 2.
Seismic design requirement adopted from Malaysian National Annex 2017

Ductility is the capability of the building materials, structures or systems to absorb energy with acceptable deformations, which greatly reduces the risk of a catastrophic failure (Gioncu, 2000; Taranath, 2004). Therefore, the design codes have addressed the importance of requirement seismic detailing in the design (Lu *et al.*, 2012; Malaysia, D. of S, 2017). The other design requirements to be considered are the importance of structural systems selection, for example, the concept of strong columns and weak beams, avoiding heavy cantilever in structural design, determining quality materials in the design phase, avoiding short columns and unconfined gable walls (Dogangun, 2004; Yon *et al.*, 2017).

2.3.2 Implications of non-seismically designed building. Every earthquake causes a lot of suffering in the form of loss of life and destruction. It teaches society, particularly construction industry players, about the importance of better design and construction practices. Design and planning weaknesses, insufficient research, design deficiencies and even low quality of construction can all be found in various types of structures damages (Agarwal and Shrikhande, 2011; Khoiry *et al.*, 2018).

Soft stories, mass irregularities, floating columns, poor material quality, poor quality of workmanship, wrong structural system, pounding of adjacent structures, soil and foundation impact and inadequate ductile detailing in structural components are the main causes of damage to buildings (Agarwal and Shrikhande, 2011; Damci *et al.*, 2015; Fardis *et al.*, 2015; Ganasan *et al.*, 2020; Khoiry *et al.*, 2018; Yon *et al.*, 2017). These factors can induce structural joint failure, cracks in structural and non-structural members, partial collapse and the worst-case scenario is possible to total collapse. Structural failures provide important lessons to engineers and builders that bad design and poor construction should be avoided. From a personal point of view, earthquake-resistant design cannot be relied upon on formulas and calculations alone. Still, the designers need to imagine and visualize the performance of a building to make accurate assumptions. Therefore, this is the point at which technology is required to help designers better understand and visualize the behavior of structures under seismic loads.

2.4 The use of building information modeling technology for resilient buildings

BIM can enhance the resilience of construction, starting with the design process. The seismic design approach gradually transforms from design for seismic resistance to seismic performance design procedures (Priestley, 2000). The key areas of the performance-based design approach are the assessment of building behavior and how structures are anticipated to perform under the potential hazard loads that they may experience (Alirezaei *et al.*, 2016). Therefore, this interactive design procedure should be performed with simulations to determine the probability of building damage states, such as slight, moderate, extensive and complete demolition (Alirezaei *et al.*, 2016). A study proposed by Zou *et al.* (2019) shows that BIM technology benefits interactive visualization with simulation techniques.

Apart from determining building damages, BIM can also be used to analyze the cost of damage, assess the environmental implications of damaged buildings and assess the costs of future interventions when dealing with economic losses caused by seismic events (Alirezaei *et al.*, 2016; Vitiello *et al.*, 2019). BIM features that contain structural and non-structural details concurrently with the use of the fragility curve are very important for building loss assessment (Charalambos *et al.*, 2014; Xu *et al.*, 2019a). For example, a study by Angulo *et al.* (2020) shows that the impact of an earthquake on a building can be determined whether the building can be repaired or demolished. Consequences of losses can also be calculated, such as repair costs, repair time, number of injuries and casualties. In addition, Xu (2019b) developed a virtual reality program for a virtual walkthrough to observe the distribution of seismic damage in buildings. Through 3D visualization, simulation and virtual reality scene, this sophisticated tool facilitates building assessors to conduct assessment efficiently, reduces inaccurate on-site visual inspections and helps building owners understand the actual condition of a building after an earthquake for repair strategies (Charalambos *et al.*, 2014).

After an earthquake, damaged structural and non-structural components will cause the occupants to be trapped indoors as debris and smoke obstruct the evacuation route. Moreover, many rescuers experience difficulties searching the victims as they are not familiar with the building layout. In these circumstances, rescuer teams need engineers to assist them in the safest route to reach the victims. Therefore, Xinzheng Lu *et al.* (2020) proposed post-earthquake indoor rescue simulations using building information models and virtual reality programs. Based on the analysis of the different scenarios in that study, the rescue time and speed, the risk of the rescue route and the protective equipment required by the rescuer were obtained. The results can also be a guide during search and rescue activities or even for training purposes.

