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Building Information Modelling for Prevention through Design: An Exploratory Structural Model of Factors Influencing Its Adoption

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Abstract: Prevention through design (PtD) is an approach to construction safety management. However, previous research has shown that its adoption rate in the construction industry is considerably slow because of the lack of PtD tools among designers. Previous research suggested that building information modelling (BIM) has the potential to support construction safety assessments, specifically in PtD. This study aimed to explore socio-technical factors influencing the adoption of BIM for PtD. The study examined how socio-technical aspects of BIM affected designers' decisions to adopt BIM for PtD. A theoretical model was developed by extending the technology acceptance model. The structural equation modelling analysis was utilised to substantiate the model's components based on data collected from 131 structural designers in the Philippines. The model shed light on the impact of BIM's socio-technical qualities on adopting BIM for PtD. Results determined that the perceived usefulness and the relative advantage of BIM for PtD influence the behavioural intention of designers to adopt BIM for PtD directly. However, the perceived benefit and ease of use of BIM for PtD indirectly affected the designer's intent to adopt PtD. The study further synthesised and explained the model's theoretical and practical implications. As an exploratory effort to empirically model the adoption of BIM for PtD through integrating the socio-technical qualities of BIM, this study contributes to a deepened understanding of how designers will interact with BIM to implement such innovative technology for PtD.

Keywords: Prevention through design, BIM, TAM, Construction safety, The Philippines

INTRODUCTION

A construction project consists of a series of phases that must be completed within a specific timeframe. According to Reese and Eidson (2006), construction safety should begin with the design phase and continue throughout the construction project. This is because a construction site poses multiple hazards and risks that could endanger employees' well-being. As a result, ensuring the safety of employees in the building and construction industry is crucial. For example, emphasising safety safeguards the workforce, enhances productivity, minimises accidents and cultivates a favourable work atmosphere.

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Construction safety planning is typically conducted discretely from the initial planning phase. However, in most construction projects, safety specialists are limited to planning inspections rather than participating in developing and modifying plans (Bansal, 2011). Nonetheless, it is advisable to take a proactive approach to detect safety issues early, implement preventive actions and remove threats before they escalate. Adopting a proactive safety approach involves anticipating incidents, being prepared, reducing response times and minimising injuries. Thus, the concept of prevention through design (PtD) evolves as a practical method for evaluating construction safety. Several studies (Gambatese, 2008; Ho, Lee and Gambatese, 2020; Jin et al., 2019b; Toole and Erger, 2019) indicate that safety management could be implemented during the design phase of a construction project to eliminate or reduce the potential for risks and hazards. By implementing PtD principles, safety can be enhanced at the earliest stages of a project, resulting in long-term benefits (Hecker, Gambatese and Weinstein, 2005).

However, the uptake of PtD is still low in the construction industry due to its numerous challenges. Many professionals in the construction industry, including designers, architects and engineers, may have limited awareness or understanding of PtD principles, which can hinder the integration of safety considerations into the design phase (Goh and Chua, 2016; Zarges and Giles, 2008). Moreover, according to previous research (e.g., Ibrahim and Belayutham, 2020; Goh and Chua, 2016; Labadan, Panuwatwanich and Takahashi, 2022; Marefat, Toosi and Hasankhanlo, 2019), the lack of PtD tools is one of the causes of the slow adoption of PtD. To assist designers in understanding and using PtD, the accessibility of software analysis tools is important.

Building information modelling (BIM) shows great promise for occupational risk management and prevention (Martínez-Aires, López-Alonso and Martínez-Rojas, 2018). The PtD method utilised in construction safety management has been identified as an area where BIM has compelling applications. For example, the study by Jin et al. (2019a) proves that BIM tools could evaluate the safety risk for an entire multistorey project and visualise safety risks in a specific time, workspace and task, even prior to construction. Thus, it is necessary to conduct a comprehensive investigation into the relevance of BIM to PtD in order to determine how the use of BIM technology could serve as an innovative strategy for promoting the implementation of PtD. Despite the apparent qualifications of BIM as a tool for PtD, few studies have examined its features in the context of PtD adoption. The current study aimed to explore the framework of socio-technical factors influencing the adoption of BIM for PtD. The socio-technical qualities of BIM were analysed to see how they could influence designers' adoption of BIM for PtD.

THEORETICAL BACKGROUND

Prevention through Design and Prevention through Design Adoption Challenges

PtD is gaining traction in the construction sector as a progressive approach that shows promise in mitigating construction accidents. Its fundamental concept is the consideration of construction safety during the design process (Behm, 2005; Gambatese, 1998; Toole and Carpenter, 2013). The concept proposes a proactive construction safety assessment that takes into consideration the design phase of the project as a possible stage for considering construction safety. During the execution of design in the design phase, a designer must consider the safety of construction workers. This mandates that designers make design decisions based on how the project affects construction workers' inherent risk. However, it does not require a designer to play an active role in construction safety during construction, nor does it hold the designer partially liable for any construction accident (Gambatese, Michael Toole and Abowitz, 2017).

