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A Study on a Building Information Modeling-based Process Design to Facilitate Prevention Through Design for Improving Safety Management in Philippines

設計段階での予防促進による安全管理の高度化を可能とするビルディング・インフォメーション・モデリングのフィリピンでの導入要件に関する研究

by

Rimmon LABADAN

A dissertation submitted in partial fulfillment of the requirements for the degree of

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Supervisor: Assoc. Prof. Sho TAKAHASHI

Co-supervisors: Prof. Kenetu UCHIDA

Prof. Kunihiro KISHI

Prof. Toshio YOSHII

Assoc. Prof. Koji MATSUMOTO,

Assoc. Prof. Kriengsak PANUWATWANICH

Examination Committee:

Chair: Prof. Shinei TAKANO

Members:

1. Prof. Takashi MATSUMOTO
2. Prof. Yasunori MIYAMORI
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10. Prof. Kenetsu UCHIDA
11. Assoc. Prof. Satoshi SUGIURA
12. Assoc. Prof. Kriengsak PANUWATWANICH
13. Assoc. Prof. Sho TAKAHASHI

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To God be the glory!

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ABSTRACT

Working within the construction site environment is synonymous with heightened exposure to occupational hazards, making it an inherently high-risk profession. Despite the Architecture, Engineering, and Construction (AEC) sector's aspirations to create accident-free work environments, the realization of this idea remains elusive. Extensive research has sought to dissect these accidents, pinpoint their root causes, and develop strategies to prevent their recurrence. Empirical research has substantiated a correlation between various design elements and the construction process, identifying them as significant factors contributing to the incidence of accidents in the industry. Improvements to the design may have reduced the accident risk level based on the cases evaluated. This recognition resulted in the development of an innovative safety management called Prevention Through Design (PTD).

PTD is an innovative concept that has been gaining momentum in the construction industry, primarily due to its promising potential in reducing construction-related accidents. However, the widespread adoption and implementation of PTD have encountered significant challenges within the industry. Research has pointed out that barriers to adopting PTD were a lack of construction safety knowledge, unavailability of analysis tools, cost incentives, the complexity of industry structure, and fear of liabilities. The absence of adequate tools for designers has pinpointed one of the critical obstacles to adopting PTD practices, and one of the potential avenues for intervention is to harness the capabilities of existing Building Information Modeling (BIM) technologies. The research stressed that equipping designers with computational and analytical tools can enable the successful implementation of PTD. Thus, a BIM-based approach to PTD adoption was explored to see how it may intervene in PTD adoption and provide empirical evidence to support such an argument.

The study was divided into three distinct phases, each aligned with a specific objective. First, the study comprehensively assessed the current level of awareness and comprehension of the PTD concept among structural designers in the Philippines. This preliminary investigation was a foundational step in gaining insights into the existing knowledge surrounding PTD, which is pivotal for informing subsequent intervention strategies. The results unveiled that, for most structural engineers in the Philippines, PTD was a relatively novel concept. Despite lacking familiarity with PTD, the respondents acknowledged its significance and deemed its implementation essential within the construction industry. In essence, they recognized the value of PTD even though the concept was still in its early period within the country. The first

objective, conducted as a preliminary study, also explored the prominent obstacles to implementing PTD. The study revealed that the designer was concerned about inadequate methods and tools for addressing PTD and promoting construction safety awareness. Thus, the second part of the study aimed to assess the applicability of BIM as a tool for PTD. The second objective was divided into two feasibility studies. In the first feasibility study, the applicability of BIM for PTD was demonstrated by developing a BIM-based PTD tool. Next, the applicability of BIM for PTD was assessed based on the expert's perception. This different approach enabled the study to gauge the potential benefits, practical challenges, and limitations associated with using BIM in the context of PTD, ultimately providing a well-rounded understanding of its applicability. Overall, the study's outcomes have conclusively substantiated the practical viability of employing BIM for PTD. The research outcomes provide concrete evidence of how BIM, through its advanced functionalities, can effectively contribute to integrating safety considerations throughout the various phases of construction projects, thereby affirming its applicability in promoting a proactive and safety-conscious construction environment.

Thirdly, the study aimed to examine the idea of BIM-based PTD from the perspective of its adoption by gathering insights from a broader range of participants. The third objective explored socio-technical factors that may impact the adoption of BIM for PTD. A theoretical model was developed by extending the Technology Acceptance Model (TAM). The Structural Equation Modelling (SEM) analysis substantiated the model's components. This research examined the causal impacts of each element based on data collected from 131 respondents who were structural designers in the Philippines. Results showed that the perceived usefulness and the relative advantage of BIM for PTD were determined to influence the behavioral intention of designers to adopt PTD directly. However, the perceived benefit and the perceived ease of use of BIM for PTD indirectly affect the designer's intent to adopt PTD. The study's findings supported most hypothesized causal pathways that led to behavioral intention to adopt BIM for PTD. As an exploratory effort to empirically model the adoption of BIM-based PTD through integrating the qualities of BIM for PTD, this study contributes to a deepened understanding of how designers may interact with BIM to implement such innovative technology for PTD.

In summary, this research has expounded on the instrumental attributes of BIM that facilitate the integration and adoption of PTD principles within the construction industry. The insights derived from this study hold the potential to serve as a valuable resource for the construction

sector, offering innovative ideas on harnessing the capabilities of BIM to realize proactive construction safety analyses, particularly among design engineers during the crucial design phase. The research output explains the transformative potential of BIM in enhancing safety protocols. It provides practical suggestions for leveraging this technology to advance the industry's collective commitment to construction safety.

Keywords: Construction Safety, Health and Safety, Prevention Through Design, Building Information Modeling, Construction Management, Technology Adoption

< This dissertation is modified and revised from the following original journals and proceeding>

1. "Awareness of the prevention through design (PtD) concept among design engineers in the Philippines. Engineering Management in Production and Services", 2022, vol .14(1), pg.78-92 https://doi.org/doi:10.2478/emj-2022-0007

2. "Building Information Modelling (BIM) for Prevention Through Design (PTD): An Exploratory Structural Model of Factors Influencing Its Adoption." (Journal of Construction in Developing Countries - Manuscript ID JCDC-OA-06-24-0109)

3. "Intervening Qualities of Building Information Modelling (BIM) on the adoption of Prevention Through Design (PTD)" (2023). 13th Conference on Engineering, Project and Production Management, 29th November – 1st December 2023, Auckland, New Zealand.

4. "Development of A BIM-based Automated Fall Hazzard Identification as Prevention-through-Design(PTD) Tool for Structural Designers" (2023). IEEE 12th Global Conference on Consumer Electronics (GCCE), 10th – 13th October 2023, Nara Japan

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INTRODUCTION

1.1 RESEARCH BACKGROUND

Working within the construction site environment is synonymous with heightened exposure to occupational hazards, making it an inherently high-risk profession (Gupta et al., 2018). Construction workers are vulnerable to accidents primarily due to the persistent and immediate threats linked with their work activities. The dynamic nature of the construction workplace further amplifies these risks, with ever-changing conditions and evolving project phases increasing the complexity of ensuring worker safety (He et al., 2016; Li et al., 2016). Statistics compiled by the Occupational Safety and Health Administration (OSHA) emphasized the severity of safety concerns, implying the imperative for improved safety within the construction industry. OSHA data revealed that, on average, one out of every five workplace fatalities can be attributed to the construction sector. This alarming statistic attests to the pressing need for more robust safety measures and practices to protect the well-being of construction workers (Sousa et al., 2014). Thus, these complications necessitate attention to safety protocols and practices in the construction industry (Hallowell et al., 2013; Hinze et al., 2013).

Despite the Architecture, Engineering, and Construction (AEC) sector’s fervent aspirations to create accident-free work environments, this ideal remains elusive in the practical sense. Incidents continue to be recorded, emphasizing the significant gap between intent and actual outcomes (Zhou et al., 2019). Tragically, the count of fatal accidents in the construction industry persists in its upward trajectory (Zhou et al., 2015). This trend stresses the urgent demand for comprehensive and effective safety strategies and initiatives fundamental to curbing the escalating toll of construction-related accidents and fatalities.

Moreover, technically, construction accidents are complex events with causative factors spanning from direct exposure to risks to engineering and management deficiencies (Han et al., 2019; Manu et al., 2014; Suraji et al., 2001; Vasconcelos & Junior, 2015). Extensive research has sought to dissect these accidents, pinpoint their root causes, and develop strategies to prevent their recurrence. A foundational perspective proposed by Hopkins (2006) distinguished between attributing accidents to the individuals involved or identifying systemic flaws, with the focus heavily influenced by contextual factors. This concept has paved the way for deeper investigations into the complicated dynamics of construction accidents. While it is common to feature the role of construction workers' activities in accident occurrence (Fang & Wu, 2013; Suraji et al., 2001), it is equally important to consider other contributing variables, such as the safety of the working environment and the quality of supervision (Haslam et al., 2005). Consequently, understanding the complicated nature of construction accidents necessitates a comprehensive examination of the interplay between human behavior, safety protocols, and management systems.

The National Institute for Occupational Safety and Health (NIOSH), under the United States Centers for Disease Control and Prevention (CDC), recommended a hierarchy of measures for controlling occupational risk (NIOSH, 2015). These controls can be from simple personal protective equipment to a higher approach to eliminating risks. The proposed hierarchy of controls depicts that a proactive approach (e.g., elimination or substitution) is more effective than a reactive approach (e.g., supplying personal protective equipment). In most instances, a proactive stance is adopted before the commencement of the project’s construction phase, as it is possible to undertake this action within a particular stage of the construction’s design phase (Ganah & John, 2015).

Empirical research (Behm, 2005; Gambatese et al., 2017; Gambatese et al., 2005; Mahamadu et al., 2019) has substantiated a correlation between various design elements and the construction process, identifying them as significant factors contributing to the incidence of accidents in the industry. Their studies searched into the relationship between design considerations and construction procedures, focusing on their role in shaping safety outcomes and accident occurrences within the construction sector. The findings of their empirical studies emphasized the importance of addressing design-related aspects to enhance overall safety in construction projects, thus stressing the pivotal role that thoughtful design can play in accident prevention and risk mitigation within the construction domain. According to Haslam et al. (2005), improvements to design may have reduced the accident risk level by over half, based on the cases evaluated. Additionally, researchers conducted a retrospective analysis of past construction accidents to determine whether specific designs were associated with the occurrence of these events on building sites. Behm (2005), for instance, found that design was a contributing influence in 42 percent of 224 fatality reports from the NIOSH database, which was used to analyze construction fatality reports. According to the research conducted on work-related fatalities in Australia, the design was found to be a factor in the causation of construction accidents (Driscoll et al., 2008). Acknowledging the significance of design in construction safety has established the groundwork for an innovative concept: integrating safety considerations into the project's design phase (Manu et al., 2019). The construction design features and its methods are recognized to influence construction accidents. This recognition resulted in the development of a safety management innovation known as the Prevention Through Design (PTD).

The fundamental principle of PTD revolves around integrating OSH considerations within the design phase of a construction project (Behm, 2005; Gambatese, 1998; Toole & Carpenter, 2013). Integrating safety considerations during the design phase is a proactive measure intended to minimize risks and hazards before they materialize, thus creating a safer and more secure working environment for construction personnel. This approach draws attention to the importance of incorporating safety as an integral aspect of the design process, aligning with the goal of accident prevention and occupational safety enhancement within the construction industry. PTD advocates for a proactive approach to evaluating construction safety. It positions the project's design stage as a viable stage of construction for safety assessments well before actual construction activities. Under the PTD paradigm, designers expand their roles beyond traditional design responsibilities, emphasizing the safety of construction workers (Rajendran & Gambatese, 2013). PTD requires a conscious examination of how the design choices may introduce inherent risks to the construction workforce. While PTD encourages designers to play an active role in enhancing construction safety throughout a project, it is important to note that they are not legally liable for accidents occurring during the construction phase (Toole & Gambatese, 2017).

1.2 RESEARCH PROBLEM

PTD is an innovative concept gaining momentum in the construction industry, primarily due to its promising potential to reduce construction-related accidents. Several comprehensive studies, including those conducted by Hinze & Wiegand (1992), Poghosyan et al. (2018), and Ibrahim et al. (2020), have advanced the idea that designers hold the key to creating designs with minimal hazards for site engineers, construction workers, and facility operators. These findings feature the transformative impact that PTD can have on OSH in construction.

However, the widespread adoption and implementation of PTD still have encountered significant challenges within the industry (Toole & Gambatese, 2017; Tymvios et al., 2012).

Many professionals in the construction sector exhibit reluctance to integrate PTD methodologies into their work practices. This hesitancy arises from a variety of factors, including limited awareness of PTD's potential benefits, concerns about added complexity in the design process, and resistance to change (Weidman et al., 2015a). While some countries, such as the USA, Australia, Singapore, and Hong Kong, have pioneered the PTD concept, it remains relatively new and not yet mandated in many other countries. This divergence in PTD adoption presents a unique landscape within the global construction industry, with various attitudes and approaches toward its implementation.

Furthermore, studies by Karakhan & Gambatese (2017a) and Toole & Carpenter (2012) have pointed out that barriers to the adoption of PTD are lack of construction safety knowledge, unavailability of analysis tools, cost incentives, the complexity of industry structure, and fear of liabilities. Specifically, designers often give little attention to construction safety and do not have enough "feel" of the impact of their work on safety (Zhang et al., 2013). Gangolells et al. (2010) also pointed out that a significant number of designers generally lack the requisite experience and understanding of construction-related OSH matters, as well as the intricacies of construction procedures, which hinders their ability to effectively evaluate safety aspects or identify potential hazards during the construction phase. In the case of structural designers, even though they were one of the primary prospective implementers, they were not typically concerned with construction occupational safety and health because their primary concern was structural safety. Traditionally, structural engineers do not consider construction safety in their design or take an active role in construction occupational safety and health concerns (Toole & Carpenter, 2013). These challenging tasks associated with PTD may deter designers from adopting the concept. Addressing these challenges and encouraging a broader acceptance of PTD is crucial for promoting a safer and more secure work environment in the construction sector worldwide.

Nevertheless, in the context of the ever-evolving landscape of digital technologies within the construction sector, Building Information Modelling (BIM) has been continuously advancing to align with the growing complexity, needs, and standards of the contemporary construction industry (Mostafa et al., 2020). Following the broad adoption of digital technologies for design, modeling, analysis, and detailing, the nature of building design has shifted considerably (Azzouz & Papadonikolaki, 2020). It has become common practice, particularly in the engineering sector. Owing to the different advantages of BIM technologies, they have emerged as innovative and extensively adopted tools in the contemporary era. These technologies have transformed the construction sector, presenting a wide scale of applications (Abuaddous et al., 2020). BIM technologies have notably modernized project management processes, reducing intricacies and challenges in the field (Du et al., 2020; He et al., 2017). One developing advantage of BIM is the application of construction safety (Mering et al., 2017; Nguyen et al., 2014; Teizer & Melzner, 2018). From its information-rich technical capabilities, BIM plays a major role as a risk review system with complex rules and knowledge enrichment (Hossain et al., 2018).

Thus, linking the absence of adequate design tools has pinpointed one of the key obstacles in adopting PTD practices. Literature and preliminary studies conducted on this research suggested that one potential avenue for intervention to address these challenges is to harness the capabilities of existing BIM technologies (Kamardeen, 2010; Kasirossafar et al., 2012; Labadan et al., 2022). Gambatese (2019) emphasized that equipping designers with computational and analytical tools can enable the successful implementation of PTD. This approach can significantly enhance designers’ awareness and knowledge concerning the OSH aspects of their designs. Consequently, it becomes imperative to explore the feasibility and practicality of integrating PTD principles with BIM technologies, as it can offer a promising pathway to improve construction safety within the industry. Advancing technologies, such as BIM, could increase the feasibility of engineering innovations. Thus, a BIM-based PTD approach must be explored to see how it may push PTD adoption and provide empirical evidence to support such an argument.

1.3 RESEARCH OBJECTIVES AND SCOPES

To overcome the research gaps, the general aim of this study was to explore the integration of PTD within the Philippine construction industry, mainly through the utilization of BIM. In achieving this aim, the study was structured around the following specific objectives:

RO1: To investigate the PTD current level of awareness among the structural engineers in the Philippines.

RO2: To assess the applicability of BIM as a tool for PTD.

RO2a: To demonstrate the applicability of BIM for PTD by developing a BIM-based PTD tool.

RO2b: To asses the applicability of BIM for PTD based on the expert’s perception.

RO3: To explore the framework of socio-technical factors that may impact the adoption of BIM for PTD.

Furthermore, the study has been conducted within the confines of the following scope:

1. Although it was desirable to achieve comprehensive research of the PTD in the construction industry involving all design trades, each design trade comes from a distinct background and has a different approach to construction health issues. Thus, this study was limited to a specific trade of structural design to have a practical application of research.

2. The scope of this research was explicitly limited to examining the experiences and practices of structural designers working within the Philippine construction industry. Given this focused approach, the applicability and relevance of the study's findings were primarily contextualized within this specific group and geographic region. Therefore, it is crucial to acknowledge this limitation when considering the broader implications or potential generalizations of the research outcomes. This consideration is essential for ensuring the accurate and appropriate application of the study's insights in broader or different contexts.

3. Because the study focused on the investigation of BIM-based PTD for structural designers, it did not consider other construction management factors or stakeholders other than the structural designers.

4. The BIM software used for case studies was limited to the software that structural designers popularly use.

1.4 RESEARCH NOVELTY AND SIGNIFICANCE

The novelty and significance of this Ph.D. research were seen in:

1. By situating the research within the specific context of the Philippine construction industry, the study addressed a gap in the literature regarding adopting PTD practices in developing countries and emerging early adopters.

2. The empirical investigation into BIM's role in facilitating PTD practices introduces a novel perspective on how digital technologies can influence safety in construction.

3. Stressing the critical position of designers as early adopters of PTD practices offers a new angle on the importance of involving design professionals in safety planning.

4. The examination of stakeholder influences and policy implications on PTD implementation sheds light on the broader socio-technical ecosystem surrounding construction safety.

5. The enhancement and broadening of the evolving PTD concept for assessing construction safety represent a crucial advancement in the field of construction management and safety practices.

6. The proposition of an innovative idea for the construction of OSH within the context of the Philippines, for which PTD has not been introduced.

REVIEW OF LITERATURE

2.1 OVERVIEW

A literature review is a systematic approach to discovering, analyzing, and synthesizing the current collection of finished and documented work from scholars, researchers, and practitioners (Fink, 2005). It serves as the foundation for developing new knowledge and can be advantageous in plotting a particular field of research progression (Elsbach & van Knippenberg, 2020). A literature review must be systematic (Booth et al., 2016). Thus, a systematic review of the literature, which included academic journals, theses, technical papers, institutional articles, and industry reports, provided a way to develop the theoretical and technical principles that served as the foundation for this research. Thus, the literature review sought to examine and extract knowledge in the following areas:

- Construction safety concepts
- Accident causations theories
- PTD Concepts
- BIM
- Technology adoption models

This research activity has been crucial to comprehending and thoroughly examining the chosen research areas. It aimed to analyze different aspects of the selected topics to uncover insights, theories, and practices applicable to PTD in construction. In addition to consolidating existing knowledge, the review process plays a vital role in identifying potential deficiencies in the current understanding of PTD. This identification of gaps will serve as an initial step toward defining areas that require additional research and scholarly focus. Hence, this research endeavor aimed not only to enhance the current knowledge base but also to provide guidance and information for future research efforts, promoting the continuous development of insights in the field of construction safety and design practices.

2.2 OCCUPATIONAL SAFETY AND HEALTH (OSH)

Safety is characterized by the absence of danger, risk, or injury (Holt, 2008). Ideally, nothing goes wrong, but more cautiously, it is defined as a state in which the number of wrong things is kept to a manageable number of instances. A risk, hazard, near miss, incident, or accident is typically regarded as the beginning point for safety concerns since they have the potential to result in negative results. Heinrich (1941), a pioneer in industrial safety, draws a distinction between accidents and injuries, which he defines as follows: the former refers to the cause, whereas the latter refers to the effect. Many risks and dangers associated with construction accidents have been found to have long-term ramifications, even though the direct consequences of the disaster are not always apparent. It includes psychological problems for construction workers, financial implications for entrepreneurs, and moral obligations for personnel.

OSH is a branch of public health focused on monitoring and analyzing patterns of diseases and injuries among workers (Nenonen et al., 2014). This field implements strategies and regulations to prevent such occurrences. It encompasses many topics, including toxicology, epidemiology, ergonomics, and violence prevention (Karwowski, 2001; Peek-Asa et al., 1997; Steenland & Armstrong, 2006). OSH plays a crucial role in helping companies keep their experienced and skilled workforce while supporting employees in sustaining productive careers. Workers' compensation and occupational health professionals are dedicated to minimizing immediate and future risks that could result in physical or mental health issues, ensuring that workplaces adhere to proper safety protocols (Spieler & Burton Jr, 2012).

2.2.1 CONSTRUCTION SAFETY

The construction industry is known as the most hazardous industry in terms of OSH. Construction's most serious safety risks include falling from heights, getting caught between objects, electrocutions, and being struck by objects (OSHA, 2019). Despite widespread knowledge and regulation in all industries about the health and well-being of employees, the data indicates the opposite is also true. Safety on construction sites is an area of construction-related activities that are concerned with protecting construction employees and others from the hazards of death, injury, disease, and other illnesses. Safety management refers to a collection of actions or policies taken to ensure the employees’ OSH. Three primary responsibilities are involved in this process: hazard identification, safety measure design, and control. Researchers have looked at various possible viewpoints, such as engineering failures (Bhattacharjee et al., 2020; Duarte et al., 2021; Liao et al., 2016), legislation (Lingard et al., 2019), lack of awareness drives (Yılmaz, 2021), lack of safety training (Yuan & Feng, 2019), and unsafe acts (Chiu & Lai, 2020).

2.2.2 PHILIPPINES' CONSTRUCTION SAFETY CONCERNS

The construction industry in the Philippines holds a significant position, constituting roughly half of all industrial jobs in the country. This sector, however, grapples with many challenges, particularly in the realm of construction health and safety, as Demeterio et al. (2019) outlined. The Philippine Statistics Authority (PSA) regularly releases comprehensive reports that provide detailed information about the country's statistical situation. These reports have revealed notable figures in the construction industry, such as the 2,115 reported occupational accidents in the 2015-2016 survey, encompassing 12,926 establishments with 20 or more employees. A closer analysis of these incidents indicates that three out of every five occupational injuries (66.1 percent or 1,399 cases) did not result in lost workdays. Instead, they were categorized as temporary incapacity cases (32.6 percent) and death cases (0.6 percent) (Philippine Statistics Authority, 2018). Despite the incorporation of machinery, construction processes in the Philippines heavily depend on the workforce. The demand for qualified construction workers is consistently high, underscoring the industry's reliance on human labor (Quezon, 2021). However, this reliance comes with inherent risks, contributing to the elevated danger of construction-related injuries. This relationship between the demand for labor, the prevalence of occupational accidents, and the broader challenges faced by the construction sector in the Philippines form a complex backdrop that necessitates a comprehensive examination and strategic interventions for enhanced safety practices.

For general occupations, the Philippines has several OSH policies and standards. Among these are the Presidential Decree (PD) 442, "Labor Code of the Philippines – Safety and Health Standards," and the Republic Act 11058, "Act Strengthening Compliance with Occupational Safety and Health Standards and Providing Penalties for Violations Thereof," which are both examples of legislation. The "Safety and Health in the Construction Industry Regulations" were promulgated to comply with Section 162 of the Philippine Labor Code, which mandates the adequate implementation of the Construction Safety and Health Program (CSHP) in every construction project. The 30-Hour OSH Program is designed to instill a sense of responsibility in workers by providing more in-depth and diverse instruction on a broader range of issues linked to workplace dangers.

Nevertheless, the construction industries in the Philippines have yet to make any institutional effort to include the notion of PTD. Moreover, no regulatory requirements compel designers to incorporate considerations for employees' safety into their designs (Labadan et al., 2022).

2.3 THE PTD RATIONALE

Several principles regarding OSH can explain why PTD should be applied in the construction industry. First is the advantage of a proactive approach in handling construction hazards; as the saying goes: "prevention is better than cure" (Green, 1992). Second is the established link between design and construction accidents, which theoretical models establish. The following subsections synthesize these reasons.

2.3.1 PROACTIVE SAFETY APPROACH

Construction projects understandably consist of several stages. Rather than a single activity, a series of phases comprised a construction project. These phases must be achieved in a specific duration. The pre-construction, construction, and post-construction stages are all depicted as being close to the actual physical construction site. Pre-construction activities include design conceptualizations, strategic planning for the project, design analysis, acquiring permissions or permits, and gathering the resources needed for the construction stage. A proactive safety approach, the opposite of reactive, means anticipating accidents, being prepared, minimizing response times, and reducing injuries. Construction safety management is viable even before construction (Zhang et al., 2014). When people think of construction safety, it is something that only matters during the construction phase. We are mistaken if we believe that construction safety is only important during the building phase. According to Reese and Eidson (2006), construction safety starts in the design stage and continues throughout the construction project's duration. Establishing an OSH program depends on several factors, including human factors, legislative requirements, and economic factors. The safety planning for construction is generally carried out in a separate phase from the initial planning phase. However, in most construction projects, the functions of safety experts are restricted to plan inspections rather than participating in the development and modification plans themselves (Bansal, 2011).

Identifying potential safety concerns at an early stage is highly recommended for taking preventative measures and eliminating dangers before becoming a problem.

2.3.1.1 THE HIERARCHY OF CONTROLS

There are two fundamental factors that support the importance of implementing a proactive construction safety approach in the workplace. Firstly, the Hierarchy of Controls recommended by NIOSH (Fig. 2.1) graphically conveys the notion that, in an effort to improve safety, proactive hazard eliminations, even during the design phase, are considered better than the reactive approach. An example of a reactive approach is the provision of personal protective equipment (PPE) to employees. Second, it is more likely that construction goals will be met concerning project cost, time, and quality if safety is taken into consideration early in the planning period. The McLeamey Curve (Fig. 2.2) serves as an illustration of this concept. This notion refers to the safety of construction workers. Taking steps to mitigate or reduce construction risk in the design phase will result in more significant benefits and a better likelihood of those benefits being realized in the future. Considering the worker's safety during the planning process is significantly preferable to requiring contractors to construct a project with many inherent safety concerns that they are not aware of. The NIOSH started its PTD project by seeking to make PTD a standard practice in the construction OSH approach.

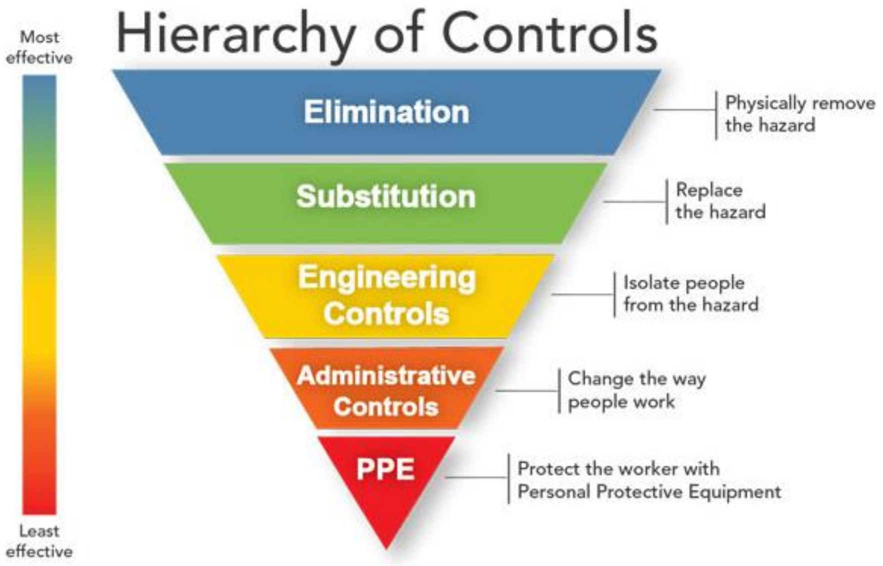

Figure 2.1 The Hierarchy of Controls. (Adapted from NIOSH, 2015).

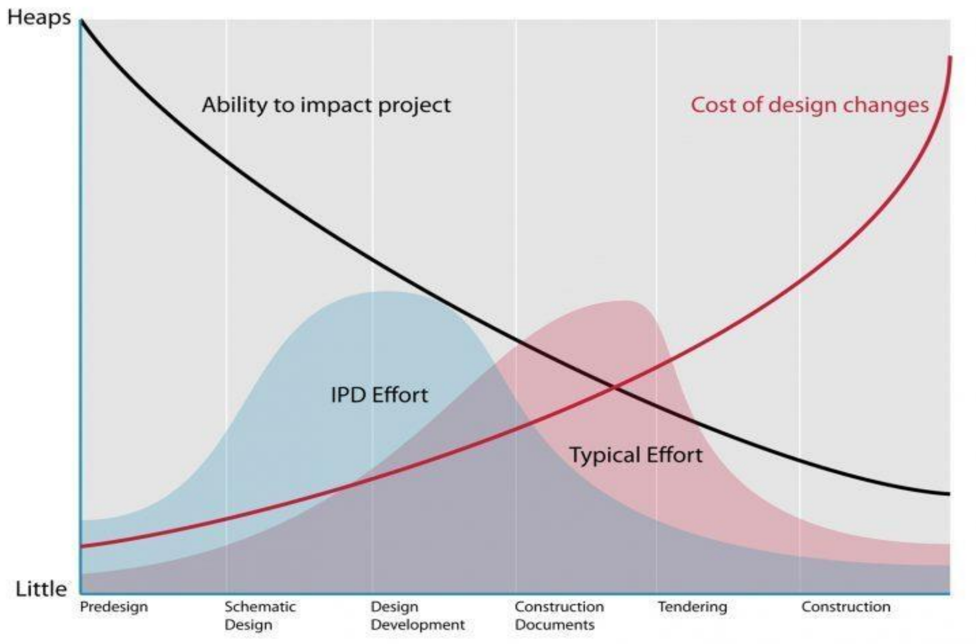

Figure 2.2 The MacLeamy Curve (McLeamy, 2004)

2.3.1.2 THE TIME AND SAFETY INFLUENCE CURVE

The construction project's design phase has the most potential to impact safety positively (Swuste et al., 2012). It has been observed in numerous construction industry studies that the chances to lessen health and safety risks are most significant at project conception, and they weaken as the project progresses (Toole & Gambatese, 2008). According to Szymberski (1997), construction safety should be prioritized at the conceptual and early design stages. Over the course of a project's lifecycle, as Szymberski hypothesized, an organization's influence on safety performance decreases exponentially from the predesign period (Fig. 2.3). When it comes to ensuring safe working conditions for construction workers, Szymberski proposes that the best way to do so is to make safety a top priority during the early phases of a project. As a project progresses through its multiple phases, the theoretical curve illustrates how the “ability to influence safety” quickly lessens as it progresses from the conceptual stages.

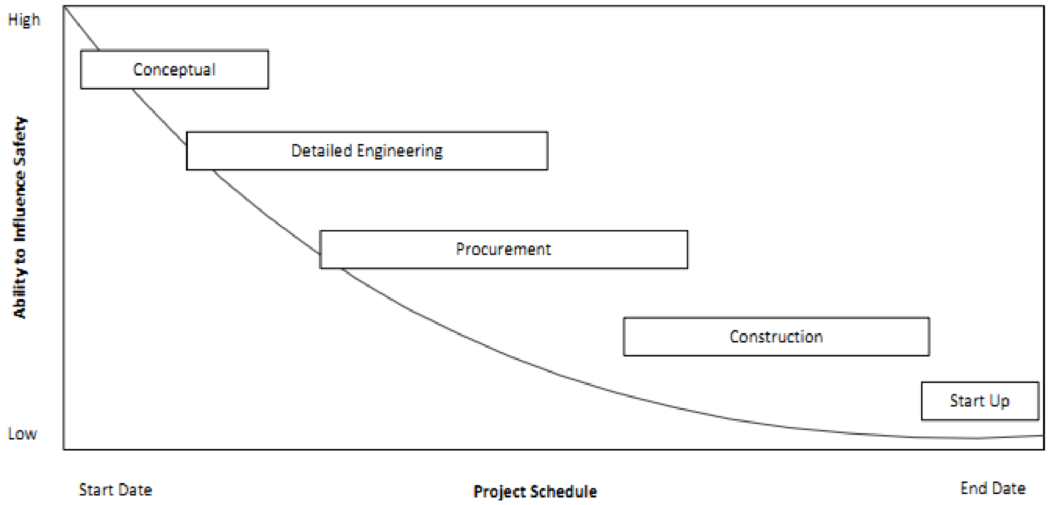

Figure 2.3 The "Time versus safety influence curve."

However, Szymberski's concept lacks empirical evidence. Nevertheless, Lingard et al. (2013) tested the hypothesis that incorporating OSH concerns early in the construction phase would lead to better outcomes by conducting interviews with stakeholders engaged in planning, designing, and executing construction projects in New Zealand, Australia, and the United States. The study was based on the design elements’ design decisions, the construction process, and the methods used to control health and safety hazards. The study’s findings established the limit to which OSH risk measures were assessed and approved prior to the beginning of construction and the project’s cost. Results showed that the overall quality of risk control results showed a positive relationship. Meaning that the greater the number of risks recognized and selected prior to construction, the higher the quality of risk controls. Additionally, the study fortifies its hypothesis by showing a statistically significant result (Lingard et al., 2013). Thus, the research establishes a link between early consideration of OSH before construction and the application of higher-order controls for risk to health and safety. The study’s findings emphasize the critical nature of addressing construction workers’ OSH while making design decisions.

2.3.2 THE CONSTRUCTION ACCIDENTS' LINK TO PROJECT DESIGNS

Researchers attempted to determine the theoretical causes of these construction accidents. Their research model's goal was to trace the causes of accidents using accident reports. These models aid in identifying accident root causes, and through this process, the argument is that design is one of those factors in construction accidents. Not only are the researchers looking into the causes of accidents, but they are also looking into injury predictions as part of their research vision. Some models can predict variable injury severities based on construction accident reports. Additionally, machine learning techniques were utilized to manage the enormous data in construction reports. Text mining techniques were used to classify construction accidents, and machine learning techniques were used to do so.

2.3.2.1 ACCIDENT CAUSATIONS THEORIES

Accidents are unplanned events that are common on construction sites with materials, objects, and people, with accompanying damage and lost injuries. It is a fallacy to presume that an accident has a single or primary cause (Hopkins, 2006) because accidents are multi-cause events that are caused by a mix of co-occurring circumstances. Knowing the fundamental causes of these events is essential to reduce the likelihood of future occurrences. Thus, the research into proactive mitigation of potential dangers in the construction industry is a never-ending aspiration. Gibb et al. (2007) stated that solid collaboration between design and construction teams appears to be the most effective method. Several theories attempted to explain why accidents happen in construction and general occupations. Several theories have been developed to explain why accidents occur in the construction industry and general occupations. The models advocate for accurate assessment of cumulative hazards and interactions between the three systems to inform risk assessment and decision-making.

2.3.2.1.1 BLAMING THE VICTIM OR BLAMING THE SYSTEM

Hopkins (2006) provided two main groups of ideas about the causes of accidents and occupational illnesses: the victim and the system. Essentially, the concept may be applied to any occupation. Victim blaming implies that any workplace injury or accident is the result of a mistake on the part of the worker. According to Hopkins, the qualities of the workers make them more susceptible to injury and sickness. The risk can be increased if safety regulations are not followed or if employees are negligent at their jobs. Furthermore, Hopkins believes that risky behavior is merely the final link in a chain of causation and that it is not necessarily the most effective link to concentrate on to prevent accidents. Other systems can impact the conduct of employees, perhaps leading to such dangerous behavior. Hopkins indicated three types of systems: social, technological, and organizational systems.

2.3.2.1.2 THE SWISS CHEESE MODEL (SCM)

Developed by James Reason (1990, 2000), the SCM is a causation model for accidents that demonstrates how assessments of significant accidents and catastrophic system failures frequently reveal several smaller failures preceding the actual hazard. According to the model, accidents can be attributed to factors causing them. It is an empirical explanatory tool that interconnects the interactions and chains that occur when a complex, well-protected system suffers a failure, as described above. The concept describes an organization's defenses from failures through a sequence of fences. Each of the barriers is represented by a cheese slice. The holes in the cheese slices reflect specific flaws in various system components, and their size and placement vary continually across all slices (Fig. 2.4). When the holes of all slices momentarily align, the system fails, allowing for a trajectory of accident opportunity to be established. This results in an accident because the risk penetrates through all the defenses and causes a hazard to occur. Organizational systems that have gaps or holes in them create conditions that lead to poor outcomes. The message is completely apparent: no single human or technological failure is sufficient to cause an accident. Instead, it entails the unlikely and frequently unpredictably occurring convergence of several contributing factors arising at various system levels. Even though the SCM model was intentionally developed for any industry, it has served as a starting point for developing construction accident causation models.

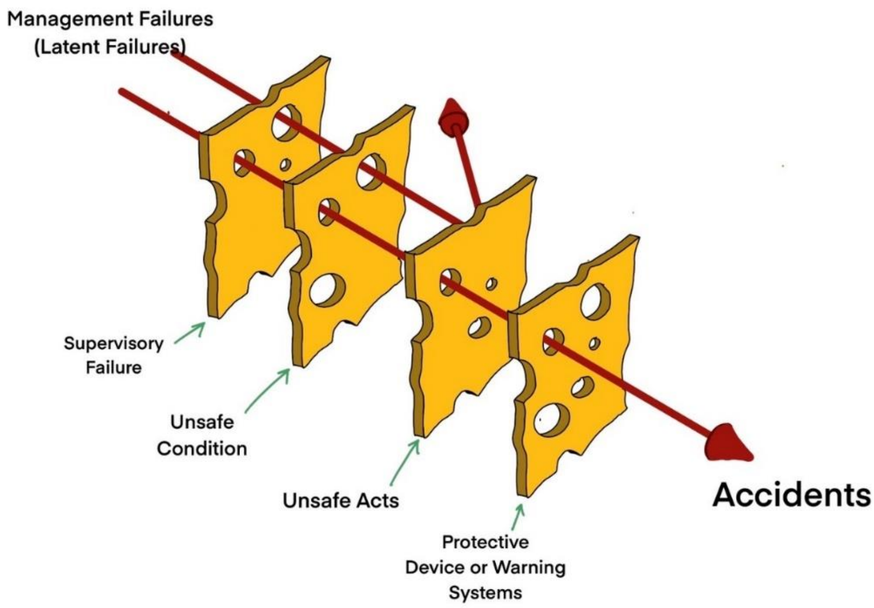

Figure 2.4 Reason’s Swiss Cheese Model (Adapted from Reason, 1990).

Numerous systemic issues, such as poorly planned work schedules, a lack of teamwork, and variations in the design of critical equipment between and even within institutions, have been pointed out by Reason. Many of these issues are so pervasive that many of the cheese slices already have their holes lined up. In such instances, a single piece of cheese may be all that separates the patient from a potentially fatal condition. Many of these circumstances interact with human behavior, such as cost-cutting or prioritizing material supply over safe production processes, leading to human error. According to the model, while many unsafe actions are possible, only a small number of unsafe actions result in accidents due to the built-in security of the systems. Organizational incidents occur when the defense fails to protect the organization. Thus, construction accidents can be linked to workplace design and work systems, according to the SCM causal model that has been developed to determine the“root cause” of accidents.

2.3.2.1.3 The Constraint-Response causal model

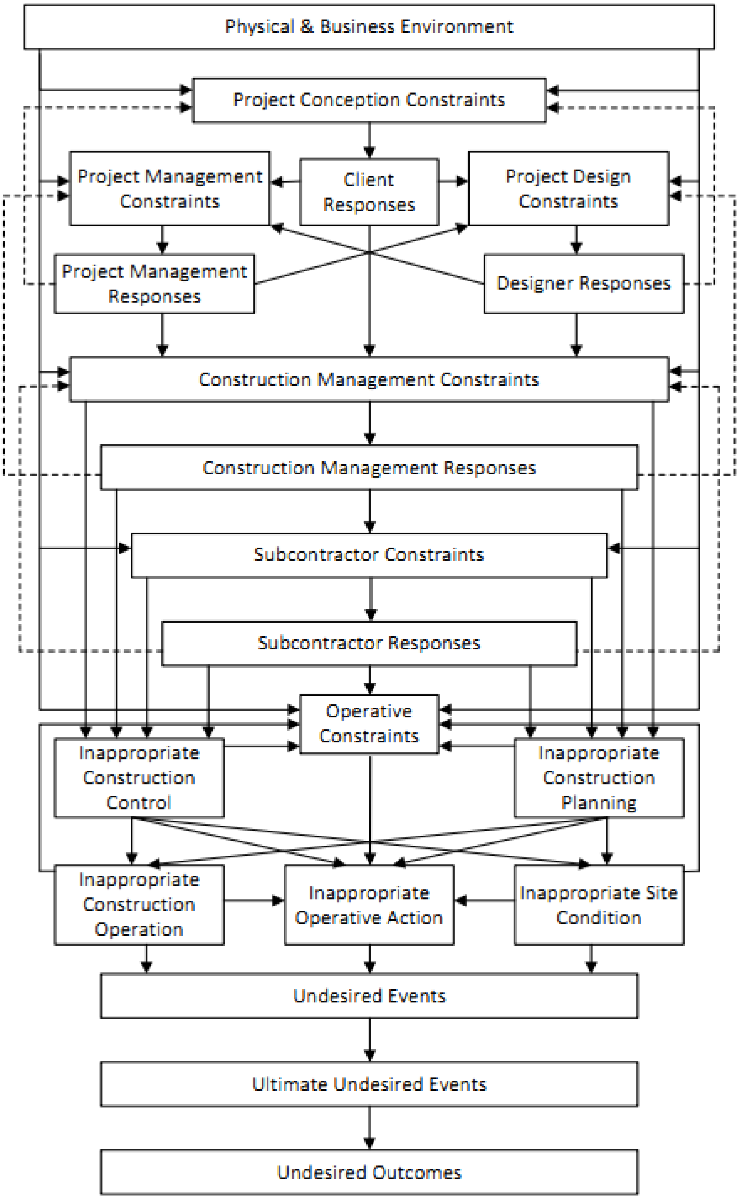

Figure 2.5 The Constraint-Response Causal Model.