A study by Zeibak-Shini *et al.* (2016) investigated that as-damaged BIM model can be constructed using as-built BIM models and laser scanning. The study was able to identify the location of damaged reinforced concrete components, assess the damage level, estimate repair costs or plan reconstruction work, and, most importantly, provide guidance for rescue teams to reach survivors safely. This study demonstrates that BIM is beneficial not only for building assessment but also for response activities. Latest, a study by Park and Seo (2021) also shows that risk assessment for earthquake damaged-building can be improved by comparing BIM-based 3D modeling visualization with point cloud data using 3D scanning technology. This proposed risk assessment technology can be an appropriate methodology for measuring current building values.

Repair cost and time are important indicators for seismic resilience. Understanding the details of the repair process beforehand will aid in the evaluation and decision-making for building seismic resilience. Therefore, Zhen *et al.* (2020) proposed a 5D simulation method based on BIM to help decision-makers choose the optimal repair options. The animated repair process provides a detailed cost change process, repair period and dynamic resource requirements.

Based on the findings above, it has been proven that BIM can improve the efficiency of SBD and the accuracy of seismic damage risk assessment. The application of BIM in building construction is unarguable as it is a repository of information. BIM facilitates detailed investigations on building seismic behavior and the level of vulnerability or damage of building elements through simulations techniques and 3D presentations. Therefore, BIM technology gives great advantages for SBD and should be embedded in the design work process as it is also beneficial for post-disaster.

2.5 Preliminary study on seismic building design work process in the government technical agency

A preliminary study of the existing building design work process in the government technical agency was conducted based on available design manuals collected from the agency’s official website and online discussion with the officers. Based on the documents, it was found that the design process is a traditional-based method. The current process is a decentralized system, whereby the design team works separately, drawings are produced independently and designs are coordinated manually. The most crucial part is that all design information and data management are not integrated properly, which can pose problems in seismic building assessment, especially during post-earthquake.

Furthermore, although BIM technology has been introduced in the organization to improve the quality of the project delivery system since 2014, the use of BIM technology for

SBD does not exist. Therefore, as BIM technology is significant for seismic disaster resilience, it is vital to integrate the current SBD work process with BIM technology to be more efficient, have better building performance, and thus be resilient to earthquake disasters.

3. Research method

The research framework of this study is illustrated in Figure 3. This study uses qualitative methods for primary data collection. Therefore, the government technical agency was selected as the case study as the Malaysian Government mandates this organization for constructing and maintaining all public infrastructures in Malaysia. The information obtained from interviews was analyzed by conducting content analysis, and data were categorized into four themes. The results were then used in the discussion section to propose improvements for the SBD work process for Malaysian Government projects.

3.1 Data collection

Data collection methods used to achieve the research objectives include documents review and semi-structured interviews. These research techniques are complementary to each other to construct validity for this study. In the initial phase, a literature review was conducted to identify the use of BIM technology for SBD. At the same time, documents on guidelines, procedures and other documents related to the building design work process were reviewed to understand the existing work process and help develop the interview questions. The second phase of this study is primary data collection, in which a semi-structured interview was used to understand and evaluate the current SBD work process for Malaysian Government projects. This research technique was chosen because the information and data cannot rely solely on documents, for which each process needs an in-depth explanation by the practitioner.

According to Abdul Majid *et al.* (2017), obtaining expert validation on the interview guide is essential to iron out some unnecessary questions before proceeding with a full-scale study. It also helps to eliminate biased statements that may exist during the interview sessions to provide accuracy and validity of the data. Therefore, initial discussions were held with professional experts while constructing the interview questions for this study. They were; structural engineers and seismic experts and BIM experts. Both are actively involved in developing guidelines and providing technical advice in their respective fields.

3.2 Document review

Over the years, organizational and institutional documents became the basis of qualitative research. As a result, the number of research papers and journal articles mentioning document analysis as part of the methodology has increased recently (Bowen, 2009). Therefore, document review is very important before the actual study is conducted. In this study, the organization's documents provide preliminary research data. The purpose is to understand the organization's work process, find voids in the current work process and help develop interview questions. The documents used in this research include manual design guidelines, project reports and organizational standard procedures. All documents were accessed through their official website and e-mails from the officials of the organization.