Nevertheless, the construction industry encounters challenges in terms of adapting and implementing PtD (Toole and Gambatese, 2017; Tymvios, Gambatese and Sillars, 2012). While many countries, such as the United States, Australia, Singapore and Hong Kong, have begun to adopt and enforce the notion of PtD, this approach remains relatively novel in numerous other countries. In addition, previous research conducted by Karakhan and Gambatese (2017) and Toole and Carpenter (2012) has identified several obstacles that hinder the implementation of PtD, namely a deficiency in construction safety knowledge, limited access to analysis tools, financial disincentives, the intricate nature of the industry's structure and concerns regarding legal responsibilities.

Designers frequently neglect construction safety and lack a comprehensive understanding of the safety implications of their work (Zhang et al., 2013). According to Gangolells et al. (2010), a significant number of designers in the construction industry lack the necessary expertise and understanding of construction Occupational Safety and Health (OSH) as well as construction procedures.

Building information Modelling for Prevention through Design

In light of the progress made in digital technologies within the building sector, BIM has significantly developed to align with the contemporary construction business's growing intricacy, expectations and prerequisites (Gao, Liu and Yan, 2020; Nekouvaght Tak et al., 2020). BIM technologies are ideal for PtD because of their digital, three-dimensional (3D) nature and information-holding capacity (Labadan et al., 2023). BIM can be customised with a variety of transdisciplinary applications due to its digital nature. Its applications include knowledge-based tools (Bloch and Sacks, 2020; Fargnoli, Lombardi and Haber, 2018; Zhang et al., 2013), fall prevention (Jin et al., 2019a) and risk identification and quantification (Bhagwat, Kumar and Delhi, 2021; Kasirossafar and Shahbodaghlou, 2013).

The use of BIM in the building industry can increase worker safety (Fargnoli and Lombardi, 2020; Ganah and John, 2015). Designers can evaluate a project's 3D model, directly or in collaboration with other stakeholders and perform a visual or virtual safety evaluation of PtD problems. Besides the 3D model's inherent information, additional information can be linked or attached as a decision-making aid suitable for OSH assessment. In general, BIM-based construction safety tools can be used as a foundation to improve worker safety by implementing these new technologies. Integrating information and decision-making systems within the BIM has become viable. Hence, BIM is fit for safety assessment even during the design phase and aids safety knowledge for the designers. Therefore, since this study assumed that BIM technologies can facilitate the adoption of PtD, it is necessary to examine the adoption of BIM for PtD through the lens of technology adoption theories.

Technology Acceptance Model

Numerous theories and models have been developed to forecast the determinants that impact the adoption of a novel technology. The technology acceptance model (TAM), which was developed by Venkatesh and Davis in 2000, is widely recognised as the most commonly employed model in the field. TAM has gained recognition as a concise and effective framework for comprehending the behaviour of users in adopting technology (Davis, 1989; Davis, Bagozzi and Warshaw, 1989; Pavlou, 2003; Venkatesh and Davis, 2000). Based on TAM (as shown in to Figure 1), it is evident that the elements of "Perceived usefulness" (PU) and "Perceived ease of use" (PEOU) exert a substantial influence on an individual user's inclination to embrace novel technology.

PU refers to an individual's perception of the degree to which using a specific system will enhance their job performance. Meanwhile, PEOU refers to the degree to which an individual holds the belief that utilising a system may be accomplished without the need for excessive exertion. Subsequently, TAM has been regularly corroborated by numerous specialists across various contexts, leading to its extensive application in studies on adopting technology (Sanchís-Pedregosa, Vizcarra-Aparicio and Leal-Rodríguez, 2020; Wu and Chen, 2017;

Xu, Feng and Li, 2014). TAM has been regarded as a very straightforward theoretical framework that may be modified or expanded through several approaches. Consequently, many expansions have been published, presenting various combinations of alternative hypotheses and giving rise to divergent frameworks (Bryan and Zuva, 2021; Poong and Eze, 2008; Qin et al., 2020).

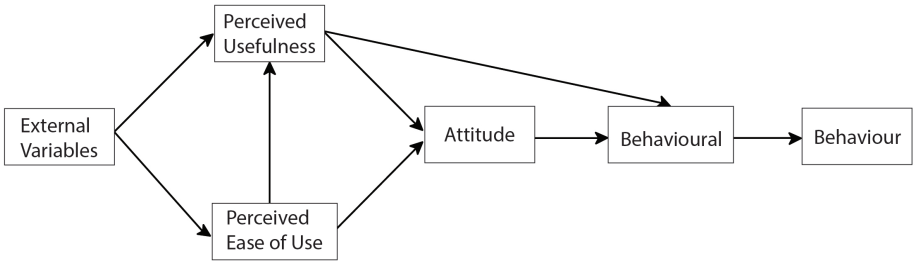


Figure 1. The classical technology acceptance model

Source: Adapted from Venkatesh and Davis (2000)

Behavioural intention (BI) refers to an individual's deliberate inclination or motivation to partake in a particular behaviour. It influences behaviour, signifying an inclination to partake in said behaviour with enjoyment and a willingness to utilise the service, recommend it to others and then revisit it for further use (Namkung and Jang, 2007). The concept of BI to adopt refers to the degree of an organisation's future intention to utilise the technology (Taylor and Todd, 1995). Wang and Song (2017) examined the influence of five variables on the satisfaction levels of BIM users within the architecture, engineering and construction (AEC) sector. Three factors were derived from TAM: PU, PEOU and attitude. While TAM does not explicitly include "attitude" as a separate construct, attitudes toward technology are implicitly embedded within the model. Attitude refers to an individual or organisation's overall positive or negative evaluation of BIM. If necessary, researchers can incorporate attitude as a separate construct in their specific research context. TAM is often used in conjunction with other models or frameworks that include attitude as a key factor. For example, the unified theory of acceptance and use of technology (UTAUT) and the technology-organisation-environment (TOE) frameworks explicitly consider external factors such as organisational context, social influence and environmental conditions. Thus, the present research incorporated characteristics that complemented the two recognised components of TAM.