The constraint-response causal model explains the factors that contribute to a chain of events that results in a construction accident. For example, conflicting design goals, technical difficulties, and time constraints are all considered to be contributing factors (Fig. 2.5). The designers' response to these constraints becomes the constraints that the project manager must deal with during the construction phase. Throughout the process, these constraints accumulate from one stage to another. Consequences of constraints may include unforeseen events and results, such as accidental injury. Suraji et al. (2001) demonstrated the interrelationships among the elements that influence the likelihood of construction site accidents. The model asserts that multiple stakeholders participating in each stage of the construction project’s life cycle are constrained in their ability to make decisions. As a result, the responses to these constraints hinder participants’ behaviors during the project’s subsequent phases. If the situation is not handled carefully, the cumulative impact of restrictions and countermeasures may be regarded as hazardous situations on the construction site, unsafe working practices, or risky activities on the construction site. As a result, accident sources can be traced back to “immediate site-level conditions,” actions, and practices, as well as to the planning and control activities of site supervisors and managers, as well as to the “constraints and responses” encountered by contractors, and designers and clients during the design and conception stages of a project.

2.3.2.1.4 THE CONAC MODEL

A holistic model of accident causation was validated using the accident causes of 100 construction workers. The study gathered information from those who were directly involved in the accidents to describe the cause-and-effect processes in construction. On the basis of this analysis, they established the Construction Accident Causation Model (ConAC) (Fig. 2.6). The premise is analogous to SCM by Reasons. The construction industry, on the other hand, serves as a backdrop for “constraint-response” and ConAC models. As a result, the model directly addresses some of the distinctive organizational characteristics of construction, such as the process of making a product personalized to the customer, the division of design and construction, and the widespread use of lengthy subcontracting networks (Hide et al., 2003). The initial research on design safety in the construction sector tried to establish an empirical link between design activities and health and safety outcomes, particularly accidents, injuries, and deaths. This investigation entailed an examination of the accident's causes primarily in order to determine whether the project was to blame. The ConAC model acknowledges that construction site accidents are the consequence of a complicated process involving both current and pre-construction elements.

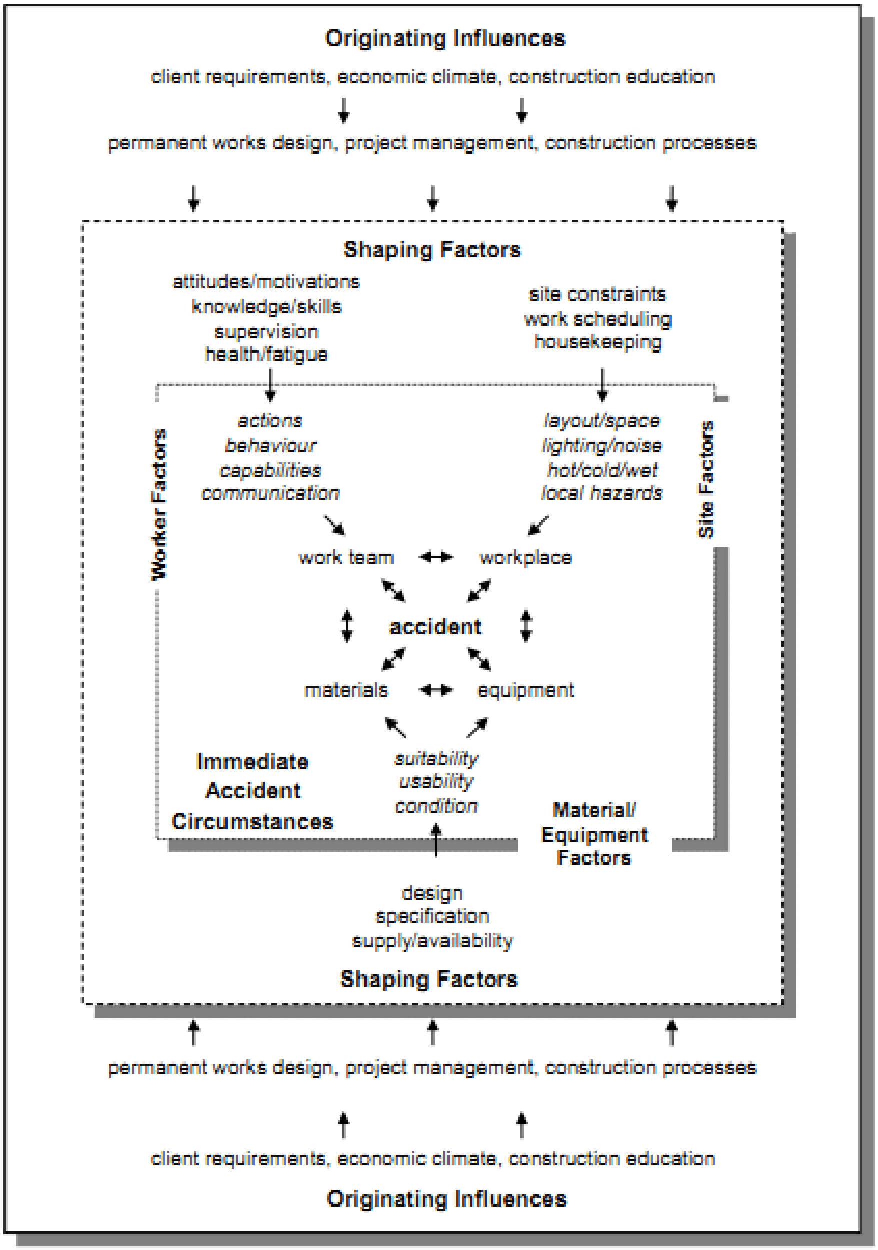

Figure 2.6 The ConAC Model.

2.3.2.2 RETROSPECTIVE ANALYSIS

A retrospective study looks back and examines the results to determine the causes. The retrospective viewpoint helped to justify a correlation between design and construction accidents. Previous research into construction design safety was focused on establishing an empirical relationship between the design and adverse safety consequences like accidents, injuries, or deaths. Research mainly involved analyzing the causes of accidents to weigh whether the design was one of the causes. As Lorent (1987) stated, the fatalities were caused by choices made ahead of construction, including design and organizational issues. Similarly, accidents sustained by workers in different design trades have been connected to particular design tasks. Lorent concluded that 60 percent of fatal construction site accidents are the result of decisions taken ahead of the worksite (Lorent et al., 1989, 1991). The following paragraph summarizes previous research studies into retrospective analysis conducted in different countries:

- Research in the United Kingdom found that the design of permanent works should be taken into account when there are construction-related accidents. Such an argument came after they looked into the causes of non-fatal accidents reported in the construction. The data were analyzed by a group of experts in the construction industry. It was up to the experts to think of ways in which an accident could have been avoided had a different structure or facility been used instead of the one that was used. Furthermore, they were asked their opinion on whether the designers could have lessened the hazards. Forty-seven percent of the time, experts said that if different design decisions had been made for permanent works, the chances of an accident would have gone down (Haslam et al., 2005).
- In the United States, similar experiments were conducted. Behm (2005) examined the NIOSH’s Fatality Assessment, Control, and Evaluation (FACE) record to determine the causes of fatalities. There were only two subjects included in the study: “permanent works and final product design.” The analysis excluded the construction process and plant and equipment design. According to Behm’s research, design played a role in 42% of fatal accidents he examined. Behm (2005) developed thirty design recommendations as part of his research. He revealed that safety in design might assist construction workers in remaining safe during the initial stages of construction and during maintenance, rehabilitation, and repair work, as well as reducing risk in all types of construction projects. Gambatese et al. (2008) conducted a follow-up investigation

to ascertain the validity of Behm's findings. A panel of experts in the construction industry examined a subset of the 224 death instances examined in the prior study, which the same group of researchers conducted. The panel was tasked with determining if the design contributed to the accident. According to the study, the panel agreed with Behm's findings. There was a high correlation between safety and design in 71% of fatalities examined. The panel of experts, all of whom were engineers or worked in the construction business, agreed on the notion that designing for construction safety was an effective technique to reduce hazards on building sites.

- Driscoll et al. (2008) indicate that design-related fatalities were reported for 44% of construction fatalities in Australia in 2008. However, they admit that it is difficult to ascertain which of the three factors contributed to this case's death: the permanent structure design, plant/equipment, or the construction procedure, which includes temporary works in this case. Cooke and Lingard (2011) used additional data from the National Coroners' Information System to examine how the permanent building design or structure led to fatal construction accidents. According to the study's findings, 14% of participants had a causal relationship with fatal construction accidents that could be detected in many of them. Cooke and Lingard based their findings on the ConAC model of accident causation. They looked at the permanent structure's construction and how it led to the catastrophic disaster. As a result, each case was investigated for the reasons that contributed to the case as well as the immediate circumstances. Because design decisions were made with the awareness that complicated conditions cause workplace accidents, a diverse range of shaping factors and present situations resulted. Additionally, other pathways connected the structure's design to the work process's design and, from there, unsafe actions like inappropriate equipment used for the job.
- Smallwood (2004) investigated industry stakeholders' perceptions of the correlation between design and construction OSH in South Africa. The study result showed that nearly half of the 71 general contractors interviewed regarded design as a negative component or issue affecting their capacity to operate safely during their work operations. Compared to other factors that influence safety, the design was found to have the most significant impact on safety.

2.3.2.3 RETROSPECTIVE ANALYSIS THROUGH MACHINE LEARNING

Machine learning (ML) is a rapidly expanding topic of computational algorithms that aims to replicate human intelligence through observation of the environment. In comparison to traditional statistical approaches, machine learning is more accurate at forecasting future results (Sarkar et al., 2019). ML is applied to swiftly recognize hazards through the transformation of predominantly unstructured digital accident data into structured attributes, facilitating a more data-driven approach to safety management. Consequently, ML has implemented accident or events classification and prediction in many areas.

Predicting construction accident outcomes is critical for implementing more effective safety management practices. Records of construction accidents can provide valuable information for forecasting possible incidents and possibly reducing their consequences. Thus, Machine learning (ML) techniques can be used to improve construction safety based on data collected from various organizations. Multiple input variables are used to estimate the output variables in machine learning methods.

As a result, machine learning has been applied to the classification and prediction of accidents and events in a variety of fields. The construction industry is a widely used application of the machine learning approach. Thus, researchers have taken a variety of approaches to underlining construction safety concerns. Numerous historical cases are also analyzed. For instance, the extraction of hazards from injury reports through the use of Text Mining (TM) and Natural Language Processing (Rupasinghe & Panuwatwanich, 2021), thereby providing detailed information about the cause of injuries and injured body parts (Utterback et al., 2012). Injury data are analyzed to ascertain the most common causes of accidents and to develop effective preventive measures (Jacinto et al., 2009). Machine learning techniques have been used to estimate the consequences of accidents in particular (Kakhki et al., 2019). This is because machine learning-based approaches are capable of processing large amounts of data and, more importantly, of predicting and interpreting results.

Numerous machine-learning techniques were implemented through the analysis of construction accidents, including:

- Random Forest (RF) (Zhou et al., 2019; Zhu et al., 2021)
- Support Vector Machine (SVM) (Yuan & Cheu, 2003; Zhou et al., 2017)
- Naïve Bayes (NB) (Goh & Ubeynarayana, 2017; Zhu et al., 2021)
- Artificial Neural Network (ANN) (Goh & Chua, 2013; Soltanzadeh et al., 2016)

- Deep Neural Network (DNN) (Sarkar et al., 2018; F. Zhang, 2019)
- Adaptive Boosting (AdaBoost) (Choi & Ryu, 2019; Choi et al., 2020)

A large amount of investigation reports are submitted in the construction industry that details the accident in detail, generally including the events leading up to the accident and the causal elements, as part of the enforcement inspection following each catastrophic construction accident. Construction engineers, project managers, and regulatory agencies can analyze such reports to detect faults with construction design, project management, and field engineering adjustments. As a result, appropriate prevention methods can be developed to limit future hazards. The retrospective analysis is a fair point of view in determining reasons linked to accidents. However, researchers acknowledge that a retrospective analysis has limitations. While researchers have claimed that design changes had the potential to diminish the risk by nearly half, they have been careful to use the words “potentially,” “may not necessarily have prevented,” and “may not necessarily have prevented” to emphasize that the modifications did not necessarily prevent the accidents from occurring. Another disadvantage of retrospective analyses is that they provide little information about current safety in design initiatives and tools and their potential influence on future OSH in the construction industry because they focus on outcomes. Observing and conducting research in “live” projects may better understand the relationship between considering safety during the pre-construction stage and actual safety performance. The ability to see connections between design and accidents may be overstated. Such an analysis cannot provide conclusive evidence about the relationship between design safety and improved safety performance on its own. Although the correlation is low, it is insisted that even if the correlation is low, a researcher can consider a direct link. Furthermore, Lundberg et al. (2009) insisted that the causes discovered during an investigation reflect the accident model’s assumptions, adhering to the “What-You-Look-For-Is-What-You-Find” or WYLFIWYF principle.

According to preliminary evidence derived from retrospective studies of construction accidents in the research outlined above, design work in the construction sector is associated with construction OSH. Incorporating construction safety into the design phase of a new project can help enhance the health and safety of construction employees. Working on construction sites appears to be difficult due to the dynamic nature of the conditions and activities involved. Thus, risk mitigation on building sites is a complicated subject, owing to the numerous factors that lead to accidents. Despite increasing research into the relationship between design and performance, OSH performance remains a point of contention. Because prevention via design can improve OSH outcomes, research efforts on this aspect are still increasing.

2.4 THE CONCEPT OF PREVENTION THROUGH DESIGN

2.4.1 DEFINITION OF PTD

In general application, PTD is a risk mitigation approach successfully implemented in various industries, including manufacturing, telecommunications, healthcare, and construction. By incorporating best design principles, risk management, and lessons learned, PTD workers reduce hazard exposures on operation sites. The term “design” is most frequently used in the construction industry to refer to “the process of designing the end product to be built.” The PTD concept covers the design of equipment, materials, tools, methodology used, and the design of the built environment itself. As a result, hazards can be reduced in various ways, including modifications in material composition, tool selection, procedures, and design.

PTD in the construction industry is the practice of foreseeing and designing out possible OSH hazards and risks linked with the physical structures, the methods, the tools, and equipment used, and the organization of works, insertion of safety awareness during the plans and specifications preparations and minimizing residual risks (Manuele, 2008). It scrutinizes and modifies particular permanent objects of a project for safety considerations during construction (Behm, 2005). To some extent, safety is considered during construction and the project life. Most of the research conducted so far in PTD in the construction sector has emphasized risk reduction in the occupational safety domain (Weidman et al., 2016). The idea of PTD captures researchers’ interest because it promises to minimize risks through a proactive elimination of construction hazards. Economically, by minimizing injuries and claims, PTD can reduce construction costs. Its application encompasses construction, maintenance, and facility management (Schulte et al., 2008). The safety and health of those impacted by design in each downstream lifecycle phase, from concept development and detailed design, construction or manufacturing, operations, maintenance, and eventual disposal, are considered during planning and design.

The earliest research published in this field of study related to PTD is by Davies (1986). The study described how consultants were attempting to meet their health and safety responsibilities by introducing safety systems in the design. Gambatese (1998) and Behm (2005) strengthened and promoted this concept by publishing a paper that links construction fatalities to design and indicated liabilities of designing on construction safety. Gambatese explained the concept of PTD and elaborated its research and legal issues on the application of PTD (Gambatese, 2008). Aside from the designers' role, he also looks at the owners' role toward construction safety and later establishes the motivation behind the concept of PTD (Gambatese et al., 2017).

PTD has been called Construction Design Management (CDM) in the United Kingdom, Design for Safety (DfS) in Singapore, and Safe Design in Australia. NIOSH (2007) launched PTD, which aims to be a standard practice for analyzing OSH hazards. They targeted preventing and reducing injuries, illnesses, and deaths at work by integrating prevention matters into policies. In Singapore, the Ministry of Manpower implemented the Design for Safety (DfS) Regulations in 2015, and enforcement commenced in 2016. Meanwhile, in Malaysia, the Occupational Safety and Health in Construction Industry (Management) (OSHCI(M)) introduced guidelines based on PTD. These initiatives show the regional commitment to enhancing safety practices in the construction industry.

Scientific papers employed various terms to reference the concept of PTD, as indicated by the following terminologies:

- "Safety in Design" (Horberry, 2014; B. Li et al., 2020; Taiebat et al., 2012)
- "Design For Safety (DfS)" (Jin et al., 2019; Mering et al., 2017)
- "Design for occupational safety and health (DfOSH)" (Manu et al., 2019; Poghosyan et al., 2020)
- "Design Risk Management" (Harvey et al., 2019; Mesaros et al., 2019)

The different terminologies used are all phrases devised by researchers to express the central notion of designing for the construction workers' safety.

2.4.2 DRIVERS AND BARRIERS TO PTD ADOPTION

Studies asserted that construction stakeholders could influence the OSH of workers (Gambatese et al., 2005; Toole & Gambatese, 2008). Unfortunately, many design engineers and architects accept this idea but with reservations. Primarily because of construction safety responsibilities

(Toole & Erger, 2019). The following list includes activities and resources recognized as practice facilitators of PTD (Gambatese, 2019):

- committed owner or client who is actively involved in the project
- Proactive safety culture in OSH
- Inclusion of PTD in project delivery methods
- Availability of design tools and analysis aid
- Construction safety knowledge for designers
- Involvement of the contractor in design reviews
- Consideration of PTD as soon as the project commences from its conceptualization
- Insertion of PTD in the project contracts

The PTD concept is known to be a promising practice in the field of OSH. However, various problems arose within the company that formed up to become barriers to its full implementation of construction OSH. The following are mentioned as potential barriers to PTD implementations:

- Lack of designer's knowledge and training on OSH
- Fear of possible liabilities when accidents happen on-site
- Exclusion on project delivery process.
- Lack of analysis tools and design guidelines for the designers
- Additional design cost
- Competing stakeholders' priorities
- Vague authority and responsibility
- Complexity in forecasting construction hazards while designing
- A lack of motivation toward the designer's proactive safety culture
- Lack of action from the regulatory institutions

2.4.3 PTD TECHNOLOGICAL TOOLS

The utilization of technologies in the construction industry is undeniably inevitable. Technologies improved the work's quality and efficiency in the construction process, leading to savings and increased profits. Also, construction safety management utilizes construction technologies for safety assessments. A survey made by Nnaji and Karakhan (2020) indicated that using technologies for construction safety improves workers' hazard awareness in the workplace. Additionally, it can eliminate hazards during the design and planning process.

2.4.1.1 RISK-BASED ANALYSIS TOOLS

Irrespective of the level of skill in implicit and explicit OSH knowledge, designers require digital design tools that may aid them in addressing safety concerns throughout the design stage. Since designers lack information on possible hazards in their designs, research has been implored to provide safety knowledge and decision-making tools for designers. The following paragraph summarizes previous research studies on Risk-based PTD tools:

- A quantitative approach was established by Gangolells et al. (2010) to calculate hazards in the design and help designers conform to safety requirements.
- Ontology-based semantic modeling was developed by Zhang et al. (2015) for automated job hazard analysis (JHA) to systematically inculcate safety pieces of information to the designers.
- Cheng and Teizer (2014) used mixed-reality simulations to train and educate construction workers and equipment operators on how to identify and mitigate OSH dangers.
- Along with the emerging technologies mentioned above, programs, software, and software tools (extensions, plugins., etc.) also evolved.
- Gambatese et al. (1997) developed the "Design For Construction Safety ToolBox," tool aiding designers in identifying hazards and incorporating design recommendations. The software was developed because of frequent falls occurring on the construction sites due to the architectural and structural design scopes.
- Gangolells et al. (2010) proposed a quantitative strategy for mitigating construction safety risks. It helped designers by analyzing the safety-related performance of residential construction designs. The study established the necessary foundations and criteria for statistically assessing the safety performance of building projects. By comparing the design's overall safety risk level to the design elements' absolute relevance, the PTD technique ranks the significance of the design's various safety concerns.
- Dharmapalan et al. (2015) conducted additional research to estimate the construction safety risk associated with each design aspect seen in typical multistory structures in the USA. The tool is a design risk assessment called the "SlideRule," which was

available online. It incorporates risk factors into the design of all building systems and features. The risk factors were produced using statistical analyses of data on each aspect's frequency, severity, and exposure constructed by a broad sample of experienced general and trade contractor site staff.

Addressing the safety issue requires designers to be able to recognize a hazard. To get a more thorough understanding of danger detection, designers would need to gain further experience and safety knowledge. However, risk assessment is complex and requires expert advice on severity and likelihood scales.

2.4.1.1.1 RISK IDENTIFICATION TOOLS

The initial step of a risk assessment is the identification of possible hazards. Unknown site hazards may result in unmanageable design risks. The majority of existing PTD tools are intended to assist designers in identifying hazards, and some are also intended to recommend ways to mitigate such hazards. Multiple platforms have been used to construct the proposed tools. Examples of risk identification tools are the checklist-based program "Design for Construction Safety ToolBox" (Gambatese et al., 1997) and the web-based "Total-Safety" (Carter & Smith, 2006). Likewise, government agencies have established educational materials and guidelines to assist designers in identifying potential hazards in their designs. A notable example is OSHA's hazard identification training tool, which is intended to assist non-safety professionals in recognizing common construction site hazards. However, as previously mentioned, current tools require designers to spend additional time seeking appropriate safety resources for their ideas, which may drastically disrupt the design process or limit their creative freedom.

2.4.1.1.2 RISK QUANTIFICATION TOOLS

Risk quantification is a strategy used during the design stage to solve potential safety concerns. The concept provides the basis and establishes the criteria for quantifying the safety performance of construction projects. Such a risk-based mechanism for evaluating safety performance can aid construction firms in improving their safety performance on the construction site. It can serve as the basis for designers to address construction hazards explicitly during the design phase. Without limiting their creative possibilities, designers can analyze alternative construction methods and processes and determine the acceptable level of safety risk.

A risk is the product of the probability of a harmful event occurring and the degree of injury or illness caused by the occurrence. The overall rationale for safety risk assessments is to consider risks in terms of their occurrence frequency and the consequence severity (Carter & Smith, 2006). Probability is defined in the studies as the possibility of a hazard's potential being realized and resulting in an incident or sequence of incidents resulting in harm or damage. The term "severity of consequences" refers to the level of damage caused by a hazardous situation (Manuele, 2008).

Numerous studies (e.g., Dharmapalan et al., 2015; Jin et al., 2019; Karakhan & Gambatese, 2017a; Peila et al., 2011) have focused on quantifying the risk associated with identified issues in order to help decision-making. Quantifications are generally based on the frequency, severity, and exposure to specific building tasks. While the measurement of safety risks and the sources of risk data are conflicting, some research studies (e.g., Behm, 2005) rely on historical occupational injury and mortality data. In comparison, other studies (e.g., Hide et al., 2003) rely on the qualitative risk assessments of safety specialists. While the tool can assist designers in determining the level of construction safety risk associated with their design, most often, it cannot provide a design solution due to limited knowledge of the safety issues posed by each design alternative.

2.4.1.2 AUTOMATED SAFETY-CHECKING TOOLS

Historically, design evaluations against health and safety norms and regulations have been completed manually by health and safety professionals rather than by designers, most likely due to the designer's inadequate knowledge of health and safety. However, this traditional method is time-consuming, costly, and prone to inaccuracy. Thus, engineers employed computer automation to do so. One of the primary uses of computer technologies in the construction sector is to analyze building designs in line with the regulations and standards through several rule-checking and simulations. A "rule-based checking system" is a type of software that examines a building's design against existing building codes (Eastman et al., 2009). Its objective is to set rules and criteria through interpretation and check the design automatically against these machine-readable rules. Numerous researchers have devised rule-checking techniques to circumvent this impediment. Examples of methods for evaluating safety rules are:

- Falls from height (Melzner et al., 2013; Zhang, 2015),
- Temporary structures (Kim et al., 2016),
- Construction site layout planning (Schwabe et al., 2019),
- Knowledge Library (Hossain et al., 2017),
- Scaffolding construction (Kim & Cho, 2015), and
- Clash detections (Getuli et al., 2017; Teo et al., 2016).

Some frameworks for safety rule checking include guidelines for assessing the compliance of architectural elements with fall protection law by programming software Plug-Ins. These Plug-ins can be incorporated within an existing BIM platform, which can check BIM models against the guidelines. Furthermore, it can generate automatic quantity take-off for safety systems and quantify materials necessary to mitigate risks. Qi et al. (2014) used two model-checking software for buildings, “Solibiri Model Checker” and “BIMServer,” to establish fall protection rules. (Yuan et al., 2019) constructed a set of rule-checking commands by analyzing safety regulations for the terms “should,” “should not,” and “must.” This set of rules was converted into a Revit Plug-In and run against the design model to identify potential safety concerns and offer appropriate mitigation strategies to eliminate or at least lessen these risks.

2.4.1.3 VISUALIZATION TOOLS

Numerous studies and industrial applications have been generated in the domain of hazard visualization as a result of BIM’s visualization capabilities. Visual technologies such as BIM, augmented reality, and virtual reality create a three-dimensional world in place of two-dimensional drawings. The following paragraph summarizes previous research studies on visualization tools:

- Park and Kim (2013) used augmented reality to visualize construction equipment. They demonstrated how this technique could assist users in making the optimum crane selection that is optimized for efficiency and safety as development progresses.
- Researchers have recognized that visualization tools enable designers to more effectively detect time-space conflicts, such as fall detection using BIM (Zhang, Sulankivi, et al., 2015), and to facilitate communication between designers and builders, such as safety dialogue via virtual reality (Sacks et al., 2015).

- Apart from utilizing BIM and augmented reality to improve safety management through visualization, a novel approach dubbed infographic was proposed for visualizing extremely complicated problems (Edirisinghe et al., 2016).
- Guo et al. (2013) developed a novel framework for applying virtual prototyping (VP) to model and simulate construction to aid in safety management. Project managers, safety managers, and site employees are the key benefactors of its use. However, these frameworks are still conceptual and require additional development.
- Teo et al. (2016) included a pre-project planning function in their tool framework. Designers and project managers can use this tool to visualize the potential of any hazard occurring during any building activity. Some have suggested that 3D visualization alone is incapable of identifying all possible threats. For instance, multiple collisions can occur as a result of insufficient construction planning and can be avoided by altering construction schedules and/or practices. 2D drawings or 3D models may not provide an adequate picture of possible hazards for identifying and managing them. This can be addressed by incorporating 4D technology alongside 3D during the pre-construction stage. The majority of academic research in this field has concentrated on the construction stage, with scant attention paid to the design and/or pre-construction phases.
- Jin et al. (2019) also used BIM, scheduling, and risk management tools to suggest a strategy for integrating schedule and risk throughout the design process. This proposed method enables designers to distinguish high-risk tasks and associated work areas using risk simulation and visualization.
- Hare et al. (2020) recommended that the strategy be used only in design-build procurement procedures, as contractor interaction and input are critical. Their study addressed a restricted number of design features, so it is critical to consider a broader range of design aspects and quantify their associated hazards for future applications. Additionally, the actual effects and benefits of such uses have not been explored or established.

2.4.1.4 SAFETY TRAINING TOOLS

Education should be tailored to inexperienced designers and engineering students (Mann III, 2008). It is commonly acknowledged that incorporating safety into the design process is crucial for construction safety. For example, the 2007 NIOSH workshop in the United States of

America underlined the necessity of raising designers' understanding of worker safety and health concerns through increased education and training (Sacks et al., 2015). Additionally, the Construction Design and Management Regulations 2015 in the United Kingdom requires designers to possess the requisite skills, knowledge, and experience to perform their design functions safely and healthfully. Within this context, education and training are two essential factors influencing the effectiveness of PTD implementation (Manu et al., 2019). In a variety of sectors, including aviation, mining, and offshore gas, using simulations and computer games to teach PTD has been found to be a more effective approach to safety training (Din & Gibson, 2018; Park & Kim, 2013). These findings are positive and suggest that academics should examine ways to include these technologies in PTD safety training for construction industry designers in greater detail. Adding serious gaming principles and augmented virtual environments into occupational health and safety training may offer a variety of advantages (Albert *et al*., 2014). They recommended that construction workers be trained in hazard awareness through the use of serious games and augmented reality platforms. Additional instructional platforms and applications on the web and on mobile devices have been developed to educate construction workers about PTD concepts.

2.5 THE BUILDING INFORMATION MODELING

2.5.1 THE DEFINITION OF BIM

BIM is the "use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions" (BS EN ISO 19650-1:2018). It is one of the most valuable innovations for the AEC industry. The creation of a digital building information model enables every stakeholder involved with the building project to optimize their activities. By and large, BIM technology enables an accurate virtual model of how a building is built. Upon completion, this virtual model is referred to as a building information model that contains the exact geometry and relevant data needed for building design, procurement, manufacture, and construction (Eastman *et al*., 2011). BIM is more than just a technology - it is a complex planning and construction process that can help architects create innovative buildings of the future. BIM supports decision-making over the entire life cycle of a construction project.

2.5.2 BIM PROCESS, MODEL, INFORMATION, AND INTEROPERABILITY

A “building information model” is a digital description of all aspects of a built asset based on information gathered and updated in different project phases (Eastman *et al*., 2011). BIM are computer files that are not in a proprietary format but contain proprietary data extracted and exchanged over a network to support building decision-making. Advanced BIM systems include databases of associated building information and intelligent data, including cost, construction sequencing, and life cycle management data. It enables document management, collaboration, and simulation through the project’s life cycle. BIM data provide comprehensive modeling of the construction organization and essential information about design and performance. Better decisions about the design, construction, and operation of building facilities; thus, BIM models ensure that proper information is produced in an appropriate format at the right time. Using a common digital representation of a building facilitates the planning, construction, and operation process and forms a reliable basis for decision-making.

However, not one BIM software processes all capabilities for all design trades, and sharing and passing design models to different design trades software may incur some errors. A common format must be developed to allow interoperability between design-specific BIM software. Thus, the Industry Foundation Classes (IFC) were included in the standard. The International Alliance for Interoperability (IAI) developed IFC through EXPRESS language. IFC effectively represents integrated information in BIM models, such as geometric and material properties, building elements, costs, project schedules, and organization. With the use of IFC, end-users can effectively share model data through IFC files, irrespective of the BIM application being used, thus improving interoperability between design trades.

Furthermore, BIM developers have allowed users and programmers to improve BIM capabilities without changing the software core since there is no BIM nowadays with complete capabilities for each trade. The idea is made possible by the Application Programming Interface (API). It enables software programmers to communicate with a software product. API allows the programmer to write instructions for BIM to execute commands or plugin scripts. For example, Autodesk provides powerful APIs and SDKs (Software Development Kits) that allow users to improve more excellent value from the software by tailoring it specifically to the user's needs.

2.5.3 THE TECHNICAL CAPABILITIES OF BIM FOR PTD

The technical capabilities of BIM drive the approaches to using BIM for PTD. Aside from BIM's primary 3D visualization capability, several technological enhancements were incorporated within BIM. Primarily, BIM is known for its dimensions, which are an added feature to its 3D model for a specific application. These dimensions are the extended capabilities of BIM to incorporate various design information from different applications or disciplines (Fu et al., 2020), such as cost, construction sequences, accessibility, sustainability, energy savings, acoustic, and thermal. By incorporating more factors into this modeling, project teams can better understand the data they are attempting to model. Thus, a 3D BIM is a 3-dimensional digital geometric model linked with information (Eastman et al., 2011). A 4D BIM augments model construction sequences with scheduling information (Zhou et al., 2013), while a 5D BIM is the addition of cost information to a model (Akanmu et al., 2013). A 6D BIM term is frequently used in the AEC sector to describe the logical connection of all 3D CAD components or assemblies to all project lifecycle management information areas (Succar & Sher, 2014), and 7D BIM augments the information set with sustainability information (Volk et al., 2014). It enables the analysis of a building's energy usage and the generation of energy estimates during the earliest design stage. It ensures precise energy consumption requirements for the construction life cycle. Moreover, 8D BIM is concerned with the safety and avoidance of accidents on the construction site (Kamardeen, 2010). It quantifies risk in the model, making safety recommendations for those with a high-risk profile and suggesting risk control and job safety for those with an uncontrollable risk profile.

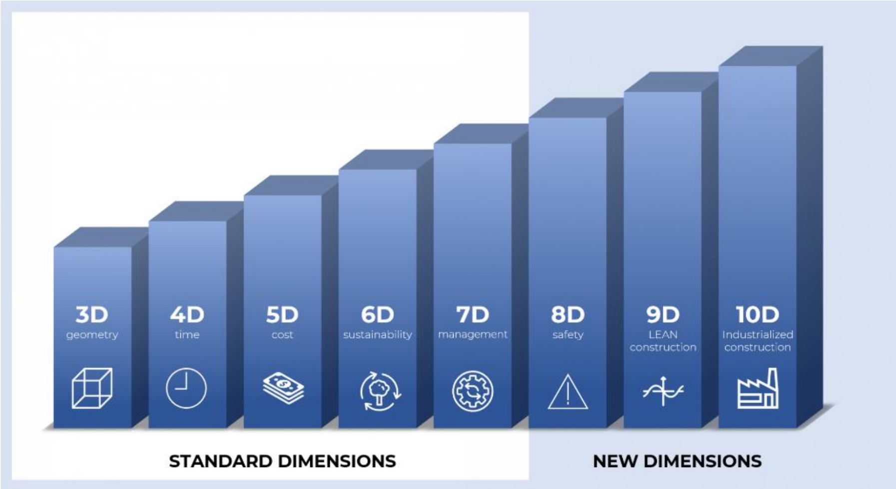

Figure 2.7 BIM Dimensions.

No BIM software processes all the capabilities for each BIM dimension. Therefore, working with different software for different analyses is not viable. Thus, BIM's interoperability capability can help close this gap. BIM's interoperability allows its use across disciplines that impact all disciplines involved in the design. It refers to the capacity of BIM applications to share, exchange, gather, and process identical data via a standard set of exchange formats by utilizing the same file formats and protocols (Grilo & Jardim-Goncalves, 2010; Shehzad et al., 2021). Interoperability across BIM models improves coordination and collaboration within the dispersed construction sector, and enterprise-level interoperability requires addressing conceptual, organizational, and technological dimensions (Muller et al., 2017). Industry Foundation Classes (IFC) is an open data exchange standard that is used in BIM. It establishes the technical standard for the exchange of files containing model data and is certified (ISO 16739-1:2018). IFC can be considered an integral part of a collaborative-lifecycle BIM, as it strives to assure software interoperability (Aldegeily, 2018). The IFC file format (".ifc") enables the exchange of data not only about the geometric properties of components such as walls, beams, and columns but also about their heterogeneous attributes, such as their mechanical and physical properties, their costs, and the time required to complete construction work. The IFC format is intended to provide true interoperability of an object-oriented data model of a civil engineering construction between multiple software programs (Gerbino et al., 2021).

Furthermore, using open BIM programming to dynamically share contents and data between applications is an application of Application Programming Interface (API) technology. The interface allows developers to develop apps that integrate with the BIM platform to extend its capabilities in different environments. API applications are not new in the field of information technology research. However, innovative contributions might still be produced by developing appropriate procedures for completing new or impending research projects. APIs generally define how various software components communicate, including access to the computer's database or hard drives (Oti et al., 2016). It is based on programming source codes and includes specifications for programming language routines, data structures, classes, and variables. API specifications help to present functions and subroutines in human-readable formats in procedural languages. For example, in object-oriented languages such as C#, API helps to specify the interactions by which objects, including their attributes, are derived from their class definitions. The usefulness of BIM for PTD

BIM stands as a crucial asset to the construction industry, heralding a substantial transformation within its operational landscape. Its profound impact is evident in its ability to optimize collaboration, streamline decision-making processes, mitigate risks, facilitate project visualization, and enable efficient project management throughout the entire lifecycle of building or infrastructure projects. However, BIM's perceived usefulness exhibits distinctions contingent upon the diverse stakeholders engaged in the process. Offering a comprehensive digital representation, BIM spans the entire lifecycle of a project, encompassing design, construction, operation, and maintenance stages. Eastman et al. (2011) posited that stakeholders can access and effectively oversee project data, including specifications, timelines, costs, and maintenance information, thereby fostering a holistic understanding of the project's lifecycle.

Moreover, BIM plays a pivotal role in enhancing collaboration and communication among the various stakeholders involved in a project, such as architects, engineers, contractors, and owners. As Zhou (2014) stressed, BIM technology facilitates the instantaneous exchange of project data, promoting the synchronization of design and construction tasks and encouraging collaboration across diverse professional expertise in the construction industry. Thus, it significantly improves project coordination, optimizes operational efficiency, and mitigates errors or conflicts. The transformative potential of BIM extends beyond its technical capabilities to fundamentally reshape the dynamics of the construction industry, fostering a more integrated and efficient approach to project delivery.

The concept of PTD encompasses integrating safety considerations into the initial phases of a project, making BIM technology a particularly suitable tool for its implementation (Jin et al., 2019; Kamardeen, 2010; Kasirossafar et al., 2012). The design phase involves the generation of preliminary sketches or plans for an upcoming project, placing significant emphasis on shaping and organizing its geometry and structure. In this context, the significance of BIM in the design process becomes apparent. BIM plays a pivotal role in enabling various stakeholders engaged in a building project to comprehend and replicate designs (Buhamdan et al., 2021; Hilfert et al., 2016). This functionality prompts stakeholders to adopt a proactive stance, engaging in safety evaluations during both the design and construction phases. BIM proves instrumental in the promotion of a collective understanding of spatial relationships, aiding in the identification of conflicts or interferences, evaluating diverse design alternatives, and representing construction hazards to ensure overall construction safety. Beyond its role in safety, BIM significantly contributes to the enhancement of decision-making processes throughout the design and planning stages of a project. The technology facilitates a comprehensive approach to project management, empowering stakeholders with the insights needed to make informed choices that align with safety protocols and project objectives. BIM's usefulness with PTD elevates safety measures and the overall efficacy and strategic planning involved in construction projects.

2.5.4 BIM’S SOCIO-TECHNICAL NATURE FOR PTD

On the point of emphasis, BIM has made it possible to create a virtual replica of a building that includes 3D dimensions with incorporated physical and functional information on its elements. The AEC industry has been moving toward fully implementing BIM because of its ability to facilitate rule checking and run construction sequence simulations. With the various information attached to BIM, the resulting model is a data-rich, intelligent, object-oriented, and parametric digital depiction of the building and building construction process. These views and data are appropriate to AEC’s need to generate analysis to make decisions and improve construction. This gives the personnel the advantage of visually understanding health and safety issues as work progresses during the onsite BIM usage (Ganah & John, 2015).

BIM is changing the construction safety management approach. Several efforts have extended the use of BIM for automated hazard identification during construction phases. It is the most capable tool for including safety in the project’s design phase (Bansal, 2011). BIM reflects its design attributes and environmental conditions visually and by rule-checking engines embedded in it. Thus, the rise of employing BIM in the project has become prevalent. The known visualization capability of BIM makes it suitable for hazard prevention before the construction phase of safety planning and even further back during the conceptualization and design phase of a project.

Besides the 3D model's inherent information, additional information can be linked or attached as a decision-making aid for BIM suitable for OSH assessment. The idea of integrating information and a decision-making system within the BIM has become viable. The works of Hsu et al. (2020) demonstrate the development of a "knowledge-based system" for settling design clashes in BIM models, Jalaei et al. (2015) in integrating a decision support system within BIM for sustainability issues, and PTD knowledge integration on BIM by Yuan et al. (2019). Hence, BIM is very fit for safety assessment even during the design phase and aids safety knowledge for the designers. BIM is also changing the construction safety management approach. 3D geometry is an essential part of the BIM model that allows designers to perform several essential design activities such as clash detection, visualization and walkthrough, and high-quality rendering. BIM has been used in various ways to check safety issues during design and construction. Construction Safety Management uses BIM technologies for simulation, visualization, mixed reality, and animations (Olugboyega & Windapo, 2019).

2.5.4.1 THE EASE OF USE OF BIM FOR PTD

The assessment of technology's perceived ease of use revolves around users' subjective views on the simplicity and user-friendly nature of the tools and procedures involved (Bonn et al., 2016; Oentoro, 2021). Within the realm of BIM software, the user interface emerges as a critical determinant influencing its perceived ease of use. The design of a user-friendly interface, characterized by intuitive elements like clear menus, icons, and navigation options, plays a pivotal role in enhancing user interaction and expediting access to essential features. Research indicates that an intuitive interface positively impacts technology acceptance and user satisfaction, emphasizing the significance of design in shaping users' experiences (Park et al., 2019; Son et al., 2012).

Furthermore, the user-friendly nature of BIM software is amplified by its integration capabilities with a spectrum of commonly used software and applications. This integrative feature significantly contributes to its accessibility and user-friendliness, aligning with the findings of Oentoro (2021). The software's ability to connect with various tools and applications ensures a smooth flow of data, enhancing the overall usability of the platform in diverse contexts. A remarkable aspect contributing to the perceived ease of use is BIM software's proficiency in importing and exporting data with commonly employed design software and construction management systems. This functionality facilitates interoperability, streamlining data exchange processes and aligning with industry standards (Gouda et al., 2020; Maskil-Leitan et al., 2020). Such capabilities demonstrate the adaptability of BIM software and provide users with a familiar environment, allowing them to leverage their pre-existing knowledge and workflows. In essence, BIM technology's perceived ease of use is tied to the design of its user interface, the integrative features that enhance accessibility, and the adaptability that allows users to integrate their existing knowledge and workflows.