Figure 3.
Research framework

3.3 Semi-structured interview

This study covers a small sample size of internal and external stakeholders. They were sought among personnel from the government technical agency and consultants-linked government projects. The interviewees were seven personnel altogether. Five of them were from the government technical agency. The rest were government-appointed consultants, who are currently involved in ongoing projects with the government technical agency. They are Civil Engineers, an Architect, a Quantity Surveyor and BIM expert with at least five years of experience in building design and more than 10 years of experience in building construction. To facilitate discussion in the next section, they were coded based on their profession, followed by the sequence of respondents. For example, RS1 refers to the first respondent. The meaning of coding is as in Table 1.

4. Findings and analysis

Pikas *et al.* (2020) state that it is impossible to work efficiently if the work process is inefficient. Therefore, to further improve building design and management practices, it is necessary to understand the nature of design and management activities. Figure 4 depicts the general conventional workflow of a building construction project based on thorough discussions with all respondents during interview sessions and documents review. Based on their explanation, the design process can be divided into three phases: concept design, preliminary design and detailed design. The average time to complete the design process is three months, depending on project size. As presented in Figure 4, the detailed design process begins with architects, and then, the architect will distribute the final architect drawings to the structural engineer. At this stage, the structural engineer will perform SBD and the detailed process of SBD, as shown in Figure 5.

4.1 Current state of seismic building design work process

Findings show that the design process is limited to structural design software, such as TSD, Etabs and StaadPro. SBD has not yet been integrated into the BIM work process. In addition, SBD is currently a resistant-based design approach. Therefore, it can be concluded that the design process is still based on conventional methods.

4.2 Findings in the existing seismic building design work process

Issues raised by respondents were categorized into visualization, variation of work, data management and coordination.

4.2.1 Visualization. Structural analysis is a crucial part of seismic design and assessment. Therefore, visualization is very important to help designers understand the response of structures under seismic loads. With this regard, RS1, RS2, RC1 and RC2 mentioned that the capabilities of the existing software limit certain analytical work. For

Table 1.
Respondent codes

No.	Codes	Background
1.	RA	Architect
2.	RS1	Structural Engineer 1
3.	RS2	Structural Engineer 2
4.	RQ	Quantity Surveyor
5.	RC1	Civil and Structural Consultant 1
6.	RC2	Civil and Structural Consultant 2
7.	RB	BIM Expert