Hypotheses Formations

BIM is exceptionally useful to the construction industry and has brought about a significant transformation within the sector (Liu, Lu and Peh, 2019; Yap, Lee and Wang, 2021). The usefulness of BIM can exhibit variability contingent upon the distinct stakeholders engaged in the process. BIM offers a comprehensive digital depiction of a building or infrastructure project over its entire lifecycle, encompassing design, construction, operation and maintenance stages (Khan and Panuwatwanich, 2021; Kymmell, 2008). According to Zhou (2014), BIM can facilitate the instantaneous exchange of project data, enhance the synchronisation of design and construction tasks and promote collaboration among many professional domains. Previous research has consistently demonstrated that PU directly and substantially influences users' BI to adopt technology (López-Nicolás, Molina-Castillo and Bouwman, 2008; Wu et al., 2011). This well-established principle has been further validated in studies related to BIM adoption, particularly in the context of South Korea, where the PU of BIM significantly impacts the BI of various stakeholders within the construction industry (Kim et al., 2017; Son, Lee and Kim, 2015; Xu, Feng and Li, 2014). Comparative research, such as the one conducted by Lee and Yu (2016) examining BIM acceptance in South Korea and the United States, has reaffirmed the critical role of PU at both the individual and organisational levels. Hence, it is hypothesised that PU positively influences BI, denoted as +H1.

Technology's PEOU typically pertains to users' perceptions regarding the simplicity and user-friendliness of tools and procedures (Oentoro, 2021). The user interface of BIM software is of paramount importance in determining its PEOU. BIM software integrates with many regularly utilised software or applications, augmenting user-friendliness (Panuwatwanich, 2013; Xu, Feng and Li, 2014). BIM features can also import and export data from commonly utilised design software or construction management systems (Lai, Deng and Chang, 2019). Additionally, users have the opportunity to utilise their pre-existing knowledge and workflows. Notably, in the original TAM framework, PEOU does not directly impact BI. However, the evolving landscape of technology adoption research has revealed that PEOU directly affects users' intentions to employ technology (Calisir, Gumussoy and Bayram, 2009; Lee, 2020). In the context of BIM adoption, PEOU is expected to positively impact users' BI of BIM technology. This is supported by Wang et al. (2023) that integrated the theory of planned behaviour (TPB) and TAM to explore the adoption behaviour mechanism of BIM from the perspective of owners. The study found that the PU of BIM is a significant factor affecting owners' BI when applying BIM technology. While PEOU positively impacts the adoption intention, its role is limited compared to other factors such as PU and subjective norms. Additionally, a study by Yuan, Yang and Xue (2019) on TOE and TAM frameworks explained that BIM technical features and government BIM policies positively affect PU, which in turn, along with PEOU, significantly affects the BI towards BIM adoption among project owners. This implies that when BIM is perceived as easier to use, it positively influences the intention to adopt it, as easier use is closely linked with its PU. Thus, it was hypothesised that PEOU positively affects BI, denoted as +H2. Furthermore, research has consistently shown that the ease with which a system can be utilised could positively affect the PU of that technology (Chung et al., 2008; Gefen and Straub, 1997). This interplay suggests that PEOU enhances the PU of BIM in technology adoption. Therefore, a supplementary hypothesis, denoted as +H2a, was postulated, affirming this positive relationship between PEOU and PU.

Relative advantage refers to the belief that an innovation holds superiority over the idea it replaces, is now being utilised or is readily accessible. It responds to the inquiry: "Is it better?" The cost and social status incentives play a significant role in deciding the relative advantage of innovations (Poong, Eze and Talha, 2009). The adoption rate tends to rise when a prospective user can easily perceive the advantages associated with a particular invention. The likelihood of adoption increases in proportion to the degree of perceived advantage by the adopter (Wang et al., 2018). According to Ahmed (2019) and Chen et al. (2019), the most crucial and influential part of the BIM adoption process is BIM's comparative advantage over other forms of technology. More specifically, previous research has demonstrated that relative advantage is a strong driving force behind the implementation of BIM for construction health and safety (Matthei and Abualdenien, 2021). This relationship suggests that when individuals perceive technology as having superior benefits compared to existing solutions, they are more likely to find it useful (Wang et al., 2022). As a result, the hypothesis that perceived relative advantage (PRA) had a favourable influence on BI (+H3) was developed.