While comprehensive training programs, workshops, and resources play a crucial role in equipping individuals with the skills and knowledge to effectively utilize BIM tools and processes, the accessibility of BIM to a broader spectrum of users significantly influences the perceived ease of use, especially in the context of PTD. BIM software offers standardized templates, libraries, and pre-defined objects, streamlining the modeling process for construction hazards and risks. This accessibility is pivotal in enhancing the user experience and facilitating efficient PTD implementation. Various BIM software, such as Tekla Structures, Autodesk Revit, and Cype, integrate object-oriented modeling tools specifically designed to include construction safety items. These tools are instrumental in simplifying the incorporation of safety considerations into the design and planning phases. The provision of readily available components and templates within these software platforms diminishes the necessity for users to create models from scratch, thereby expediting the BIM modeling process for PTD assessments. This aligns with the findings of previous studies (Akram et al., 2019; Tallgren et al., 2020) that emphasize the importance of tool accessibility and pre-defined objects in influencing the perceived ease of use of BIM in construction-related applications.

2.5.4.2 THE RELATIVE ADVANTAGES OF BIM FOR PTD

For a product, process, or idea to be considered an innovation, it is not necessary to be entirely original at the time of creation. Instead, its level of novelty can be assessed based on the extent to which it is seen as new or unique by the user or implementing unit. Rogers posits that the characteristics or attributes of innovations, which can be quantitatively assessed, are linked to the processes of adoption and decision-making (Poong et al., 2009). Innovations might assume a wide range of forms (Panuwatwanich et al., 2008). According to the research conducted by

Rogers (1983), there were five perceived characteristics of an innovation that were determined to impact its acceptance rate. The factors under consideration are compatibility, relative advantage, complexity, observability, and trialability. As posited by Moore and Benbasat (1991), the evaluation of inventive traits is a determining factor in individuals' responses to the invention. Nevertheless, it has been consistently acknowledged in previous studies that three out of the five attributes of innovation, namely relative benefit, compatibility, and complexity, play a crucial role in shaping individuals' perceptions of the implementation of an invention (Moore & Benbasat, 1991; Taylor & Todd, 1995). Relative advantage refers to the belief that an innovation holds superiority over the idea it replaces, is now being utilized, or is readily accessible. It responds to the inquiry: "Is it better?" Cost and social status incentives play a significant role in determining the relative advantage of innovations. 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.

Safety professionals use dedicated tools and methodologies designed for safety assessments, such as hazard analysis, safety audits, and safety management systems. However, BIM complements these efforts better by providing a holistic view of the project and enabling safety considerations to be integrated into the overall project plan and design (Ganah & John, 2017). One of the advantages of BIM is its ability to improve accuracy and reduce errors (Khosakitchalert et al., 2019). Unlike traditional 2D drawings, BIM provides a detailed 3D model of a building or structure, including all the elements and components. This approach enables designers and builders to identify inconsistencies, conflicts, and errors early in the design process, improving the project's quality and reducing the potential for rework. Such capabilities makes BIM more convenient technological tool for PTD.

2.5.4.3 THE BENEFITS OF USING BIM FOR PTD

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 et al. (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. In the context of the construction industry, the perceived benefits of incorporating technology in areas such as fundamental design, group collaboration, data visualization, acquisition, and management have been shown to significantly enhance work efficiency, productivity, quality, as well as health and safety considerations (Chen & Chang-Richards, 2022).

BIM offers a multitude of significant benefits to many stakeholders, encompassing both direct and indirect returns. This has resulted in the widespread acceptance and implementation of BIM throughout the construction sector. 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 has had advantageous outcomes from adopting BIM. This technology has facilitated enhanced cooperation and communication within the industry, resulting in improved design visualization, streamlined construction management, and efficient facility operations. By adopting BIM, stakeholders can leverage its capabilities to enhance project results, decrease expenses, expedite timelines, and create more environmentally friendly, robust, and efficient structures (Sacks & Barak, 2008).

BIM has the potential to enhance the incorporation of construction safety considerations into the design process, hence providing designers with valuable support in doing PTD analysis. According to Ganah and John (2015), BIM models, which include 3D views and data, are suitable for meeting designers' requirements. These models provide analysis that aids in making decisions related to PTD and enhancing the construction process. Furthermore, they contribute to a better knowledge of construction safety, even prior to the commencement of the construction phase. Yuan et al. (2019) conducted a technical analysis and concluded that the attributes of BIM software and its usability played a crucial role in the adoption of BIM. Furthermore, the perceived advantages associated with the implementation of BIM in building projects, such as enhanced management of scheduling, time efficiency, cost reduction, facility management, and less rework, serve as substantial incentives for the utilization of BIM (Herr & Fischer, 2019). Barlish and Sullivan (2012) assert that the magnitude of the project, the presence of proficient BIM professionals within the team, and the effectiveness of communication among team members are pivotal factors that determine the success of BIM adoption.

2.6 BIM-BASED PTD RESEARCH

PTD continues to be a significant challenge. The potential PTD strategy has run into difficulties during implementation. Apart from a lack of understanding of building safety, designers are hesitant to apply due to the added responsibility and liability associated with an accident. Because PTD is a proactive approach to identifying and eliminating potential construction hazards during the project's conception or design phase, construction actors must be included in the safety assessment process. An example framework is the one formulated by Kamardeen (2010), a BIM-based framework for PTD (Fig. 2.8).

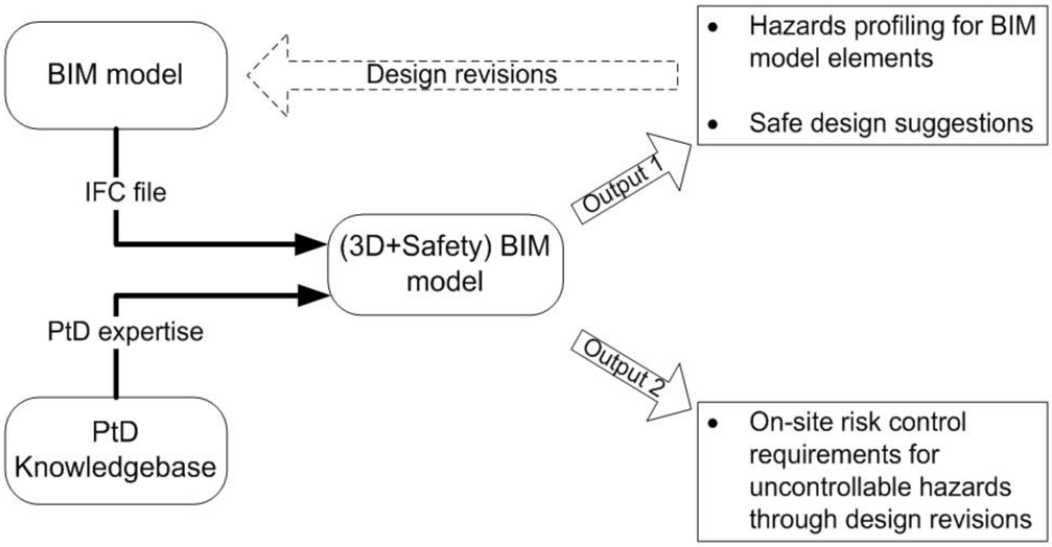

Figure 2.8 A BIM-Based PTD Framework by Kamardeen (2010).

A complete model must be developed for how to incorporate PTD into the scope of the designer's work and how they can participate enthusiastically in safety assessment decision-making. A framework can be envisioned as an approach to a safety culture that focuses on the designer's mindset toward PTD procedures. Academically, the topic has not been adequately integrated into the institution's curriculum. While younger engineers are becoming more aware of this concept, industry organizations and government agencies still need to do more to reach out to engineers (Goh & Chua, 2016). Rubio-Romero et al. (2014) investigated students' attitudes regarding PTD, but a comprehensive method for instilling the PTD concept throughout the school curriculum has yet to be explored.

On the technical side of PTD, research patterns indicate the critical nature of BIM use. The researcher faces a considerable barrier in integrating construction safety knowledge derived from construction accident data. Numerous Artificial Intelligence techniques have been developed to handle such data and provide accident classification or harm prediction. This accident report processing could be brought into BIM as a tool for safety understanding. Research may examine the integration of such data to assist designers in making decisions. The study of Yuan et al. (2019) demonstrated the feasibility of constructing BIM plugins for PTD data by displaying pop-up alert windows. A decision assistance system based on Artificial Intelligence ideas may be critical for enhancing the BIM safety assessment process. If PTD decides to use BIM, various issues may arise. Studies must address the interoperability issue through BIM and cross-disciplinary collaboration for safety assessment. Additionally, achieving design automation and optimization for construction safety assessments that perform design review and code compliance checking is noteworthy.

The following paragraph summarizes some of the previous research studies into the impact of BIM on occupational safety and health:

- Benjaoran and Bhokha (2010) introduced a rule-based four-dimensional computer-aided design (CAD) safety and construction management model that can detect hazards associated with working at height and indicate essential safety measures.
- Zhang et al. (2013) created an automated approach for verifying BIM's safety regulations. They employed a table-based approach to detect the risk of falling from a height and offer a design solution automatically.
- Qi et al. (2014) have described a BIM-based model for preventing falls from height during construction worker design. Nonetheless, the primary disadvantage of these systems is that they can prevent only one type of hazard (fall from height) through design, with the rules being hard-coded into the algorithms.
- Zhang et al. (2014) proposed a comprehensive BIM-based job hazard analysis (JHA) by formalizing construction safety knowledge, which is capable of automatically identifying safety concerns prior to beginning a construction activity and recommending mitigation solutions.
- Malekitabar et al. (2016) used BIM as a foundation to identify potential safety concerns in a project by reflecting design attributes and environmental variables and processing with rule-checking engines.
- Hossain et al. (2018) describe a structured rule-based DfS knowledge library that can be obtained as a stand-alone knowledge database and used by designers even before

the BIM model is produced. The knowledge library is then integrated with the BIM platform, resulting in a BIM-integrated risk evaluation system that enables designers to compare the risk of their design parts to safety standards and handle them appropriately. Building a “construction risk knowledge management” system utilizing BIM allows the interdependencies between risks to prevent risks during the construction process or technique selection (Ding et al., 2016).

- Fadoul et al. (2021) examine how contemporary process- and object-oriented models might be leveraged to provide a framework for representing the subjective nature of design constructability in order to inform decision-making. As a result, it suggests doing the assessment using a BIM-based model that incorporates embedded information from the design environment. The modeling framework is composed of three critical components: the Constructability Model (CM), which expresses user-based knowledge; the BIM Design Model, which contains the necessary data for the assessment; and the Assessment Model (AM), which reasoned using the formulated knowledge and the BIM Design Model. The modeling framework is written in C# and utilizes the.NET Framework and the Revit API.
- Nguyen et al. (2014) proposed a framework for formalizing DfS knowledge. Additionally, DfS knowledge must be integrated with the BIM platform, as BIM has been identified as the central hub for information management shared by all stakeholders involved throughout the lifecycle of a construction project, from design to construction, operation, maintenance, and finally, demolition.

2.7 THE TECHNOLOGY ADOPTION MODELS

Technology adoption models are conceptual frameworks that delineate the progression by which individuals, organizations, or societies embrace and incorporate novel technologies. These models explain the sequential phases of adoption, the determinants impacting adoption choices, and the attributes of adopters. The following are several widely recognized technology adoption models.

2.7.1 ROGERS' DIFFUSION OF INNOVATIONS

Everett M. Rogers' (1983) Diffusion of Innovations theory is a widely recognized framework that explains how and why new ideas, products, or technologies spread and are adopted by individuals, organizations, or societies. The theory (Figure 2.5) outlines the adoption process and identifies various factors influencing the adoption rate. An innovation refers to an idea, practice, or object perceived as new by an individual or group. This can include technological advancements, new products, services, or even novel ideas and behaviors. Rogers categorizes individuals into five adopter groups based on their willingness to adopt an innovation:

- Innovators: The first to adopt, risk-takers, adventurous.
- Early Adopters: Opinion leaders, social influencers.
- Early Majority: Pragmatic, deliberate decision-makers.
- Late Majority: Skeptical, adopted after the majority.
- Laggards: Traditional, resistant to change.

The diffusion process consists of five stages that individuals go through when adopting an innovation:

- Knowledge: Awareness and understanding of the innovation.
- Persuasion: Formation of a positive or negative attitude toward the innovation.
- Decision: Commitment to adopt or reject the innovation.
- Implementation: Putting the innovation into use.
- Confirmation: Reinforcement of the decision through positive or negative feedback.

Rogers identified several factors that influence the rate of adoption:

- Relative Advantage: The perceived superiority of the innovation over existing solutions.
- Compatibility: The degree to which the innovation fits with existing values and needs.
- Complexity: The perceived difficulty of understanding and using the innovation.
- Trialability: The ability to experiment with the innovation on a limited basis.
- Observability: The extent to which the results of the innovation are visible to others.

Different adopter categories tend to use specific communication channels. Innovators often rely on more specialized and technical sources, while mass media and interpersonal communication may influence the majority. The rate of adoption varies across different innovations and is influenced by factors such as the innovation's complexity, visibility, and the social system in which it is introduced.

Rogers' Diffusion of Innovations provides a comprehensive framework for understanding the dynamics of innovation adoption. It has practical applications in fields such as marketing, technology implementation, and public health, helping to predict and manage the adoption of new ideas and technologies.

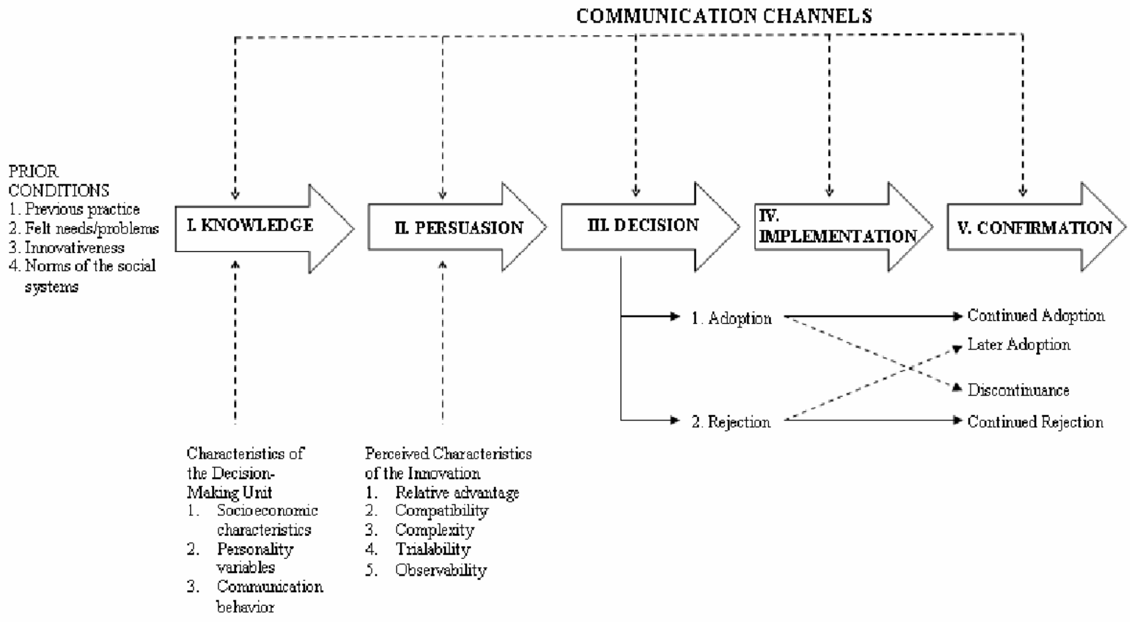

Figure 2.9 Diffusion of Innovations by Rogers (2003).

2.7.2 THE TECHNOLOGY ACCEPTANCE MODEL (TAM)

The TAM model, conceived by Venkatesh and Davis in 2000, is preeminent and widely utilized in information systems and technology management. Acknowledged for its conciseness and efficacy, TAM provides a robust framework for comprehending user behavior in the context of technology adoption (Davis, 1989; Davis et al., 1989; Pavlou, 2003; Venkatesh & Davis, 2000). The model, illustrated in Figure 2.6, features the fundamental role of "Perceived Usefulness" (PU) and "Perceived Ease of Use" (PEOU) in influencing an individual's inclination to accept novel technology. Perceived usefulness pertains to an individual's perception of how using a specific system will enhance their job performance, while perceived ease of use relates to the belief that utilizing a system can be achieved without intentional exertion.

Behavioral intention denotes an individual's purposeful inclination or motivation to engage in a specific behavior, applying significant influence over subsequent actions. This inclination suggests a tendency to participate in the behavior, a readiness to employ the associated service, recommend it to others, and express a willingness to engage with it repeatedly (Namkung & Jang, 2007). The concept of behavioral intention to adopt extends to organizational settings, reflecting the extent of an organization's future intent to employ a particular technology, as articulated by Taylor and Todd (1995). Although TAM does not explicitly delineate "Attitude" as a distinct construct, the model completely encompasses attitudes toward technology. In this context, attitude signifies an individual's or organization's holistic positive or negative evaluation of technology. Researchers may choose to incorporate attitude as a discrete construct fitted to their specific research context.

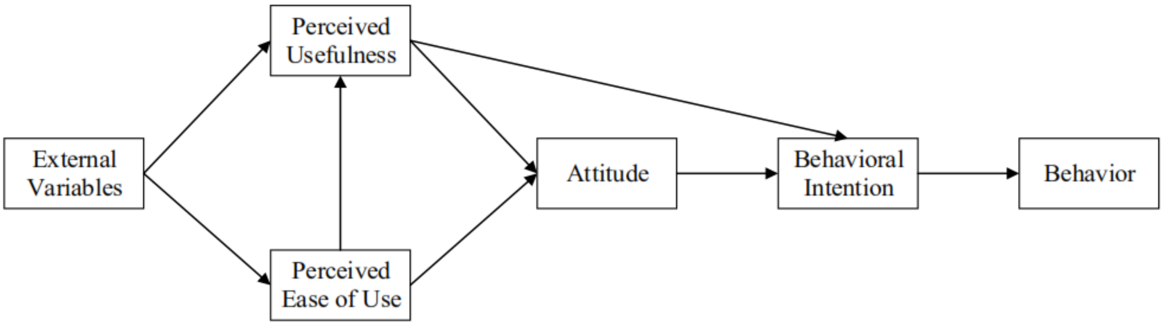

Figure 2.10 The Classical Technology Acceptance Model.

Notably, TAM is frequently employed in combination with other models or frameworks that explicitly consider attitude as a pivotal factor. For instance, the Unified Theory of Acceptance and Use of Technology (UTAUT), an extension of TAM, integrates social influence, facilitating conditions, and performance expectancy—encompassing perceived usefulness and attitude (Williams et al., 2015). TAM's robustness is evidenced by its consistent validation across diverse contexts, substantiated by various researchers in studies on technology adoption (Sanchís-Pedregosa et al., 2020; Wu & Chen, 2017; Xu et al., 2014). Widely recognized for its straightforward theoretical framework, TAM is a foundation for researchers to modify or expand using different approaches. Numerous extensions have been proposed, introducing alternative hypotheses and yielding divergent frameworks (Bryan & Zuva, 2021; Poong & Eze, 2008; Qin et al., 2020). This adaptability demonstrates TAM's significance as a foundational model, fostering a rich literature on the adoption of technology in diverse domains.

Furthermore, the TAM model provides a comprehensive understanding of the factors broadly influencing technology adoption, investigating the complex relationship between external influences and internal perspectives (Son et al., 2015). Within the theoretical framework, individual adoption behavior is tied to the intention to employ a specific system, shaped by perceptions of its utility and ease of use. However, it is imperative to recognize the inherent limitations of TAM, notably the omission of certain external factors that might exert an influence. These factors may potentially impact the model's explanatory power within the context of a particular study. As emphasized by Legris et al. (2003), while TAM is valuable, its efficacy can be enhanced by integrating it into a more comprehensive framework that accommodates additional dimensions, encompassing human, technological, and social factors capable of indirectly shaping user attitudes and intentions to adopt. In line with this perspective, the present study aligns with the recommendations of Legris et al. (2003) by incorporating characteristics extending beyond TAM's limitations. Recognizing the need for a more expansive approach, the research incorporates insights from the Unified Theory of Acceptance and Use of Technology (UTAUT) (Huang, 2023; Williams et al., 2015) and the Technology-Organization-Environment (TOE) (Bryan & Zuva, 2021; Qin et al., 2020) framework. These frameworks explicitly account for external factors, such as organizational context, social influence, and environmental conditions, acknowledging the versatile nature of technology adoption. By integrating these additional dimensions, the present research endeavors to construct a more nuanced understanding that complements the foundational elements of TAM and reflects a more holistic appraisal of the factors shaping technology adoption in the specific context under investigation.

2.7.3 THE UNIFIED THEORY OF ACCEPTANCE AND USE OF TECHNOLOGY (UTAUT)

UTAUT is a conceptual framework that aims to understand and predict individuals' acceptance and use of information technology (IT) within an organizational context (Fig 2.7). It was developed by Venkatesh, Morris, Davis, and Davis in 2003 as a synthesis of several existing TAMs.

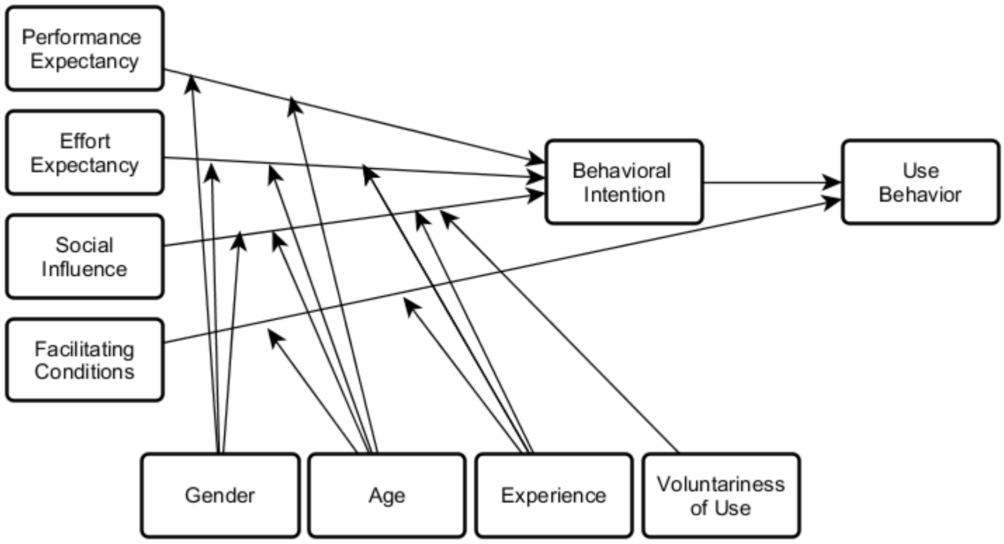

Figure 2.11 The Unified Theory of Acceptance and Use of Technology (UTAUT).

Performance expectancy refers to the degree to which an individual believes that using a particular technology will help them enhance job performance or achieve specific goals. It is influenced by perceived usefulness from earlier technology acceptance models. Effort expectancy is the perceived ease of use associated with adopting and using a technology. It reflects an individual's belief that using the technology will be free of effort or difficulty. This concept is akin to the ease of use component in other models, such as the TAM. Social influence measures the impact of social factors on an individual's decision to accept and use technology. It encompasses subjective norms, or the perceived expectations and opinions of significant others, as well as social factors, such as influence from colleagues and superiors. Facilitating conditions refer to the perceived organizational and technical support for using technology. It includes the availability of resources, infrastructure, and technical support that make it easier for individuals to adopt and use the technology. Intent to use is the individual's intention or willingness to use a particular technology in the future. It is a key precursor to actual technology use. Intent to use is influenced by the three main determinants mentioned above (performance expectancy, effort expectancy, and social influence). Behavioral intention represents the individual's likelihood of engaging in a specific behavior, in this case, using a particular technology. It is a direct precursor to actual technology use and is influenced by performance expectancy, effort expectancy, social influence, and facilitating conditions.

Furthermore, UTAUT acknowledges that factors like gender, age, prior experience with technology, and the voluntary nature of technology use can moderate the relationship between the core determinants and technology acceptance. For example, younger individuals might be more inclined to adopt technology voluntarily compared to older individuals. UTAUT has been widely used and extended in various research contexts, and it has proven valuable for understanding and predicting technology acceptance in organizational settings. Researchers and practitioners often use UTAUT to guide the design and implementation of IT initiatives within organizations.

2.7.4 THE TECHNOLOGY-ORGANIZATION-ENVIRONMENT (TOE) FRAMEWORK

TOE framework is a theoretical model that aims to explain the factors influencing the adoption and assimilation of technological innovations within organizations (Bryan & Zuva, 2021). It was developed to provide a comprehensive understanding of the interplay between technological, organizational, and environmental factors that shape the adoption process (Fig. 2.8). The TOE framework was introduced by Tornatzky and Fleischer in the early 1990s.

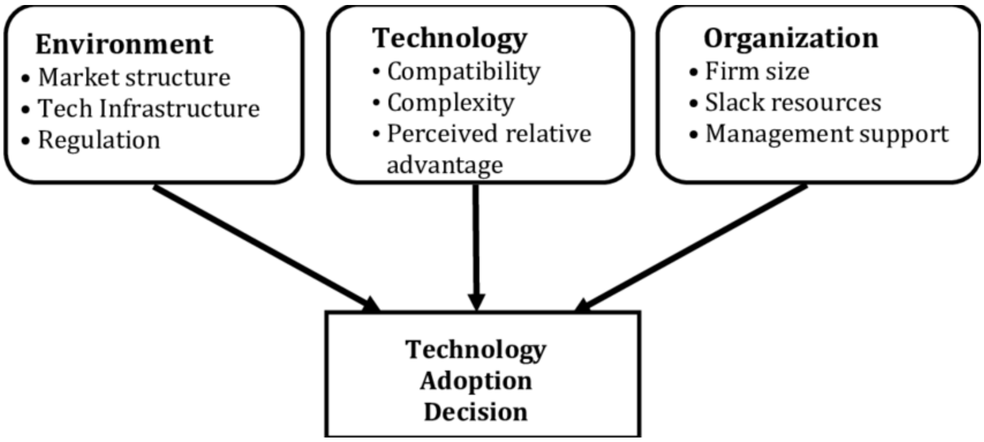

Figure 2.12 The Technology-Organization-Environment (TOE) Framework.

This dimension focuses on characteristics related to the technology itself. It considers factors such as the perceived advantages, compatibility with existing systems, complexity, and trialability of the technology. Organizations assess these technological aspects before deciding to adopt a new innovation. The organizational context refers to internal factors within an organization that influence the adoption of technology. Key elements include the organization's size, structure, culture, and existing systems. Factors such as leadership support, communication channels, and the presence of IT specialists also fall under the organizational context. The environmental context involves external factors outside the organization that may impact the adoption of technology. This includes industry regulations, market competition, economic conditions, and the overall socio-economic environment. External pressures or opportunities may drive organizations to adopt specific technologies.

Furthermore, the TOE framework recognizes that the three contexts—technology, organization, and environment—do not operate in isolation. Instead, their interactions influence the adoption process. For instance, the successful adoption of technology may depend on how well it aligns with the organization's structure or how responsive the organization is to external pressures. The TOE framework considers both internal and external processes associated with technology adoption. Internal processes involve decisions and actions within the organization, such as the evaluation of the technology's fit with existing systems and the decision-making process. External processes pertain to the external influences that impact the adoption, such as industry trends and regulatory changes. The TOE framework also acknowledges the existence of moderating factors that may influence the strength or direction of the relationships between the three contexts. For example, the level of technological uncertainty, the availability of skilled personnel, and the organization's absorptive capacity can moderate the impact of technology, organizational, and environmental factors on adoption.

The TOE framework provides a comprehensive and holistic view of technology adoption within organizational settings. It has been widely applied in research to study technology adoption and implementation in various industries and contexts, offering insights for both academics and practitioners.

2.8 CHAPTER’S SUMMARY

The objective of this chapter was to conduct a comprehensive and critical evaluation of the literature pertaining to the fundamental principles of PTD from various theoretical and technological perspectives to illuminate key insights. The inquiry commenced by digging into occupational safety topics, establishing a foundational understanding of concepts related to construction safety. Additionally, diverse viewpoints on the significance and rationale of PTD were explored, aiming to substantiate the claim that a correlation exists between design decisions and construction-related injuries and fatalities. The research findings emphasize the crucial necessity of implementing PTD in the construction industry, emphasizing its fundamental importance. The extensive literature review served as a crucial source of background knowledge, advancing comprehension of PTD. Despite its implementation in certain countries, notable barriers hinder its widespread adoption in the construction sector, with a notable obstacle being the absence of tools and guidance for conducting PTD analyses. The investigation also searched into potential technological instruments that could serve as PTD tools, revealing BIM as a potent technology with the capacity to propel the adoption of PTD in construction.

Furthermore, the study explored the concept of innovation within the context of BIM and PTD. While scholars acknowledged BIM and PTD as innovations in the construction industry, the prevailing viewpoint remains somewhat limited. The characteristics of technology adoptions were looked at to analyze the attributes of a BIM-based PTD that would attract designers to embrace this innovative approach. This exploration revealed crucial insights into how BIM, as a PTD technology, can be effectively incorporated into design processes.

Therefore, it becomes evident that a knowledge gap exists that demands further investigation, and the subsequent chapter aims to address and bridge this gap. The research journey has illuminated the significance of PTD, the barriers to its implementation, the potential role of technological tools like BIM, and the complex interplay between adoption constructs and PTD in the construction industry.

METHODOLOGIES

This chapter establishes a structured and methodological foundation for the research aim of integrating research methodologies. This chapter discusses the study's methodology, including the approach, design, and primary analysis techniques used in this research. Section 3.1 presents a detailed exposition regarding the research design. This section outlines the key phases of the study, detailing the initial research activities, their goals, and the resulting inputs and outputs. Section 3.2 comprehensively accounts for the exploratory study conducted within the designated research setting. The process of preparing and administering the questionnaire, the precise methods employed in sample selection, and the strategies that underpin the sampling framework are detailed. Likewise, this section explains the data analysis techniques employed to derive meaningful insights from the gathered data. Section 3.3 and Section 3.4 shift the focus toward the feasibility study, providing a comprehensive overview that encompasses the creation of the framework, the development of pertinent tools, and a detailed examination of the qualitative feasibility study undertaken. Lastly, Section 3.5 extensively reviews the empirical analysis, particularly emphasizing the quantitative research model. This section examines the construction of the conceptual model, formulates hypotheses, and describes the methodologies used to collect and analyze data.

3.1 RESEARCH DESIGN

The research design functions as a methodical and organized roadmap, portraying the steps, procedures, and methodologies to be utilized in a research study. It acts as a structured framework, guiding researchers in effectively and efficiently pursuing their study objectives (Marczyk et al., 2010). These elements include the selection of a research strategy, formulating research questions and hypotheses, identifying variables, establishing assumptions, determining data collection techniques, and specifying statistical tests.

3.2 RESEARCH ROADMAP

The research methodology utilized to achieve the research objectives is depicted in the research roadmap (Figure 3.1). Every objective in the study was associated with an anticipated output expected to be generated upon the successful completion of each research activity. Phases were arranged sequentially, with each phase pertinent to the subsequent phase in the given sequence. As a standard operation, the ground stage of every research assignment was thoroughly examining the existing body of literature to solidify the research topic, identify gaps in existing knowledge that warrant further inquiry, and develop specific research questions and objectives. Additionally, a thorough examination of the current body of literature was conducted at each phase in order to acquire the necessary information for the research. The current study comprises three distinct phases, each with a specific research approach: preliminary exploratory study, feasibility studies, and exploratory study.

Before embarking on any strategy to promote the adoption or dissemination of a particular concept, it was imperative to conduct a comprehensive assessment of the current level of awareness and comprehension of that concept. In cases where there is a notable scarcity of relevant literature focusing on the subject of PTD within a particular country, it becomes imperative to undertake an initial exploratory study. This preliminary investigation served as a foundational step in gaining insights into the existing knowledge base and the context-specific hints surrounding PTD, which are pivotal for informing subsequent intervention strategies. Hence, the study's first objective was:

RO1: *To investigate the PTD current level of awareness among the structural engineers in the Philippines.*

It was anticipated that this research segment would provide an in-depth understanding of the specific factors influencing the adoption of PTD within the country. Doing so has set the stage for informed strategies to advance PTD adoption in the construction industry. It also explored the prominent obstacles to implementing PTD. The initial findings of the exploratory investigation revealed that the designer expressed significant concerns over the absence of adequate methods for addressing PTD and promoting construction safety awareness. It also found that providing designers with PTD tools, such as BIM software, could help designers embrace the principles of PTD. Within this context, two paramount concerns emerged: the deficiency in construction safety knowledge and inadequate tools for PTD implementation. It became evident that these challenges could potentially hinder the successful integration of PTD principles into construction processes. In response to these challenges, the potential of BIM emerged as a noteworthy solution. Thus, the second objective of the study was to:

- **RO2:** To assess the applicability of BIM as a tool for PTD.

To comprehensively evaluate the applicability of BIM as an efficient instrument for enacting PTD, it was crucialial to conduct a thorough and in-depth feasibility studies. This evaluation includes various dimensions, including the technical capabilities of BIM, its integration within the design process, its alignment with safety considerations, and its practical usability by designers. Through this approach, the study aspired to make a feasible and practical contribution to the adoption of BIM for PTD within the construction industry. The objective was divided into two distinct feasibility studies, both aiming to assess the applicability of BIM for PTD. The feasibility study objectives were:

- **RO2a:** To demonstrate the applicability of BIM for PTD by developing a BIM-based PTD tool.
- **RO2b:** To asses the applicability of BIM for PTD based on the expert's perception.

The first feasibility study (RO2a) enabled an in-depth examination of the framework's potential in addressing construction health and safety concerns, thereby contributing valuable insights to the field. With its multiple capabilities and applications, BIM was posited as a resource capable of addressing these identified deficiencies. The research aim entailed the development of a technical framework explicitly tailored for the integration of BIM into the context of PTD within structural design applications. This framework was created and was primarily fortified by a conceptual study of the intricacies of structural design principles, the core ideas of PTD, and the capabilities of BIM technology. By combining these key domains of knowledge, the research was able to construct a comprehensive methodological framework. This framework, in essence, served as a blueprint, offering a structured and systematic approach for the incorporation of BIM into the PTD process within structural design applications. This work contributed to a more efficient and safety-conscious approach to structural design in the construction industry.

The second feasibility sudy (RO2b) sought to augment its technical framework by eliciting the perspectives and insights of experts within the field. Thus, an in-depth interview was conducted with experts with experience and knowledge in structural design, to talk about BIM technology, construction safety, and PTD. These interviews were designed to gauge the designers' perception of the practicality and effectiveness of employing BIM as a tool for PTD. By engaging with these experts, the research collected qualitative data that provided an informed understanding of how BIM could be optimally utilized to enhance safety and design considerations in structural applications. The combined outcomes of framework development and expert interviews were instrumental in advancing the study's comprehension of the synergies between BIM and PTD within the specialized context of structural design. This inquiry shed light on how BIM could be harnessed to bridge the knowledge gap in construction safety and serve as a practical solution for PTD adoption.

Finally, the study aimed to explore the concept of "BIM for PTD" further by considering socio-technical factors from the perspective of its adoption by gathering insights from a wider range of participants. Thus, the third objective was:

- **RO3:** To explore the framework of socio-technical factors that may impact the adoption of BIM for PTD.

The research explored the complex relationship of socio-technical elements that could impact the adoption of BIM for PTD and initiated a thorough and methodical investigation. This exploration needed an examination of the interplay between the social and technical components that will shape the adoption of PTD. By exploring these socio-technical factors, the study was expected to unravel the complexities that influence the decision-making processes of designers. The third objective shifted the research trajectory towards a more profound exploration of PTD adoption dynamics within the industry. The investigation required a thorough analysis of the interaction between the social and technical factors that influence the adoption environment. As a result, the research was carried out according to recognized technological adoption theories to test the predicted hypotheses quantitatively. This study offered an analysis of the complexities, potential benefits, and underlying factors involved in the implementation of BIM for PTD and explained the interplay and correlations of social and technical components, which collectively influence the outcome of BIM for PTD adoption.

In the concluding phase of the research, a comprehensive synthesis was undertaken to align all the study's objectives and outcomes, ensuring a cohesive understanding of the findings. This final step involved an in-depth analysis and extrapolation of the research implications, extending its relevance and applicability to both the academic and practical fields. This integrative approach facilitated understanding of the study's impact, stressing its significance in advancing knowledge and informing practices within the construction industry and beyond.

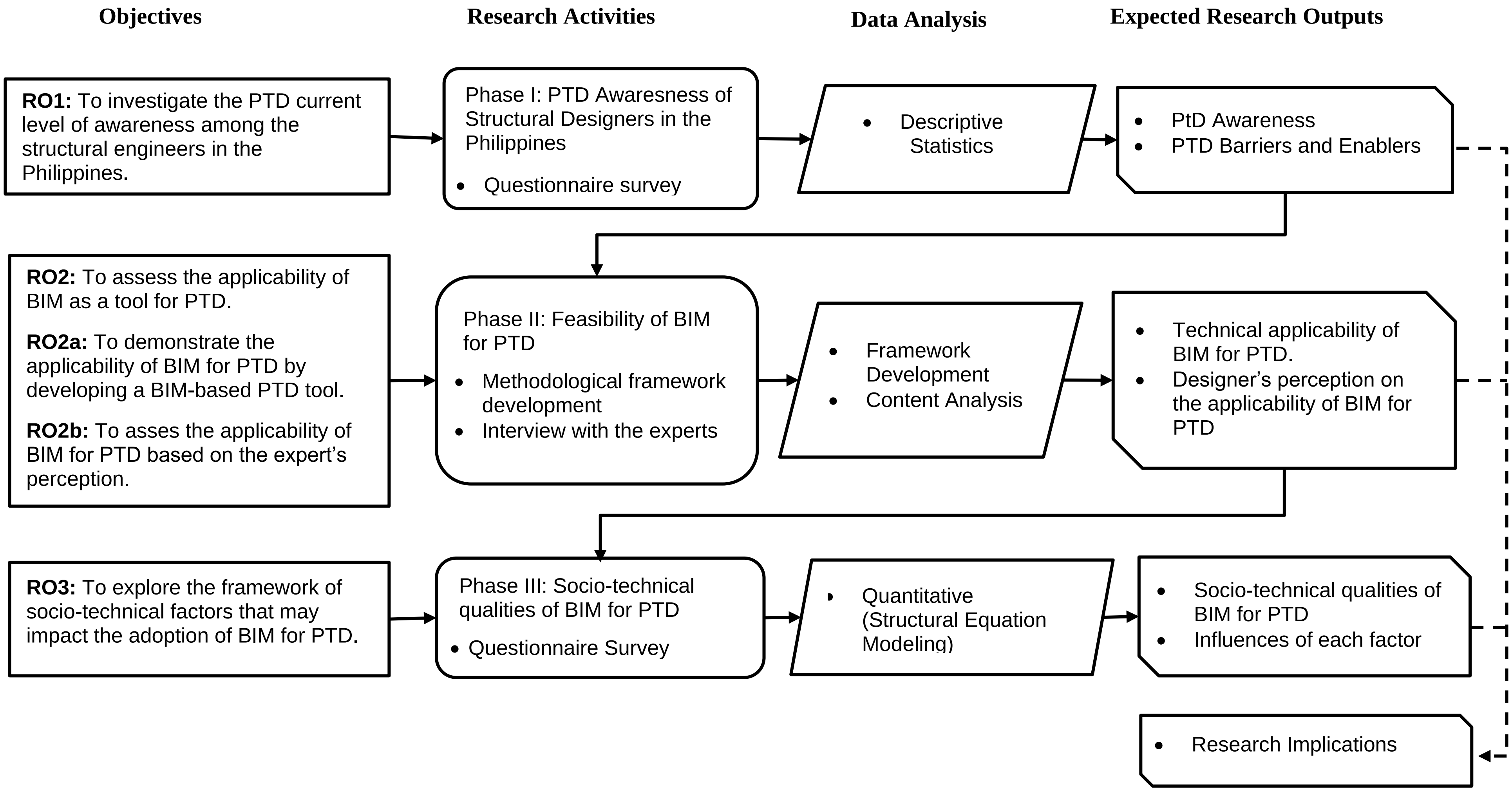

Figure 3.1 Research Roadmap.

3.3 PHASE I: PTD AWARENESS OF STRUCTURAL DESIGNERS IN THE PHILIPPINES

3.3.1 STUDY APPROACH

Exploratory research represents a distinct research approach characterized by its focus on investigating a problem that lacks a well-defined and delineated scope before its commencement. The exploratory research approach primarily focuses on expanding the comprehension of current conditions and revealing hidden patterns that can assist in describing and understanding the matter being investigated (Stebbins, 2001). It also identifies overarching trends that might have previously eluded recognition. It does so by probing the issue's depths and scrutinizing it from multiple angles. It is essential to recognize that while exploratory research may yield certain outcomes, these findings are often preliminary and not definitive. This research methodology is typically deployed during the initial phases of problem exploration and formulation, providing researchers with a headstart to launch more targeted and in-depth investigations.

Moreover, following the research design, exploring potential adopters' current awareness and knowledge levels is imperative before determining a starting point for adopting a concept. Hence, this initial investigation sought to discern the designers' perspectives and apprehensions regarding PTD and its implementation. The study employed a nationwide cross-sectional survey to gauge designers' views and concerns related to its implementation. The collected data has been analyzed to pinpoint perceived enablers or obstacles in implementing PTD in the Philippines. Consequently, the study aimed to establish a foundational understanding of initiatives to introduce or enhance the adoption of PTD in the Philippines, specifically focusing on the construction industry as the context for this research.