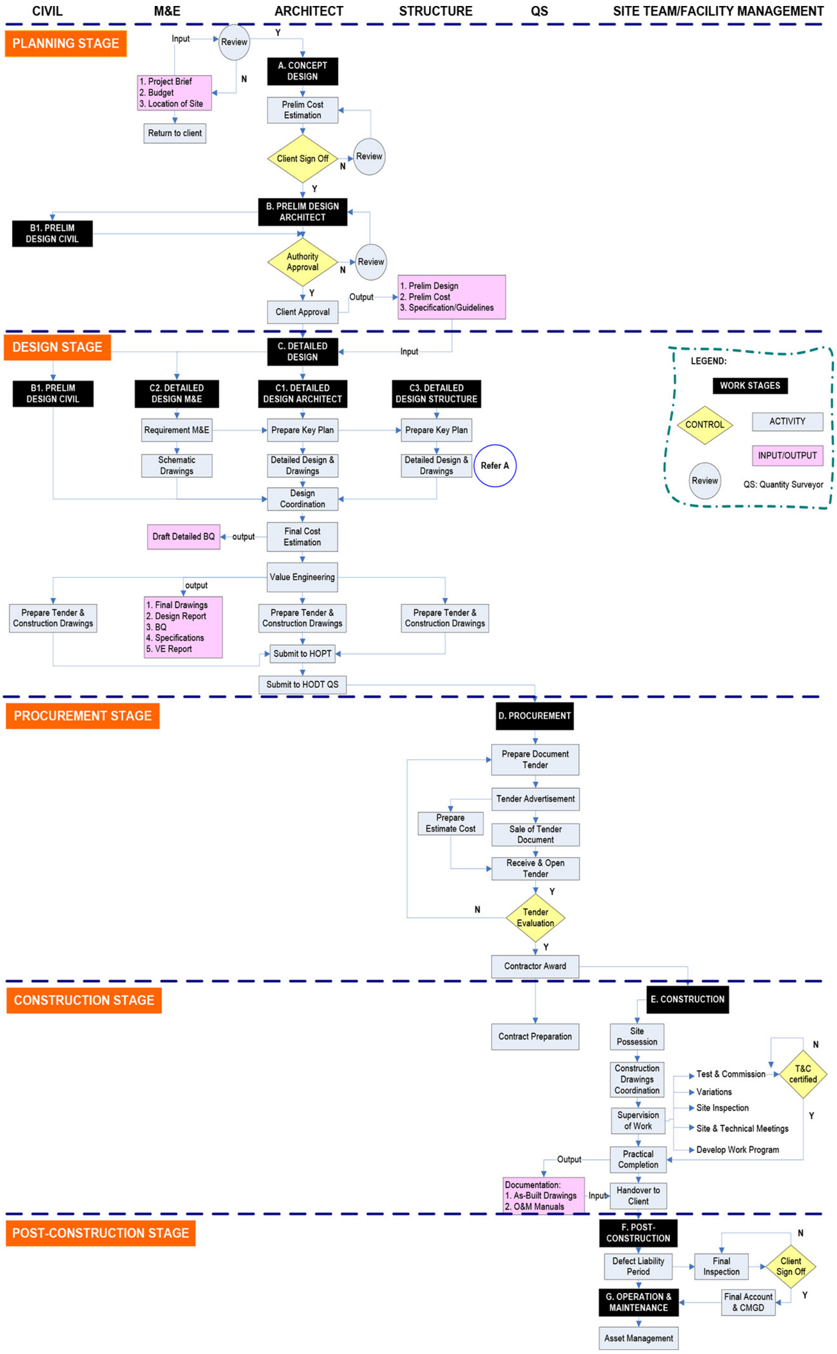

Figure 4.
Conventional building design work process

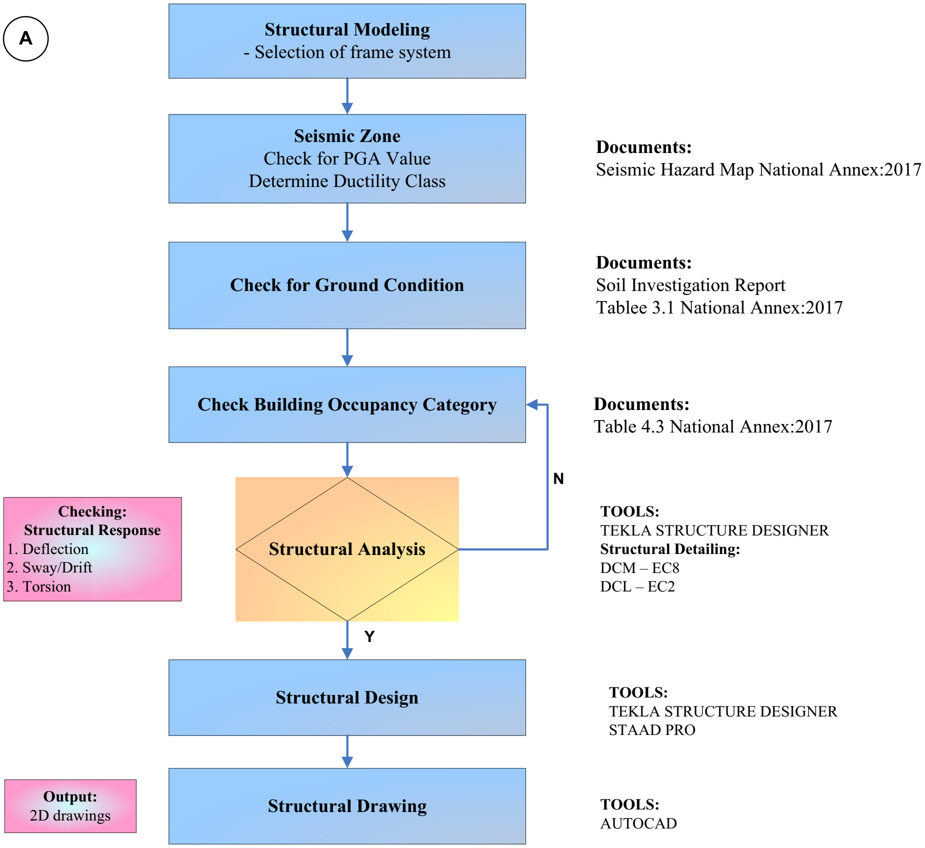

Figure 5.
Seismic building design work process

example, they could see the sway and deflection of the building, but the mode of failures cannot be seen in detail. Therefore, the design process is limited to structural analysis only.