The relationship between PRA and PU in the adoption of technologies like BIM was emphasised by Wang, Meister and Wang (2008). They argued that while PU explains technology adoption to an extent, incorporating PRA allows for the consideration of the benefits of new technologies over existing ones. This distinction is crucial for understanding technology adoption when multiple alternatives are available. Also, according to Xu, Feng and Li (2014), the PU and simplicity of using BIM technology are positively associated with the relative benefit of BIM technology. The greater the PRA of an innovation, the higher its rate of technology is based on its PEOU (Bandara and Amarasena, 2018), which led to the formulation of the hypotheses +H3a and +H3b. The relationship between perceived benefits (PB) and organisational support to user satisfaction in BIM implementation has been explored, indicating that factors such as PU and PEOU are crucial for BIM's user satisfaction (Pullen, 2012). This suggests that the PRA of BIM could significantly impact its PB, contributing to greater user satisfaction and acceptance (Wang and Song, 2017); thus, it was also hypothesised that PRA positively affects PB (+H3c).

Perceived benefit, as defined by Leung (2013), encompasses the subjective evaluation of advantageous consequences that arise from a specific course of action. According to Davis, Bagozzi and Warshaw (1989), the determination to adopt a novel technology is influenced by the degree to which consumers consider it to be more economically advantageous compared to the existing method of delivering goods or services. BIM offers stakeholders many significant benefits, encompassing direct and indirect returns. The perceived advantages of BIM, as reported by early adopters and the results of many studies, suggest that the implementation of BIM-based techniques contributes to the successful completion of projects with reduced expenses, shorter timelines, enhanced quality and increased customer satisfaction (Jäväjä et al., 2013). Moreover, the AEC sector experiences outcomes from adopting BIM. This technology facilitates cooperation and communication within the industry, resulting in improved design, construction and facility operations. By adopting BIM, stakeholders can leverage its capabilities to enhance project results, decrease expenses, expedite timelines and facilitate the creation of more environmentally friendly, robust and efficient structures (Sacks and Barak, 2008). It is proven that the PB strongly predicts adoption intent (Rice and Webster, 2002), which is consistent with the findings of various other studies. With BIM, Chan, Olawumi, and Ho (2019) demonstrated that the Hong Kong construction industry opted to adopt BIM because of the key benefits of using BIM. If a potential user has a poor opinion of the technology, they would be hesitant to accept it in their everyday life. As a result, the researchers presumed that PB had a favourable impact on BI (+H4). According to Marimuthu and Muthaly (2009), PB affects the adoption of technology in terms of both the PEOU and PU of technology. These perceptions, including efficiency improvements, error reduction and enhanced collaboration, drive the intention to adopt BIM within the construction industry. Sattineni and Bradford (2011) explored how PB and usefulness impact BIM adoption decisions among professionals. Consequently, this study hypothesised that PB positively influenced PU (+H4a) and PEOU (+H4b).

Figure 2 shows the summary of the previously formulated hypotheses. This study examined BIM's role in facilitating designers' adoption of the PtD concept. The predicted influence of the compatibility between the intervening qualities of BIM on designers' BI to utilise BIM for PtD might be either direct or indirect. In the present investigation, the following model constructs were defined as follows:

1. BI to adopt BIM for PtD: Designers' motivation and self-inclination towards a BIM-based PtD adoption.
2. PU of BIM for PtD: The degree to which designers believe BIM would improve or enhance PtD assessments and analyses.
3. PEOU of BIM for PtD: The extent to which designers believe that using BIM for PtD requires no deliberate effort and is easy for them.
4. PRA of using BIM for PtD: The degree to which using BIM for PtD is better than other approaches to PtD.
5. PB of using BIM for PtD: The degree to which using BIM increase the efficiency, productivity and quality of PtD.

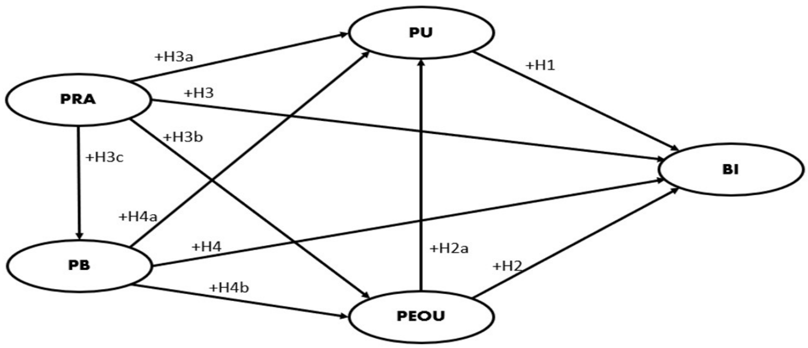


Figure 2. Conceptual model

METHODOLOGY

Research Design

The study utilised a measurement strategy that permits the simultaneous testing of a network of relationships between multiple dependent and independent variables. A quantitative method of measurement permits formalisation and evaluation of hypotheses regarding the relationships between variables is essential for the development and validation of theories. The study, therefore, employed structural equation modelling (SEM). SEM is a statistical technique for analysing relationships between observed and latent variables (Muthén and Muthén, 2009). It is a powerful tool for testing complex causal models and evaluating theoretical frameworks. SEM combines factor, multiple regression and path analysis to provide a comprehensive approach to understanding and modelling complex relationships among variables (Heck and Thomas, 2020; Hoyle, 1995). SEM allows for estimating and testing direct and indirect effects, enabling researchers to examine complex relationships and account for measurement errors (Kline, 2023). Due to its ability to account for measurement errors in statistical data analysis, SEM enables the use of numerous indicators to measure unobserved variables, making SEM an extension of multivariate techniques (Hair et al., 2009; Harlow, 2014).