3.3.2 QUESTIONNAIRE DESIGN AND DEVELOPMENT

The researchers employed a structured questionnaire to carry out a cross-sectional study on a national scale. This research tool was chosen because a questionnaire survey offers a more comprehensive picture of the investigated phenomenon (Bryman, 2016). A questionnaire stands as an essential and extensively employed instrument for data acquisition in empirical research (Rathi & Ronald, 2022). In its most fundamental configuration, a questionnaire represents a structured series of inquiries strategically constructed to elicit information or data from individuals to investigate a specific issue or topic. In addition, questionnaire surveys have the advantages of being easily administered, rapid, cost-effective, and adaptable in scale (Dalati & Gómez, 2018). Thus, questionnaires were regarded as a suitable survey tool for conducting this research. The questionnaire's framework for development was patterned with the research conducted by Goh and Chua (2016) and Che Ibrahim & Belayutham (2020) regarding the Knowledge, Attitude, and Practice (KAP) of PTD. Figure 3.2 shows an example part of the questionnaire (see Appendix A for the complete questionnaire). The KAP questionnaire is commonly used in health studies. Nevertheless, the essential elements of the PTD concept were considered suitable for this study, which sought to ascertain the level of awareness of the PTD concept among design engineers in the Philippines, as shown by their familiarity with its major components.

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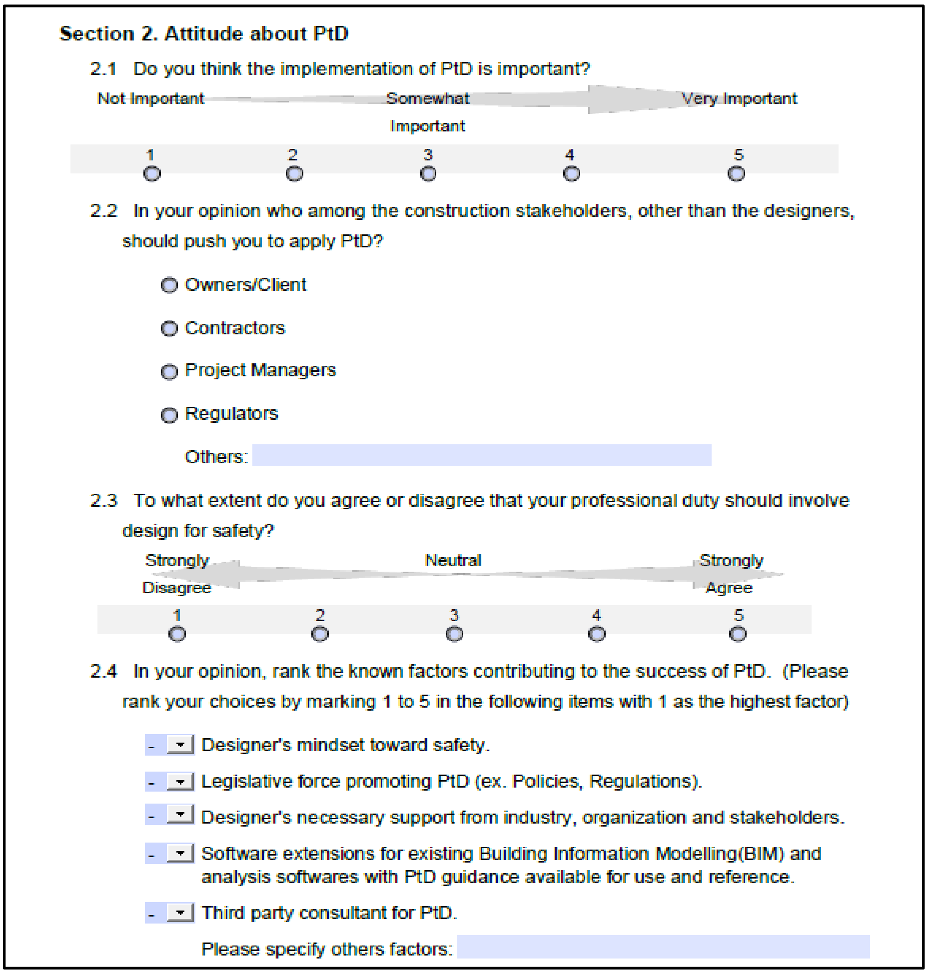

Section 2. Attitude about PtD

2.1 Do you think the implementation of PtD is important?

Not Important — Somewhat Important — Very Important

1 ○ 2 ○ 3 ○ 4 ○ 5 ○

2.2 In your opinion who among the construction stakeholders, other than the designers, should push you to apply PtD?

○ Owners/Client

○ Contractors

○ Project Managers

○ Regulators

Others:

2.3 To what extent do you agree or disagree that your professional duty should involve design for safety?

Strongly Disagree — Neutral — Strongly Agree

1 ○ 2 ○ 3 ○ 4 ○ 5 ○

2.4 In your opinion, rank the known factors contributing to the success of PtD. (Please rank your choices by marking 1 to 5 in the following items with 1 as the highest factor)

- Designer's mindset toward safety.
- Legislative force promoting PtD (ex. Policies, Regulations).
- Designer's necessary support from industry, organization and stakeholders.
- Software extensions for existing Building Information Modelling(BIM) and analysis softwares with PtD guidance available for use and reference.
- Third party consultant for PtD.

Please specify others factors:

Figure 3.2 Printscreen of the Questionnaire.

A KAP questionnaire is a specific type of survey instrument designed to assess what people know, believe, and do in relation to a particular topic. This type of survey is commonly used in public health, education, and social sciences to evaluate public awareness and behaviors concerning various issues like health practices, environmental policies, and safety measures. The structure of a KAP questionnaire typically consists of three main sections: knowledge, attitude, and practices (World Health Organization, 2008). The knowledge section aims to assess the respondents' factual information about the subject. Questions are designed to gauge understanding or awareness of specific facts, processes, or concepts. These can be structured as multiple-choice questions, true/false questions, or open-ended questions where respondents provide an answer without prompts. For example, in a health-related KAP survey, this part might include questions about a disease's symptoms, transmission routes, and prevention strategies (Launiala, 2009). Attitude questions explore respondents' feelings, beliefs, and perceptions about the issue at hand. These questions are crucial for understanding the subjective and psychological aspects that might influence individuals' behaviors. Attitude questions are often structured using Likert scales where respondents indicate their agreement or disagreement on a five-point scale ranging from strongly agree to strongly disagree (Bührmann et al., 2022). The practices or behaviors section assesses what respondents do in relation to the topic. This part looks at the actions taken by individuals, which may or may not be in alignment with their knowledge and attitudes. Questions here typically ask about past behavior or intended future behavior and can be formatted as yes/no questions, frequency measures (how often something is done), or descriptions of specific actions (Valente et al., 1998). For instance, in an environmental KAP survey, questions might be asked about recycling habits (Besar et al., 2013) or the use of public transportation (Tripathi et al., 2022)

3.3.3 RESPONDENT SAMPLING AND DISTRIBUTION

This study explicitly investigated the implementation of PTD in structural design. The researchers sought to perform a comprehensive analysis by collecting data from multiple design trades. Nevertheless, it was crucial to acknowledge that each design trade encountered in a construction project poses unique occupational safety challenges, requiring a thorough and personalized assessment. Thus, the study was limited to structural designers working in the Philippines.

In 2020, the Philippine Institute of Civil Engineers (PICE) reported a total of 92,316 active professional members engaged in various civil engineering occupations. Accurately determining the number of structural engineers from the provided list was challenging because individuals with a civil engineering license in the Philippines are permitted to work as structural designers. However, the Association of Structural Engineers of the Philippines (ASEP) has documented over 900 currently participating members as of 2020. The roster was employed to communicate with all potential participants. An additional search endeavor was conducted on the professional networking platform LinkedIn. The online professional networking platform is widely used to promote career progression and facilitate connections among professionals in different fields, including structural designers and engineers. The step was taken to augment the inclusiveness of the study and collect perspectives from a wide array of structural designers associated with various institutions.

Consequently, an extensive exploration was conducted on LinkedIn's professional networking platform to identify suitable participants. This exploration involved employing specific search terms, including "Structural Engineer Philippines," "Senior/Junior Structural Engineers Philippines," and "Proprietor/Owner/Principal Structural Engineers Philippines." A total of 300 active prospects engaged in structural design were identified, contacted, and formally invited to participate in the questionnaire, forming the basis for the sample frame in this research study. Of these, 145 participants agreed to take part. Participants were then instructed to distribute the questionnaire within their professional networks, which included colleagues, subordinates, and friends working as structural engineers in the Philippines. The survey administration began with researchers obtaining consent from prospective participants before disseminating the questionnaire, opting for email as the mode of distribution due to the COVID-19 pandemic. A total of 145 questionnaires were sent out, resulting in the receipt of 61 completed forms, reflecting a response rate of 42%.

3.3.4 ANALYSIS

Descriptive statistical analysis was employed to derive findings for each question and the overall study. Descriptive statistics gain an initial comprehension of data and detect patterns, outliers, and significant characteristics (Johnson & Bhattacharyya, 2019). Data visualization tools are essential for summarizing and presenting data clearly and concisely. This facilitates the task of researchers and analysts in making well-informed decisions, identifying patterns, and conducting additional statistical examinations or deriving significant insights from the data. Consequently, showing the findings in plots or graphs was imperative to offer straightforward descriptive visuals. In the process of scaling the Likert scale, it is important to ensure that the linear numeric response values are accurately represented at each point. Therefore, the dataset falls into the parametric category, suggesting that statistical descriptors like the mean and standard deviations can be utilized for descriptive purposes (Norman, 2010; Sullivan & Artino Jr, 2013).

3.4 PHASE II: FEASIBILITY OF BIM FOR PTD

The study's second objective is a feasibility study that aims to assess the applicability of BIM as a tool for PTD and a catalyst for PTD adoption. A feasibility study is a comprehensive assessment used to determine a proposed project's viability before significant resources are committed (Kerzner, 2017). A feasibility study's main purpose is to evaluate a project's practicability and identify any potential obstacles that could impede its success (Kulwin, 2017; Mesly, 2017). This study evaluated whether BIM is practical and applicable for implementing PTD principles within construction projects or organizational workflows. Feasibility studies in this area are critical because they provide concrete data and insights that help decision-makers understand the practical implications of integrating new technologies like BIM into established practices (Arunkumar et al., 2018).

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3.4.1 TECHNICAL FEASIBILITY OF BIM FOR PTD

This part of the study looked into the domains of structural design, BIM technology, and PTD to explain how these elements can synergize to establish a comprehensive BIM-based PTD framework and demonstrate the applicability of BIM as PTD tool. The developed technical framework emphasized the capabilities of BIM to enable structural designers to perform OSH analysis effectively. This work examined the interplay between structural design, BIM technology, and PTD, culminating in developing an innovative framework that empowers structural designers to engage in OSH analysis.

3.4.1.1 STUDY APPROACH

The research approach for this study relies on a case study approach, primarily oriented towards developing and validating a framework. The case study method is a valuable research scheme suited for in-depth investigations and real-world applications (Yin, 2014). In this context, the research aimed to advance knowledge and understanding by crafting a methodological framework that pertains to the integration of BIM technology in the domain of construction health and safety, particularly in the context of PTD.

3.4.1.2 METHODOLOGICAL FRAMEWORK DEVELOPMENT

After gathering the requisite information through a literature review, the research developed a BIM-based PTD framework. This PTD framework served as an illustrative representation of the applicability and feasibility of BIM within this particular context of PTD. The methodological framework aimed to emphasize structural engineers' ability to execute PTD assessments with the aid of BIM. It was designed to serve as a practical tool that rationalizes the PTD process and facilitates the integration of new BIM technologies and software functionalities. This framework's construction was informed by the technical capabilities of BIM, ensuring that it was grounded in the practical and technological realities of the field. Designed to be methodological, this framework serves as a structured guide, outlining the processes and principles for effectively integrating BIM into construction safety practices..

3.4.1.3 FRAMEWORK VALIDATION

The developed framework was validated by creating and applying a BIM-based PTD tool specifically designed for this purpose. The Tekla Structures® 2022 software served as the core platform for this endeavor (as depicted in Figure 3.3), with the study making use of the software's student version to conduct the research. The development of this innovative tool was propelled forward by leveraging Microsoft Visual Studio and employing the C# programming language for coding purposes (illustrated in Figure 3.4).

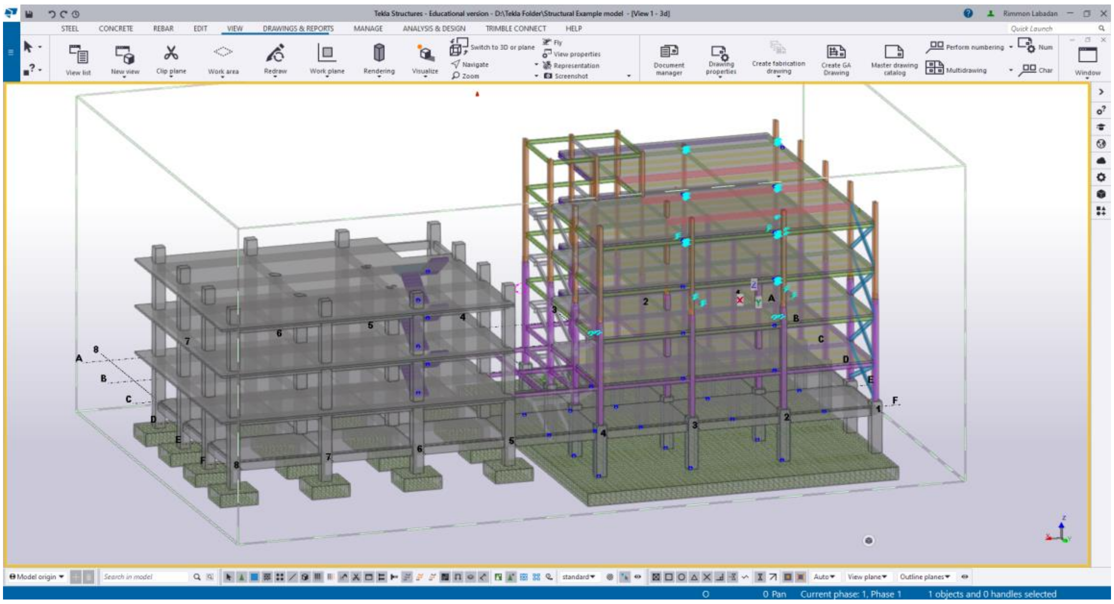

Figure 3.3 The Tekla Structures Software.

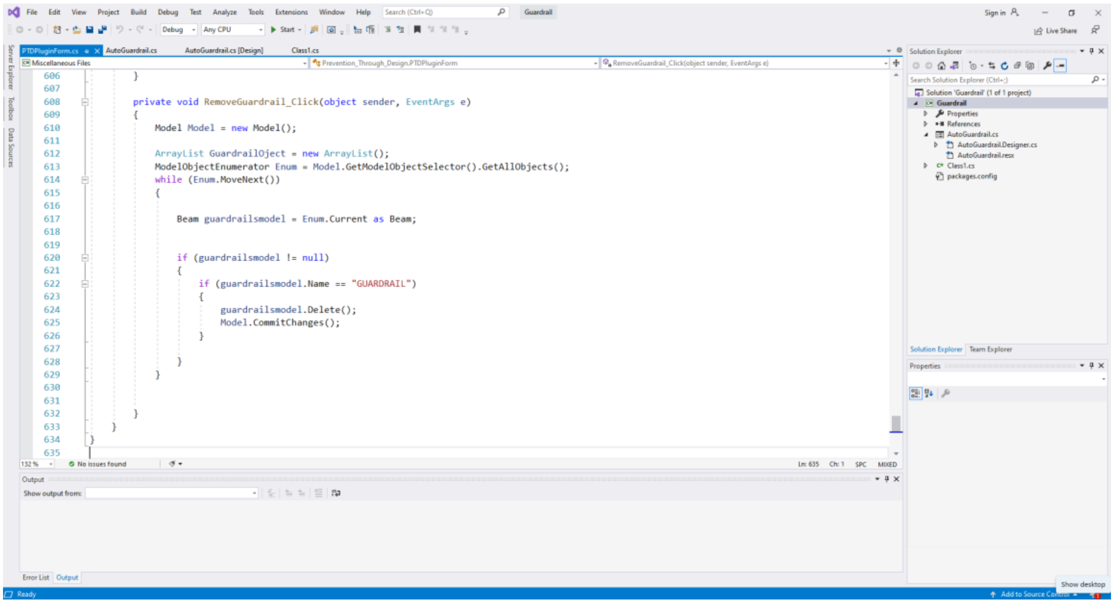

Figure 3.4 The Visual Studio Software.

For a focused analysis, this research focused on a particular type of construction accident, namely "falls-from-heights," which are frequently attributed to the hazards presented by unprotected edges. The study adopted a strategic modeling approach centered around effectively using slab objects within the BIM model to provide tools for structural designers to mitigate this prevalent safety issue. These slab objects were instrumental in deriving the corner coordinates necessary for modeling the hypothetical guardrail. This methodical approach showed the practical application of the BIM-based PTD tool in addressing specific safety challenges, thereby demonstrating the framework's validity and utility in enhancing construction site safety. Furthermore, the developed tool was tested through a hypothetical structural BIM model. This application of the framework within a simulated project aimed to assess the developed tool's applicability.

3.4.1.4 TOOL'S FEASIBILITY CRITERIA

The criteria used to judge the tool's technical feasibility in integrating PTD principles into BIM software involved various aspects of functionality, integration, user experience, and compliance with industry standards. The primary criterion is the tool's ability to perform its intended functions effectively. This includes modeling guardrails and other safety features within the BIM environment. The tool must reliably execute tasks such as the automatic placement of guardrails at designated points, ensuring that these features are consistent with PTD guidelines. It should also allow for modifications and updates without errors or significant delays, thereby enhancing the workflow efficiency for structural designers.

The tool's feasibility heavily depends on its compatibility and integration with existing BIM software platforms, such as Tekla Structures. The tool must integrate without disrupting the typical functionalities of the BIM software. This integration includes the ability to access and manipulate existing data structures and models within Tekla and the capability to add new functionalities, like the automated guardrail feature, without causing instability or performance issues in the software.

An essential aspect of technical feasibility is the user experience. The tool must be user-friendly, with intuitive interfaces allowing designers to easily access and use the PTD features. The complexity of operations should be minimized, and features like selecting guardrail materials and positioning should be straightforward. Support for customization and flexibility in adapting to specific project requirements is also vital for enhancing user satisfaction and broadening the tool's applicability.

The tool must comply with relevant industry standards and safety regulations, including those specified by organizations like OSHA. Compliance ensures that the safety features designed and implemented using the tool are up to the legal and professional standards required in the construction industry. This compliance is crucial for the adoption of the tool in real-world projects where safety and regulatory compliance cannot be compromised. The tool should be scalable and adaptable to various types of construction projects, from small-scale buildings to large infrastructural projects. This involves the tool's ability to handle different sizes and complexities of data and its adaptability to various safety scenarios and requirements.

Finally, the technical feasibility is judged based on thorough testing and validation. The tool must be rigorously tested under various operational conditions to verify its functionality and reliability. This includes testing for bugs, performance bottlenecks, and the accuracy of its safety assessments. Validation involves ensuring that the tool meets the practical needs of structural designers and effectively enhances safety management in BIM projects.

3.4.2 DESIGNERS' ASSESSMENTS ON THE APPLICABILITY OF BIM FOR PTD

3.4.2.1 STUDY APPROACH

This study was designed to assess the feasibility and effectiveness of using BIM tools within the framework of PTD, focusing on the direct experiences of structural designers in the Philippines who have integrated BIM technologies into their workflows. The aim was to investigate the practical aspects of BIM application in enhancing safety and efficiency in construction projects through the lens of those at the forefront of adopting these technologies. To thoroughly understand this matter, the research adopted an exploratory approach characterized by the implementation of semi-structured interviews. These interviews were conducted with a carefully selected group of professionals with significant expertise and experience in leveraging BIM tools in their projects. This method allowed for an in-depth exploration of their insights, challenges faced, and the tangible benefits realized from integrating BIM in their design processes, particularly concerning PTD principles.

The choice of semi-structured interviews as the primary data collection method provided the flexibility to probe deeper into the participants' experiences, allowing for the emergence of nuanced understandings of how BIM technologies are being utilized in practice. This approach facilitated a rich, detailed examination of the practical implications of BIM for PTD in the Philippine construction context, shedding light on the potential of BIM to transform safety and design practices in the industry.

3.4.2.2 STUDY SAMPLING

By employing a purposive sampling approach (Burger & Silima, 2006), the researchers systematically identified and selected highly qualified structural engineers from the Philippines with extensive experience in structural design and implementing BIM within their construction projects. Following identifying these individuals, a verbal invitation was extended to the selected participants, inviting them to partake in the interview. To ensure the utmost confidentiality and anonymity of the respondents, following Cassell & Symon’s (2004) recommendations regarding qualitative research methods, all identifiable information regarding the participants, such as their names and specific profiles, has been deliberately omitted during the report-writing process. Instead, each participant has been assigned a unique code or identifier, for example, "DESIGNER 1." This coding system not only safeguards the privacy and confidentiality of the respondents but also rationalizes the reporting process by providing a convenient means of reference. The respondents chosen for the interviews were strategically selected from the middle and top management levels within their respective organizations and had adequate experience in vertical structure projects. This selection aligns with the perspective advocated by Smith and Tardif (2009), who asserted that these managerial levels carry considerable influence and decision-making authority within their organizations. Hence, the insights and perspectives of respondents at these organizational levels hold particular relevance in understanding the dynamics of BIM adoption and its associations with structural design within the construction industry.

In qualitative research, one of the concerns is ensuring the credibility and trustworthiness of the gathered data, and the issue of sample size plays a pivotal role in addressing this concern.

Determining what constitutes an adequate sample size is inherently relative, varying depending on the specific research context (Sandelowski et al., 1995). Some studies may suffice with a sample size as small as five, while others necessitate a larger sample size, and this determination often aligns with the underlying research philosophy and objectives. In this qualitative investigation, a total of seven (7) interviews were conducted, which the researchers believed to be sufficient. This number adheres to the guidelines recommended by Creswell (2003), who advises that qualitative studies, particularly those focused on phenomenology, often involve a sample size ranging between five (5) and twenty-five (25) interviews. This choice is well-justified in the context of the study's objectives, which aim to comprehensively understand the diverse roles played by individuals as social actors within their unique environments, drawing upon their own experiences. It is also worth noting that the implementation of BIM in the construction industry in the Philippines is still relatively novel (Rodriguez et al., 2019), with only a limited number of companies having integrated BIM into their construction projects. Consequently, securing interviews with more than five individuals from different companies who are actively using BIM posed a considerable challenge. This scarcity of participants within the industry significantly influenced the decision regarding the sample size. Additionally, it is essential to emphasize that qualitative research primarily focuses on achieving analytic generalization rather than statistical generalization (Yin, 2009). In this manner, the study prioritizes in-depth understanding and the extraction of rich insights from a relatively minor number of interviews, ensuring that the collected data are thoroughly explored, interpreted, and understood within the specific context of the research.

3.4.2.3 THE INTERVIEW QUESTIONS STRUCTURE

The semi-structured interviews (see Appendix B) comprised a series of 19 carefully designed questions intended to obtain in-depth responses from the participants. These questions were constructed to allow the interviewees to express their viewpoints and share their experiential insights openly. The interview sessions typically spanned approximately 50 to 60 minutes, allowing ample time for the participants to provide comprehensive feedback and reflections. The formulation of interview questions drew upon an extensive review of pertinent literature, mainly focusing on BIM's technical capabilities as determined in prior literature reviews. Key areas of emphasis included 3D modeling, visualization, data integration, and collaboration of

BIM technology. By concentrating the interviews around these specific aspects, the study aimed to gain valuable insights into how structural designers perceive and experience these technical capabilities of BIM. This approach facilitated an exploration of the practical applicability of BIM tools in the context of PTD from the perspective of these industry professionals, contributing to a deeper understanding of their experiences and perspectives.

Each questionnaire category was structured into three distinct segments, each serving a unique purpose. The segmentation allowed for a comprehensive exploration of the participants' insights and perspectives regarding the integration of BIM and PTD within the context of their professional experiences. In the initial segment, the focus was on assessing the participants' current utilization of BIM within their ongoing work. This portion sought to explore BIM's technical capacities as manifested in their day-to-day professional roles. The second segment of the interview questionnaire showed the participants' perceptions regarding the applicability of BIM on PTD. This part was designed to elicit the interviewees' viewpoints on the feasibility and potential of BIM technology in the context of safety and design. However, before the second segment of the interview, the concept of PTD was explained to the interviewees. The final section featured a set of summative questions strategically designed to solicit the interviewees' confirmation and validation of the notion that BIM integration would lead to increased implementation of PTD. By seeking the participants' agreement, this segment served as a concluding reflection on the overarching research objective – to understand the potential impact of BIM on the adoption and implementation of PTD. Through their responses, the interviewees provided valuable insights into the link between BIM, PTD, and the prospects for safety measures in the construction sector.

3.4.2.4 ANALYSIS OF DATA

In qualitative research, the interpretation of data poses a substantial challenge. Handling qualitative data involves analyzing much information (Fossey et al., 2002; Patton, 1990). This challenge encompasses cleaning extensive data into a more manageable form, recognizing meaningful patterns within the data, and constructing a cohesive framework for effectively conveying the insights gathered. This complexity is worsened by the nature of qualitative data, which primarily consists of words, each of which can hold multiple interpretations, potentially leading to erroneous conclusions (Bryman, 2004; Creswell, 2003). In light of these challenges, researchers have turned to various strategies to navigate the intricacies of data analysis. Scholars (Forman & Damschroder, 2007; Miles & Huberman, 1994; Patton, 1990; Service, 2009) have proposed Content Analysis as a valuable method for systematically analyzing qualitative data. Content Analysis involves a structured process of identifying pertinent quotes, coding them to assign specific meanings, and categorizing the resulting codes into themes or concepts. Subsequently, it employs a mapping approach to expound the links among these different groups. Therefore, in the context of this study, Content Analysis emerged as the preferred method for scrutinizing and extracting insights from the interview data. This approach allowed for a systematic examination of the data's content and enabled the researchers to uncover themes, patterns, and relationships embedded within the qualitative responses, thus shedding light on the participants' experiences and perspectives.

3.5 PHASE III: SOCIO-TECHNICAL QUALITIES OF BIM FOR PTD

3.5.1 STUDY APPROACH

The research examined the intricate interplay between socio-technical factors that affect the implementation of BIM for PTD, conducting a detailed and systematic exploration. It focused on understanding how the combination of social aspects and technical elements, such as BIM functionalities, impacts the adoption of PTD practices. The study's third objective steered the investigation towards a deeper understanding of how PTD is embraced within the industry, examining how social and technical influences create the environment for its adoption. This involved carefully studying how these factors interact and influence each other. The research applied established theories of technology adoption, employing quantitative methods to test the formulated hypotheses.

3.5.2 COMPILATION OF KNOWLEDGE

In achieving a comprehensive understanding of the topic, the present study was founded on an intensive exploration of a vast depository of knowledge, drawing from a wide array of sources, both national and international literature. This comprehensive knowledge base served as the foundation upon which the subsequent phases of the study were built, providing a solid framework for formulating research questions, analyzing findings, and developing practical recommendations pertaining to the following terms:

- PTD
- BIM
- TAM
- The usefulness of BIM for PTD
- The ease of use of BIM for PTD
- The relative advantage of BIM for PTD
- The benefits of using BIM for PTD

The results obtained from the research effort yielded a comprehension of the subjects under investigation. The insights garnered from the data, analyses, and reviews were instrumental in shaping a robust theoretical framework. This framework, built upon empirical evidence, not only synthesized the existing knowledge but also extended the boundaries of understanding within these domains.

3.5.3 EXPLORATORY STUDY’S THEORETICAL FRAMEWORK

Figure 3.6 served as a visual representation of the set of factors considered to form the theoretical framework. This framework lays a theoretical foundation by underlining the significance of designers' acceptance of BIM-based PTD. At its core, the framework relies on the TAM as a well-established theoretical framework, and it embraces a socio-technical perspective for the comprehensive examination of PTD implementation. This socio-technical viewpoint acknowledges the relationship between the technological aspects of BIM and the socio-cultural context in which it is employed. It is rooted in the understanding that successful technology adoption is not solely dependent on the technology's inherent features but is significantly shaped by the social dynamics surrounding it.

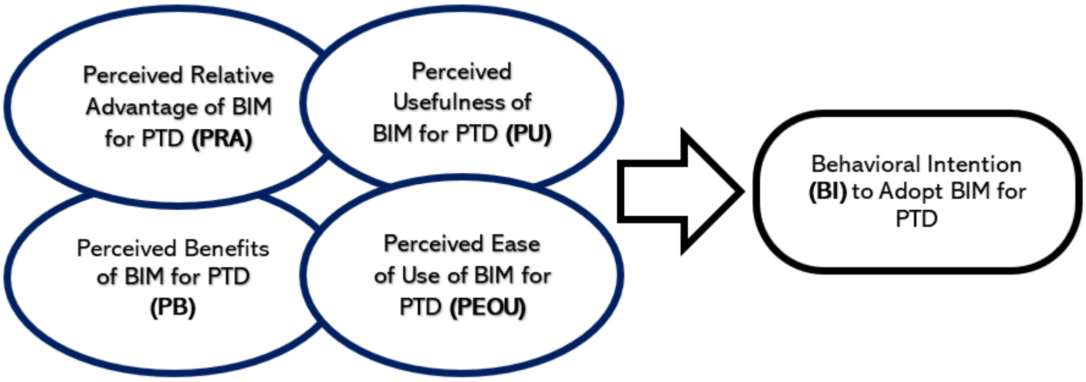

Figure 3.5 Theoretical Framework.

The study aimed to examine BIM's pivotal role in encouraging and facilitating designers to embrace the PTD concept. This concept emphasizes proactive safety measures and design interventions to enhance safety and reduce risks in construction projects. The anticipated influence of the compatibility between the various attributes of BIM on designers' behavioral intention to utilize BIM for PTD could manifest directly or indirectly. The following constructs were essential building blocks in the comprehensive analysis of how designers' decisions and intentions are shaped within the context of BIM-based PTD:

- *Behavioral intention to adopt BIM for PTD (BI)* means designers' motivation and self-inclination towards a BIM-based PTD adoption.
- *Perceived usefulness of BIM for PTD (PU)* means the degree to which the designer believes BIM would improve or enhance PTD assessments and analyses.
- *Perceived ease of use of BIM for PTD (PEOU)* means the extent to which the designer believes that using BIM for PTD needs no deliberate effort and is easy for him/her.
- *Perceived relative advantage of using BIM for PTD (PRA)* means the degree to which using BIM for PTD is better than other approaches to PTD.
- *Perceived Benefits of Using BIM for PTD (PB)* means the degree to which using BIM will increase the efficiency, productivity, and quality of PTD.

3.5.4 HYPOTHESES FORMATION

In studies utilizing Structural Equation Modeling (SEM), it is quite typical to emphasize hypotheses rather than distinct research questions. This approach is particularly prevalent in research grounded in a well-established theoretical framework that aims to examine specific interactions among variables (Kline, 2023). The work of Hoyle (2012) provided an overview of SEM applications and discusses how hypotheses derived from theoretical frameworks are tested using SEM. It emphasizes the methodology's reliance on hypothesis testing rather than exploratory research questions. The research, therefore, focused on the hypothesis formations.

As the research progressed, a notable gap in the existing knowledge base emerged during the review process. This gap signified a critical area where the current understanding was lacking, and the necessity for developing a conceptual model became evident. The conceptual model (Figure 3.7), conceived in response to these identified deficiencies, serves as a strategic solution to bridge the knowledge gap and provide a structured framework that addresses the hitherto unknown subject matter. It offers a systematic and comprehensive approach to further sort out the complexities, relationships, and dynamics within these fields, thereby propelling the research and understanding of the topics to new heights.

Previous research has consistently demonstrated that perceived usefulness (PU) directly and substantially influences users' behavioral intentions to adopt technology (López-Nicolás et al., 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 perceived usefulness of BIM significantly impacts the behavioral intentions of various stakeholders within the construction industry (Kim et al., 2017; Son et al., 2015; Xu et al., 2014). Comparative research, such as the one conducted by Lee & Yu (2016) examining BIM acceptance in South Korea and the United States, has reaffirmed the critical role of perceived usefulness at both the individual and organizational levels. Hence, it is logical to hypothesize that PU positively influences Behavioral Intention (BI), denoted as +H1. Notably, in the original TAM framework, perceived ease of use (PEOU) did not have a direct impact on behavioral intention. However, the evolving landscape of technology adoption research has revealed that PEOU does indeed possess a direct effect on users' intentions to employ technology (Calisir et al., 2009; Chung et al., 2008; Gefen & Straub, 1997; Lee, 2020; Szajna, 1996). In the context of BIM (Building Information Modeling) adoption, the Perceived Ease of Use (PEOU) is expected to have a positive impact on the Behavioral Intention (BI) to adopt BIM technology. This is supported by a study (Wang et al., 2023) that integrated the Theory of Planned Behavior (TPB) and the TAM to explore the adoption behavior mechanism of BIM from the perspective of owners. The study found that the perceived usefulness of BIM is a significant factor affecting owners' behavioral intention to apply BIM technology. While PEOU positively impacts the intention to adopt, its role is limited compared to other factors like perceived usefulness and subjective norms. Additionally, a study by Yuan et al. (2019), based on the technology-organization-environment (TOE) framework and the TAM, explained that BIM technical features and government BIM policies positively affect perceived usefulness, which in turn, along with perceived ease of use, significantly affects the behavioral intention 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 perceived usefulness. Thus, it was hypothesized that PEOU positively affects BI, denoted as +H2.

Furthermore, research has consistently shown that the ease with which a system can be utilized could positively affect the perceived usefulness of that technology (Calisir et al., 2009; Chung et al., 2008; Gefen & Straub, 1997; Lee, 2020; Szajna, 1996). This interplay suggests that PEOU enhances the perceived usefulness of BIM in technology adoption. Therefore, a supplementary hypothesis, denoted as +H2a, is postulated, affirming this positive relationship between PEOU and PU. These hypotheses implied the dynamics between perceived usefulness and ease of use in influencing the intentions and perceptions of technology users, particularly within the context of BIM adoption.

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, the research that has been done in the past demonstrates that relative advantage is a strong driving force behind the implementation of BIM for construction health and safety (Matthei & 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 PRA has a favorable influence on BI (+*H3*) was developed. The relationship between PRA and PU in the adoption of technologies like BIM is emphasized by Wang et al. (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 et al. (2014), the perceived usefulness and simplicity of using BIM technology are positively associated with the relative benefit of BIM technology. The greater the perceived relative advantage of an innovation, the higher its rate of technology is based on its perceived ease of use (Bandara & Amarasena, 2018), which led to the formulation of the hypotheses +*H3a* and +*H3b*. The relationship between perceived benefits and organizational support to user satisfaction in BIM implementation has been explored, indicating that factors such as perceived usefulness and ease of use are crucial for BIM user satisfaction (Pullen, 2012). This suggests that the perceived relative advantage of BIM could significantly impact its perceived benefits, contributing to greater user satisfaction and acceptance (Wang & Song, 2017); thus, it was also hypothesized that PRA positively affects PB *(+H3c*).

It has been proven that the perceived benefits strongly predict adoption intent (Lee et al., 2003; Rice & Webster, 2002), which is consistent with the findings of various other studies. With BIM, Chan et al. (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, then they will be hesitant to accept it in their everyday life. As a result, the researchers presumed that PB had a favorable impact on BI (+*H4*). According to Marimuthu and Muthaly (2009), perceived benefits affect the adoption of technology in terms of both the perceived ease of using the technology and the perceived usefulness of the 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 perceived benefits and usefulness impact BIM adoption decisions among professionals. Consequently, this study hypothesized that PB positively influences PU (+*H4a*) and PEOU (+*H4b*).

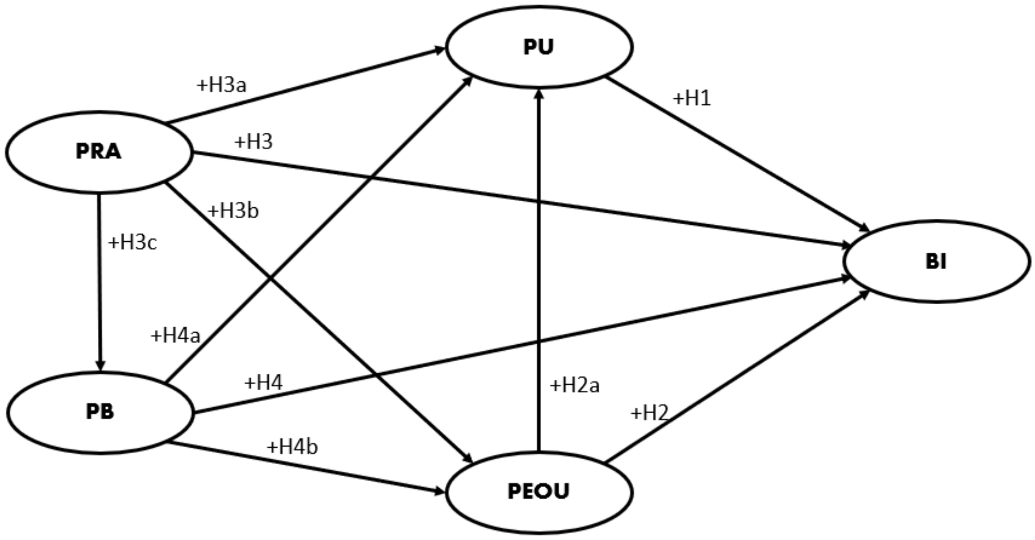

Figure 3.6. Conceptual Model.

Table 3.1 Summarized Hypotheses Formations.

Hypothesis Notation	**Interaction of Constructs**	**Sources**
+H1	PU → BI	López-Nicolás et al. (2008), Wu et al. (2011), Kim et al., (2017), Son et al. (2015), Xu et al. (2014)
+H2	PEOU → BI	Wang et al. (2023), Yuan et al. (2019)
+H2a	PEOU → PU	Calisir et al. (2009), Chung et al. (2008), Gefen & Straub (1997), Lee (2020), Szajna (1996)
+H3	PRA → BI	Ahmed (2019), Chen et al. (2019), Matthei & Abualdenien (2021)
+H3a	PRA → PU	Wang et al. (2008), Xu et al. (2014)
+H3b	PRA → PEOU	Bandara & Amarasena (2018), Xu et al. (2014)
+H3c	PRA → PB	Pullen (2012), Wang & Song (2017)
+H4	PB → BI	Lee et al. (2003), Rice & Webster (2002), Chan et al. (2019)
+H4a	PB → PU	Marimuthu & Muthaly (2009)
+H4b	PB → PEOU	Marimuthu & Muthaly (2009)

3.5.5 QUESTIONNAIRE SURVEY

A questionnaire stands as an essential and extensively employed instrument for data acquisition in empirical research (Rathi & Ronald, 2022). In its most fundamental configuration, a questionnaire represents a structured series of inquiries strategically constructed to elicit information or data from individuals to investigate a specific issue or topic. In quantitative research, questionnaires are designed to facilitate the collection of structured, numerical data that lends itself to statistical analysis (Queirós et al., 2017). Quantitative questionnaires typically encompass a set of closed-ended questions that offer respondents pre-defined response options, ensuring a systematic and quantifiable approach to data collection. These questions are thoughtfully crafted to be easily quantifiable and may take the form of multiple-choice queries or Likert scale questions, which enable respondents to express their opinions or preferences with a degree of agreement. Given the research objectives of this study, which sought to examine and analyze data to draw statistically significant insights, it was deemed appropriate and logical to employ a quantitative questionnaire survey as the most effective and efficient method for data collection. This approach ensures that the research objectives are met with the necessary rigor and precision, aligning with best practices in empirical research.

Moreover, the development of the questionnaire underwent a process that commenced with a review of the pertinent research literature and a comprehensive analysis of the findings derived from prior empirical investigations. This initial phase provided the foundational structure for the questionnaire, ensuring that it encompassed the most relevant and significant dimensions within the research domain. Subsequently, the preliminary questionnaire (see Appendix D) underwent a careful assessment through expert evaluation involving scholars and professionals who possessed substantial expertise in the subject matter. Their insightful feedback and recommendations played a pivotal role in refining the questionnaire and effecting several additional modifications to enhance its clarity, coherence, and relevance. In addition to these preparatory measures, the questionnaire was specifically designed as a web-based instrument (Figure 3.8) to facilitate online completion by the respondents. This web-based approach was chosen for its inherent advantages, including the potential to reach a broader and more geographically diverse audience compared to traditional paper-based surveys. It was distributed electronically through a range of online messaging applications, thereby harnessing the convenience of digital platforms for data collection.