4.2.2 Variation of work. During the design process, design changes often occur between disciplines. Almost all respondents replied that design changes caused rework, mistakes and delays. According to all structural engineers in this study, problems occur when structural changes are involved. Seismic analysis and structural design is a lengthy process. Therefore, it will slow down the work process, and the designer may make mistakes when making changes. Additionally, *RQ* also added that design changes would cause all measuring work and documentation to be revised. Due to time constraints and remeasurements are performed manually, there may be inaccuracies in quantity measurement. It also causes all the whole process delays, for which QS is frequently held responsible.

4.2.3 Data management. In the conventional building industry work process, drawings from different disciplines are often prepared independently, working separately from one another. When asked about documentation and data management and who is responsible for keeping all information, all respondents replied that the respective design office keeps all design data and project information. To date, they do not have a centralized system.

4.2.4 Coordination. According to the responses of all interviewees, design coordination among team members is maintained through meetings, e-mail and correspondence. In addition, design information and drawings were exchanged using computer files. All administrative works were recorded in paper-based and carefully documented in the file.

In addition, all structural engineers in the study have pointed out that problems often arise when multiple versions of drawings are distributed, causing them to be confused and difficult to keep track of the latest version. This scenario also contributes to the occurrence of disputes between structural and architectural drawings. RA mentioned that design coordination between design teams is performed manually, resulting in inaccurate clash analysis. Meanwhile, *RQ* added that they frequently receive drawings that are not well coordinated. As a result, many clashes issues cause measurement work to be delayed. Moreover, information on drawings is also frequently inconsistent between disciplines, not updated, incomplete and inconsistent between drawings and detail notes.

5. Discussion

The purpose of this section is to provide a discussion of the findings derived from the previous section. Respondents' viewpoints toward the existing design work process appeared to be needing some improvements. Therefore, upon careful analysis, the issues highlighted were combined with literature to propose improvements to the existing SBD work process.

5.1 Seismic building design work process outcome

As mentioned previously, the current work process still relies on conventional methods. Using traditional methods, integrating multiple sectors in the AEC industry is costly and time-consuming. Additionally, the results often had inaccuracies, and the drawings were inconsistent due to the lack of interoperability issues (Alirezaei *et al.*, 2016). Based on this statement, this study found that it occurs in the current SBD work process that needs to be improved.

5.1.1 The performance-based design. The primary concern of building codes has always been safety and collapse prevention. However, this conventional prescriptive design has shifted over time to performance-based seismic design (Joyner and Sasani, 2020; Priestley, 2000), where buildings are tailored to the owner's performance requirements (Amirebrahimi *et al.*, 2015). The impact of building performance is a significant step toward community resilience. Seismic performance is usually expressed in possible casualties, repair and replacement costs, repair time and environmental impacts. Therefore, the performance-based design required an iterative design procedure. The current design practice by the government technical agency is a resistance-based design. It requires the engineer to verify that the structure complies with a series of code requirements. However, the design did not consider non-structural elements that are often vulnerable to accelerations and displacement arising from the structure's seismic response, which significantly affect the function of the building during and post-earthquake.

Figure 6 illustrates the performance-based seismic design approach. The first two stages represent the traditional seismic assessment approach that is currently practiced in the organization. Since the performance-based design is of paramount importance for resilient infrastructures, the last two stages are recommended to be included in the existing seismic design work process. It assesses the vulnerability and cost of damage components, where a cost-benefit analysis can be used to select the most cost-effective alternatives. The integration of structural and non-structural elements in the same model would allow identifying optimum seismic design solutions and improve the seismic performance of the building.

5.2 Leveraging building information modeling for earthquake-proof structural designs

Based on findings in the literature, earthquake retrofitting, design coordination, enforcing building codes and developing efficient earthquake-resistant building designs are some areas in which BIM plays a vital role with its imperative virtual design and construction tools. BIM incorporates early earthquake-safe design considerations and, at the same time to eliminate design modifications once the construction begins. In addition, BIM provides rich information in intelligent 3D models, which is beneficial while complying with seismic specifications. There are uncountable benefits of BIM in SBD that have been discussed in the literature. Using BIM is undoubtedly the most cost-effective and efficient tool for developing resilient infrastructure projects. Therefore, it is justified that BIM is significant and should be embedded in the SBD work process. The use of BIM will be a new benchmark, particularly for structural engineers when designing earthquake-resistant structures.