The SEM analysis performed for this study followed a two-step procedure so that the results of this investigation could be accurately interpreted. Thus, to attain this objective, the measurement model was first specified and evaluated. Then, the structural model was tested to investigate the relationships among constructs. The degree to which the hypothesised model accurately describes the data is called the model fit (West, Taylor and Wu, 2012). Both stages require an evaluation of the model's fit to the data. The study used these five prevalent model fit indicators: the normed chi-square (χ^2/df), goodness-of-fit index (GFI), comparative-fit index (CFI), incremental-fit index (IFI) and root mean square error of approximation (RMSEA). The quality of each index was evaluated based on how well it met the criteria suggested by Hair et al. (2009): $\chi^2/df < 3.00$; GFI, CFI and IFI all equalled 0.90; RMSEA < 0.08.

QUESTIONNAIRE SURVEY

A questionnaire is an essential and widely employed data acquisition instrument in empirical research (Rathi and Ronald, 2022). Quantitative questionnaires are designed to gather structured, numerical data that can be analysed statistically (Queirós, Faria and Almeida, 2017). Quantitative questionnaires typically consist of closed-ended questions with pre-defined response options. These questions, such as multiple-choice questions or Likert scale questions, are often designed to be easily quantifiable. A quantitative questionnaire survey was the most effective method for accomplishing the objectives of this study. A questionnaire was developed in a web-based version so that respondents could complete the survey online. Because this approach can potentially cover a larger geographical area than any other, most of the questionnaire was distributed electronically through several online messaging applications. The distributed questionnaire was made up of two parts. The first part consisted of five sections corresponding to the five constructs of the proposed model depicted in Figure 2, with three questions for each construct. A five-point Likert scale ranging from 1 = Strongly Disagree to 5 = Strongly Agree was utilised to evaluate each item in both survey sections. The second part included the respondents' demographic background information, such as years of experience and work positions.

Research Sampling

The respondents selected for this study were specifically focused on individuals working in the capacity of structural engineers and their current employment is in the Philippines. The data collection phase was carried out over three months, commencing in March and concluding in May 2023. Before respondents embarked on the questionnaire, they were requested to provide their explicit consent to participate in the study, underscoring the principles of ethical research conduct (Apeagyei, Otieno and Tyler, 2007). In addition to their participation, each respondent was further requested to actively assist in the distribution of the questionnaire to their network of fellow structural engineers who were also actively engaged in professional roles within the Philippines. This snowball sampling method enhanced the sample's representativeness, encompassing the perspectives of a more extensive group of structural engineers, thereby increasing the robustness and comprehensiveness of the research findings.

DATA ANALYSIS AND RESULTS

Respondents Demographics

Initially, approximately 300 engineers were sought to participate in the survey. This quantity was selected as a representative sample of the entire population. The response rate was 44%, as 131 questionnaires out of 300 were returned complete. To pursue a career as an engineer in the Philippines, one must obtain a bachelor's degree in civil engineering before taking the relevant licensing examination. As a result, every respondent possessed a degree equivalent to that of a bachelor's degree. A total of 32% of the respondents held a master's degree, while only 5% held a doctorate. The proportion of respondents between the ages of 26 years old and 30 years old represented 43% of the total, while 68.7% had at least 10 years of experience. Notably, the majority of respondents (28%) were senior structural engineers, the same proportion as freelance structural designers.

Data Screening and Test for Normality

Data screening was conducted to see if the collected data were appropriate for the modelling analysis. In general, the z-score indicates the number of standard deviations separating an observation from a normal distribution's mean. Kim (2013) asserted that if the data are normally distributed, a z-score of 3.29 indicates that the observation is more than three standard deviations from the mean, which is an extremely uncommon occurrence. The z-score threshold of 3.29 corresponds to a p-value of 0.001, a commonly used statistical significance level in many fields. The total scores of all variables were transformed into standardised z-scores to detect extreme deviations in the present study. Cases with a z-score absolute value greater than 3.29 (three standard deviations at $p < 0.001$) were deemed outliers (Tabachnick and Fidell, 2007). In 131 responses, there were no missing data and no z-values greater than 3.29. Also, the evaluation of normality was checked because the analysis of the current study relied on numerous statistical techniques that assumed normality. Both skewness and kurtosis were between +2.00 and –2.00, indicating a distribution considered to be normal (Garson, 2012). Hence, the findings provided support for the utilisation of maximum likelihood estimates (MLE) in confirmatory factor analysis (CFA).

Validity of Measurement Constructs

Customarily, exploratory factor analysis (EFA) is used to validate the number of factors underlying the model structures as well as the loading pattern. However, EFA is not required to adopt existing, well-established measures (Green, Tonidandel and Cortina, 2016). Following the recommendations provided by Hair et al. (2006), the 131 instances met the minimum acceptable sample size of 100, and this criterion was exceeded in terms of the cases-to-variable ratio, which should be at least 5:1 for each construct. Nevertheless, the validity of measurement constructs was computed (as shown in Table I). The results showed a Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) values greater than 0.6, a KMO value deemed inadequate for factor analysis. The alpha coefficient values for all five scales, ranging from 0.652 to 0.875, were well above the permissible lower limit (0.60 to 0.70) and the majority fell within the very satisfactory range (0.80 to 0.90) (Hair et al., 2009). Thus, the analysis shows that the measurement scales comprise a set of consistent variables for capturing the meaning of the model constructs.