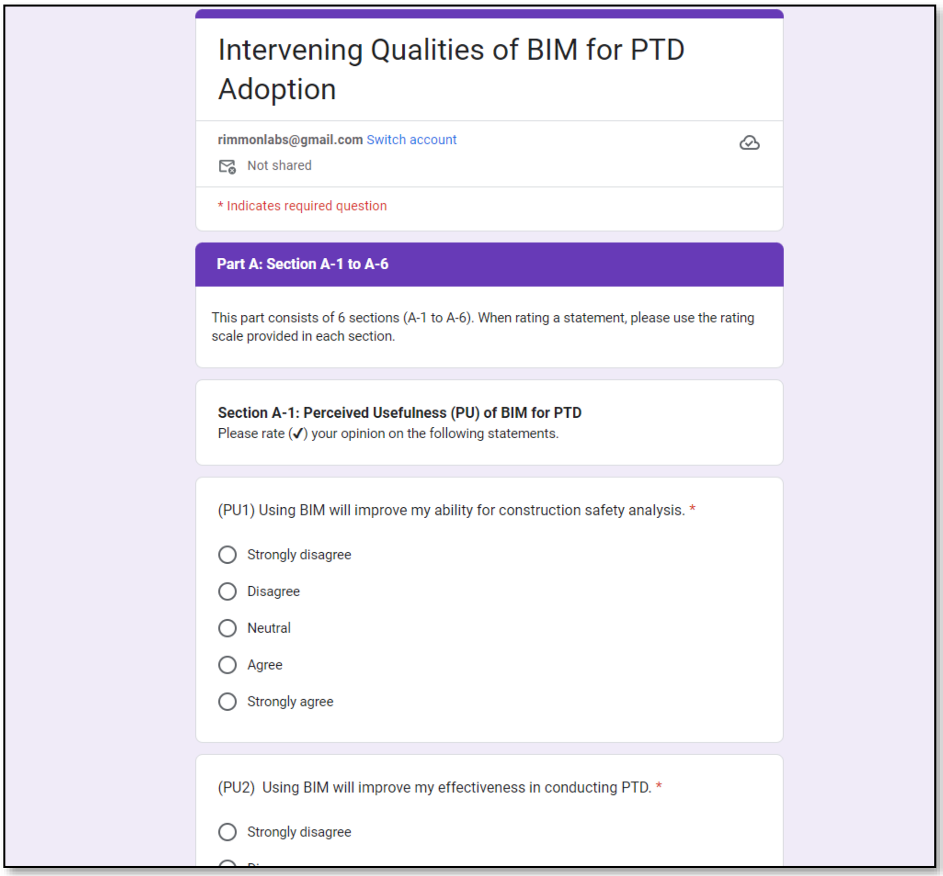

Figure 3.7 A Printscreen of the Questionnaire.

The questionnaire, as distributed, comprised two distinct parts. The first part was organized into five sections, each corresponding to one of the five core constructs under examination. In each section, respondents were presented with three specific questions, and their answers were documented using a five-point Likert scale, where 1 represented strong disagreement, and 5 represented strong agreement. This scaling approach allowed for a nuanced and quantifiable assessment of each item within both survey sections. The second section of the questionnaire focused on collecting crucial demographic background data from the participants, including variables such as their years of experience and job positions. The objective of this comprehensive approach in questionnaire design was to thoroughly capture the respondents' perceptions of the research constructs and gather important information about their professional backgrounds. This would enhance the depth and scope of the research data. Please refer to Appendix E for complete details of the questionnaire.

3.5.6 RESEARCH SAMPLING

The respondents selected for this study were specifically focused on individuals working in the capacity of structural or civil engineers, and their current employment was situated within the geographical context of the Philippines. The data collection stage was carried out over a span of three months, commencing in March and concluding in May 2023. This duration allowed for a comprehensive and thorough examination of the chosen target group, ensuring that a diverse range of experiences and perspectives among structural designers in the Philippines were considered.

The process of survey administration was initiated by the research team with a primary step emphasizing the importance of informed consent. Before respondents started on the questionnaire, they were requested to provide their explicit consent to take part in the survey, following the principles of ethical research conduct. In addition to their own 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 collaborative approach to data collection expanded the survey's reach and leveraged the expertise and insights of a broader community of professionals within the field. 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.

3.5.7 DATA ANALYSIS

This study sought to quantitatively assess the influence of various factors on system adoption, employing a measurement approach that enables the concurrent examination of a network of interrelated dependent and independent variables. A quantitative measurement method was utilized to formulate and assess hypotheses pertaining to the relationships between these variables. Such an approach is integral to theory development and validation. Consequently, Structural Equation Modeling (SEM) was employed in this study. Prior to undertaking SEM analysis, a series of preliminary statistical procedures is essential to ensure the robustness and reliability of the data. These preliminary steps include data screening, validating measurement constructs, and performing Confirmatory Factor Analysis (CFA).

3.5.7.1 DATA SCREENING

The initial stage of this research involved a process of data screening to ensure that the data collected were suitable for the subsequent modeling analysis. Data screening is an initial statistical step that involves an examination of the dataset for accuracy and completeness. It checks for missing values, outliers, normality, and other anomalies that could potentially bias the results (Johnson & Wichern, 2002). One of the key statistical tools used for this purpose was the z-score, which serves as a reliable indicator of how far a particular observation deviates from the mean of a normal distribution in terms of standard deviations. In a normally distributed dataset, a z-score of 3.29 signifies an observation that is more than three standard deviations away from the mean, an exceedingly rare occurrence. To put this into perspective, this z-score threshold of 3.29 corresponds to a commonly used statistical significance level in many scientific fields, which is a p-value of 0.001. All the total scores of the variables were transformed into standardized z-scores. This transformation allowed for the identification of any extreme deviations in the dataset. In this study, cases with an absolute z-score value greater than 3.29 (indicating observations that are more than three standard deviations from the mean at a significance level of p 0.01) were considered outliers, as Tabachnick and Fidell (2007) recommended.

3.5.7.2 VALIDITY OF MEASUREMENT CONSTRUCTS

Once the data is screened, the next step is to validate the measurement constructs. This involves assessing whether the survey items or indicators used in the study accurately represent the theoretical constructs they are intended to measure. In traditional research practice, the process of Exploratory Factor Analysis (EFA) is commonly employed to validate the number of underlying factors within model structures and to understand the loading patterns of variables onto these factors. However, it is noteworthy that in the present study, well-established measures were adopted, suggesting there is no need to conduct EFA, as Green et al. (2016) suggested. This decision was made based on confidence in the reliability and validity of the existing measurement instruments. In line with the recommendations provided by Hair et al. (2009), the sample size of 131 instances was deemed adequate, surpassing the minimum acceptable sample size of 100. Moreover, the cases-to-variable ratio, which is an essential criterion for factor analysis, was exceeded, with each construct boasting a ratio of at least 5:1, further strengthening the suitability of the dataset for factor analysis.

3.5.7.3 CONFIRMATORY FACTOR ANALYSIS (CFA)

Following the validation of measurement constructs, CFA is conducted as a more stringent test of the model structure. CFA is used to confirm the hypothesized factor structure established during the exploratory phase and to assess the construct validity(Kline, 2023). It involves specifying a model, defining the relationship between observed variables and their underlying latent constructs, and testing how well this model fits the data. CFA is critical as it provides statistical evidence of the reliability and validity of the constructs, ensuring that the SEM analysis will be based on a well-specified and valid model. Advanced software in the form of AMOS was employed to facilitate the CFA procedure, and the widely accepted maximum likelihood estimate (MLE) method was chosen for parameter estimation (Jöreskog et al., 2016).

3.5.7.4 STRUCTURAL EQUATION MODELING (SEM)

SEM, a statistical technique, provides a robust means of analyzing connections between both observable and underlying variables. It is a powerful tool for scrutinizing causal models and assessing theoretical frameworks. SEM combines factors, multiple regressions, and path analysis to offer a comprehensive methodology for comprehending and modeling complex interactions among variables. These relationships between variables are visually represented using path diagrams, which depict the postulated causal connections among them through arrows or paths. SEM permits the estimation and testing of both direct and indirect effects, enabling researchers to scrutinize associations while considering potential measurement errors. Given its capacity to account for measurement inaccuracies in statistical data analysis, SEM allows for the use of numerous indicators to gauge unobserved variables. This feature is a key reason why SEM is seen as an extension of multivariate techniques (Hair, 2009).

The SEM analysis in this study followed a two-step process to ensure the accurate interpretation of the research findings. Initially, the "measurement model" was delineated and evaluated, which was then succeeded by the examination of the "structural model" to investigate the relationships between various constructs. This sequential method is integral to realizing the study's objectives. Both stages necessitated assessing how well the model fits the data, referred to as "model fit." This study employed five commonly used model fit indicators to evaluate the model's appropriateness. The quality of each of these indicators was assessed against the criteria recommended by Hair (2009):

- Normed chi-square ($\chi 2/df$) < 3.00,
- Goodness-of-fit index (GFI) ≥ 0.90,
- Comparative-fit index (CFI) ≥ 0.90,
- Incremental-fit index (IFI) ≥ 0.90, and
- Root mean square error of approximation (RMSEA) < 0.08.

3.5.8 CROSS-VALIDATION

In the context of empirical research, validation of a model is a critical step to ensure its reliability, accuracy, and generalizability. An empirical model, which is developed based on observed data, aims to explain, predict, or describe phenomena within specific contexts. However, methodological approaches in social science research support the concept that full validation of a model may not always be immediately possible or practical, especially in the context of exploratory or preliminary studies. In their work on research design, Creswell and Creswell (2017) stressed the iterative nature of research, where initial exploratory studies may not always provide a comprehensive validation of models due to the preliminary nature of the investigation. Creswell also emphasized that in the early phases of research, the focus might be more on developing and exploring concepts rather than on rigorous validation, acknowledging that this stepwise process evolves over time. Additionally, Patton (2014), in his book, discussed the value of preliminary research in laying the groundwork for future, more detailed studies.

Patton noted that early-stage research often focuses on concept development and understanding phenomena, which may not lend itself to full model validation. Therefore, the model validation was not conduted.

However, this study has conducted an internal validation of the data gathered. Validation in the context of SEM is a rigorous approach to cross-validation, ensuring that the model is theoretically sound and empirically robust across different subsets of the data. To reduce the bias inherent in randomly selecting training and testing data sets, researchers often employed k-fold cross-validation techniques. This method involves dividing the entire data set (X) into k distinct, non-overlapping subsets of roughly equal size, known as folds (X1, X2, ..., X3). The process involves training and evaluating the predictive model k times, each time using a different fold for testing while training on the remaining folds.

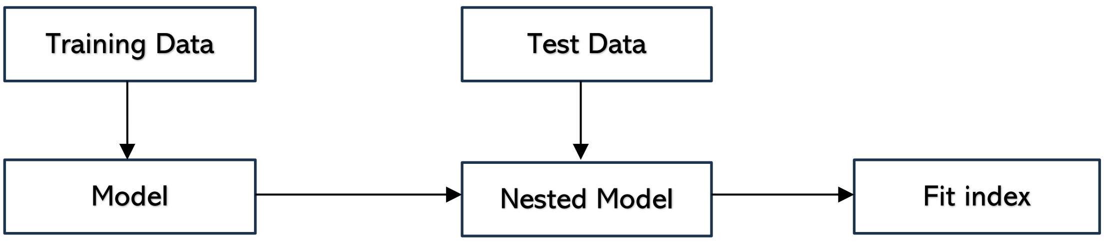

Figure 3.8 Cross-validation Concept.

Furthermore, considering that the number of responses in the research barely passes the minimum number of responses for SEM analysis, the research selected only the 3-fold (k=3) cross-validation. The overall performance metric was then determined by averaging the performance outcomes, the fit indexes, across all k iterations, as shown in equation (1).

$$Fit\ index_{ave} = \frac{1}{k}\sum_{1}^{k}(Fit\ index)_i \qquad \text{(eq.1)}$$

3.6 CHAPTER’S SUMMARY

This chapter establishes a structured and methodological framework to fulfill the research objective of integrating various research methodologies. This chapter examines the study technique, encompassing the study approach, design, and primary analytical methodologies employed in the present research. These elements entail selecting a research strategy, formulating research questions and hypotheses, identifying variables, establishing assumptions, determining data collection techniques, and specifying statistical tests. The chapter provides an in-depth explanation of the research methodology utilized to attain the predetermined goals. The current study unfolds in three distinct stages, each aligned with a specific objective: Preliminary exploratory, feasibility studies, and exploratory. The research incorporates mixed-method methodologies, integrating quantitative and qualitative research methods, such as a questionnaire survey and interviews with structural engineers employed in the Philippines' construction industry. The analysis of the quantitative dataset necessitated various statistical techniques, including fundamental descriptive analyses and multivariate analyses, notably Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM). This phase aimed to assess and refine the conceptual model, resulting in a final empirical model that best captured the interrelationships among the model constructs. The findings from these analyses are presented and discussed, with conclusions drawn. Additionally, future research strategies are recommended to enhance and extend the current study's findings further. Further details and results of the relevant analyses undertaken in this study are presented in Chapters 4 through 7.7.

PHASE I RESULTS AND DISCUSSIONS

4.1 CHAPTER OVERVIEW

This chapter outlines the results and discussions from Phase I of the study, which examines the demographic characteristics of the respondents and their knowledge and understanding of PTD. The initial data collection phase involved sixty-one respondents who completed the forms, representing various years of experience and age groups. The chapter also investigates the demographic classifications and their affiliations with either the private or public sectors, offering an overview of the professional backgrounds of the respondents. Furthermore, this section assesses the respondents' acquisition of knowledge and their comprehension levels of PTD, noting the differences observed across various sectors and job positions. This analysis prepares the groundwork for a more detailed understanding of how PTD is recognized and applied within the structural engineering community in the Philippines, directing future initiatives to incorporate these practices more broadly in the industry.

4.2 DEMOGRAPHICS OF RESPONDENTS

The respondents returned a total of 61 completed forms. The demographic composition of the respondents indicated a balanced representation of respondents' years of experience and ages, as depicted in Figure 4.1. Twenty-eight percent (28%) of the participants stated they had at least three years of professional experience, while 60% reported having between four and 20 years of experience. Additionally, 11% of the participants reported having more than 20 years of experience, as illustrated in Figure 4.2. In the context of the Philippines, it is a requirement for those who have completed the civil engineering undergraduate degree to undergo the board examination administered by the Philippine Regulation Commission (PRC) in order to obtain professional licensure. Additionally, candidates must meet the minimum age requirement of 21 years. Hence, the mean age of the participants was 33, with a range spanning from 22 to 61 years.

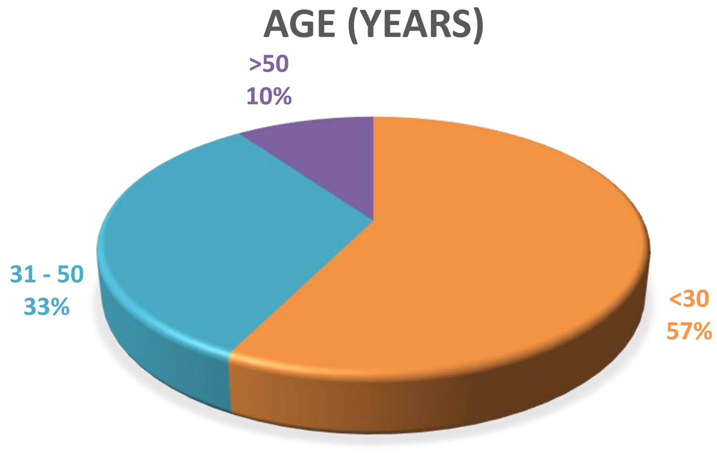

Figure 4.1 Respondents' Age Range.

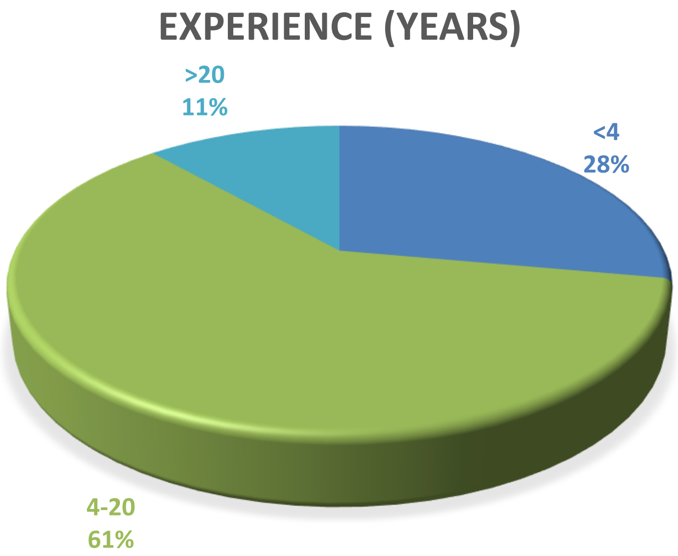

Figure 4.2 Respondents’ Experience.

In order to enhance the demographic perspective of this research, the respondents were additionally categorized by their affiliation with either private or public sectors (Figure 4.3). The private group was thereafter divided into two categories: employees and individuals with managerial or ownership positions within the organization or company. The surveyed participants were categorized into three groups: “Civil/Junior/Associate/Senior Structural Engineer (68%), Manager/Principal/Owner/Proprietor Structural Engineer (16%), and Public Design/Civil, Structural Engineer (16%)” (Figure 4.4). Including individuals with diverse job experience and age demographics enhances credibility and reduces the potential bias in the analysis since it incorporates perspectives from both beginners and more seasoned respondents.

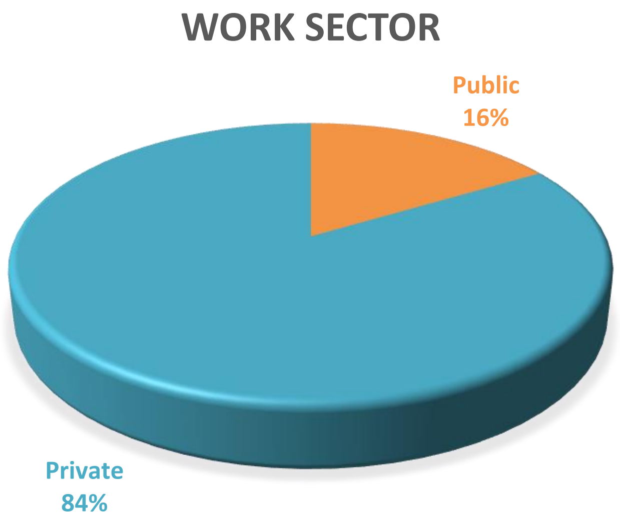

Figure 4.3 Work Sectors.

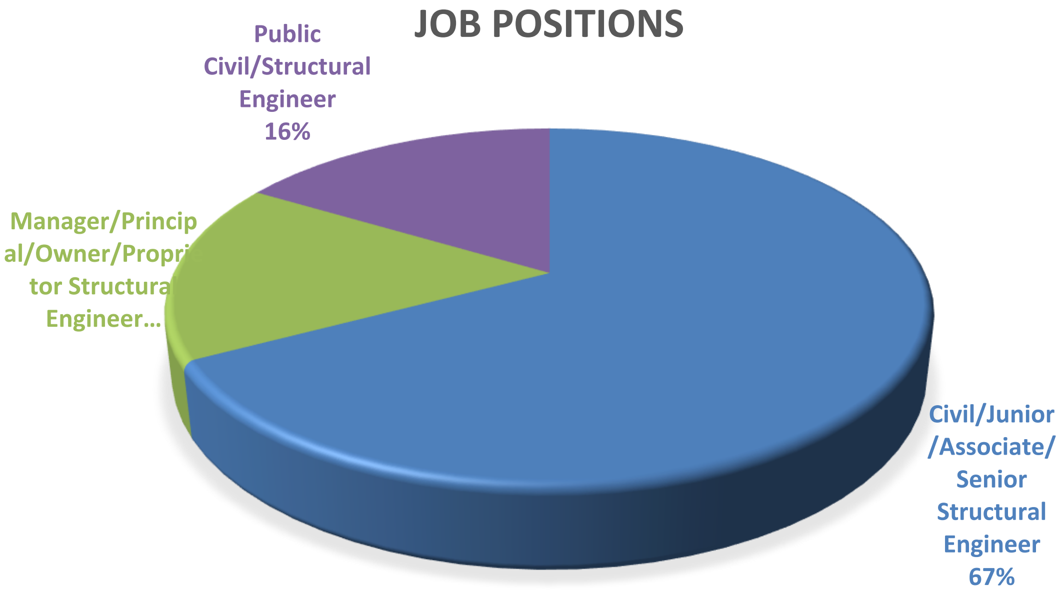

Figure 4.4 Job Positions.

4.3 KNOWLEDGE AND UNDERSTANDING OF PTD

The KAP surveys were systematically arranged, with a focus on four specific inquiries, to evaluate the participants' encounters with PTD. The analysis is reported in Table 4.1. The first two inquiries were both explicit in their request for information regarding the precise timing and method by which participants obtained knowledge about PTD. The results suggest that a majority of the participants (57%) gained knowledge of PTD immediately after they finished the questionnaire. According to the survey results, 34% of participants claimed that they gained knowledge about PTD through their organizations, whereas a smaller proportion of 12% obtained information through educational avenues such as higher education, published literature, and training programs. Only a small proportion, specifically 5% of the participants, indicated that they have participated in a PTD course.

The information presented in Table 4.2 indicates that the designers demonstrated a generally insufficient level of comprehension concerning PTD. Although a considerable number of participants claimed an understanding of PTD that was below the average level, as indicated by a mean score of 2.62, the majority of respondents demonstrated an average level of understanding with a mode of 3.0. Professionals in design employed in the public sector exhibited a greater comprehension of the mentioned concept than their private sector counterparts. Upon conducting an additional demographic analysis within the private sector, a slight disparity in the mean level of understanding was observed between owners and employees. The duration of professional experience is a significant factor influencing the proficiency of structural engineers, as a positive correlation was identified between the average level of expertise and the number of years dedicated to the field.

Table 4.1. How Designers Came Across PTD.

QUESTIONS	ANSWERS	N	%
"WHEN DID YOU FIRST LEARN PTD?"	"Just now, after reading this questionnaire."	35	57
	"After I started my profession."	21	34
	"Before I started my profession."	3	5
	Others	2	3
"HOW DID YOU FIRST LEARN PTD?"	"Just by this questionnaire."	35	57
	"Through my company."	19	31
	"Tertiary education."	4	7
	"Scholarly published papers."	1	2
	"Seminars or training courses."	2	3
"HAVE YOU ATTENDED ANY PTD COURSES?"	Yes	3	5
	No	58	95
"HOW OFTEN HAVE YOU BEEN ASKED TO ADDRESS CONSTRUCTION WORKER'S SAFETY IN THE DESIGN PHASE?"	(5) Always	0	0
	(4)	6	10
	(3) Sometimes	17	28
	(2)	11	18
	(1) Never	27	44

The information presented in Table 4.2 indicates that the designers demonstrated a generally insufficient level of comprehension concerning PTD. Although a considerable number of participants claimed an understanding of PTD that was below the average level, as indicated by a mean score of 2.62, the majority of respondents demonstrated an average level of understanding with a mode of 3.0. Professionals in design employed in the public sector exhibited a greater comprehension of the mentioned concept than their private sector counterparts. Upon conducting an additional demographic analysis within the private sector, a slight disparity in the mean level of understanding was observed between owners and employees. The duration of professional experience is a significant factor influencing the proficiency of structural engineers, as a positive correlation was identified between the average level of expertise and the number of years dedicated to the field.

Moreover, the table furnishes details on the degree of familiarity structural engineers have concerning the PTD design concept. The participants usually expressed a modest degree of familiarity, with the majority indicating a level of "somewhat familiar" (mean = 3). Conversely, individuals employed in the private sector exhibited a higher degree of acquaintance with the mentioned concept than those in the public sector. Structural engineers who had work experience exceeding twenty years exhibited an elevated level of understanding and a noticeable acquaintance with the PTD concept. Professionals with fewer than four years of experience demonstrated limited comprehension and familiarity with the PTD.

Table 4.2. Average Understanding and Familiarity Level of Designers with PTD.

VARIABLE	CATEGORY	N	UNDERSTANDING		FAMILIARITY	
			Mode	Mean	Mode	Mean
Overall		61	3	2.62	3	3.02
Work Sector	Public	10	3	3.3	1	2.4
	Private	51	3	2.49	3	3.13
	Owner/Manager	10	2	2.80	3	3.60
	Employee	41	3	2.41	3	3.02
Work Experience (years)	< 4	17	3	2.47	3.	2.65
	4–20	37	2	2.54	3	2.92
	>20	7	3	3.43	5	4.43
Scale Indicator: 1 (Very Poor/Not Familiar at All), 3 (Average/Somewhat Familiar), 5 (Excellent/Very Familiar)						

The findings displayed in Tables 4.2 and 4.3 indicate a lack of awareness among respondents about the idea of PTD in the industry. Nevertheless, the individuals managed to grasp the underlying concept upon its introduction. Moreover, the notion of PTD was found to be more recognizable to designers with greater expertise in structural design.

Moreover, It is noteworthy that "PTD" is merely one of the terminologies employed by scholars. However, at its essence, the concept revolves around the incorporation of safety measures throughout the design stage. The participants may have inadvertently applied the concept, although unfamiliar with the specific research terminology. Therefore, the designers were asked how often they were tasked with considering the safety of construction workers during the project's design phase. The findings indicated that 28% of respondents reported being asked occasionally. However, a significant proportion of the participants (44%) reported that they had never been requested to engage in such activities, as indicated in Table 4.2. Upon a thorough investigation, it has been observed that individuals assigned to integrate construction safety into their designs show a significant level of familiarity (20 out of 23, or 87%) with PTD. Upon comparing the data, it was discovered that only 25 out of 38 individuals, constituting 68% of the sample, who were not directed to consider construction safety during their design process, were acquainted with PTD, as indicated in Table 4.3. Due to infrequent demands and requests for designers to include construction OSH evaluations in the designs, the level of knowledge of this concept was correspondingly limited. Furthermore, these findings may suggest that the designers' proficiency in adequately addressing construction hazards was not acknowledged or that other essential participants in the construction sector, such as contractors and clients, were also unaware of PTD.

Table 4.3. The Impact of Being Tasked with Considering Safety in the Design.

Question: “Have you been asked to address construction worker's safety in the design phase?”	**Level of Familiarity**		**Total**
	≥ "Somewhat" (≥ 3)	< "Somewhat" (<3)	
≥ "Sometimes"	20	3	23
< "Sometimes"	25	13	38
Total	45	16	61

In accordance with the diffusion of innovation model proposed by E. M. Rogers et al. (2014), the initial stage encompasses the adoption of a new concept, product, or behavior. During the phase of knowledge acquisition, individuals become aware of an innovation and develop an understanding of its functionality. Notably, the research findings indicate a significant portion of structural engineers in the Philippines remained uninformed about the existence of the PTD concept. Further investigations unveiled that the Occupational Safety and Health (OSH) sector in the Philippines has not yet integrated the principles of PTD among designers, contrasting with the practices in Singapore and Malaysia within the Southeast Asian region (Che Ibrahim & Belayutham, 2020; Goh & Chua, 2016). This stresses that the concept of PTD remains relatively unfamiliar among structural designers in the Philippines.

Several participants reported that they have come across the concept of PTD within their respective organizations. Hence, corporations possess the potential to serve as a feasible platform for the dissemination of the PTD concept among the community of structural designers. Nevertheless, it is imperative to emphasize the significance of implementing the PTD concept into educational programs in order to cultivate early awareness among aspiring engineers. The absence of awareness of the PTD program is also the underlying cause for the absence of training opportunities or organized initiatives specifically tailored for designers. Several corporations and governmental organizations have provided and coordinated a program on Construction Occupational and Health (COSH). Nevertheless, it should be noted that the target audience for this course mostly consists of safety officers and engineers who are actively involved in on-site operations rather than structural or design engineers.

Notwithstanding the limited knowledge of PTD, the findings indicated that, on the whole, participants possessed a substantial comprehension and acquaintance with PTD. The fundamental goal of structural design is to guarantee end-users' safety in terms of the structure. This includes ensuring the stability of the building and, to a certain extent, the safety of construction workers. Within PTD or DfS (Design for Safety) frameworks, the terminologies "safety" and "design" exhibit a significant degree of proximity to the fundamental essence of a structural designer's professional undertakings. The familiarity of the notion may have contributed to the recognition of the concept among a significant number of structural engineers, as observed. Nevertheless, participants in the study were provided with a concise diagnosis of PTD within the questionnaire, potentially impacting the outcomes of the analysis.

4.4 DESIGNER'S ATTITUDE TOWARDS PTD

In order to gauge the level of understanding among structural designers on PTD, it would be beneficial to ascertain their perceptions of the idea and its specific specifics. As indicated by the information provided in Table 4.4, it is evident that every designer expressed a favorable perspective regarding the importance of employing PTD strategies. All individuals held the belief that the implementation of PTD would result in a reduction in accident rates within the construction industry. Moreover, a unanimous consensus was reached among the designers regarding the imperative nature of incorporating design elements that prioritize building safety within their professional responsibilities. No additional demographic analysis was conducted with regard to these elements due to the overall positive consensus observed in the results.

Table 4.4. Designer's Attitude Towards PTD.

Attitude Towards PTD	Level	Percentage
Implementation of PTD	5 (Very Important)	62
	4	30
	3 (Somewhat Important)	8
	2	0
	1 (Not Important)	0
Designer's duty should include design for construction safety.	5 (Strongly Agree)	77
	4	13
	3 (Neutral)	10
	2	0
	1 (Strongly Disagree)	0
PTD will decrease the rate of injuries and fatalities in the construction industry.	5 (Strongly Agree)	72
	4	18
	3 (Neutral)	10
	2	0
	1 (Strongly Disagree)	0

Table 4.5 exhibits the respondents' perceptions of the effectiveness of each example of PTD standards in enhancing construction safety, as well as the practicality of using each item in their designs. The aforementioned instances of PTD guidance for design were derived from recommendations found in previous scholarly works and design guidelines issued in various

nations. The chosen items were consistent with the principles of structural design and could be integrated into their projects. Results showed that the designers had a positive perception of the effectiveness of the provided products in reducing construction hazards. Furthermore, designers recognized the utility of incorporating each element inside their design. It was evident that certain elements exhibited elevated mean values. Upon doing a more thorough examination, it was observed that the items exhibiting elevated mean values were representative of overarching design principles that could potentially be applicable to PTD. An illustrative example of such a principle is item 1. However, with regard to design concepts that could potentially be applied to PTD (such as item 5), certain participants expressed reservations over the efficacy and feasibility of implementing such elements.

Table 4.5. Effectiveness and Practicality of PTD items.

Item No.	Examples of PTD Guidelines for Design	Effectiveness	Practicality
1	Design the structural members to withstand all anticipated construction loading during fabrication, storage, erection, and final connection.	4.62	4.11
2	Design member depths for adequate headroom clearance around stairs, platforms, valves, and all egress areas.	4.57	4.31
3	Design members that are consistent in size, light, weight, and easy to handle.	4.41	4.28
4	Design columns with holes at 21 and 41 inches above the floor level to provide support locations for lifelines and guardrails.	4.03	4.00
5	Locate column splices between 2 and 3 feet above the finished floor level, and two-story intervals.	3.95	3.92
6	Use a minimum beam width of 6 inches to allow sufficient walking surface.	3.74	3.59
7	Consider alternative steel framing systems that reduce the number of elements and where beams are landed on supports rather than suspended between them.	3.97	3.72

8	Design welded connections such that weld locations can be safely accessed.	4.46	4.23
9	Limit the lift heights of steel erection.	4.39	4.07
10	Use a metal deck and concrete fill rather than a slab that requires temporary formwork.	4.07	3.79
Scale Indicator: 1- Not alt all Effective / Not at all Practical, 3- Somewhat Effective / Somewhat Practical, 5- Ver Effective / Very Practical,			

In addition to the natural interest of designers in PTD, external motivation is needed to facilitate its implementation. This external motivation serves as a driving force to encourage designers to adopt and execute PTD practices. According to the data presented in Figure 4.5, a significant proportion of structural designers, specifically forty-four percent (44%), identified contractors as the primary motivating factor that encourages them to use the Practice of PTD. Designers were cognizant of the fact that the onus of ensuring building site safety rested with the contractor. Therefore, it is imperative to exert pressure from the primary source of concern. Moreover, as the principal constructor, a contractor holds the necessary expertise and practical knowledge regarding safety protocols at construction sites, information that should be conveyed to designers (Gambatese et al., 2017; Tymvios et al., 2012). Consequently, designers would rely on the contractors' proficiency and experience to provide guidance and address issues related to their responsibilities.

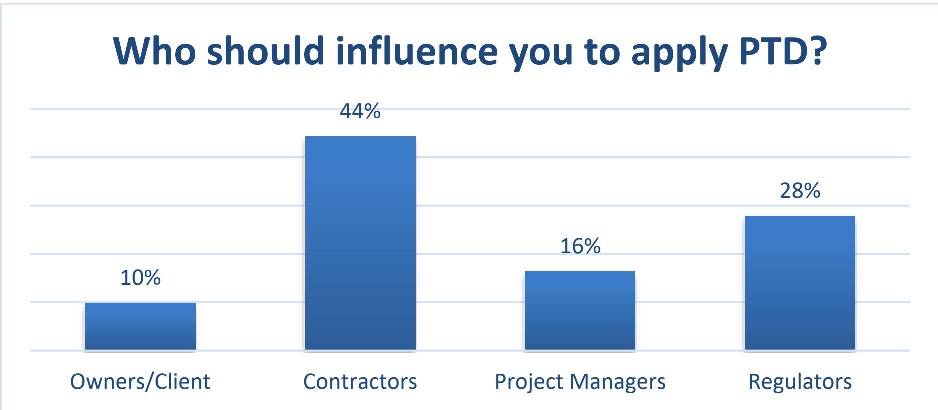

Fig. 4.5. Stakeholder’s Influences.

The notion of PTD was met with a highly positive reception by structural engineers, reflecting their hopeful perspective on the matter. A significant proportion of the participants expressed a high level of agreement with the imperative nature of integrating PTD into their professional works. Despite the respondents being relatively unfamiliar with the PTD concept, they acknowledged that its implementation would efficiently tackle safety concerns within the construction industry. Moreover, the positive mindset exhibited by the structural engineers would establish a favorable atmosphere to promote acceptance and enhance the dissemination of PTD in the Philippines.

4.5 PERSPECTIVE ON THE PTD PRACTICE

In this section, despite the absence of PTD implementation in the Philippines, the questionnaire posed inquiries to structural designers regarding their perceived obstacles and concerns regarding the potential adoption of PTD within the industry. The worries regarding the direct implications of PTD to the designers are expressed in the items presented in Table 4.7. The designers assigned ranks to these items by selecting a numerical value from a dropdown menu located next to each item. A rank of one (1) denoted the utmost level of concern, with higher rank values signifying a diminished level of care. Each assigned rank was treated as a score. The ranking process involved computing the sum of scores for each item and arranging them in ascending order, where the item with the lowest sum received the highest rank. The central concern for designers primarily centered on the potential legal responsibilities associated with undertaking the PTD process. Furthermore, the designers expressed apprehension regarding the provision of supplementary incentives for undertaking such tasks, as they were unable to engage in this work on a voluntary basis due to financial constraints.

Table 4.7. Designer’s Concerns on PTD Implementation.

RANK	DESIGNER’S CONCERNS ON PTD IMPLEMENTATION.
1	“It will give me liabilities for accidents that may occur during the construction.”
2	“I have to do it voluntarily.”
3	“It will result in complications in the procurement process.”
4	“It will compromise my design creativity.”

The participants were provided with an open-ended inquiry regarding the overarching challenges they would encounter when engaging in PTD. Participants were given the opportunity to identify and address a specific issue or, alternatively, choose from a set of provided instances. The aforementioned items were identified as the perceived obstacles to the application of PTD, as documented in various literary sources. According to the data presented in Figure 4.5, the primary concern identified by designers in relation to the implementation of PTD was the consideration of cost by the client or organization, with a majority of 75%. Designers have acknowledged the existence of design guides, with a predominant percentage of 61%, along with design tools or software and checking standards for analysis, both recognized by 54% of the participants.

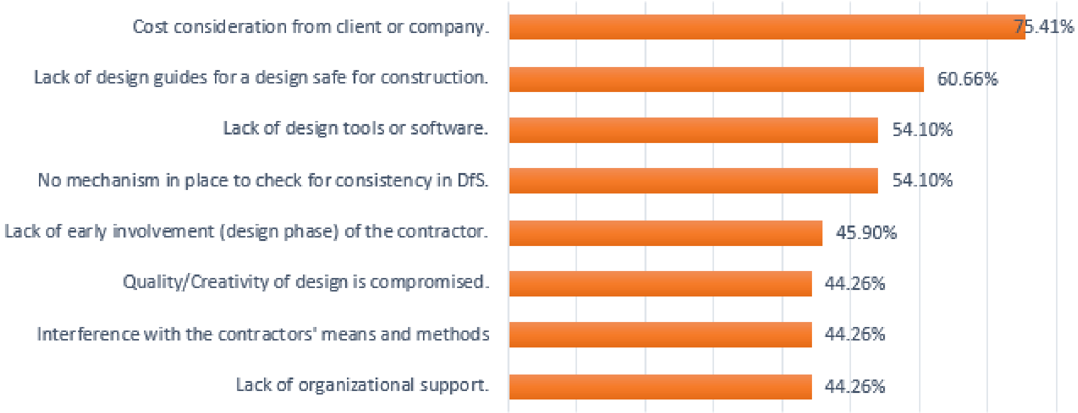

Figure 4.5. Barriers To PTD Implementation.

Primary concerns related to assuming liabilities were particularly prominent when considering the PTD aspect of the design process. Among the diverse stakeholder groups involved in risk management throughout the building life cycle, structural designers stood out, potentially exhibiting reluctance to shoulder risks on behalf of all project stakeholders (Weidman et al., 2015b). It's important to note that the PTD concept does not assign such liabilities to designers; instead, it encourages them to prioritize safety in their designs (Gambatese et al., 2008; Toole & Gambatese, 2008; Votano & Sunindijo, 2014). If implemented, PTD would introduce an additional responsibility for designers, who, in turn, expressed concerns about voluntarily taking on this task. Consequently, designers might naturally seek additional compensation, considering the perceived liabilities associated with PTD, aligning with findings in studies conducted by Che Ibrahim & Belayutham (2020) in Malaysia and Goh & Chua (2016) in Singapore.

Additionally, efforts to develop tools and guidance materials must prioritize enhancing PTD knowledge among engineers, as Jin et al. (2019) and Qi et al. (2014) stressed. The current findings emphasize the lack of PTD guidance materials and the necessity for greater awareness of available resources, a situation expected for a country that has not yet introduced the PTD concept. Nevertheless, other countries have had initiatives to develop PTD guidance materials, as evidenced by works such as Behm et al. (2012) and Workplace Safety and Health Council (2011) reports. The elements depicted in Figure 4.5 outlined specific concerns perceived as potential obstacles to implementing PTD from the designers' perspective. The results indicate that designers prioritize fundamental requirements for the adoption of PTD, emphasizing incentives and essential tools for designers, including design guidelines, software, and checking tools. Interestingly, their focus leans more towards these foundational necessities rather than on the broader management practices within the construction industry.

4.6 DISCUSSIONS ON THE BARRIERS AND ENABLERS OF PTD ADOPTION

The subsequent discussions explore the perceived barriers and key enablers that impact the adoption of PTD within the community of designers in the Philippines. These insights are derived from the responses collected through the survey questionnaire, offering valuable perspectives crucial for the integration of PTD practices in the country. The questionnaire items were intricately crafted to align with the predefined research objectives and the overarching scope of the study. Through this analysis, the intention is to illuminate the factors that could mold PTD adoption among designers in the Philippines and factors contributing to a profound understanding of the dynamics inherent in the construction industry. By discerning these barriers and enablers, the study seeks to facilitate informed strategies for promoting the effective incorporation of PTD principles into designers' practices in the Philippine context.

4.6.1 FACTORS CONSIDERED CRUCIAL FOR THE ADOPTION OF PTD IN THE PHILIPPINES

PTD, recognized as a proactive approach, has proven effective as a general concept within the occupational safety and health (OSH) field. However, the dynamic nature of the construction industry, in contrast to manufacturing industries, presents unique challenges for its implementation. The complexity of the construction sector, involving numerous stakeholders, further complicates the installation of the PTD concept without impacting system dynamics. Other countries have encountered similar challenges attempting PTD adoption, and the Philippines is anticipated to encounter similar hurdles. The concerns in Table 4.7 and Fig. 4.2 showed the evident challenges in PTD implementation. The issues and obstacles mentioned not only reflect the concerns but also impede the smooth adoption of PTD. Consequently, the adoption of PTD can be directly influenced by immediate needs, such as the provision of essential design tools. However, from a broader perspective, strategic approaches can be devised to systematically integrate PTD into stakeholders' safety culture. In essence, addressing these concerns requires a comprehensive approach, considering both the immediate needs of designers and the overarching systemic changes necessary to adopt PTD in the construction industry effectively. This understanding is crucial for devising tailored strategies to navigate the intricate dynamics of the construction sector and advance a comprehensive and sustainable incorporation of PTD principles.

This research placed a specific emphasis on the perspective of designers and proposed specific drivers for the implementation of PTD in the context of the Philippines. PTD acknowledges the influential role that designers play in shaping the health and safety aspects of a construction site through the design of their projects. Furthermore, it explicitly emphasizes assigning a high value to safety in construction from the standpoint of designers (Tymvios & Gambatese, 2019). The core belief is that for PTD to be effectively applied, it must initiate a shift in the mindset of designers, promoting safety consciousness in their design work. This outlook resonated with the respondents. While the potential for PTD application among designers in the Philippines is recognized, practical interventions are deemed essential for its successful implementation. This implied the need for tangible and targeted measures to facilitate the incorporation of PTD principles into the everyday practices of designers, ultimately contributing to a safer and more secure construction environment in the Philippines.

4.6.2 PTD AWARENESS CAMPAIGN

Education stands out as the most effective means of introducing a concept, and this holds true for PTD. As echoed by numerous studies on PTD implementation, education emerges as a valuable information driver, particularly for younger (Behm et al., 2014; López-Arquillos et al., 2015; Olivencia et al., 2017). Mann III (2008) stressed the pivotal role of education as the primary catalyst for ensuring the realization of PTD implementation. The study emphasizes the importance of including construction Occupational Safety and Health (OSH) in the educational curriculum to promote awareness of construction safety among designers. An educational intervention for PTD adoption is seen as a key strategy to enhance students' awareness and knowledge of construction OSH (Behm et al., 2014). A dedicated PTD curriculum can equip students with comprehensive knowledge and skills, fostering the development of safety-conscious designers. Rubio-Romero et al. (2014) emphasize that designers may struggle to embrace a new concept without prior examination and understanding. Therefore, an educational drive becomes imperative to enhance PTD awareness and application. In a similar vein, providing PTD training is crucial, as a majority of respondents reported not having attended any PTD training, which is understandable considering the initial stages of PTD implementation. Designer training, seen as an integral part of the PTD adoption intervention, becomes essential for designers to thoroughly understand the technical procedures involved in building construction and be familiar with construction safety threats and mitigation measures. PTD training is pivotal in enhancing designers' efficiency in applying PTD principles (Goh & Chua, 2016). With appropriate guidance materials and information, PTD training becomes a valuable tool for equipping practicing designers to effectively implement PTD in their professional endeavors.