5.2.1 Interactive visualization and simulations. Based on the findings, the existing design software is considered sufficient for structural analysis that conforms with building codes. It also can visualize structural responses under seismic loads in an engineering-oriented manner. However, structural analysis can be enhanced by enabling simulations on structural performance and resilience of the constructions (Alirezaei *et al.*, 2016). Furthermore, a review by Khanmohammadi *et al.* (2020) also revealed that BIM provides accurate information for conducting finite element simulation for a building.

In addition, the BIM process enables users to visualize more than two-dimension and includes multiple visualization tools that help determine potential risks. As a result, it helps structural engineers understand the structural behavior, have insight into detailed results and assist them in making more appropriate design decisions. It also gives structural engineers the ability to design and assess high-quality buildings that last.

Performance-based seismic design requires engineers to predict and assess the building damages at a different level. Therefore, BIM can expedite the works in which BIM could present the details of damages through 3D visualization with minimal iteration during the design process. Besides, BIM also replaces complex engineering language with an easy-to-understand of potential vulnerabilities through 3D visualization. As a result, the non-technical individuals, especially the owners, can decide the most appropriate building performance for different occupancies.

Additionally, there is no provision for the emergency plan and building assessments in the post-disaster phase in the current work process. Therefore, deploying BIM in the pre-

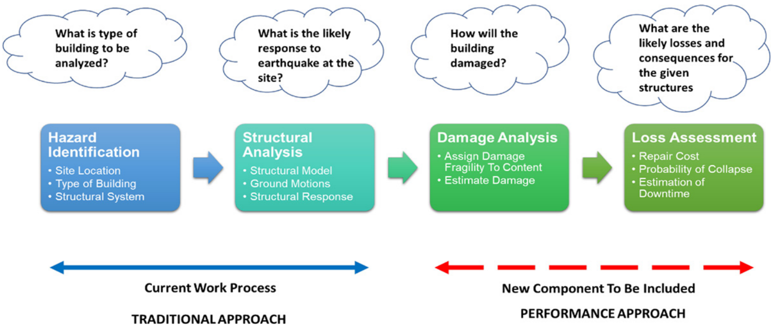

Figure 6.
Performance-based earthquake engineering. Adapted from Perrone and Filiatrault (2017)

disaster phase indirectly benefits the post-disaster phase. BIM can enhance the efficiency of building damage assessment and emergency response through advanced visualization and simulations. BIM models can replace traditional methods that have some critical limitations where people cannot interpret two-dimensional (2D) drawings or maps correctly (Khanmohammadi *et al.*, 2020).

5.2.2 Integrative design procedure. BIM is a novel technology that has solved many designs changes issues and overcome the limitations in 2D designs. For example, the integrative design procedure facilitates the data exchange between design teams. It provides real-time updating of the model while the other teams can easily identify any changes in the model (Alirezaei *et al.*, 2016). In addition, most BIM operations are automated, and human resource involvement is minimal. This means that once the BIM model is developed, there are no remodeling activities required. As a result, BIM has demonstrated its ability to improve productivity, quality and efficiency throughout the design phase. Therefore, if the seismic design work process is integrated with BIM technology, the variation of works highlighted by the respondents can be resolved.

5.2.3 Integration data management. Earthquake-induced loss of buildings is a fundamental concern for earthquake resilience cities. Therefore, integrating building data and information in a single model is vital in the seismic design process. Digital work is an extremely effective technique for retrieving, storing, indexing and recording critical information. Many studies show that the ability of BIM as an information repository can accelerate post-earthquake engineering assessment of buildings. Furthermore, the real-time capabilities of BIM during the design and construction process making it a reliable tool in providing accurate information (Welch *et al.*, 2014).

Seismic performance assessment of buildings requires highly detailed input data (Xu *et al.*, 2019a). Therefore, BIM is a key tool that can readily provide information on structural and non-structural elements detailing and quantities that will significantly expedite seismic loss assessment, such as determining repair costs and downtime estimation. In addition, BIM can be a low-cost tool in obtaining hidden structural information such as quantities of reinforcement, structural strength and stiffness, foundation details or structural mass, which are highly uncertain if accurate drawings are not available (Welch *et al.*, 2014).