Table 1. Validity of measurement constructs

Construct	KMO	Bartlett's Test of Sphericity			Cronbach's Alpha
		Approx. Chi-Square	df	Significance	
BI	0.685	234.617	3	–	0.875
PU	0.686	224.694	3	–	0.859
PEOU	0.628	57.174	3	–	0.652
PRA	0.724	186.196	3	–	0.860
PB	0.672	97.827	3	–	0.754

Confirmatory Factor Analysis

Using CFA, a dependable measurement model was created before the structural model was put through its tests during the testing phase. The subsequent belief that these aggregated components reflect identifiers of their respective constructs (as shown in Figure 3) led to the discovery of this finding. AMOS software was utilised throughout the entire CFA procedure and the maximum likelihood estimate (MLE) method was employed. Table 2 presents the findings obtained through the use of the measurement model. It was determined that the model had an acceptable level of fit based on the aforementioned criteria (χ^2 =141.82; df = 80; χ^2/df =1.773; GFI = 0.88; TLI = 0.918; CFI = 0.937; IFI = 0.939; RMSEA = 0.077). According to Hair et al. (2006), each of the indicators loaded significantly ($p < 0.001$) on their respective constructs and the loadings of all indicators were greater than 0.50.

In terms of the dependability of the indicators, several items had R^2 values substantially below the generally accepted threshold of 0.50. According to Hair et al. (2009), this indicates candidates for elimination. However, the factor loadings of all indicators were meaningful and highly significant. Hence, it was determined that all items should remain in the measurement model (Sarstedt, Ringle and Hair, 2021). These results indicate that the measurement model appears to have sufficient convergent validity. Therefore, the measurement model may be utilised for subsequent structural model evaluation.

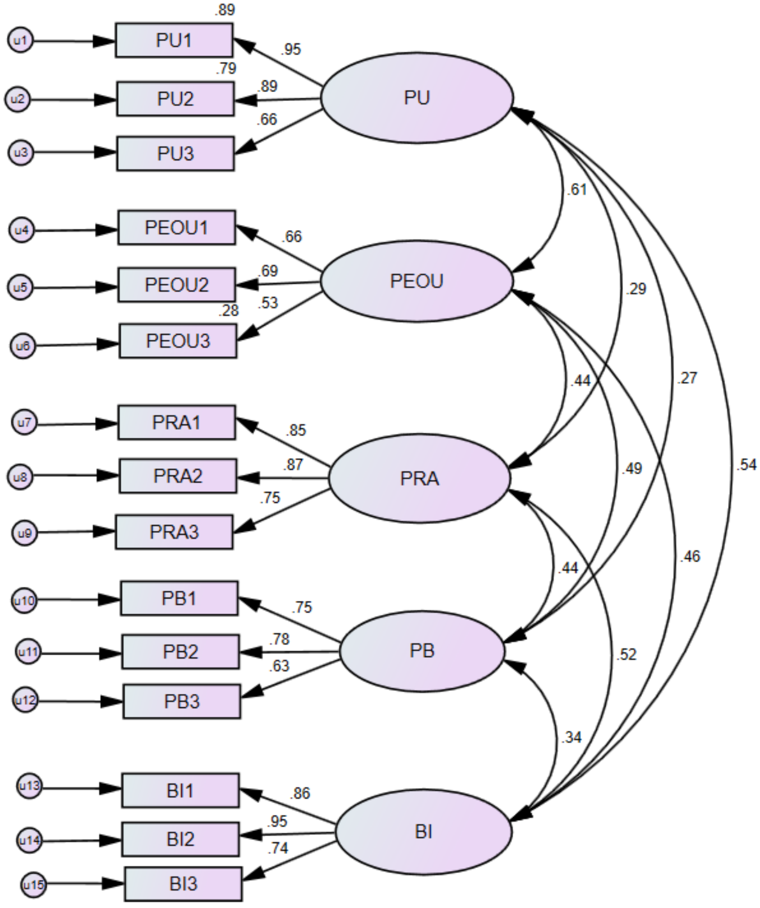


Figure 3. Measurement model

Table 2. Measurement model results

Constructs/Factors	Loadings	*t*-value*	R^2
PU			
PU1	0.945	f.p.	0.893
PU2	0.890	14.137*	0.792
PU3	0.661	8.853*	0.436
PEOU			
PEOU1	0.656	f.p.	0.430
PEOU2	0.695	5.543*	0.483

(Continued on next page)