4.6.3 BIM-BASED PTD TOOLS

Numerous technological tools, particularly software applications, are readily available for the management of construction safety. An avenue considered for enhancing designers' knowledge and application of PTD involves the availability of analysis software tools. The contemporary landscape acknowledges that design software can significantly enhance users' awareness regarding its capabilities. Notably, the advent of BIM technologies has brought about a revolutionary shift in the construction industry's safety culture and management practices (Olugboyega & Windapo, 2019). BIM technology, renowned for its dynamic visualization, especially during the design stage, is a potent tool for integrating safety management. BIM-based tools in construction safety contribute to the enhancement of workers' safety through the utilization of these innovative technologies (Bhagwat et al., 2021; Fargnoli & Lombardi, 2020). The digital nature of BIM allows for customization with various interdisciplinary applications. In the realm of Occupational Safety and Health (OSH), BIM applications include knowledge-based tools, fall prevention strategies, risk identification and quantification, and virtual realities tools (Bloch & Sacks, 2020; Fargnoli & Lombardi, 2020; Zhang et al., 2013). Research indicates that BIM in construction applications can significantly improve workers' safety performance (Fargnoli & Lombardi, 2020; A. Ganah & John, 2015). Given its digital 3D nature and information-holding capacity, BIM technologies prove highly suitable for the principles of PTD. Firstly, designers can conduct direct or collaborative assessments with other project stakeholders on a 3D model, facilitating visual or virtual safety evaluations of PTD concerns within the project's design model. Secondly, BIM's adaptability for specific trades or tasks presents an opportunity to incorporate PTD aspects into the software tools or the project model itself. Examples include the automation of safety checks (Melzner et al., 2013; Mering et al., 2017), the identification of safety risks (Malekitabar et al., 2016), and the automation of additional PTD aspects in design detailing (Rodrigues et al., 2020; Zhang et al., 2015). Practical applications of BIM thus emerge as an essential tool for PTD educational training and, more importantly, an efficient resource for designers in integrating PTD principles into their practices.

4.7 CHAPTER'S SUMMARY

This study aimed to explore and determine the current level of awareness concerning the PTD concept among structural designers in the Philippines. Its primary goal was establishing a groundwork for initiatives that could introduce or enhance comprehension and acceptance of PTD practices. The findings revealed that, for most structural engineers in the Philippines, PTD was a relatively novel concept. Despite their limited familiarity, respondents acknowledged the significance of PTD and considered its implementation crucial in the construction industry. This recognition of PTD's value, even in its early stages in the country, was noteworthy. However, concerns surfaced regarding challenges associated with PTD implementation, encompassing potential liabilities, cost implications, and the availability of essential design tools and guidelines. Identifying these elements as potential barriers to PTD implementation, the data strongly suggests that interventions for PTD adoption among designers in the Philippines should be initiated by providing tools that enhance their capabilities in PTD performance. This strategic approach addresses designers' immediate needs, ensuring they are well-equipped with essential resources to facilitate a smoother and more effective integration of PTD into their design practices.

These findings have directly informed the next phase, which assesses the feasibility of using BIM for PTD. The upcoming study will focus on how BIM can address these challenges by enhancing design tools, providing resources, and supporting PTD integration into existing workflows. It will also explore strategic implementation approaches and alignment with regulatory frameworks to facilitate the effective adoption of BIM in advancing PTD practices within the construction industry based on the results of this chapter.

PHASE II RESULTS AND DISCUSSIONS

5.1 CHAPTER OVERVIEW

This phase of the study explores the technical applicability of BIM for PTD in the construction industry, specifically among structural designers. It explores the feasibility studies undertaken to assess BIM's practical application and integration within the PTD domain. The study was divided into two feasibility studies. The first feasibility study (Section 5.2) explored the development of a methodological framework that leverages BIM's technical capabilities to apply BIM in PTD. This framework was designed to meet the specific requirements of PTD assessments and has shown significant promise in improving construction practices among structural designers. Following this, the second feasibility study (Section 5.3) provided a deeper understanding of industry professionals' perceptions regarding the applicability of BIM for PTD. It focused on how BIM can extend beyond traditional design tasks to enhance construction safety management on the side of the designers. The general results of the two feasibility studies are discussed in Section 5.4. The chapter then provided a further summary of the chapter in Section 5.5.

5.2 TECHNICAL FEASIBILITY OF BIM FOR PTD (FEASIBILITY STUDY 1)

5.2.1 FEASIBILITY STUDY OBJECTIVE

In the previous chapter, the results highlighted the necessity of PTD tools for designers to implement safety principles in their projects effectively. This recognition set the stage for the current feasibility study, which focused on exploring BIM's applicability as a facilitative tool for PTD among structural designers. The primary aim of this study was to demonstrate how BIM can be strategically utilized to embed safety features into the design process, thereby applying BIM for PTD. By leveraging the advanced technical capabilities of BIM, the study sought to promote the applicability of BIM to achieve PTD adoption among design engineers.

Thus, a methodological framework was developed and tested to ascertain its practical utility in applying safety through design in BIM. This framework harnesses BIM's functionalities, such as detailed 3D modeling, data management, and collaborative features, all essential for conducting comprehensive PTD assessments. The framework's design was tailored to meet the requirements of PTD, incorporating specific safety rules and guidelines that were directly integrated into the BIM environment. Through the application of this framework, structural designers were aimed to be equipped with the tools and processes necessary to systematically identify potential hazards and integrate preventive measures early in the design phase. The validation of this framework involved tests and simulations on a hypothetical project model that demonstrated BIM’s capacity to improve the safety planning processes and outcomes in construction projects.

5.2.2 FRAMEWORK DEVELOPMENT

The development of the framework was grounded in a comprehensive review of existing literature, which provided a solid foundation for its conceptualization and implementation. This process began with an extensive examination of scholarly articles, industry reports, and previous research studies that discussed both the technical aspects of BIM and the concepts of PTD. The literature review focused particularly on how BIM has been utilized to integrate safety measures into construction planning. It also explored various case studies where BIM-based frameworks had been successfully implemented. This deep dive into the literature informed the theoretical underpinnings of the framework and highlighted practical considerations necessary for its successful application, such as interoperability issues, the need for customized tool development, and the importance of user-friendly interfaces for structural designers. The framework was designed to leverage BIM’s capabilities to support PTD objectives specifically. It included detailed strategies for risk identification, safety rule integration, and the use of APIs to create a dynamic and adaptable toolset that can meet the evolving needs of the construction industry.

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5.2.2.1 LITERATURE REVIEW AND BENCHMARKING

The literature review offered a comprehensive overview of the numerous technical capabilities BIM technologies bring to the construction industry (see Chapter 2.4 – 2.5). These insights modeled the base for developing a technical framework that could be instrumental in promoting BIM as a tool in the context of PTD. The synthesis of findings from previous research studies presented a perspective on the strengths of BIM in enhancing project safety, which is a core aspect of PTD. Moreover, the literature also unveiled pre-existing BIM-based PTD frameworks (for example, Alfieri et al., 2020; Kamardeen, 2015; Zhou, 2014) that have been designed and tested in different contexts. These frameworks served as valuable reference points and provided potential directions for further research and framework development. They provided a critical understanding of BIM's practical realization for safety management and PTD practices. By synthesizing this extensive body of literature, a methodological framework was produced, capitalizing on the assets of information available on the technical capabilities of BIM for PTD.

5.2.2.2 Framework conceptualization

Equipped with an understanding of BIM’s capabilities and the requirements of PTD, the next step was to conceptualize a methodological framework. This involved outlining the primary objectives that the framework needed to achieve, such as improving safety management during the design phase and enabling the systematic identification of risks. The conceptualization phase focused on defining the structure of the framework, including key components like safety rule integration, risk assessment modules, and the use of APIs to enhance BIM’s functionality for PTD tasks.

The methodological framework, designed within the context of the PTD paradigm, was specifically tailored for structural designers. Consequently, the envisioned enhancements were targeted at the BIM software predominantly used by structural designers. This framework will allow structural designers the flexibility to either create custom tools through API or utilize existing BIM tool packages. This process involves providing safety rules to designers derived from established PTD design guidelines and construction safety rules pertinent to structural design. These safety rules are foundational for integrating safety considerations into the BIM environment. The acquired safety knowledge is embedded within the BIM model using APIs, complemented by an automated risk identification BIM tool. This consolidation facilitates the systematic identification of potential risks inherent in the structural design process. Consequently, designers may gain the capability to identify structural members susceptible to visual modification for PTD. The framework offers a dynamic and adaptable solution. It allows designers to engage with PtD principles efficiently while harnessing the full potential of BIM technology for structural design. It is worth noting that certain BIM software packages, such as Tekla Structures, come equipped with toolsets that can be refined and expanded to accommodate PTD functionalities. These pre-existing tools serve as a foundation that can be further developed to align with PTD principles.

5.2.2.3 DESIGN AND DEVELOPMENT OF THE FRAMEWORK

The design and development phase involved the technical construction of the framework. This stage utilized BIM’s advanced modeling and data management capabilities to build a prototype supporting PTD activities. Several avenues for enhancing BIM for PTD purposes were explored from this starting point. It shows the flexibility and adaptability of BIM technologies to accommodate PTD practices and offers a comprehensive guide for researchers and practitioners seeking to harness these capabilities. Key elements included:

- 3D modeling

  The foundation of this framework is the basic BIM 3D model, which serves as the core representation of the construction project. Modeling of safety enhancements was considered to enhance the visualization of designers upon considering PTD. This approach facilitates a more intuitive and detailed understanding of potential safety issues, enabling designers to visualize and mitigate risks during the earliest design stages. It allows for the virtual testing of safety scenarios, improving the predictability of potential hazards. Additionally, 3D modeling supports the iterative design process, where safety features can be refined and optimized based on continuous feedback.

- Integration of safety rules

  Embedding established PTD design guidelines and construction safety rules into the BIM environment will guide the designers in the design process. Thus, the depiction of safety rules and guidelines for PTD was considered. Furthermore, the extensibility of PTD implementation in BIM is not limited to BIM-specific tools; it extends to database software like Microsoft Excel® and SQL. These databases can augment BIM analysis by incorporating additional knowledge and rules related to PTD principles. This integration ensures that all design activities comply with safety standards and regulations, enhancing the project's overall safety. The systematic inclusion of these rules helps automate compliance checks for PTD inclusions.

- API utilization:

  Developing custom tools or adapting existing BIM tool packages through API to automate and facilitate safety assessments within the BIM model (Ma et al., 2021). Such an approach will broaden the idea and ability of designers to customize their design with PTD aspects. APIs serve as a bridge enabling BIM software to interact with external data sources and utilities, enhancing functionality and flexibility (Trimble, 2021). This capability supports the creation of safety features within the BIM model tailored to the project's specific needs. With APIs, designers can integrate advanced analytics and simulation tools that predict and mitigate construction risks .

- Interoperability enhancements:

  Ensure that the framework can exchange data with other software applications supported by standards like the International Foundation Class (IFC). BIM's interoperability capability allows data exchange with other software applications facilitated by the IFC format (Eastman et al., 2011). BIM's interoperability capability also allows for the integration of diverse tools and platforms, from architectural design to structural analysis and facilities management, creating a cohesive and unified approach to safety in construction projects. This interoperability is crucial for maintaining data continuity across different project phases and among various stakeholders. The proposed framework should ensure that all safety-related data is consistent and accessible.

5.2.3 PROPOSED BIM-BASED PTD FRAMEWORK

Leveraging BIM's capabilities, a proposed methodological framework was developed (Figure 5.1). The model provides a comprehensive context for understanding the various approaches to achieve a PTD-enhanced BIM model. This framework outlined the terminal point for different approaches. Each avenue was designed to lead to the realization of a PTD-enhanced BIM model by harnessing a range of BIM's technical capabilities.

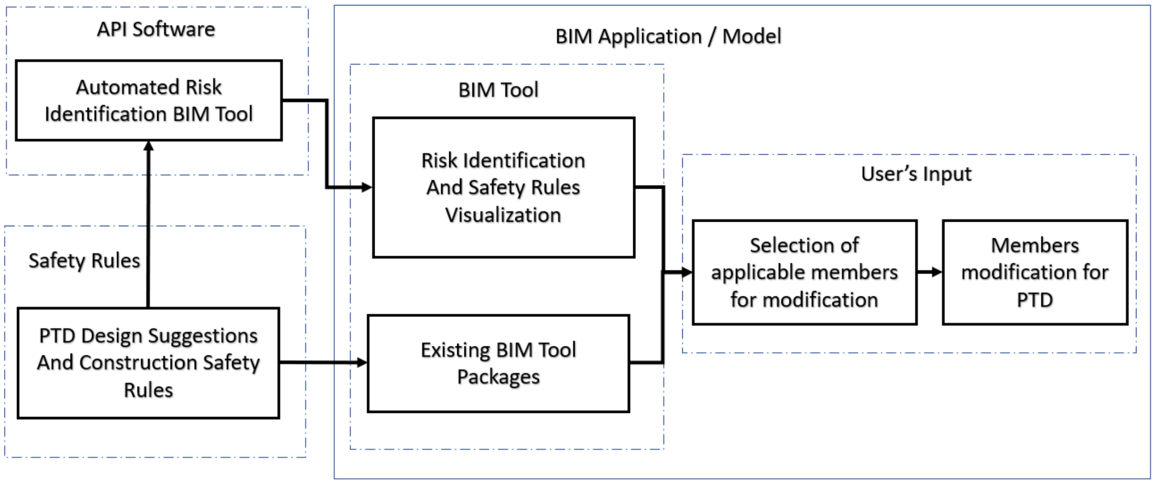

Figure 5.1 Proposed BIM-based PTD Approach Framework.

The proposed framework depicted in the diagram was designed to enhance the application of PTD within BIM software for structural designers. Each part of the framework contributes to the overall functionality. The framework incorporates API software to facilitate the interaction between custom-developed tools and the existing BIM environment. An automated risk identification BIM tool is linked via API, which integrates and processes safety rules and PTD design suggestions tailored to the specific project requirements. This integration ensures that the BIM model reflects up-to-date safety standards and practices, thereby enhancing the safety outcomes of construction projects. Additionally, this setup enables continuous improvement in safety measures as the API can dynamically adapt to new rules and regulations, making it a robust tool for ongoing risk management in the construction industry.

The BIM tool is central to the framework, functioning as the primary application or model where all the processes converge. It includes functionalities for risk identification and the visualization of safety rules, making it easier for users to understand and apply these concepts in real-time within the BIM model. This central tool acts as the hub for integrating various safety enhancements directly into the design workflow, allowing designers to see potential risks and safety requirements visually represented within the structural project. By facilitating real-time updates and visual cues, the tool helps prevent safety oversights and enhances the ability of designers to make informed decisions regarding construction safety management. Moreover, the visualization component not only aids in compliance with safety regulations but also promotes a deeper understanding of how design choices impact overall project safety. The framework's risk identification and safety rules visualization component plays a crucial role in enhancing construction safety by proactively identifying potential risks early in the design stage. This component leverages data processed through API software, which integrates safety rules and guidelines into the BIM environment, allowing for a dynamic and interactive approach to hazard identification. By visualizing safety measures that need to be implemented, this component assists designers in understanding where specific risks are located and how they can be mitigated effectively. This component not only flags potential hazards but also suggests appropriate safety interventions based on the specific conditions and configurations of the project. The visualization could be designed to be intuitive, using color-coding and other graphical elements to highlight areas of concern within the BIM model. This enables designers to see the direct implications of their design decisions on safety outcomes and facilitates a more informed decision-making process.

Designers can leverage the existing BIM tool packages available within the framework, which are strategically enhanced or customized through API to align precisely with PTD needs. This customization allows the existing tools to be utilized for PTD, adding specific functionalities that cater to the safety aspects of the project. By utilizing APIs to modify existing BIM tools, the framework ensures high flexibility and adaptability, allowing designers to integrate and apply PTD principles within their current workflows. This adaptability is crucial for accommodating diverse project specifications and evolving safety standards, which can vary significantly across different types of construction.

Users engage with the system through a direct interface that allows them to identify and select applicable members of the construction model requiring enhanced safety modifications. This interaction is facilitated by the BIM tool, which provides comprehensive insights and visualizations of potential risk areas within the building model. Typically, structural designers use this functionality to pinpoint specific structural elements—such as beams, columns, or slabs—that may pose safety risks or require redesign to meet PTD standards. Once these elements are selected, the system enables users to apply targeted modifications to these members. These modifications are designed to enhance the safety of the construction project by adhering to established PTD principles. For instance, if a particular beam's placement or size poses a risk for worker safety during later construction phases, the tool can suggest alterations in its dimensions or reinforcement that mitigate the risk. The process ensures that all modifications are integrated into the overall construction design, maintaining the project's structural integrity and aesthetic value while incorporating necessary safety precautions.

5.2.4 FRAMEWORK VALIDATION THROUGH TOOL DEVELOPMENT

This section seeks to validate the theoretical constructs and methodological approaches outlined earlier. The section on framework validation through tool development is a crucial component of this study, which aims to empirically test the practical application of the proposed BIM-based PTD framework. This part of the research demonstrates the framework's operational capability and examines its utility in real-world scenarios by developing and implementing a specific tool within the BIM environment. The process involves creating a tool that can operationalize the principles of PTD within the BIM software. It allowed for an in-depth evaluation of how these principles can be integrated into standard design practices and what impact they have on enhancing safety in construction projects.

5.2.4.1 SOFTWARE TOOL WORKFLOW

The validation of the developed framework through tool development encompasses a detailed and methodical approach to enhance safety measures within the construction industry. The workflow started with selecting specific accident scenarios prevalent in the industry. The development phase involves creating a tool using Tekla Structures software, which was enhanced by integrating with Microsoft Visual Studio and the C# programming language to incorporate safety rule algorithms and risk identification capabilities. This tool leverages the inherent features of the BIM model, focusing particularly on slab objects to automate the identification and visualization of risks associated with open edges, a common source of falls on construction sites. The tool systematically evaluates all relevant BIM elements, categorizing and analyzing them to produce detailed outputs that inform the design of necessary safety measures, such as guardrails.

Furthermore, the developed tool is embedded into the BIM environment as a Dynamic Link Library (DLL), making it an integral part of the Tekla Structures platform. This integration facilitates interoperability within the BIM software ecosystem, allowing for the real-time application of PTD principles directly within the design workflow. This phase culminates in the application of the tool within a hypothetical project setting to test its functionality, ensuring that it not only meets the theoretical safety standards but also stands up to the practical demands of construction project safety management.

5.2.4.2 SPECIFIC ACCIDENT SCENARIOS

Apparently, a variety of construction accidents exist. For model validation, the study focused on specific accident scenarios prevalent in the construction industry for illustration. The research considered fall-from-height accidents, recognizing that falls generally constitute a significant portion of fatalities in construction (OSHA, 2019). Falls have consistently been a predominant cause of fatalities in the construction sector, constituting approximately one-third of all fatalities in the industry (Driscoll et al., 2008; Socias-Morales et al., 2018). Recognizing the complexity of incidents involving falls, OSHA acknowledges that these occurrences often entail a multitude of variables (OSHA, 2019). To comprehensively address the nature of falls, OSHA's fall protection standard extends its purview to encompass human, workplace, and equipment-related aspects, aiming to safeguard employees from the inherent risks of falling. This approach is crucial for creating a comprehensive safety framework that considers diverse factors contributing to fall incidents in construction. Consequently, it is imperative to conceptualize and implement methods that effectively mitigate the risk of falling. This aim was aligned with the broader goal of reducing accidents and enhancing safety standards in the construction industry (Manuele, 2008).

In this context, the validation of the methodological framework is a critical step to ensure its practical applicability in enhancing safety measures within the construction industry. The validation process of the envisioned framework unfolds with the creation of a tangible tool designed to operationalize PTD principles within the BIM environment. Therefore, this targeted approach allows for an in-depth exploration of the complexities and variables associated with falls, contributing to developing a contextually relevant tool. This targeted analysis ensures the validation process is comprehensive and tailored to specific safety challenges within the construction domain.

5.2.4.3 ANALYSIS OF OPEN EDGES AND FALL RISKS

Within the selected falls-from-heights scenario, the validation process places emphasis on the potential dangers linked to open edges. Open edges amplify the risk of falls, making them a critical safety concern. The developed tool provided suggestions designed to address the intricacies of fall risks associated with open edges. The tool, developed on the Tekla Structures software, served as the foundational platform for its implementation. Combining Microsoft Visual Studio with the C# programming language enhances the tool's development with technical complexity, showcasing its practical use in real-world construction situations.

Open edges appear mostly after the slab is cast. Hence, the chosen modeling strategy involves leveraging the BIM model's inherent features and targeting the BIM model's slab objects. This approach could generate precise corner coordinates of the slabs, an essential step in the subsequent guardrail design process. The development of this modeling strategy is illustrated in Figure 5.2, where the tool development algorithm is presented. This algorithm, constructed through the API concept, employed Visual Studio software's capabilities and the C# programming language (See Appendix C). The guardrail will automatically be modeled along the slab edges (Figure 5.3), visually indicating to designers which beams and columns need modification and preparation for further implementing PTD aspects.

The algorithm utilizes an enumeration method, systematically evaluating all solid objects within the model and categorizing those BIM elements labeled as "slabs." This process ensures a selection of the relevant members for subsequent analysis. Subsequently, the calculated slab corner coordinates emerge as a result of an analysis of the solid's geometric properties. This involves a sequential progression from solids to faces and ultimately to vertices, sorting out the spatial details that constitute the coordinates for the design of guardrails.

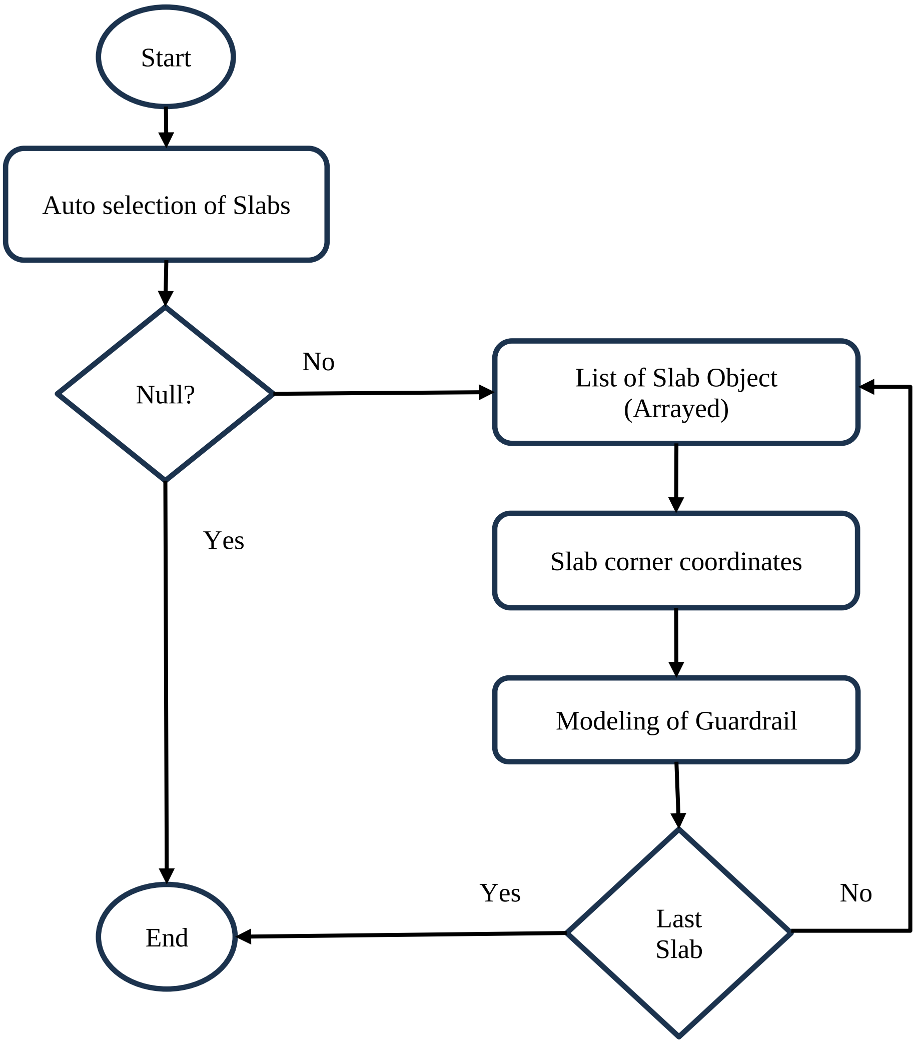

Figure 5.2 Modeling of Guardrails Algorithm.

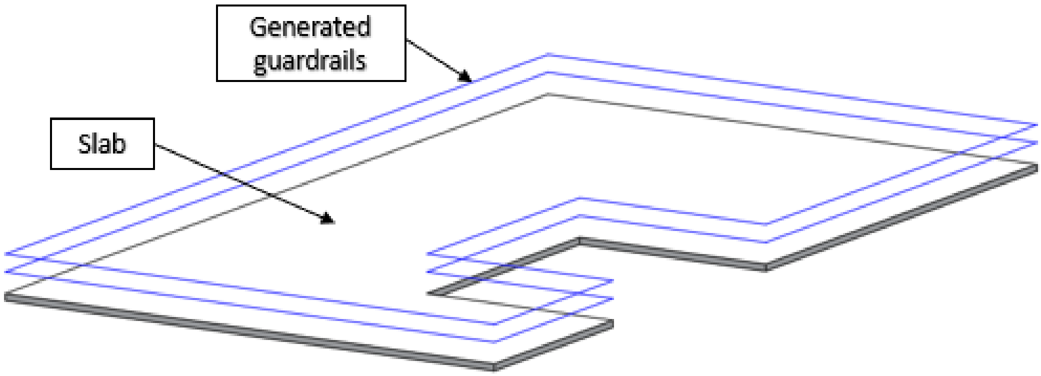

Figure 5.3 Guardrail Modeling Concept.

5.2.4.4 BIM PLUG-IN CHARACTERISTIC

The plugin was designed to integrate with Tekla Structures software. Tekla Structures, being a widely used BIM software among structural designers in the Philippines, offers capabilities for API integration, facilitating the incorporation of external tools and functionalities. This interoperability allows for the effective embedding of the developed plugin, ensuring a cohesive and integrated workflow within the platform (Trimble, 2021). This approach powers the software's API embedding capabilities, emphasizing the adaptability and interoperability required for the integration of the plugin's functionalities into Tekla Structures. This choice ensures compatibility with industry-standard BIM practices and enhances the accessibility and usability of the developed plugin within a familiar and widely utilized BIM environment. The developed tool was evaluated and inserted in BIM software as a Dynamic Link Library (DLL) executable file. A DLL is a file format commonly used in Microsoft Windows operating systems to store multiple codes and procedures essential for various programs to function (Microsoft, 2021). DLL files contain reusable code and data, allowing multiple applications to share the same functionalities without replicating code. Once inserted into the software, it will appear as one of the extension tools (Figure 5.4).

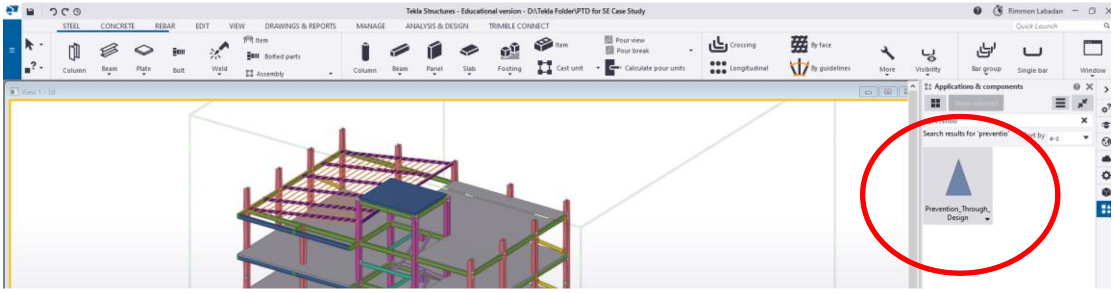

Figure 5.4 The PTD Plug-in.

5.2.4.5 THE PLUG-IN FUNCTIONALITY

The tool developed for this study was integrated into Tekla Structures, where it is accessible as one of the tools and applications within the software interface, as shown in Figure 5.4. The tool became a native component of Tekla Structures, allowing structural designers to easily incorporate PTD principles into their projects using familiar software workflows. Specifically, this tool is labeled "Prevention Through Design," reflecting its purpose and functionality. This integration ensures that the tool is readily available for users directly within the Tekla environment, enhancing usability and accessibility.

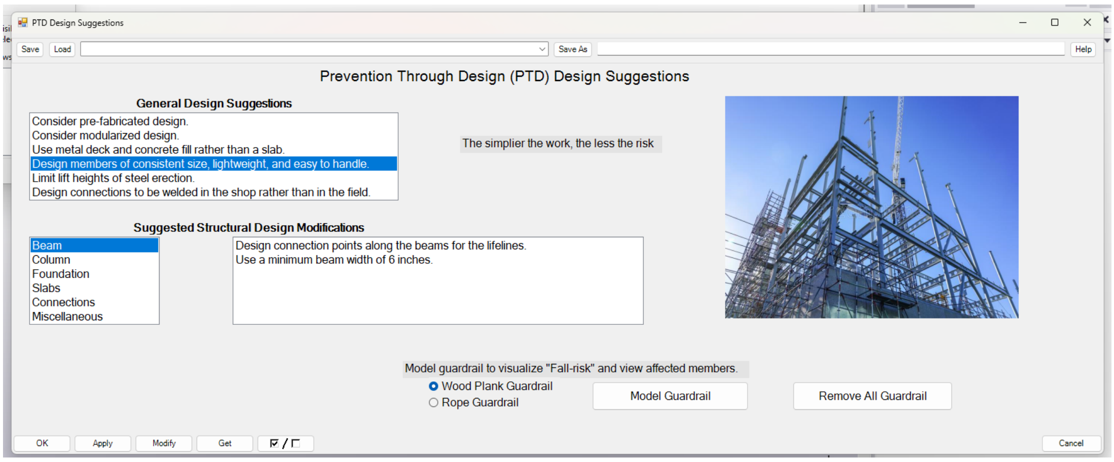

Figure 5.5 Tool Interface.

Upon activating the tool by clicking on its icon, a user interface window, or form, will be displayed (refer to Figure 5.5). This form presents an array of design suggestions framed within the PTD methodology, suggesting structural designers' practical and actionable guidelines designed to enhance safety. These suggestions, constituting a repository of PTD knowledge, serve as a resource to offer designers insights into refining their models following the identification of risks. The lists of PTD knowledge embedded within the plugin have been systematically gathered from various published policy requirements related to PTD principles, mostly from the works of Gambatese (2019). Although it was feasible to dynamically link these suggestions to external data files for real-time updates, they were embedded directly within the form for this demonstration to simplify access and use. The design suggestions were categorized into two main groups: General Design Suggestions and Suggested Structural Design Modifications (see Figure 5.6). The latter is detailed further according to the type of structural elements, such as columns and beams, ensuring that the advice is specific and directly applicable. In the context of this study, the chosen PTD recommendations are specifically prepared for structural designers, ensuring that the guidance provided aligns with the unique considerations and responsibilities of professionals in this domain. A short explanation was also added alongside the design suggestion. This organization helps designers easily navigate and apply the suggestions to the appropriate elements, providing a more intuitive integration of safety measures into their projects.

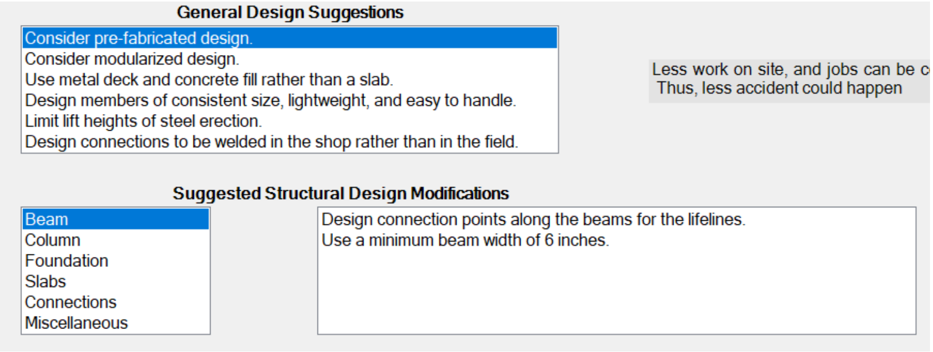

Figure 5.6 PTD suggestions.

The guardrail modeling feature is integrated into the user interface, as illustrated in Figure 5.7. Within the form, users were presented with a choice between two types of guardrail materials: a traditional wood plank or a more flexible rope guardrail. Upon selecting, the user can initiate the modeling process by clicking the "Model Guardrail" button. This action triggers the assigned guardrail's automatic rendering directly within the BIM model, accurately placing it along designated edges. To accommodate adjustments, an option to delete all previously modeled guardrails is also included within the tool. This functionality ensures that users can visualize risks within their projects, allowing for iterative design improvements and the flexibility to adapt PTD.

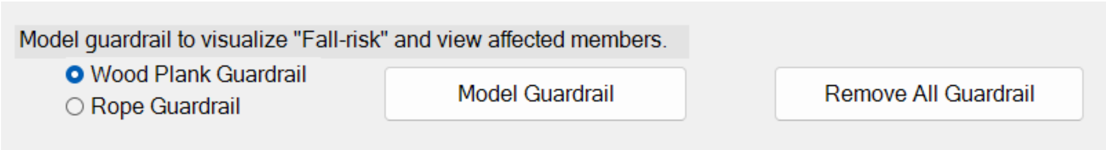

Figure 5.7 Automated Guardrail Modeling Button

5.2.5 HYPOTHETICAL PROJECT APPLICATION

To substantiate the viability of the developed BIM-based PTD application, the devised tool underwent testing within a hypothetical project setting (El Kontar et al., 2020). This testing phase aimed to assess the functionality, efficacy, and adaptability of the BIM-based PTD approach within the context of a practical project scenario. The tool that was developed has been seamlessly integrated into the Tekla Structures software, enabling its functionality directly within the platform. Following this integration, a BIM project was created using Tekla Structures to demonstrate the tool's application of PTD in a design scenario.

5.2.5.1 THE BIM MODEL

A structural BIM (Figure 5.8) was created to establish the foundation for the subsequent assessment and testing of the newly developed plug-in. This designed model served as a representative prototype, embodying the key elements essential for structural design within a construction project. Specifically, the model emulated a four-story building, incorporating fundamental structural components integral to the design process, including foundations, columns, beams, and slabs.

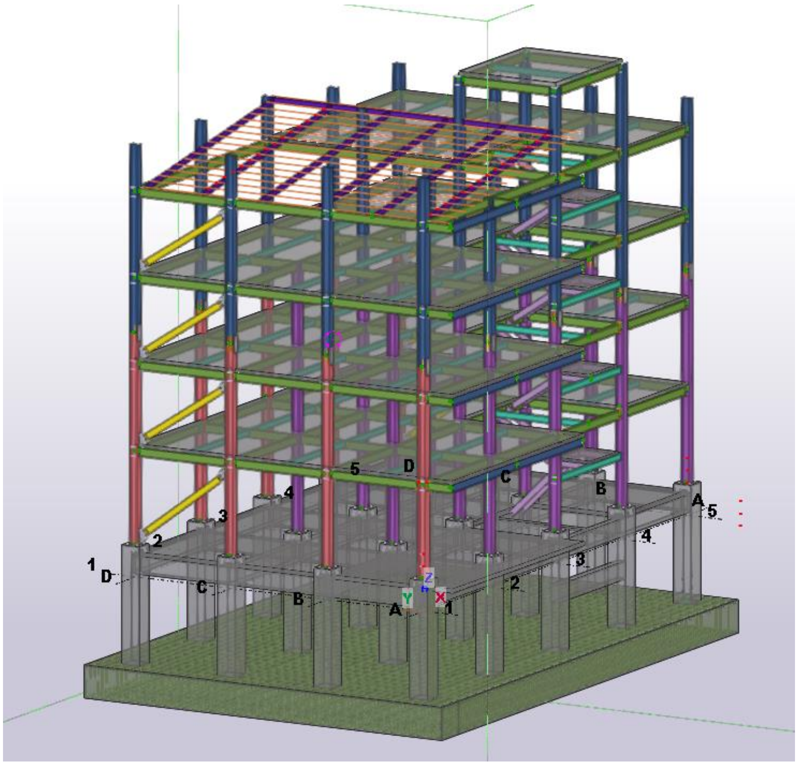

Figure 5.8 Structural BIM Model

5.2.5.2 APPLICATION OF THE DEVELOPED TOOL

The PTD plugin was employed to automatically generate guardrails within the BIM model, as illustrated in Figure 5.9. These guardrails, essential for enhancing safety on construction sites, were meticulously positioned along the edges of slab components to mitigate the risk of falls from heights. This strategic placement is integral to the design, aligning with the preventive measures outlined in the initial conceptualization of the project. The automated nature of the guardrail generation not only streamlines the design process but also ensures that safety features are consistently and accurately implemented across the model.

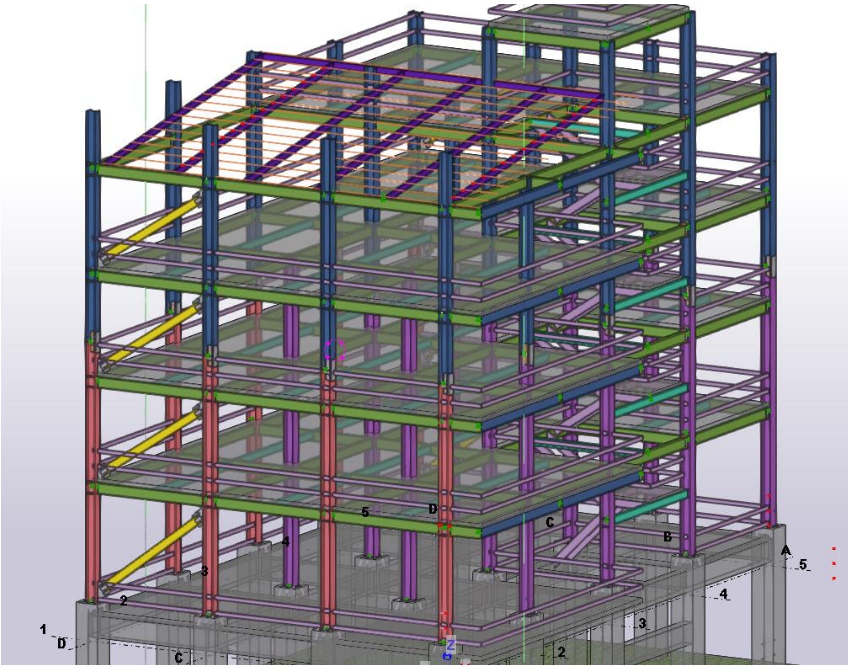

Figure 5.9 BIM Model with Guardrails

5.2.5.3 SOFTWARE TOOL LIMITATIONS

It is essential to note that these visual representations do not serve as the actual guardrails to be implemented on the construction site; they function as visual aids to depict open edges. This risk depiction allows designers to identify potential risks associated with open edges and devise corresponding PTD actions. The automated guardrails, while serving an illustrative purpose, can be selectively removed later in the modeling process. For instance, designers may opt to create additional openings in columns and beams, a proactive measure suggested by some PTD guidelines. Tekla Structures supports creating openings in beams and columns. Tekla Structures provides a platform for customized detailing that aligns with the PTD principles advocated for enhanced construction safety.

5.2.6 FINDINGS AND DISCUSSIONS OF THE FIRST FEASIBILITY STUDY

The results from the application of this BIM-based PTD framework signify a significant advancement in the field of construction safety. By providing structural designers with a powerful tool that enhances their ability to foresee and mitigate risks, the framework encourages a shift towards more safety-conscious design practices. Furthermore, the successful implementation of this framework among structural designers not only boosts their efficiency and efficacy in managing safety aspects but also sets a precedent for the adoption of similar practices across the industry. This feasibility study confirms the technical viability of BIM for PTD and underscores its potential to transform traditional construction practices by embedding a culture of safety right from the design stage, paving the way for safer construction environments.

This research illustrated BIM's significant potential for the construction industry, focusing on its utility in embedding PTD principles within structural design projects. With its comprehensive set of features, BIM offers a unified framework for addressing safety considerations at every stage of a project's lifecycle, with a special focus on the crucial design phase. This ability to incorporate safety from the outset represents a concept shift towards a more proactive and preventive approach to construction safety management. While it's acknowledged that not every BIM software was conceived initially with 8D capabilities, which include safety analysis as a core function, BIM's flexibility allows for customization and enhancement. This adaptability makes it possible to conduct specialized analyses, such as construction safety assessments, within the BIM environment. Practical demonstrations have shown how BIM facilitates the integration of safety measures into the design process, effectively enabling designers to identify and address potential hazards before they materialize.

Regarding the technical feasibility of the developed tool for integrating PTD principles into BIM software, several key factors were considered, including functionality, integration, user experience, and compliance with industry standards. The primary evaluation criterion centered on the tool's performance capabilities, specifically its ability to accurately model guardrails and other safety features within the BIM environment. The tool needed to execute tasks like the automatic placement of guardrails at precise locations consistently with PTD guidelines and allow for modifications and updates without introducing errors or delays, thereby streamlining the workflow for structural designers. Another critical factor was integrating with existing BIM platforms, such as the Tekla Structures. The tool was integrated smoothly, maintaining the standard functions of the BIM software while enabling access to and manipulation of existing data structures.