Furthermore, time and physical restrictions on the hazardous site during post-earthquake assessment can lead to rushed analysis, thus reducing the reliability of results. Rapid visual inspections with various individual judgments and interpretations on structural safety will never provide accurate estimations of the structural conditions (Welch *et al.*, 2014). Therefore, to avoid such circumstances, data integration is crucial for future reference, eliminating uncertainties, enabling faster and more efficient analysis and enhancing the quality of building seismic assessment.

5.2.4 Systematic coordination and communication. BIM can pave the roads of information and communication to be more efficient through a single virtual model that allows for better coordination in building design (Goh *et al.*, 2014).

The issues of coordination and communication raised by respondents are common problems of the traditional method in the construction industry. Drawings and building design provided by paper-based documents are often complicated due to the lack of intelligent coordination applications and limited design communication. Information presented in the conventional drawings does not properly facilitate visualization, interpretation and collaboration (Goh *et al.*, 2014). In addition, coordination of drawings using 2D Computer-aided design (CAD) still leads to errors and inaccurate analysis. Therefore, these issues are expected to be resolved if all projects use BIM technology to its maximum potential.

5.3 Propose improvement for seismic building design work process

Based on the findings and discussion above, the improved SBD work process was then proposed, as in Figure 7. The proposed SBD work process is expected to improve the efficiency of the design process. The improvement comprises; visualization and simulations, integration design, integration data, coordination and auto-generated documents.

As discussed findings in the previous section, Table 2 compares current and improved SBD work processes. Again, it can be seen that the use of digital tools can improve the current work process to be more efficient.