Table 2. *Continued*

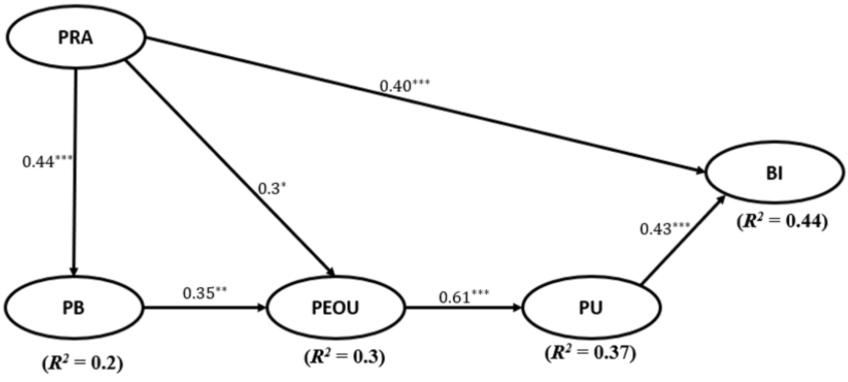
Constructs/Factors	Loadings	*t*-value*	R^2
PEOU3	0.534	4.709*	0.285
PRA			
PRA1	0.853	f.p.	0.727
PRA2	0.873	10.986*	0.762
PRA3	0.746	9.368*	0.556
PB			
PB1	0.748	f.p.	0.559
PB2	0.781	6.722*	0.610
PB3	0.626	6.058*	0.392
BI			
BI1	0.858	f.p.	0.736
BI2	0.953	13.766*	0.907
BI3	0.744	10.102*	0.553

Notes: Model fit indexes: χ^2 =141.82; df = 80; χ^2/df =1.773; GFI = 0.88; TLI = 0.918; CFI = 0.937; IFI = 0.939; RMSEA = 0.077; f.p. = Parameter is fixed for estimation purpose; *All *t*-values are significant at $p < 0.001$.

Structural Model Assessment

After establishing the validity of the measurement model, a structural model was investigated. Since the model was a reasonable fit for the data, the conceptual structural model was not revised and the hypothesised relationships between the model constructs were examined. In order to ensure that the final model provides the most accurate explanation for the data, the fit indices of the conceptual model were compared with those of the refined model. Figure 4 depicts the results of the final structural model with standard path coefficients. The fit indices indicated that the level of model fit was satisfactory (χ^2 = 142.45; df = 84; χ^2/df = 1.696; GFI = 0.88; TLI = 0.93; CFI = 0.94; IFI = 0.94; RMSEA = 0.073).

An exogenous construct is a variable that is not influenced by any other construct within the model but can affect other endogenous constructs (Lleras, 2005). The PRA construct, which is an exogenous construct, was found to have a significant impact in a positive direction on the PB construct (0.44, $p < 0.001$), PEOU construct (0.3, $p < 0.05$) and the BI construct (0.4, $p < 0.001$). The PB construct was also found to significantly impact PEOU construct (0.35, $p < 0.01$), PEOU construct was found to impact the PU construct (0.65, $p < 0.001$) and the PU construct was found to impact the BI construct (0.43, $p < 0.001$). Contrary to what was hypothesised in the conceptual model, neither the PB nor PEOU construct was found to impact the BI construct directly. The PB to PU construct and PRA to PU construct were also not significant; hence, the hypothesised paths (H2, H3a, H4 and H4a) were removed from the model (as shown in Table 3).



Notes: Model fit indices: χ^2 = 142.45; df = 84; χ^2/df = 1.696; GFI = 0.88; TLI = 0.93; IFI = 0.94; RMSEA = 0.073; *p < 0.05; **p < 0.01; ***p < 0.001.

Figure 4. Final structural model with standardised path coefficients

Table 3. Standardised path coefficients of the final model

Path	Hypothesis	Standardised Path Coefficient	*t*-value
PU → BI	H1	0.43	5.105***
PEOU → BI	H2	<<<<< Path removed >>>>>	
PEOU → PU	H2a	0.61	4.432***
PRA → BI	H3	0.40	4.639***
PRA → PU	H3a	<<<<< Path removed >>>>>	
PRA → PEOU	H3b	0.30	2.376*
PRA → PB	H3c	0.44	4.070***
PB → BI	H4	<<<<< Path removed >>>>>	
PB → PU	H4a	<<<<< Path removed >>>>>	
PB → PEOU	H4b	0.35	2.536**

Notes: *p < 0.05; **p < 0.01; ***p < 0.001.

DISCUSSIONS AND RESEARCH IMPLICATIONS

The results of the analysis revealed several noteworthy findings regarding the relationships between these constructs. This finding suggests that designers' perceptions of the relative advantage of BIM over alternative tools and methods for PtD play a pivotal role in shaping their attitudes and intentions toward using BIM. In other words, when designers perceive BIM as more advantageous and appropriate for PtD in comparison to other available options, it has a significant positive influence on their perceptions and intentions related to BIM adoption for PtD. The study observation also highlighted the interconnectedness of PB and PEOU, implying that designers' perceptions of how beneficial it was to use BIM significantly shape their perceptions of how user-friendly and accessible BIM is for PtD. Similarly, PEOU construct's substantial effect on the PU construct implied that designers' PEOU was strongly associated with their PU. However, it is noteworthy that the study's findings did not support the hypothesised direct relationships between the PB or PEOU constructs and the BI construct. This may suggest that other factors or variables that were not considered in the model had mediated the relationship between these constructs and BI, as suggested in the research of Burton-Jones and Hubona (2006) and Sun and Zhang (2008).