Furthermore, new functionalities, such as the automated guardrail feature, were added without destabilizing the software or causing performance issues. The tool was user-friendly, with intuitive interfaces that allow designers straightforward access to PTD features. Minimizing the complexity of operations and supporting customization for specific project requirements were essential to enhance user satisfaction and extend the tool’s utility across different project types. Compliance with industry standards and safety regulations, including those set by organizations such as OSHA, was attained. The tool's compliance ensures that the safety features it designs and implements meet the legal and professional standards necessary for real-world application in the construction industry.

Finally, the tool underwent testing and validation under the hypothetical project to confirm its functionality and reliability. This process included identifying and resolving any bugs, optimizing performance, and verifying the accuracy of its safety assessments. Validation efforts focused on ensuring that the tool meets the needs of structural designers and effectively supports enhanced safety management practices in BIM projects. These comprehensive evaluations confirm the BIM’s feasibility for PTD in structural design, demonstrating its potential to improve PTD integration in construction design significantly.

5.3 TECHNICAL QUALITIES OF BIM FOR PTD (FEASIBILITY STUDY 2)

This case study was undertaken to assess the feasibility and effectiveness of using BIM tools within the framework of PTD. The focus was to investigate the direct experiences of structural designers who have implemented BIM technologies in their projects. To thoroughly understand this matter, the research adopted an exploratory approach, which involved conducting semi-structured interviews with professionals with significant expertise and experience using BIM tools in their design works. This method allowed for an in-depth exploration of their insights, challenges faced, and the benefits realized through the application of BIM in enhancing safety and efficiency in design processes.

5.3.1 THE INTERVIEW PROTOCOL

Interviews ranged from 50 to 70 minutes, with five conducted online and two in person. Following the method outlined in the methodology section, the interview questions were organized into three main parts. The first part assessed how participants currently use BIM in their ongoing projects. In the second part, after introducing and explaining the concept of PTD and presenting examples of its implementation through BIM, participants were asked about their perceptions of BIM's applicability to PTD. This section aimed to gather their views on the feasibility and potential of BIM in enhancing safety and design practices. The final part of the interview consisted of conclusive questions designed to confirm and validate the participants' views on whether integrating BIM could lead to a broader adoption of PTD principles.

5.3.2 DEMOGRAPHY

The potential interviewees selected for this study were structural designers based in the Philippines who possess substantial experience in design work and a track record of utilizing BIM software in their projects. Despite extending invitations to many professionals, only seven individuals expressed willingness to partake in this research initiative. These participants, representing five distinct companies, were denoted as "Designer 1," "Designer 2," "Designer

3," "Designer 4," "Designer 5," "Designer 6," and "Designer 7." A detailed overview of their professional backgrounds, years of experience, and BIM software preferences is presented in Table 5.1.

Every participant interviewed possesses extensive experience in structural design and holds significant managerial roles. While their primary affiliation is with structural design offices, several of them have also worked in design and construction companies. Each structural designer has been involved in the design process or contributed to the design of at least one mid-rise building, with some extending their expertise to design warehouses, bridges, and towers. These designers have utilized BIM software for various aspects of their work, including design, detailing, and collaboration. Beyond conventional structural analysis 3D software, Tekla Structures and Revit emerged as the most commonly used BIM software tools among structural designers.

Table 5.1 Respondent's Profile

Respondents	Position	Years of experience	Type of Company	Type of projects	BIM Software Used (aside from 3D design software)
Designer 1	Structural Asst. Manager	12	Design and Construction	High-rise buildings, warehouse, hangar,	Revit, Revit, Navisworks
Designer 2	Principal Designer	14	Structural Firm	Mid-rise building, warehouse, bridge	Tekla structures, Revit
Designer 3	Associate Structural Engineer	10	Design and Construction	Mid-rise buildings, warehouses, towers	Revit, Tekla Structures, Archicad
Designer 4	Principal Structural Engineer	18	Design and Construction	High-rise buildings, warehouses, towers, bridges, gymnasiums, tunnel	Tekla Structures, Civil 3D
Designer 5	Associate Structural Engineer	8	Structural Firm	High-rise buildings, warehouses,	Tekla Structures, Revit
Designer 6	Associate Structural Engineer	8	Design and Construction	Mid-rise buildings, warehouses, gymnasiums,	Tekla Structures, Revit
Designer 7	Principal Structural Engineer	9	Structural Firm	Mid-rise buildings, bridges	Tekla Structures

5.3.3 CONTENT ANALYSIS FINDINGS

The interviews with structural engineers, as outlined in the Methodology section, were organized around important themes, with a primary focus on the technical capabilities of BIM. The themes included four fundamental features of BIM technology: 3D modeling, visualization, data integration, and collaboration. The interviews attempted to extract significant insights from industry specialists regarding the applicability of BIM for PTD by concentrating on these subjects. The subsequent discussion combines responses obtained from the interviews, with the synthesis process beginning with extracting the designers' viewpoints on the technical capabilities of BIM in their design work.

5.3.3.1 3D MODELING CAPABILITIES OF BIM

5.3.3.1.1 The 3D modeling capability of BIM for structural designing

BIM offers 3D modeling capabilities that revolutionize the AEC industries. The detailed, three-dimensional digital representations of buildings facilitate a comprehensive understanding of their spatial characteristics and components. Respondents were asked to describe their experience with using BIM to create detailed 3D models of a project’s building elements, systems, and components. The agreement among the interviewed design engineers in the Philippines was widespread, with many affirming and expounding upon the benefits derived from the 3D-modelling capabilities offered by BIM in their design jobs. The feedback from structural engineers showed the significant enhancements that BIM's 3D modeling capabilities bring to their work. Designers emphasized the efficiency gains in constructing 3D models for building elements, suggesting that BIM enhanced their workflow. They echoed this sentiment, noting the efficiency and speed with which BIM allows for the creation of various design elements in a three-dimensional space, making the design process both easier and faster. The complexity and comprehensiveness that working with a 3D model introduces to their analysis indicate that BIM facilitates a more detailed and thorough examination of designs.

[…] *Based on my experience, using BIM to create 3D models, especially for building elements, makes my work efficient.* […] Designer 1

[…] *I found it very efficient to create certain elements in design. It can model almost all of the design components three-dimensionally. It makes my work easy and fast.* […] Designer 4

[…] *To work in a 3D model makes my analysis complex and comprehensive.* […] Designer 6

These responses pointed out the value of BIM's 3D modeling in enhancing efficiency, speeding up the design process, and enabling more complex and comprehensive analyses in structural engineering work. This finding indicated the significant impact that the 3D modeling capabilities of BIM have on improving both the efficiency and effectiveness of designers' work. Specifically, when it comes to managing and manipulating various building elements, the three-dimensional aspect of BIM provides a more intuitive and comprehensive platform for designers to work with, according to Hu et al. (2010). Visualizing structures in three dimensions allows for a faster and more accurate assessment of structural systems. This level of detail not only facilitates a smoother design process but also aids in identifying and resolving issues at an early stage, thereby reducing the likelihood of costly and time-consuming modifications during the construction phase (Liu et al., 2017). Additionally, within BIM software, designers identified specific tools or features that prove highly effective in precisely depicting building components and systems in 3D representations. The respondents enumerated the following items that can be modeled efficiently using BIM: parametric elements, curve structures, steel connections, and customized components.

5.3.3.1.2 The 3D modeling capability of BIM for PTD

The interviewees expanded the possibility of using BIM to implement the PTD approach of OSH based on their considerable experience with 3D modeling in BIM. They were asked to anticipate the utilization of BIM to create 3D models for construction OSH in their design works. The respondents projected that these models would be vital in proactively detecting and addressing safety issues during the design phase of construction projects. The designer stressed that:

[…] *Through 3D visualization and construction sequencing, you can identify what areas of the structure need to be designed for safety and what type of safety hazard must be addressed.* […] Designer 5

[…] *Construction safety elements could be completely incorporated into BIM software. Thereby making it feasible to identify risks for construction safety analysis.* […] Designer 2

[…] *The 3D model of a project could be a big advantage for seeing the risks possibly encountered during the construction.* […] Designer 7

The responses from structural engineers regarding their anticipation of using BIM's 3D modeling capabilities for PTD revealed a strong consensus on its potential to enhance construction safety. They saw the benefit of 3D visualization and construction sequencing, which allows for the identification of specific areas within a structure that require safety design considerations and the types of safety hazards that need to be addressed. The construction safety elements could be fully integrated into BIM software, making it a powerful tool for risk identification and construction safety analysis. Similarly, they mentioned the significant advantage of having a 3D model for visualizing potential risks that might be encountered during the construction phase. Therefore, these insights cemented the value of BIM's 3D modeling in improving the anticipation, identification, and management of construction safety risks, thereby supporting the effective implementation of PTD practices. Furthermore, engineers were asked to offer suggestions and provide definite instances of safety-related components or characteristics they deemed necessary to be integrated into BIM software. One proposed idea was improved tools for immediate safety analysis, allowing designers to detect and address potential dangers as they engage with the developing model. In addition, the engineers suggested incorporating 3D models, enabling the automatic identification and inclusion of safety issues when designing, such as cranes, lifelines, open hole coverings, guardrails, ladders, and risky edges.

Nevertheless, the designers expressed their concerns regarding the 3D modeling of BIM for PTD. While recognizing the potential benefits, they noted several challenges that could impede effective implementation. One major concern is the complexity and associated with mastering advanced BIM functionalities, which can be a significant barrier for those not already proficient with the software. Additionally, the integration of PTD into BIM requires not just technical know-how but also a shift in cultural practices within design teams, which can be resistant to new workflows and standards. These challenges necessitate targeted training and perhaps a phased approach to implementation to ensure that all team members are competent and comfortable with using BIM for PTD effectively.

5.3.3.2 THE VISUALIZATION CAPABILITY OF BIM

5.3.3.2.1 The visualization capability of BIM for structural designing

BIM offers advanced visualization capabilities that significantly enhance the understanding and communication of complex construction projects. Through BIM, stakeholders can generate realistic, visually immersive representations of buildings and infrastructure, aiding in effective communication and decision-making (Björnsson et al., 2018; Eastman et al., 2011). In this study, the respondents were asked to evaluate how BIM enhances the visualization of a designer's work throughout the design process and how it can help with PTD analysis. Within the field of structural designing, designers emphasized how helpful the visualization capabilities of BIM are:

[…] *It helps a lot with visualization of the whole project, and it is easier to check if something is wrong with the model. Also, you can foresee the problems you might encounter in the construction and resolve them while it is still in the design phase, for example, clashes between structural and plumbing lines and other trades, especially in architecture.* […] Designer 3

[…] *The combination of each graphical interface, such as plans, elevations, and 3D sectional views, constantly updates once there are changes in the 2D view.* […] Designer 1

[…] *BIM can visualize the stresses and deflections during analysis.* […] Designer 6

The feedback from structural engineers revealed the significant enhancements that BIM visualization capabilities bring to their work. To them, the comprehensive visualization of the entire project that BIM facilitates makes it easier to identify and rectify issues within the model. This capability allows for anticipating and resolving potential construction problems, such as clashes between different trades, while still in the design phase. The dynamic nature of BIM's graphical interface, where updates in 2D views automatically reflect in plans, elevations, and 3D sectional views, ensures consistency and accuracy across all representations. Designers noted BIM's ability to visualize stresses and deflections during the analysis phase, clearly depicting how the structure behaves under various conditions. Mutually, these responses showed how BIM's advanced visualization capabilities significantly improve the design process, from identifying and solving problems early on to ensuring the structural integrity and safety of the project.

Designers’ responses expounded on the substantial benefits of utilizing BIM in structural designing, particularly from a visualization standpoint. The ability to visualize the entirety of a project in a cohesive, three-dimensional space significantly enhances the capacity to inspect and verify the integrity of the model (Golabchi et al., 2018; Jin et al., 2019). This thorough visualization goes beyond mere aesthetics, allowing for an in-depth examination of the structural layout, including the connection between various elements such as plumbing lines, electrical systems, and other architectural components. One of the key advantages mentioned is the early detection of potential conflicts or "clashes" between different systems within the building design, such as structural components interfering with plumbing lines. BIM's sophisticated tools enable designers to identify these issues well before construction begins, a process that is far more challenging to undertake with traditional two-dimensional drafting methods. This preemptive identification of problems is critical in avoiding costly and time-consuming revisions during construction.

5.3.3.2.2 The visualization capability of BIM for PTD

In the context of design practices, designers have offered instances of particular BIM visualization features or techniques that they have actively incorporated into their design processes (Chen et al., 2020; Zhang et al., 2015). These examples were the practical application of BIM visualization tools within the structural design, implying various ways designers used BIM technology to enhance their projects. Through these practical examples, designers articulate the versatility of BIM in transforming conceptual ideas into visually immersive representations, contributing to more informed decision-making throughout the design phases. These are member stresses visualization, building deflections and drifts, steel connection details, and rendered view.

Thus, engineers were also surveyed regarding their conceptualization of utilizing BIM to visualize and identify safety hazards in the initial design stages of a construction project. Their responses provided valuable insights into the potential applications of BIM as a proactive tool for safety considerations in the early phases of project development. This involves utilizing visualization BIM functionalities to simulate and inspect the construction environment virtually, anticipating and mitigating safety issues before the physical construction begins. Engineers envisioned BIM to:

[…] *I believe that using BIM to visualize and identify safety hazards during the design phase of a construction project is an effective and proactive approach to enhance safety.* […] Designer 6

[…] *Using BIM for safety in design means creating a detailed 3D model to spot and address potential safety issues early. By incorporating safety data visually, the model ensures the overall visibility of construction site problems.* […] Designer 3

[…] *The idea of visually incorporating safety concerns in the model is feasible. We can view the entire building, even up to cross-section details, in three dimensions.* […] Designer 4

The responses from structural engineers regarding their anticipation of using BIM visualization capabilities for PTD emphasize BIM's potential to enhance construction safety significantly. Designers expressed confidence in BIM as an effective tool for visualizing and identifying safety hazards early in the design phase, advocating for a proactive approach to safety enhancement. They elaborated on this by describing the process of using BIM to create detailed 3D models that allow for the early spotting and addressing of potential safety issues. This approach facilitates the visualization of safety data and improves the overall visibility of potential problems on the construction site. Similarly, they stressed the feasibility of visually incorporating safety concerns into the BIM model, noting the advantage of being able to view the entire building in detail, including cross-sections in three dimensions. Mutually, these insights showed the anticipation among structural engineers that BIM's advanced visualization capabilities can be leveraged effectively for integrating safety considerations into the design process.

One significant concern is the resource intensity associated with high-resolution 3D modeling, which demands considerable computational power and can lead to longer processing times, potentially slowing down project workflows. Another challenge lies in the necessary detail and accuracy required in the models to effectively identify and mitigate safety hazards, which can be difficult to achieve consistently without rigorous standards and protocols in place. The complexity of integrating comprehensive safety data into BIM models also presents a technical challenge, as this requires consistent updates and management to ensure all safety aspects are correctly visualized and accounted for throughout the project lifecycle. Furthermore, there may be resistance from some project stakeholders who are accustomed to traditional methods and may be reluctant to rely on digital models for safety planning, perceiving it as an unnecessary complication rather than an enhancement.

5.3.3.3 THE DATA INTEGRATION CAPABILITY OF BIM FOR PTD

5.3.3.3.1 The data integration capability of BIM for structural designing

BIM is a powerful method that integrates data from various sources, such as CAD and BIM software, spreadsheets, and more, to improve building design, construction, and operation. BIM enables better collaboration, communication, and data management among stakeholders, leading to more efficient, cost-effective, sustainable, faster, and safer construction projects (Bhagwat et al., 2021; Ozturk, 2020; Shehzad et al., 2021). A shared data environment is essential for managing the enormous amounts of digital data generated throughout the lifecycle of a building project, and BIM plays a crucial role in facilitating this process. Thus, respondents were asked to describe their experience with using BIM to integrate diverse data types, such as project information, material specifications, and construction methods, to improve the efficiency and accuracy of construction projects.

[…] *It is very convenient and helps a lot because all the needed information and specifications are already available on the software. It also minimizes the queries that may arise during the construction stage. The updating and exchanging of information between the designer and the contractor is much easier.* […] Designer 5

[…] *Data information allows easy interoperability with other software. Data transfer is easy. For example, determining the material quantity is fast since we have the geometries and unit weights.* […] Designer 6

[…] *The information associated with the components makes structural analysis more mathematically precise. Parametric information makes me do simulations very fast.* […] Designer 7

The responses from structural engineers regarding the enhancements BIM's visualization capabilities have brought to their work emphasize the system's convenience and efficiency in improving construction project workflows. The convenience of having all necessary information and specifications readily available within the BIM software reduces the potential for queries and issues during the construction phase. Furthermore, designers noted that BIM facilitates easier updates and exchanges of information between designers and contractors. The advantages of BIM in terms of data interoperability with other software are that it makes data transfer straightforward and efficient. They specifically mentioned the speed at which material quantities can be determined, thanks to BIM's immediate access to geometries and unit weights. The precision BIM introduces to structural analysis is attributed to the detailed information associated with components within the model. The parametric information available in BIM allows for rapid simulations, making the structural analysis process faster and more mathematically precise. These insights indicated the significant improvements BIM's visualization and data management capabilities bring to the construction industry, from facilitating detailed and precise analyses to enhancing communication and enhancing interoperability, thereby contributing to more efficient and effective project outcomes.

5.3.3.3.2 The data integration capability of BIM for PTD

Designers were inquired about the practicality of directly incorporating data related to construction safety into BIM models for projects. This question was designed to investigate how extensively BIM can be employed both as a design and visualization tool and as a platform for incorporating detailed safety information. The aim was to determine BIM's effectiveness in augmenting construction projects' safety planning and management dimensions. Notably, all of the designers positively agreed on these possibilities. They also suggested integrating construction safety-related data in a BIM model.

[…] *Provide automated notes upon choosing the type of material or member sections.* […] Designer 4

[…] *Use clash detection tools in BIM software to identify clashes between different elements in the project, including safety-related features such as fall protection systems, guardrails, and emergency exits.* […] Designer 5

[…] *Using layers or color-coding can help distinguish safety features and facilitate clear communication of safety protocols.* […] Designer 7

The responses from structural engineers regarding their expectations for utilizing BIM data integration capabilities for PTD affirmed the potential of BIM to enhance safety measures within construction projects. They anticipated the benefit of having automated notes for material or member section choices, which can simplify the selection process and ensure compliance with safety standards. The value of employing BIM's clash detection tools is to preemptively identify conflicts between various project elements, including critical safety features like fall protection systems, guardrails, and emergency exits, thereby preventing potential hazards. Designers suggest the use of layers or color-coding within BIM to distinguish safety features, making it easier to communicate safety protocols clearly and effectively among project stakeholders. Together, these insights elaborated the anticipated advantages of BIM’s data integration capabilities in facilitating a more proactive and integrated approach to safety planning and management through PTD.

Nonetheless, one major hurdle perceived by the designers was the complexity of integrating diverse data sources into a single BIM model. Safety data, construction specifications, and compliance information must be synchronized and updated continuously, which can be technically challenging and prone to errors if not managed carefully. Furthermore, the reliance on automated systems for safety checks, such as clash detection, requires high precision in the BIM model. Any inaccuracies in the model could lead to overlooked safety risks, making it crucial for data to be precise and thoroughly verified. There was also the issue of data overload, where the vast amount of information managed within BIM systems can sometimes lead to confusion and errors if not properly handled.

5.3.3.4 THE COLLABORATION CAPABILITY OF BIM

5.3.3.4.1 The collaboration capability of BIM for structural designing

Reflecting on the utilization of BIM collaboration features, professionals have encountered a transformative experience in promoting teamwork among diverse project stakeholders (Hamidavi et al., 2020; Zhang et al., 2018). The dynamic nature of BIM collaboration tools has provided architects, engineers, contractors, and clients with an integrated platform for interaction and information exchange. This collaborative environment enables real-time communication and coordination, enhancing the collective understanding of project goals and requirements. Engineers, in turn, benefit from BIM as a communication channel, easing the exchange of critical information with architects and contractors. Structural designers shared the following experiences regarding BIM's collaborative capability:

[…] *A good example in our project was ducting passed above the ceiling in the corridor area, and there were drop beams. By using BIM, designers were informed during the design stage, and available clear heights were determined in the early stage. This prevented delays and waste of resources while increasing the quality of work.* […] Designer 1

[…] *I had this experience before. The architecture will not look good when our structural designs are too conservative and reflected in the 3D model. So, by this, we can adjust our designs concerning the architectural intent. Thus, as well as the plumbing and ad electrical* *embedments, we can openly discuss all the problems that may happen on-site and solve them earlier while it is still in the design phase. For the contractors, it is effortless to answer all the RFIs (Request for Information) during construction, and lastly, the clients also have an overview and idea of the whole project. They can quickly evaluate what is happening on the project.* […] Designer 3

[…] *Our steel building projects can be easily communicated to manufacturers. The manufacturer can directly see the conflicts and communicate with us quickly.* […] Designer 7

[…] *As structural engineers, we conform to the architectural plans. So, receiving a 3D rather than a 2D model makes our work easy, and we can communicate our concerns efficiently.* […] Designer 2

Structural engineers have noted the substantial positive effects on project efficiency, quality, and communication due to the improvements in BIM's collaboration capabilities. They shared an example where BIM enabled the early identification of spatial conflicts between ducting and structural elements in a corridor, allowing for adjustments during the design phase. This proactive approach prevented potential delays and resource wastage, ultimately improving the quality of the work. They benefited from BIM in harmonizing structural design with architectural aesthetics and other trades like plumbing and electrical systems. BIM facilitated early discussions and resolutions of potential on-site issues, making it easier to respond to RFIs during construction. Additionally, BIM provided clients with a comprehensive project overview, enabling them to assess project progress more effectively. Also, designers mentioned the ease of communication with manufacturers on steel building projects, where BIM allowed for direct conflict identification and swift communication, streamlining the fabrication process. Thus, these perceptions on BIM's role in promoting a more integrated, communicative, and efficient design and construction process. BIM's collaboration capabilities facilitate the early resolution of design and construction challenges and enhance overall project management and stakeholder engagement, leading to higher-quality outcomes and more satisfied clients.

5.3.3.4.2 The collaboration capability of BIM for PTD

Designers strongly favored the conception that BIM technology significantly promotes communication and coordination across project stakeholders. As designers perceive it, this collaborative environment could go beyond conventional aspects and may include safety-related information and preventive measures crucial for supporting PTD initiatives.

[…] *Having a visualization of what we are dealing with, our communication with the party involved will be efficient. So it will be easy to explain to the contractors whatever construction safety features we have included in our designs.* […] Designer 2

[…] *The collaboration features within BIM software can enhance the coordination of safety-related information by allowing real-time sharing and updating of safety measures among all stakeholders.* […] Designer 6

[…] *By leveraging the collaboration features within BIM software, project stakeholders can enhance communication, coordination, and decision-making related to safety measures, ultimately improving the prevention of safety hazards through effective design and construction practices.*. […] Designer 5

The responses from structural engineers regarding their expectations for utilizing BIM's collaboration capabilities in support of PTD practices featured the significant potential for improving construction safety through enhanced communication and coordination. Designers emphasized the efficiency in communication that BIM visualization offers, making it more straightforward to convey construction safety features included in designs to contractors. The ability to visually present what is being dealt with will improve the explanation process of safety features, facilitating a more precise understanding among all parties involved. Designers pointed out the collaborative features within BIM software as a key factor in enhancing the coordination of safety-related information. The real-time sharing and updating of safety measures among stakeholders ensure that everyone is on the same page regarding safety protocols. BIM's collaboration will enable stakeholders to improve communication, coordination, and decision-making related to safety measures. This collaborative approach is instrumental in enhancing the prevention of safety hazards, as it effectively integrates safety considerations into design and construction practices. Together, these insights showed the anticipation among structural engineers that BIM’s collaboration capabilities will play a crucial role in advancing PTD by fostering a more integrated, transparent, and efficient approach to managing construction safety. This collaborative environment is seen as vital for embedding safety into every phase of the construction process.

However, designers also raised concerns regarding collaboration through BIM. One of the primary obstacles is the inconsistency in the adoption levels of BIM technologies across different stakeholders. Not all parties involved in a project may be equally proficient with BIM tools, leading to discrepancies in how safety information is shared and understood. This disparity can result in communication gaps and misinterpretations of safety protocols, ultimately affecting the seamless integration of safety measures into the project lifecycle. The infrastructure required to support real-time collaboration and data sharing can also be complex and costly. Ensuring all stakeholders have real-time access to the same updated information demands robust IT support and can strain resources, especially for smaller firms. There was also the challenge of integrating BIM systems with other technology platforms used by various contractors and subcontractors, which may not always be compatible.

5.3.3.5 The technical capabilities of BIM for PTD adoption

BIM catalyzes transformation, providing a platform that integrates safety considerations into the design and construction processes (Mansouri et al., 2020). Advanced technologies are essential for creating a safer and more environmentally friendly built environment (Farghaly et al., 2021). Thus, this study also postulates that the BIM's mediating role significantly impacts the implementation of PTD concepts in the building sector. The capacity to generate 3D models in this paradigm shift allows for visualization of the construction project and intrinsically incorporates safety aspects. According to Hardison et al. (2019), BIM's thorough approach improves the detection and reduction of possible dangers at the design stage, which is in line with the proactive principles of PTD. Incorporating BIM in adopting PTD is a crucial turning point in promoting safety practices in the construction sector.

The insights gathered from discussions with designers showed a prevailing belief in the impact of adopting BIM technology on the implementation of PTD practices within the construction industry. Designers express a collective view that embracing BIM introduces a paradigm shift, positioning it as a catalyst for elevating safety considerations in the construction process. The multiple capabilities of BIM, ranging from enhanced visualization to comprehensive data integration, are perceived as instrumental in promoting a proactive approach to safety within the industry. Designers foresee that the integration of safety considerations within the BIM framework not only streamlines the design process but also lays a foundation for robust PTD practices.

[…] *Yes. I strongly believe that BIM, as our main tool, designers will soon apply such a concept of PTD. Even in our design analysis, there are many aspects of designs we can manipulate now that we didn't do before because of the absence of tools, but we can do now because of technology. So, I guess PTD will not be impossible for BIM.* […] Designer 4

[…] *As an engineer myself, I can attest that this technology, as it progresses, will make a lot of impact in the engineering and construction industry.* […] Designer 3

[…] *Yes. BIM's ability is comprehensive, and that may include the PTD soon.* […] Designer 7

Designers firmly believed in BIM's transformative potential as a pivotal tool for the architectural and engineering sectors, particularly in adopting PTD principles. The designer emphasized that BIM expands the scope of design analysis, enabling the manipulation and examination of various design aspects that were previously unattainable due to technological limitations. These capabilities could be conducive to integrating PTD into routine design practices. Designers further reinforced this perspective by outlining the benefits of adopting BIM technology in facilitating TD practices.

While designers recognize BIM's transformative potential for adopting the PTD concept, they also perceive significant challenges that could impact the widespread adoption of this integration. One primary concern is the existing technological limitations within some firms, particularly smaller ones, which may lack the advanced infrastructure required to implement and fully utilize BIM's capabilities. This gap could hinder the uniform adoption of BIM for PTD, as not all stakeholders might be equipped to handle BIM's sophisticated analysis and visualization. Additionally, there is a cultural resistance to change within the industry. The shift from traditional design and construction practices to those that incorporate BIM and PTD requires changing long-established workflows, which can meet significant resistance. Designers may be hesitant to adopt new methods without clear evidence of immediate benefits, and the industry might show reluctance in altering standard practices that have been effective in the past. In order to attain the implementation of PTD through BIM in the construction industry, designers suggested the critical steps that should be taken to facilitate this transition, such as compatibility of computers and software, inclusion in project contracts, policies, education, and standardization of PTD. Overall, while the potential benefits of integrating BIM with PTD practices are clear, the actual adoption faces practical challenges related to technology access, skill requirements, and acceptance among designers, and within the construction industry.

5.3.4 DISCUSSIONS ON THE SECOND FEASIBILITY STUDY

The feasibility study investigated the designers' perspectives on the applicability of BIM for PTD. By assessing their views on the effectiveness of BIM in their everyday design work, the following investigation explored their experiences and opinions on the appropriateness of these technical features for implementing PTD principles in the construction industry, particularly among structural designers. This systematic approach guaranteed a comprehension of how professionals viewed and utilized BIM's technical capabilities, specifically in the context of incorporating safety issues from the perspective of PTD.

5.3.4.1 The usefulness of BIM for PTD adoption

Integrating BIM technology into structural design fundamentally transforms conventional methodologies, resulting in greater efficiency, enhanced precision, more effective collaboration, and greater project results. Research supports the notion that BIM enhances decision-making by utilizing advanced visualization and simulation tools to detect and resolve design inconsistencies. The alignment of real-world experiences from designers with academic and research-based evidence implied BIM's significant impact in reshaping and improving the processes and outcomes of structural design.

This feasibility study revealed BIM's usefulness, which can significantly enhance construction safety and project efficiency. Firstly, BIM's 3D modeling capabilities allow structural engineers to visualize entire projects in three dimensions, which is instrumental in identifying potential safety hazards at the early design stages. This early detection capability enables designers to make informed decisions to mitigate risks before construction begins. Another significant advantage is BIM's ability to integrate a wide range of data, including safety guidelines and regulations, directly into the project model. This integration facilitates a comprehensive approach to safety management, where all necessary safety measures are considered and incorporated during the initial stages of design. It also allows for continuous updates and easy access to the most current safety standards, ensuring that the project complies with all regulatory requirements.

Moreover, BIM enhances collaboration among various stakeholders in a construction project. BIM enables seamless interactions between architects, engineers, contractors, and clients through its advanced sharing and communication tools. This improved coordination helps in aligning safety measures across different phases of the project and ensures that everyone is aware of and adheres to the safety protocols established during the design phase. This collaborative environment fostered by BIM is crucial for effectively implementing PTD principles, as it ensures that safety is a collective responsibility and is integrated into every aspect of the project lifecycle. These capabilities of BIM rationalize the design and construction processes and could be embedded with a safety-first approach from the outset, aligning perfectly with the objectives of PTD. The adoption of BIM for PTD thus holds the potential to transform traditional construction practices, making safety a foundational component of project design and management.

5.3.4.2 CHALLENGES TO THE APPLICATION OF BIM FOR PTD

While structural engineers recognize the substantial benefits of using BIM's 3D modeling capabilities for PTD, several challenges could persist, according to the designers. First, integrating comprehensive safety elements into BIM software demands significant customization and development to ensure all relevant safety data are appropriately visualized and actionable within the model. Engineers must also navigate the complexity of accurately translating safety standards and regulations into programmable features within BIM, which can be both time-consuming and technically demanding. Additionally, the effectiveness of 3D modeling for safety analysis depends on the accuracy and completeness of the input data; incomplete or inaccurate data can lead to misidentification of risks and potentially unsafe design decisions.

According to the designers, one significant challenge on BIM application for PTD is the need for extensive training and expertise to fully exploit the advanced visualization features of BIM software. Designers must be proficient in manipulating and interpreting complex 3D models to ensure accurate identification and analysis of safety hazards. Additionally, the integration of comprehensive safety data into the BIM visualization process requires robust data management systems and protocols to maintain data accuracy and relevance. Another challenge lies in the scalability of these visualization tools to handle large-scale projects where the complexity of the safety analysis significantly increases. Overcoming these challenges is crucial for enabling structural engineers to effectively implement PTD practices using BIM tools, thereby enhancing safety outcomes in construction projects. Additionally, there was the issue of training and expertise required to utilize these advanced visualization tools effectively. Not all designers may have equal proficiency with BIM software, leading to disparities in how effectively safety considerations are integrated into project designs. These challenges underline the need for tailored training programs, enhanced computational resources, and broader changes within the construction industry to leverage BIM's capabilities for PTD fully.

5.4 CHAPTER’S OVERALL DISCUSSIONS

The first feasibility study focused on the technical capabilities of BIM to enhance safety within construction projects through the development and validation of a methodological framework. This framework was designed to leverage BIM’s robust modeling, data integration, and visualization capabilities to effectively integrate PTD principles. The results from this study indicated significant promise; BIM's modeling and automated tools were effectively utilized to enhance safety by identifying risks and implementing preventive measures early in the design process. However, the study also highlighted challenges, primarily in terms of requiring substantial adaptation of existing BIM tools and the need for additional functionalities to support PTD-specific tasks. These challenges necessitate further development and customization of BIM tools to fully realize their potential in promoting safety.

The second feasibility study assessed the practical applicability of BIM for PTD from the perspective of structural designers through interviews and practical demonstrations. Designers acknowledged the advantages of BIM in facilitating a proactive approach to safety, particularly through enhanced visualization and collaboration capabilities that allow for the early detection and mitigation of potential hazards. Despite these benefits, designers expressed concerns about BIM technologies and the cultural shifts required within firms to adopt these new practices.

Both studies affirmed the transformative potential of integrating BIM with PTD, showcasing how such integration can fundamentally enhance the approach to safety in construction projects. BIM's capabilities can significantly improve the identification and management of risks, thereby embedding safety into the earliest stages of design. However, the transition to a BIM-based PTD approach is not without its challenges. These include technological limitations, the need for extensive training, and resistance to change from traditional practices, which could slow down adoption rates.

Moreover, the studies implied a critical need for industry-wide standardization and regulatory support to encourage the adoption of BIM for PTD. Ensuring that BIM tools comply with industry standards and safety regulations is crucial for their acceptance and effectiveness in real-world scenarios. The feedback from structural designers also indicates that while the potential for BIM to improve safety outcomes is recognized, the actual implementation requires concerted efforts in terms of training, support, and modifications to existing systems of the Philippines' construction industry.

Additionally, the subsequent subsections offer further discussions based on observations made in this feasibility study:

5.4.1 APPLICABILITY OF BIM TECHNOLOGY TO PTD AMONG STRUCTURAL DESIGNERS

The inherent technical capabilities of BIM facilitate the development of intelligent, dynamic models that maintain consistency and accuracy across all project elements. When modifications are made to any part of the model, BIM technology ensures that all related components are automatically updated to reflect these changes, thereby preserving the integrity and coherence of the overall design. This feature is particularly valuable in conducting safety assessments, where precision is paramount. Kamardeen (2010) emphasized that the advanced technical features of BIM render it an indispensable tool in embedding safety considerations within the design phase. By leveraging BIM, designers gain the ability to recognize and mitigate potential safety risks preemptively. This proactive approach to hazard identification and resolution shows the critical role of BIM's technical versatility in facilitating the effective incorporation of PTD principles.

BIM emerges as an important tool, surpassing traditional methods for construction safety assessment, especially in the context of PTD. BIM's distinct advantage lies in its complex technical capabilities, making it an advantageous asset for PTD. This is further reinforced by the fact that BIM empowers designers with the ability to proactively identify and address potential health and safety issues during the construction phase of their designed projects (Ganah & John, 2017). In practical terms, BIM possesses the potential to address the construction industry's ongoing challenges in PTD adoption by heightening designers' awareness of construction hazards. It equips designers to be cautious regarding the potential health and safety risks that might arise during the construction phase of projects. This awareness, in turn, can lead to enhanced safety measures, risk reduction, and overall improved project outcomes.

The engineers perceived an enhancement of BIM software to become a more robust and safety-oriented tool. Designers in the Philippines highly sought the proposed addition of 3D model features that would simplify the identification and handling of safety considerations during all stages of the construction project. In essence, BIM’s technical features have become instrumental in improving the designers' ability to consider complex aspects of designs. Thus, this alignment between BIM technology and PTD implementation was viewed to be pivotal in raising a safety-conscious culture among design professionals. They emphasized how BIM enhances communication among project stakeholders, enabling real-time data sharing and producing a more collaborative work environment. This immediate exchange of information ensures that all parties are informed and engaged throughout the project lifecycle. Moreover, BIM's ability to integrate design and construction processes modernizes project workflows, improves decision-making by providing comprehensive data insights, and increases overall project efficiency.

Therefore, these responses from structural designers explained the optimistic outlook on the applicability of BIM technology for PTD. The consensus is that BIM's advanced capabilities not only enhance current design and construction practices but also will pave the way for a more safety-conscious approach to project development, aligning with the principles of PTD.

5.4.2 BENEFITS OF BIM TECHNOLOGY TO STRUCTURAL DESIGNERS

Using BIM technology in structural designing brought many benefits, transforming traditional design processes into more efficient, accurate, and collaborative practices (Gragnaniello et al., 2024). Structural designers gained the ability to create detailed digital representations of physical and functional characteristics of structures, which facilitates a range of advantages (Abuhussain et al., 2024; Chiu & Lai, 2020). The responses provided by the present study's designers aligned with existing research findings regarding the advantages of utilizing BIM technology within structural designing (Bai et al., 2021; Chiu & Lai, 2020). This alignment showed the consistency and reliability of BIM's impact on the AEC industries. The designers' feedback reflects a broad consensus on the positive outcomes associated with BIM.
The study affirmed BIM’s ability to develop precise and detailed digital models of structures, encompassing all design elements, including materials and geometrical dimensions. Structural designers stressed that BIM could provide powerful visualization tools that allow designers to view the structural model in three dimensions and visualization of structural behaviors (e.g., stresses, deflections, and deformations). This capability simulates various scenarios, such as structural loads and performance under different conditions.

One of the significant benefits of using BIM is its ability to detect clashes or conflicts between different design elements, such as pipes running through beams (Chahrour et al., 2021). Structural engineers agreed that early detection of these issues helps resolve them before construction begins. As a result, they save time and money associated with rework. Subsequently, once conflicts are identified, designers can collaborate with other designers (e.g., architects and electrical engineers) using BIM. The shared digital environment enables real-time communication and coordination, ensuring that all parties are aligned and informed, which helps avoid conflicts and delays.

5.5 CHAPTER’S SUMMARY

The initial feasibility study conducted a comprehensive technical demonstration to investigate the practical application of BIM in the field of PTD. The exploration led to the creation of a comprehensive framework that acts as a methodological framework, providing insight into the possible integration of PTD principles and safety management practices into BIM environments. This framework utilizes BIM's technical capabilities and customizes these functionalities to address the specific requirements and important factors for conducting PTD assessments. The framework was validated through the development of a PTD tool. It offered practical perspectives on design models, implying the substantial advantages of BIM technologies when implemented in PTD initiatives. As a result, the combination of BIM tools and PTD strategies has been proven to be applicable for industry practitioners, particularly structural designers, by improving the safety and efficiency of construction projects.

The second feasibility study focused on assessing the industry professionals' perspective on the feasibility of integrating BIM for PTD. The investigation revolved around structural designers' familiarity with BIM and aimed to extrapolate their perceptions of BIM’s applicability to PTD. The study strategically centered on the well-established capabilities of BIM in design work and sought to gauge professionals' insights into its potential extension to construction safety assessment and PTD. Designers actively articulated the advantages and benefits derived from employing BIM in their design tasks, attributing their positive experiences to the platform's multiple technical capabilities. Building upon this foundation, designers voiced ideas about the conceivable applications of BIM in the domain of construction safety assessment and its potential role in facilitating PTD principles. Collectively, designers expressed a favorable view, asserting that BIM holds substantial promise for PTD applications. Moreover, there was unanimous agreement among industry professionals that BIM, as a tool, could serve as a significant enabler for adopting PTD practices within the construction industry.

Therefore, the applicability of BIM for PTD is grounded in its technical capabilities, which facilitate the systematic identification and mitigation of construction-related hazards during the design phase. This part of the study has explored BIM's applicability for PTD on two sides.

This agreement further points out BIM's perceived value and potentially transformative impact in enhancing safety considerations throughout the project lifecycle, as Hardison et al. (2020) and Eastman et al. (2011) pointed also in their works. In principle, the insights from the feasibility studies emphasized how BIM transforms the design phase, making it a more dynamic, interactive, and error-resistant process and how it could transform safety analysis. Moreover, PTD is well applicable to PTD, and the construction industry can implement PTDs by leveraging BIM's capabilities.

Furthermore, the findings from the two feasibility studies serve as a foundation for the third phase of this research by providing insights into the practical applicability of BIM in PTD. This comprehensive understanding of BIM's technical feasibility and integration challenges directly supports the next phase of the study by offering a tested framework of BIM’s socio-technical qualities to improve PTD adoption through BIM technology.

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PHASE III RESULTS AND DISCUSSIONS

6.1 INTRODUCTION

This chapter presents the results and discussions from the third phase of the study, focusing on the socio-technical framework influencing the adoption of BIM for PTD among structural engineers. The study begins by analyzing responses from a survey of structural engineers, initially examining respondents' demographic and professional profiles (Section 6.2). It then progresses to data screening in Section 6.3 to test the suitability of data for the proposed methods. Chapter 6.4 assesses the validity of measurement constructs to confirm the relationships among indicators and constructs. Section 6.5 details the results of the confirmatory factor analysis. The main method of analysis, the Structural Equation Modeling, is covered in Section 6.6, which also includes the necessary cross-validation of data to validate the model internally (Section 6.7). Subsequent discussions in Section 6.8 address the theoretical and practical implications of the model. The chapter concludes with a summary of the findings.

6.2 RESPONDENTS' DEMOGRAPHICS

At the beginning of the research, the study aimed to engage the perspectives of approximately 300 engineers through a comprehensive survey. As outlined in Chapter 3, this particular number was carefully chosen to serve as a representative sample of the broader population of structural engineers. Notably, the response rate to the survey was 44%, meaning that 131 out of the 300 questionnaires distributed were successfully returned with complete responses. Consequently, the researchers had enough dataset comprising 131 responses to analyze and draw conclusions.

In the context of the engineering profession in the Philippines, it is a prerequisite for aspiring engineers to earn a bachelor's degree in Civil Engineering prior to becoming eligible for the relevant licensing examination. Thus, each of the one-hundred-thirty-one respondents possessed a degree equivalent to a bachelor's. However, it is interesting to observe that a significant portion of the respondents (32%) had taken their education a step further and held master's degrees, demonstrating a commitment to advanced learning and specialization. In contrast, a smaller fraction (5%) held doctorate degrees, signifying the presence of highly educated and expert engineers in the sample (Figure 6.1).