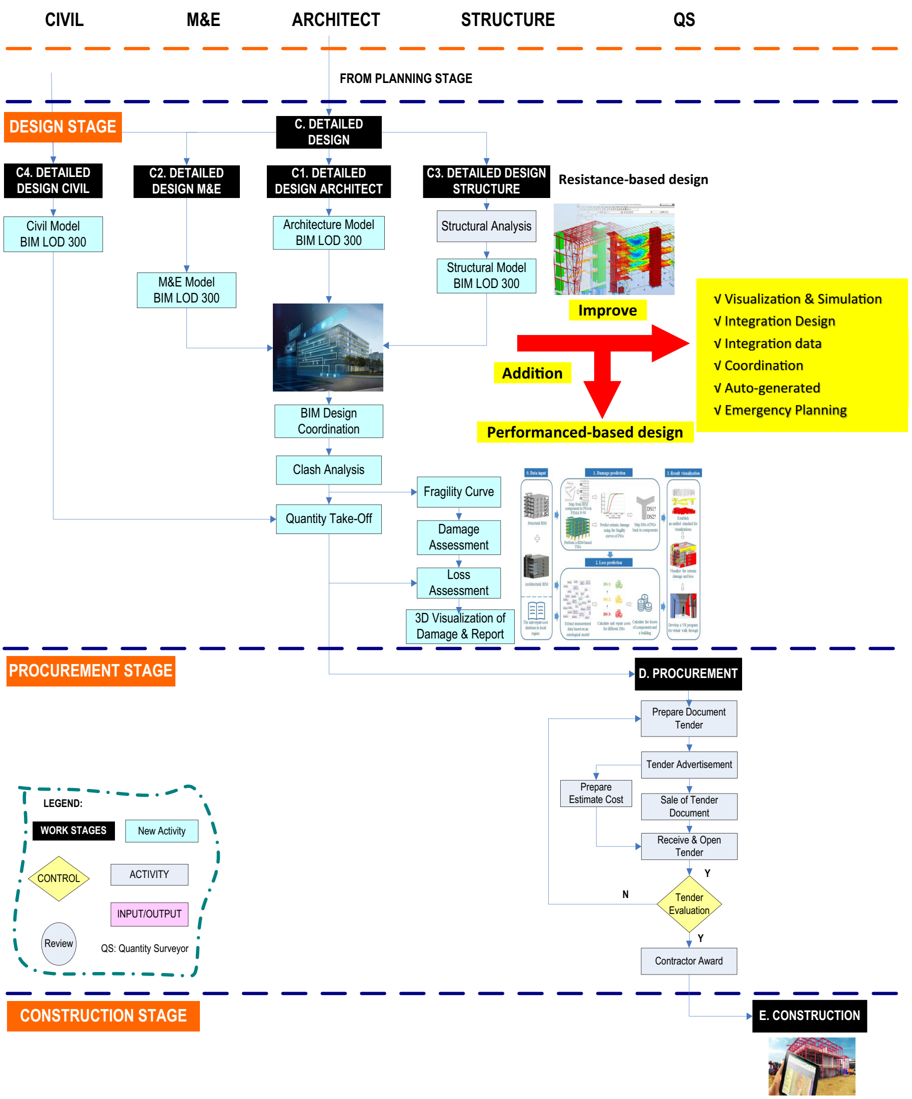

Figure 7.
Propose improvement for seismic building design work process

No.	Elements	Current work process	Improved work process
1.	Visualization and simulations	Structural behavior No structural performance 2D emergency plans Complex engineering language Non-virtual environment	Structural behavior Structural performance Dynamic emergency plans Versatile-easy to understand Virtual environment
2.	Variation of works	Manual updating Manual tracing Many resources	Real-time updating Easy identify changes Minimal resources
3.	Data management	Paper-based documents Independent data storage	Digitized data and reports Centralized data
4.	Coordination	Manual clash analysis using 2D-CAD drawings Manual design changes Design correction time-consuming 2D drawings-based multiple versions of drawings Drawings distribute via e-mail and correspondence	Integrated models clash analysis Automated changes On the spot correction 3D models-based updated models and drawings Server-based
5.	Design approach	Resistant-based design	Performance-based design

Table 2. Comparisons the current and improved seismic building design work process

In addition, this is an opportunity to incorporate a performance-based design into the SBD work process. It will improve the performance of the building, thus resilient to earthquake disasters. Designers can simultaneously assess the vulnerabilities and costs of damage to building components, enabling them to leverage the cost-benefit analysis to determine the most effective solution. This will also help building owners make more informed decisions. A study by Amirebrahimi *et al.* (2015) stated that BIM is useful in decision-making because BIM can increase the confidence of decision-makers when evaluating the proposed development through 3D visualization and various design options.

Apart from that, emergency planning strategies, for example, evacuation and pre-disaster rescue route planning, can now be part of the design process. Furthermore, the designers can provide high-performance designs and increase safety performance by developing a simulation of indoor post-earthquake. The evacuation and rescue route can be designed dynamically in a virtual reality scenario by considering fallen debris, fire and building damage conditions. The outcomes of the design can be used as a training tool for building occupants. Therefore, this is the other benefit a designer can offer the building owner compared to the current work process.

In addition, the up-to-date models and information provided in the digital form can be a source of fast and quick response during an emergency (Musella *et al.*, 2020), especially relating to any damage affecting structural components. Therefore, the proposed improvements work process in the design stage is also beneficial in the post-earthquake phase.

6. Conclusion

The earthquake hazard has now become a great concern to Malaysians. Furthermore, the recent event contributes the third most significant damage and loss in Malaysia. Earthquake-related design studies in the Malaysian construction industry are still minimal. For this reason, this study is critical for future resilience infrastructures.

Since BIM is a promising technology for resilient design, leveraging BIM in SBD is the right move. BIM permits optimization of design with analysis, simulations and visualization by providing reliable building data. Thus, it will assist building designers in evaluating their design accurately and providing the most cost-effective alternatives. Furthermore, non-technical stakeholders will easily understand the potential risk in the buildings compared to the traditional method that uses complex engineering language, which can assist them with more informed decisions.

Furthermore, by using BIM technology, resistant-based design can be shifted to performance-based design. This is a significant step toward a resilient infrastructure and community. Finally, as we live in a data-driven era, digital tools are essential to ensure all works can be delivered efficiently. Therefore, the proposed SBD work process using BIM technology will not only bring efficiency to the entire construction process but also, most importantly, ensure design accuracy that complies with seismic codes.

In conducting this research, obstacles were encountered when the COVID-19 cases in Malaysia suddenly increased around May 2021. Movement Control Order and working restrictions imposed by the Malaysian Government limits access to the respondents. Therefore, the proposed improvement for SBD work process is recommended to be validated by professional experts. The future study can also be extended to other government agencies and ministries in evaluating SBD work processes and making comparisons between them to obtain better results. The proposed work process in this study covers buildings projects only. However, future studies could replicate the findings for other linear disaster resilience projects similar to seismic risk mitigation, such as flood risk mitigation and fire response.

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Corresponding author
Mohamad Syazli Fathi can be contacted at: syazli@utm.my