The PU of BIM for PtD could significantly influence the intention to adopt PtD, which is consistent with the prediction of classical TAM. It also indicates that the BI to implement PtD is influenced directly by the PU of BIM for PtD and its relative advantage for PtD. PEOU is more strongly linked to BI than PU, while PEOU significantly affects PU. In some studies, PEOU is considered an important factor in influencing users' attitudes and behaviours. It is worth noting that the relationship between PEOU and BI can vary depending on the specific context, product or system being considered. However, consistent with previous research (i.e., Calisir, Gumussoy and Bayram, 2009; Davis, 1989; Jackson, Chow and Leitch 1997), results indicated that there was no significant direct relationship between BI and PEOU.

Following the study expectations, PRA of BIM for PtD was found to affect the BI to adopt PtD directly. BIM's relative advantage is a crucial characteristic that could encourage the adoption of a concept such as PtD. The results on BIM adoption in the construction industry were also affirmed in the study of Ahmed (2019) and Chen, Zhang and Min (2019). Additionally, the PB of using BIM for PtD does not significantly influence the designer's intention to engage in PtD. However, the PB construct positively affects the PEOU of BIM for PtD. While these PB of BIM was widely recognised, the actual realisation of these benefits may vary depending on factors such as project complexity, stakeholder collaboration and the level of BIM adoption and implementation within an organisation or industry. Several constructs were found to not inhibit relationships. These results underscore the complexity of the relationships between these constructs and the need for further investigation to uncover potential mediators or moderators affecting users' BI and technology adoption.

From the structural designers' perspective, BIM was a relatively valuable tool over other methods in construction safety assessment, especially in PtD. This means that the availability of BIM as a tool for PtD will be a great factor for designers to adopt PtD since BIM has numerous technical capabilities that make it useful for PtD. Practically, BIM can meet the industry's challenge with PtD adoption by enhancing designers' awareness of construction hazards, enabling designers to be conscious of the possible health and safety issues during the construction of their designed projects. If designers and other stakeholders perceive that using BIM in the design phase will enhance safety, reduce risks and improve overall project outcomes, they are more likely to embrace PtD as a practical approach. As stated in the literature review, the 3D model of BIM has made it more efficient to visualise possible construction hazards in the design stage. Among these hypothesised external antecedents, it was determined that BIM's relative advantages and benefits carry weight in terms of PU and PEOU. This finding reveals that project stakeholders must pay attention to the technical characteristics of the introduced BIM platform or tools. From a technical feasibility standpoint, doing so would substantially increase the likelihood of successful PtD adoption. It is important to note that while BIM can provide valuable support for occupational risk management and prevention, its effective use is contingent on factors such as the quality and accuracy of the model, the expertise of the users and the incorporation of safety considerations into design and planning. In addition, BIM should be viewed as a tool that enhances and complements existing safety practices and standards instead of as a stand-alone solution. The construction industry must increase stakeholders' awareness of BIM's capabilities for PtD. The easier a BIM technology is to use, the more useful it is perceived to be. Therefore, to promote the designer's intention to adopt PtD, the industry should promote the BIM's usefulness and relative advantage more than its PEOU and the benefits of using BIM.

CONCLUSIONS AND STUDY LIMITATIONS

As an exploratory effort to empirically model the adoption of BIM-based PtD through integrating the qualities of BIM for PtD, this study provided a deeper understanding of how designers interact with BIM to implement such an innovative technology for PtD. The model was analysed using SEM to justify the model's components. This study presented an empirically derived model illustrating the mechanisms of BIM quality constructs that determine the degree of adoption of BIM for PtD. BIM's usefulness and relative advantage for PtD were the primary factors for the designer's BI on PtD adoption. However, the ease of using a BIM indirectly affected the formation of intentions. Overall, the study suggests that the qualities of BIM considered in the analysis could intervene in adopting PtD among designers. Valuable findings of this study reveal that it is important because it contributes to the research on PtD adoption in the construction industry and addresses the barriers that designers face. The model has the potential to serve as the basis of a framework for PtD adoption to diagnose their current state and use the resulting insights to enhance the diffusion of PtD among designers. The findings reinforce the need to devise policies for PtD implementation in the construction industry from a technical perspective. Moreover, this study investigated the correlations between these fundamental concepts and how they intervened in the adoption of PtD among designers. The study's findings support most hypothesised causal pathways that led to behavioural intent to adopt PtD. Furthermore, the research's theoretical findings and practical implications in the construction industry are crucial aspects of any study.

The presented research findings should be interpreted in light of their limitations. The constructs of the developed model were based on TAM model. Some researchers argued that TAM model lacks robustness, considering it only has two (i.e., PU and PEOU) primary constructs. Although the current study incorporated other constructs (i.e., PRA and PB) to extend TAM, it may have missed other critical socio-technical factors (e.g., perceived cost). The study respondents were also limited to structural designers working in the Philippines and the current BIM adoption level was not considered. It is also necessary to look at the level of BIM adoption among structural designers to further explain the current result of a conceptual model. Furthermore, as a cross-sectional study, this investigation did not account for the time factor, an essential component of adoption theories. This necessitates a longitudinal research design. Lastly, using a questionnaire survey does not inherently explain the manifestation of such relationships. Complementing the empirical findings with a series of case studies that qualitatively validate identified relationships and elucidate the actual perception of designers underlying them would be advantageous.

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