Age-wise, the distribution of respondents revealed that the age group between twenty-six and thirty years old is most prominently represented, making up a significant 43% of the total respondents. This indicates a concentration of younger professionals in the engineering field, possibly suggesting a recent surge in interest and recruitment within this age range. Notably, most of the respondents (28%) identified themselves as senior structural engineers. This was a significant finding as it indicated that a substantial proportion of engineers in the sample had attained a high level of expertise and experience within their respective fields. 21% of the respondents were principal engineers or firm owners. An equally prominent segment of respondents, 28%, were identified as freelance structural designers and senior structural engineers (Figure 6.2). Such may indicate a trend toward more flexible work arrangements in the engineering industry or a thriving freelance market for specialized engineering services. This unique mix of professional backgrounds within the surveyed group provides valuable insights into the diverse and dynamic landscape of the engineering profession in the Philippines.

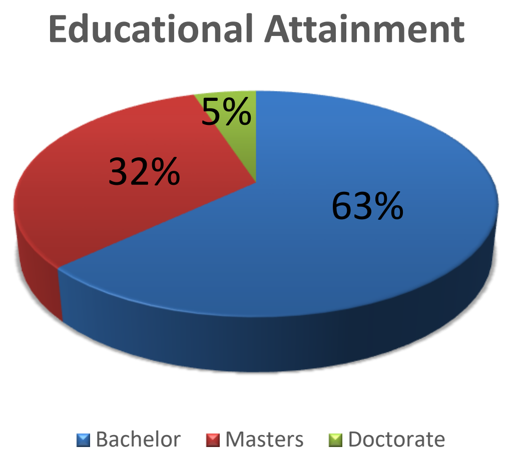


Figure 6.1 Respondents' Educational Attainment.

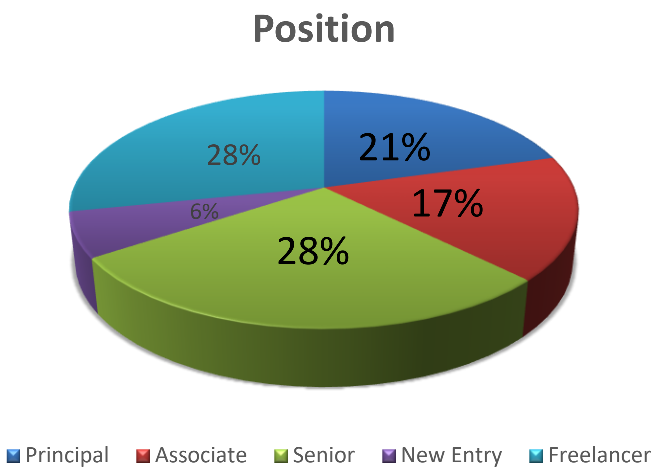


Figure 6.2 Respondent's Job Positions.

6.3 DATA SCREENING AND TEST OF NORMALITY

Among the 131 responses collected for this study, there were no instances of missing data, and none of the z-values exceeded the threshold of 3.29, demonstrating the robustness and completeness of the dataset. In addition to screening for outliers and missing data, the normality of the dataset was assessed, which is a crucial step since the statistical techniques further used in the study's analysis relied on the assumption of normality. The skewness and kurtosis parameters, which reflect the shape of the data distribution, were found to fall within the acceptable range of +2.00 to -2.00, according to Garson (2012). This indicates that the dataset can be considered to have a normal distribution. As a result, the findings from these data screening procedures provided strong support for the utilization of maximum likelihood estimates (MLE) in the subsequent confirmatory factor analysis (CFA), ensuring that the statistical techniques employed in the study were well-suited to the characteristics of the data and could yield valid and meaningful results.

6.4 VALIDITY OF MEASUREMENT CONSTRUCTS

The validity of the measurement constructs was assessed and summarized in Table 6.1, a critical step in any empirical study. This assessment revealed that the Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) values exceeded the threshold of 0.6, signifying their suitability for factor analysis. Furthermore, the alpha coefficient values for all five scales, ranging from 0.652 to 0.875, were not only well above the permissible lower limit, which typically falls in the range of 0.60 to 0.70, but the majority of these coefficients also fell within the very satisfactory range of 0.80 to 0.90, as defined by Hair (2009). This suggested that the measurement scales employed in the study were highly reliable and consistent in measuring the intended constructs. In conclusion, the analysis conducted in this study demonstrated that the measurement scales used comprised a set of reliable and consistent variables for capturing the meaning and nuances of the model constructs. These measures served as the foundation for developing combined factors, simplifying the subsequent model analysis, and bolstering the overall integrity of the research findings.

Table 6.1 Validity of Measurement Constructs.

Construct	Kaiser-Meyer-Olkin measure of sampling adequacy	Bartlett's Test of Sphericity			Cronbach's alpha
		Approx. Chi-Square	df	P-value	
Behavioral intention to adopt BIM for PTD (BI)	0.685	234.617	3	0.0000	0.875
Perceived usefulness of BIM for PTD (PU)	0.686	224.694	3	0.0000	0.859
Perceived ease of use of BIM for PTD (PEOU)	0.628	57.174	3	0.0000	0.652
Perceived relative advantage of using BIM for PTD (PRA)	0.724	186.196	3	0.0000	0.860
Perceived Benefits of Using BIM for PTD (PB)	0.672	97.827	3	0.0000	0.754

6.5 CONFIRMATORY FACTOR ANALYSIS

The results of this measurement model are presented in Table 6.2. The model's overall fit was assessed using a range of established criteria and was determined to demonstrate an acceptable level of fit. This was evident in the chi-squared statistic (χ2), which recorded a value of 141.82 with 80 degrees of freedom (df). The chi-squared to degrees of freedom ratio (χ2/df) was computed at 1.773, reflecting a favorable fit. Additional fit indices, including the goodness-of-fit index (GFI), Tucker-Lewis index (TLI), comparative fit index (CFI), and incremental fit index (IFI), all surpassed the desirable thresholds. Furthermore, the root mean square error of approximation (RMSEA) was evaluated (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), which was indicative of a reasonable fit to the data, as determined by these established criteria. Hair et al. (2009) asserted that each of the indicators loaded significantly on their respective constructs, with a significance level of $p < 0.001$, reinforcing the strong relationship between the measurement items and the constructs under investigation. Importantly, the loadings of all indicators surpassed the critical threshold of 0.50, as shown in Table 6.2, further validating the effectiveness of these measurement items in representing their respective constructs within the model.

Therefore, the deployment of CFA and the thorough assessment of the measurement model revealed that the model exhibited an acceptable level of fit to the data. Results substantiated its suitability for investigating the relationships and patterns within the study's constructs. Regarding the reliability of the indicators, it was seen that a number of items had R^2 values that fell significantly below the widely acknowledged criterion of 0.50. This suggests that these particular items might be considered for removal from the analysis. Nevertheless, the factor loadings of all indicators exhibited substantial significance. Consequently, it was concluded that all items should be retained inside the measuring model. The findings of this study suggest that the measurement model has satisfactory levels of convergent validity. Furthermore, the measurement model can be employed to evaluate the structural model due to the satisfactory fit indices obtained.

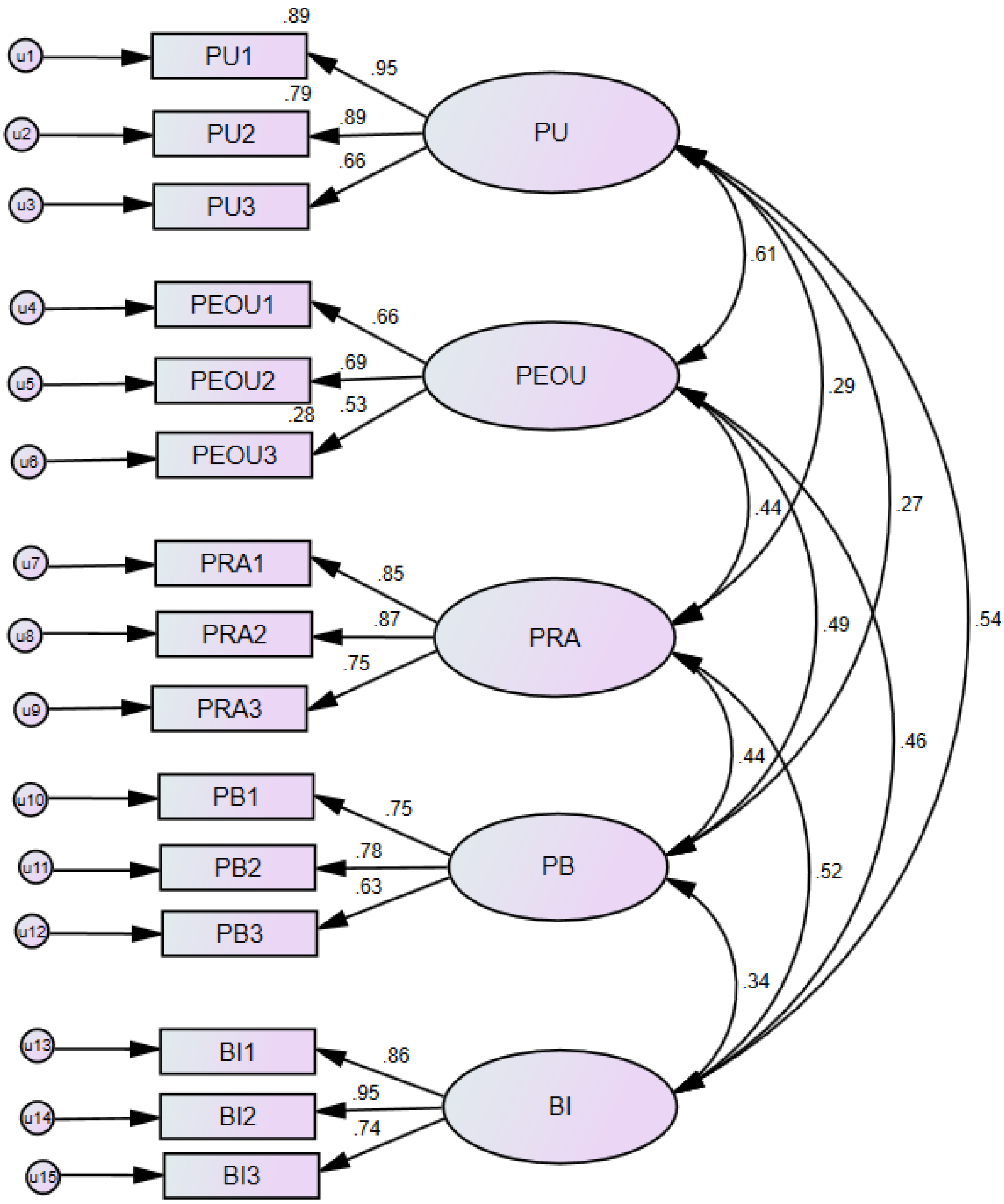


Figure 6.3 The Measurement Model.

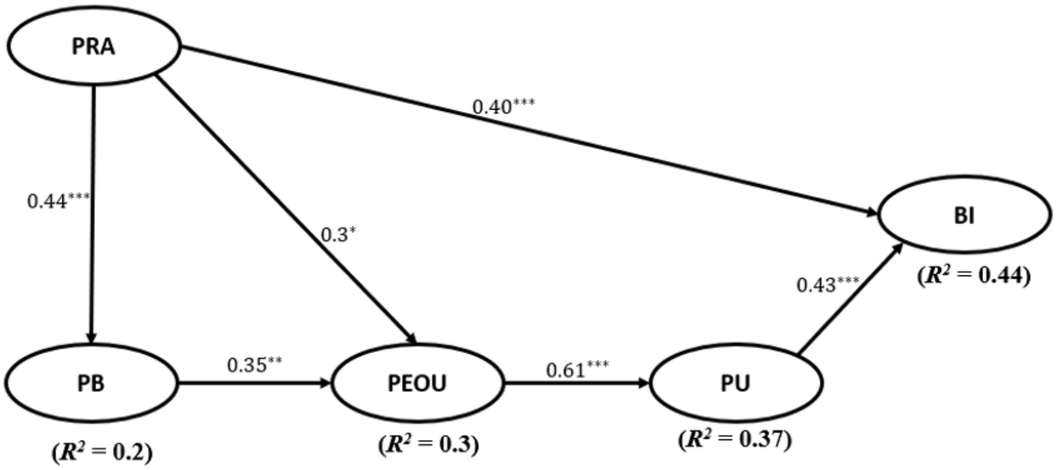
Table 6.2 Measurement Model Results.

Constructs/factors	Loadings	t-value *	R^2
Perceived usefulness of BIM for PTD (PU):			
PU1	0.945	f.p.	0.893
PU2	0.89	14.137***	0.792
PU3	0.661	8.853***	0.436
Perceived ease of use of BIM for PTD (PEOU):			
PEOU1	0.656	f.p.	0.43
PEOU2	0.695	5.543***	0.483
PEOU3	0.534	4.709***	0.285
Perceived relative advantage of using BIM for PTD (PRA):			
PRA1	0.853	f.p.	0.727
PRA2	0.873	10.986***	0.762
PRA3	0.746	9.368***	0.556
Perceived Benefits of Using BIM for PTD (PB):			
PB1	0.748	f.p.	0.559
PB2	0.781	6.722***	0.61
PB3	0.626	6.058***	0.392
Behavioral intention to adopt BIM for PTD (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 $p < 0.001$.

6.6 STRUCTURAL MODEL ASSESSMENT

Once the validity of the measurement model had been established, the study proceeded to explore the structural model. Given that the measurement model had demonstrated a fit to the dataset, there was no need to revise the initial conceptual structural model (Figure 3.5). The hypothesized relationships between the model constructs were scrutinized to understand their interactions and associations. To ensure that the final model offered the most accurate and reliable explanation for the data, a comparison was made between the fit indices of the original conceptual model and those of the refined model. This comparative analysis aimed to adjust the model and confirm that it effectively represented the underlying dynamics within the dataset. As depicted in Figure 6.4, the results of the final structural model were presented with standardized path coefficients, providing a clear visual representation of the relationships between the various constructs. This made it easier to interpret the findings and offered a basis for further analysis and discussion.



Model fit indices: 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.
* $p < 0.05$; ** $p < 0.01$; ***$p < 0.001$.

Figure 6.4 Final Structural Model with Standardized Path Coefficients (Indicators not shown).

Thus, the fit indices for the final model were scrutinized and found to be indicative of a satisfactory level of model fit (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). This suggests that the model was well-aligned with the data, reinforcing its validity and reliability in capturing the relationships and patterns between the constructs under investigation. The findings of the study revealed a complex network of relationships among the various constructs under investigation. The PRA construct, acting as an exogenous variable, was identified as a significant driver with a positive impact on several other constructs. It was observed that PRA had a substantial and positive influence on the PB construct, with a path coefficient of 0.44 ($p < 0.001$). This implies that when perceived relative advantage (PRA) increased, it had a correspondingly positive effect on the perceived behavioral intention (PB) of the individuals in the study. Additionally, PRA was found to have a significant impact on both the PEOU (0.3, $p < 0.05$) and BI (0.4, $p < 0.001$) constructs, indicating that individuals who perceived a greater relative advantage were more likely to exhibit a positive attitude toward the behavior (BI) and find the system easy to use (PEOU).

Table 6.3 Final Model Path Coefficient.

Path	**Hypothesis**	***Standardized 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	0.4	4.639***
PRA → PU	H3a	<<<<< Path removed >>>>>	
PRA → PEOU	H3b	0.3	2.376*
PRA → PB	H3c	0.44	4.07***
PB → BI	H4	<<<<< Path removed >>>>>	
PB → PU	H4a	<<<<< Path removed >>>>>	
PB → PEOU	H4b	0.35	2.536**

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

Moreover, the PB construct was identified as a significant influencer, particularly with a substantial effect on the PEOU construct (0.35, $p < 0.01$). This finding suggests that positive perceived behavioral control is associated with an easier perception of system use (PEOU). Additionally, the PEOU construct was strongly linked to the PU construct (0.65, $p < 0.001$), signifying that the ease of use was a critical factor in determining perceived usefulness. Lastly, the PU construct was found to significantly impact the BI construct (0.43, $p < 0.001$), indicating that when individuals perceive a system as useful, they are more likely to have a positive attitude toward the behavior.

Contrary to the conceptual model (Figure 3.5), the study did not find direct impacts from the PB or PEOU constructs on the BI construct, suggesting that the data did not support these relationships (H2 and H3a). Furthermore, the expected links from the PB construct to the PU construct and from the PRA construct to the PU construct were not significant. Therefore, the paths denoted by H4 and H4a were excluded from the model.

6.7 DATA CROSS-VALIDATION

This study undertook an internal validation of the data collected rather than focusing on model validation, as justified in Section 3.5.7.5. In SEM, validation involves a thorough cross-validation process that ensures the model's theoretical soundness and empirical robustness across various data subsets. This validation method is critical in SEM as it not only tests the model's consistency but also confirms its reliability and accuracy when applied to different data segments. Such rigorous validation is essential for affirming that the model can be generalized and is effective in representing the underlying phenomena across diverse conditions and samples.

The data was segmented into three parts: X1, X2, and X3. The outcomes of these cross-validations are presented in Table 6.4. For each case, the Xth segment served as the testing data, with the remaining segments used for training. The fit indices for each model were assessed in every scenario, and their averages were subsequently computed.

Table 6.4 Cross-validation Results.

Model Fit Indicators	Case 1 Test data = X1	Case 2 Test Data = X2	Case 3 Test Data = X3	Average value
χ2/df	1.39	1.87	1.557	1.72
GFI	0.74	0.75	0.73	0.74
CFI	0.89	0.87	0.89	0.88
IFI	0.89	0.75	0.89	0.84
RMSEA	0.10	0.09	0.11	0.1

Results showed that except for the Normed chi-square (χ2/df), the averages of model fit indicators were missing the ideal values: GFI $\geq$ 0.90, CFI $\geq$ 0.90, IFI $\geq$ 0.90, and RMSEA $<$ 0.08. This result was expected because of the small number of datasets. However, the Comparative Fit Index (CFI) is relatively considerable. According to Bentler (1990), among the SEM fit indices, the CFI is less dependent on sample size compared to others like the Normed Chi-Square or the Root Mean Square Error of Approximation (RMSEA). Bentler introduced the Comparative Fit Index (CFI) as part of the discussion on fit indices in structural equation modeling. He explained how CFI is calculated and discussed its properties, including its relative robustness to sample size effects compared to other indices. While CFI is less sensitive to sample size, it is important to note that no fit index is entirely unaffected by sample size. Large samples may lead to the over-rejection of models due to the detection of trivial discrepancies, while small samples may not provide enough power to detect significant model misfits. That is why SEM uses a combination of fit indices to assess the adequacy of a model rather than relying on a single index.

Therefore, the 3-fold cross-validation process conducted in the study has effectively substantiated the model's robustness and validity from both a theoretical and empirical standpoint across different segments of the data. This method divided the dataset into three distinct parts, each serving as a test set, while the remaining data were used to train the model. This approach allowed for evaluating the model's performance in predicting new, unseen data, which is crucial for assessing its generalizability and reliability.

6.8 PHASE III DISCUSSIONS

This phase of the study provides a comprehensive exploration of the theoretical and practical implications of the study's findings. The subsections critically analyzed the results from the structural equation modeling and their significance in both theoretical frameworks and practical applications, aiming to offer actionable insights and recommendations for effectively implementing BIM for PTD in the construction industry.

The empirical study produced evidence supporting most of the hypothesized causal pathways leading to the intention to adopt BIM for PTD, thereby shedding light on the potential dynamics that influence its adoption within the construction industry. The outcome of this study, both theoretical and practical, was grounded in empirical analysis, the application of relevant models or theories, and the interpretation of findings. These theoretical outcomes may include, but are not limited to, identifying relationships between variables, determining the statistical significance of findings, establishing causal links, or offering new perspectives on established concepts..

6.8.1 MODEL’S THEORETICAL IMPLICATIONS

The findings of this study represented a significant contribution to the existing body of knowledge, particularly in the context of BIM as a pivotal mediator in driving the adoption of PTD within the construction industry. While this research corroborates the existence of direct correlations, it extended beyond and uncovered valuable indirect relationships that offer academics and practitioners deeper insights into the subject. Analyses revealed noteworthy parallels with findings from prior research.

6.8.1.1 THE PERCEIVED USEFULNESS

The perceived usefulness of BIM for PTD is shown to have a substantial and direct influence on the intention to adopt BIM for PTD. This result aligned with the classic TAM (Davis et al., 1989). Perceived usefulness plays a pivotal role in determining the likelihood of technology adoption, as it reflects the extent to which individuals believe that using a particular technology will enhance their job performance or task efficiency. This result was also affirmed in technology adoption studies such as E-Learning (Park, 2009), mobile banking (Riquelme & Rios, 2010), healthcare technology (Holden & Karsh, 2010), E-Government services (Carter & Bélanger, 2005), and BIM in the construction industry (Lee et al., 2015). This concept is grounded in the belief that users are more inclined to adopt and utilize a technology if they perceive it as beneficial in improving their work outcomes or simplifying complex tasks.

6.8.1.2 THE PERCEIVED EASE OF USE

In this study, the ease of use of technology does not affect the intention to adopt the technology. It is worth noting that the relationship between ease of use and behavioral intention can vary depending on the specific context, product, or system under consideration. This study's inclusion of such a hypothesis is well-founded, acknowledging the contextual nuances that can impact technology adoption. Nevertheless, the results consistently align with previous research by indicating that there is no significant direct relationship between behavioral intention and ease of use (Amoako-Gyampah, 2007; Calisir et al., 2009; Davis, 1989; Jackson et al., 1997; S. Y. Park et al., 2012). This implies that while ease of use might be a factor in the overall acceptance and use of technology, in the current study, the simplicity of BIM does not independently predict whether designers intend to use it for PTD. However, ease of use significantly impacted perceived usefulness, emphasizing user-friendliness's importance in shaping perceptions of usefulness (Ma, 2021).

6.8.1.3 THE PERCEIVED RELATIVE ADVANTAGE

The perceived relative advantage of utilizing BIM for PTD was established as a significant direct influencer on the behavioral intention to adopt BIM for PTD. In the context of Rogers' Diffusion of Innovations theory, relative advantage refers to the degree to which an innovation is perceived as better than the idea it supersedes (Rogers, 2003). Empirical studies within the domain of construction technology adoption further support this relationship. For instance, Gu and London (2010) stressed that the perceived advantages of BIM, such as improved visualization, coordination, and error reduction, play a crucial role in its adoption for various construction processes, including safety management. Similarly, Hasanzadeh et al. (2017) found that the perceived benefits of BIM, including its capacity to enhance safety planning and risk management, directly impact professionals' intentions to integrate BIM into their practices. The assertion that the perceived relative advantage of using technology has been identified as a significant direct influencer on the behavioral intention to adopt technology illustrates the importance of perceived benefits in the decision-making process related to technology adoption. These results demonstrated that BIM's relative advantage has a pivotal role in driving the acceptance and implementation of innovative concepts like PTD.

6.8.1.4 THE PERCEIVED BENEFITS

The study revealed that the perceived benefits of using BIM for PTD do not directly influence a designer's intention to engage in PTD through BIM. This suggests that while designers may recognize and appreciate the advantages BIM offers for implementing PTD principles—such as enhanced visualization, improved coordination, and more effective hazard identification—these perceived benefits alone may not motivate a direct intention to adopt BIM-based PTD methodologies in their work. This finding aligns with the complex nature of technology adoption behaviors, where multiple factors, beyond perceived benefits, influence decision-making. For example, a study by Tarhini et al. (2014) explored the adoption of e-learning systems and found that perceived benefits indirectly influenced adoption intentions through perceived usefulness and ease of use. In mobile banking adoption, Al-Jabri and Sohail (2012) found that perceived benefits did not directly impact the intention to use mobile banking services. In the context of BIM adoption, a study by Son et al. (2015) found that while the perceived benefits of BIM (such as improved collaboration and efficiency) were important, they did not directly influence the intention to adopt BIM. Instead, these benefits influenced the perceived usefulness and ease of use of BIM, affecting the intention to adopt it.

6.8.2 MODELS' PRACTICAL IMPLICATIONS

The theoretical findings from this research substantially contribute to our understanding of the subject matter. They could serve as a foundation for practical implications that have significance in the construction industry. It is paramount to gain a comprehensive grasp of the role that technology, particularly BIM, plays in adopting PTD within the construction sector, particularly among designers who are key stakeholders in the safety of construction processes.

6.8.2.1 THE PERCEIVED USEFULNESS OF BIM FOR PTD

The SEM analysis of the available evidence from this study showed that perceived usefulness stands out as the most potent factor influencing behavioral intention. This finding holds valuable implications for management and decision-makers within the industry, revealing that designers will prioritize technology's utility and practical value over other socio-technical aspects. In addition, this means that the perceived usefulness of a BIM technology plays a pivotal role in shaping the perceptions of its users. When a BIM tool is perceived as highly useful, it becomes an appealing choice for adoption, even if it requires some level of learning or adaptation. From a management perspective, this insight signifies the importance of promoting BIM's usefulness and relative advantages in the context of PTD. It implied that industry efforts and initiatives should emphasize how BIM can significantly improve the effectiveness of safety measures, reduce risks, and enhance overall project outcomes. These aspects should be communicated as key selling points to encourage designers and other stakeholders to adopt PTD as a practical approach.

6.8.2.2 THE PERCEIVED RELATIVE ADVANTAGE OF BIM FOR PTD

The PRA is a critical factor in technology adoption theories, suggesting that if a new technology offers clear advantages over existing solutions, it is perceived that users will more likely intend to use the technology. In the context of BIM, when professionals perceive BIM as offering significant advantages over traditional construction methods, such as improved collaboration, efficiency, and accuracy, they are likely to find BIM more valuable. Among the hypothesized external antecedents, it has been determined that BIM's relative advantages and benefits carry weight regarding perceived usefulness and ease of use. This relationship suggests that when individuals perceive technology as having superior benefits compared to existing solutions, they are more likely to find it useful. It is crucial to recognize and communicate the unique advantages of BIM to potential users to increase its perceived usefulness and adoption rates during the adoption process.

6.8.2.3 INFERRED RECOMMENDATIONS TO THE CONSTRUCTION INDUSTRY

This finding revealed 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 practical 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.

While ease of use and other benefits of using BIM should not be neglected, the primary emphasis should be placed on BIM's transformative potential in terms of enhancing safety and construction processes. By effectively communicating these advantages, the industry can harness the intrinsic motivation of professionals to prioritize the utility of technology over its ease of use, thus driving the widespread adoption of BIM in the context of PTD. This approach aligns with the broader trends in technology adoption, where users increasingly seek out tools that offer tangible benefits and meaningful outcomes in their professional work.

By embracing BIM as a potent tool in PTD, designers and other industry stakeholders can enhance safety, mitigate risks, and ultimately elevate the overall quality of construction projects. This approach aligns with contemporary trends in the construction industry, where the integration of advanced technologies such as BIM is recognized as a driving force for improved safety practices and better project outcomes. In addition, BIM should be viewed as a tool that enhances and complements existing safety practices and standards instead of a stand-alone solution. The construction industry must increase stakeholders' awareness of BIM's capabilities for PTD.

6.9 CHAPTER’S SUMMARY

The study posited that technology adoption is influenced by its technical capabilities and the socio-technical dynamics surrounding it. This argument emphasizes the interplay between technological features and the social context in which the technology is embedded. It suggests that for a technology to be successfully adopted, there must be alignment between its functionalities and the industry's social, organizational, and cultural factors.

The exploratory study derived a model that offered empirical insights into the workings of BIM quality constructs and their pivotal role in shaping the adoption of PTD practices within the construction industry. The study was conducted within the Philippine construction industry, specifically among structural engineers, and involved 131 participants who completed the questionnaires. An extensive model analysis was conducted using the SEM technique to validate the model's components. One significant outcome of this research is the potential for the developed model to serve as the foundation for a comprehensive framework to diagnose the current state of PTD adoption in the Philippines. This framework, built on empirical findings, may offer valuable insights that can be used to enhance and promote the diffusion of PTD practices among designers in the construction industry.

At its core, the study revealed that BIM's perceived usefulness and relative advantage for PTD represent the primary driving forces behind a designer's behavioral intention to adopt BIM for PTD. These two factors emerge as key determinants, emphasizing the importance of recognizing BIM's usefulness and advantages to PTD practices. The ease of using BIM indirectly influences the formation of these intentions, underlining the significance of user-friendliness and accessibility in facilitating technology adoption. The study's insights hold substantial value, particularly in the construction industry context and the challenges designers face in embracing PTD practices.

Moreover, the study highlighted the need for formulating and implementing policies geared toward effectively adopting PTD within the construction sector, particularly from a socio-technical perspective. The model's insights should inform these policies and can guide policymakers in the Philippines. In summary, this research significantly contributes to the knowledge base in this field, providing practical guidance for industry stakeholders, engineers, and policymakers interested in enhancing safety and efficiency within the construction industry.

OVERALL RESEARCH IMPLICATIONS

This chapter provides further inferences based on the study's overall results. It extrapolated the findings concerning the established objectives and hypotheses, further examining how the results align with or diverge from the existing body of knowledge. Through a critical evaluation of the findings, this section also aimed to contextualize the implications of the research within broader academic and practical situations. Section 7.1 discusses targeted interventions that could facilitate the wider acceptance and implementation of PTD principles. Section 7.2 focuses on how BIM can be effectively utilized to support PTD adoption, leveraging its technological capabilities to improve safety outcomes. Section 7.3 proposes targeting designers as early adopters of PTD, recognizing their pivotal role in the integration of safety practices at the design phase. Section 7.4 explores the significant influence of stakeholders on PTD adoption, emphasizing the need for collaborative efforts across all levels of project execution. Section 7.5 addresses developing and enforcing PTD policies that could support structured implementation within the industry. Finally, Section 7.6 examines the broader drive towards adopting BIM in the Philippines' construction industry, highlighting the potential benefits and challenges associated with this technological shift.

7.1 PTD ADOPTION

The adoption of PTD in the construction industry is crucial for several compelling reasons, primarily revolving around enhancing safety, reducing costs, and improving project outcomes. Firstly, PTD focuses on eliminating hazards at the design stage, which can significantly reduce the risk of workplace injuries and fatalities. By addressing potential risks early, PTD minimizes the need for protective measures or retrofitting later in construction, leading to safer work environments (Gambatese et al., 2005). Secondly, implementing safety measures during the design phase can be more cost-effective than making changes during construction or after completion. PTD can lead to significant cost savings by avoiding the expenses associated with accidents, such as medical costs, compensation, and project delays (Hecker et al., 2005). In terms of improving project outcomes, PTD contributes to the overall quality and efficiency of construction projects. According to Toole (2002), by considering safety alongside functionality and aesthetics from the outset, PTD leads to more thoughtful and holistic project designs, enhancing project outcomes and stakeholder satisfaction. Behm (2005) explored the legal and regulatory aspects of integrating safety into design and found that adopting PTD practices can help construction firms comply with safety regulations and standards, potentially reducing legal liabilities and insurance costs associated with construction accidents.

PTD is still a novel idea for structural designers in the Philippines, as preliminarily explored in the study. As in other countries, the implementation of PTD met significant barriers (Che Ibrahim & Belayutham, 2020; Toh et al., 2017). However, there is still potential for the concept of PTD to be implemented because of its promising concept for construction safety (Toole & Erger, 2019). The study identified the lack of adequate design tools as a significant barrier to the adoption of the PTD concept within the construction industry in the Philippines. By drawing on the literature and preliminary investigations, this research has explained the potential of leveraging existing BIM technologies as a strategic intervention to overcome barriers to PTD adoption.

This research has emphasized the value of providing designers with advanced computational and analytical tools, suggesting that such resources are instrumental in facilitating the successful integration of PTD into design processes. This strategic approach augments designers' awareness and understanding of Occupational Safety and Health (OSH) considerations in their projects and enhances their ability to address safety concerns through design proactively. Given these insights, the study emphasized the critical need to examine the viability and efficacy of embedding PTD principles within technologies. This exploration held the promise of projecting a new path for elevating construction safety standards across the industry.

Adopting PTD is not just a safety measure but a strategic and innovative approach that offers comprehensive benefits, from enhancing worker safety and project efficiency to contributing to the industry's sustainability goals. This research collectively illustrates the complex advantages of PTD, advocating for its wider adoption in the construction sector.

7.2 BIM FOR PTD ADOPTION

The research findings emphasized the critical role of BIM in driving the adoption of the PTD concept within the construction industry. By capitalizing on BIM's sophisticated features at the early stages of design and planning, the study illustrated BIM's capacity to embed safety measures into the project lifecycle, thus embodying the essence of PTD. The study calls for a broader acknowledgment of BIM's role beyond its traditional applications in design and construction. It emphasized BIM as an essential facilitator of PTD principles. This BIM-based approach could encourage stakeholders across the industry to utilize BIM's capabilities to fully enhance construction safety standards. These assertions were in line with the study of Eastman et al. (2011), which provided a comprehensive overview of BIM technologies, including their implications for improving construction safety through early integration in the design process. Furthermore, Azhar (2011) also considered the broad spectrum of BIM's capabilities and potential benefits for the construction industry and emphasized BIM’s role in enhancing safety through early design interventions. The concept of integrating safety considerations into the design phase, providing a foundational basis for the principles of PTD, and emphasizing the potential of BIM in this study was also asserted by researchers (e.g., Gambatese et al. (2005) and Sacks et al. (2013)).

Consequently, adopting a BIM-based methodology for integrating PTD principles is considered highly advantageous. This approach leverages BIM's comprehensive technical capabilities to embed safety considerations directly into construction projects' design and planning phases. By utilizing BIM as a foundational tool for PTD, designers and project teams can proactively identify and address potential hazards before they manifest on the construction site, enhancing overall project safety. The socio-technical features of BIM make it appealing to PTD.

Furthermore, the socio-technical attributes of BIM, including its perceived usefulness, ease of use, relative advantage, and associated benefits, significantly contribute to its attractiveness as a tool for PTD. These features combine the social aspects of technology adoption with the technical capabilities of BIM, creating a compelling case for its integration into PTD practices. By blending social factors with technical functionalities, the socio-technical features of BIM align well with the goals of PTD, making it an appealing choice for construction professionals looking to prioritize safety from the design phase onwards.

7.3 TARGETING DESIGNERS TO BE THE EARLY ADOPTERS OF PTD

This study showed that BIM technologies could serve as instrumental tools for the implementation of PTD, with their advanced capabilities acting as catalysts to facilitate the adoption of PTD practices. However, it is important to recognize that the primary focus of PTD lies with designers. Given their pivotal role in the initial stages of project planning and design, designers are in a position to integrate PTD principles. Their capacity to incorporate safety considerations into the design phase makes them key players in the widespread adoption and successful implementation of PTD within the construction industry.

This research was conducted with the intention of focusing on designers as the crucial target group for the application of PTD, given the inherent emphasis on "design" within the PTD concept itself. The rationale behind this approach is rooted in the understanding that designers, considering their role in shaping the initial concepts and blueprints of construction projects, are strategically positioned to incorporate preventive measures against safety hazards right from the earliest stages of project development (Ibrahim et al., 2020). Recognizing designers as central figures in the PTD process acknowledges their potential to significantly influence the overall safety outcomes of construction projects. By integrating safety considerations into the design phase, designers can proactively address potential risks and ensure that preventive strategies are incorporated into the project from the outset. Thus, this research implied the designers' role in effectively leveraging PTD principles.

Moreover, designers significantly influence a construction project's entire lifecycle, from the initial concept to its completion (Gambatese et al., 2005). Designers are involved in conceptualization and planning (Aibinu & Venkatesh, 2014), detailed design and development (Gu & London, 2010), construction phase (Sacks et al., 2013), operation and maintenance (Akcamete et al., 2010), and even renovation and demolition (Volk et al., 2014). Designers often work in multidisciplinary teams, collaborating with engineers, architects, and other stakeholders. By embracing PTD principles, designers can foster a culture of safety across all disciplines, encouraging a collaborative approach to risk management and hazard elimination (Gambatese & Mroszczyk, 2006; Osburn et al., 2022). As early adopters of PTD, designers can play a crucial role in educating their peers and advocating for safety-oriented design practices within the industry. Their endorsement of PTD can inspire broader acceptance and implementation of these principles across various projects and firms (Mann III, 2008; Manzoor & Othman, 2021; Tymvios & Gambatese, 2016).

Additionally, by integrating PTD into their work, designers can contribute to setting new industry standards for safety in design. Their pioneering efforts can influence regulations, guidelines, and best practices, elevating the importance of safety in the construction industry's collective consciousness. Designers engaging with PTD from the early stages of their projects can provide valuable feedback on the effectiveness and practicality of PTD strategies (Tymvios et al., 2012). This feedback loop is essential for refining PTD approaches and ensuring their adaptability to different project types and complexities.

Thus, designers who are targeted as early adopters of PTD could play a transformative role in reshaping the construction industry toward PTD adoption. Their commitment to integrating safety at the design phase could lead to more sustainable, efficient, and inherently safer construction projects, setting a benchmark for the industry. Encouraging designers to adopt PTD can help advance a culture of safety across the construction industry. Designers can set PTD applications, influencing contractors, engineers, and other stakeholders to prioritize safety throughout the lifecycle of a project and adopt PTD. Additionally, designers may adopt it to inform regulatory standards and policies. Their experiences and challenges with PTD can provide valuable insights that help shape policies that support effective safety practices across the industry.

7.4 STAKEHOLDER’S INFLUENCE ON PTD ADOPTION

The PTD safety management, akin to numerous pivotal advancements in design and construction, inherently carries substantial risks for early adopters and various stakeholders within the construction industry (Toole & Erger, 2019). The study's findings inferred that designers are aware of the inherent risks and barriers associated with the implementation of PTD in the Philippines. While designers are recognized as the primary actors in PTD, it becomes imperative to establish a motivational force that actively promotes and supports the application of PTD. Acknowledging the potential risks and challenges, particularly in the early stages of adoption, is crucial to encouraging a culture of safety and innovation within the construction industry. Designers, being key players in the implementation of PTD, not only need to recognize these risks but also require a supportive framework that encourages their active participation and commitment to the integration of PTD principles. Therefore, in navigating the complexities associated with PTD adoption, a determined effort is necessary to provide designers with the motivation, resources, and encouragement required to apply PTD in their design processes effectively. This approach ensures a smoother transition and increased acceptance of PTD within the construction landscape.

Safety performance in the construction industry is significantly influenced by key stakeholders (Tymvios et al., 2012; Wu et al., 2016). Therefore, the motivation emanating from each stakeholder becomes crucial in propelling the adoption of PTD. External motivations, particularly from prominent construction stakeholders like contractors and clients, play a pivotal role in driving PTD practices (Gambatese et al., 2017). While some respondents in this study indicated acquiring knowledge about PTD through their companies, a limited number reported being specifically prompted by their contractors or clients to consider construction safety in their designs. These findings emphasized a prevailing lack of acknowledgment from other construction stakeholders regarding the capacity of designers to actively contribute to the mitigation of construction safety and health risks. This outcome signifies a critical need for an information drive targeted at reaching out to the direct stakeholders involved in the construction industry to raise awareness about PTD. Initiatives aimed at enhancing contractors' and clients' understanding of the integral role of designers in promoting construction safety can foster a collaborative environment that is conducive to the successful implementation of PTD practices. As such, a concerted effort is warranted to bridge this awareness gap and garner the support and involvement of all key stakeholders in promoting a safety-conscious culture within the construction sector.

The conventional practice traditionally assigns the contractor the responsibility for implementing construction Health and Safety (H&S). Consequently, regarding the drive to apply PTD, an established belief among most structural engineers is that contractors should play a pivotal role in prompting them to consider the H&S aspects of construction and apply PTD principles (Labadan et al., 2022). In a project delivery method known as "Design-Bid-

Build," collaboration between designers and contractors is not typically emphasized. However, the PTD concept seeks to enhance collaboration between these two stakeholders, signifying a motivation for improvement. Therefore, exploring alternative project delivery methods or revisiting contract standards becomes imperative to enhance the active participation of designers in the OSH. Additionally, the project owner (client) is crucial to the overall plan and wields substantial influence over project safety (Huang & Hinze, 2006). With complete control over the project and providing the necessary financial resources for the design, the owner is positioned to influence the collaboration among construction stakeholders to prioritize safety considerations (Gambatese et al., 2017). Hence, the implementation of PTD can be driven through the persuasive influence of the owner. The preliminary exploratory questionnaire results revealed that designers harbor concerns about cost considerations from clients. There was a reluctance among designers to implement PTD voluntarily, reflecting a need for convincing the designer that PTD analysis adds value. Incentives for undertaking the additional task of PTD implementation should be within the client's capacity. Unless designers are convinced of the added value of PTD and provided with appropriate incentives, the voluntary adoption of PTD principles might face resistance.

Therefore, developing collaboration between construction stakeholders is crucial in creating a supportive environment that encourages the adoption of PTD practices in construction projects. Enhanced collaboration facilitates the sharing of knowledge and best practices, ensuring that safety considerations are integrated across all stages of a project. It also helps in aligning the objectives of different stakeholders with the safety standards required under PTD. Moreover, when all parties involved in a project understand and commit to the principles of PTD, it leads to more effective risk management and decision-making processes that prioritize safety. Consequently, developing strong communication and partnership among all project stakeholders from the outset is essential to ensure the integration and sustainability of PTD practices.

7.5 PTD POLICIES

Regulatory bodies play a crucial role in reinforcing PTD legislation to ensure compliance within the construction industry. PTD was initially introduced as a voluntary arrangement in certain countries, such as Singapore and the USA. Subsequently, it transitioned into a mandate in Singapore through the Ministry of Manpower (Goh & Chua, 2016). Respondents in the initial exploratory study emphasized that regulators and engineering institutions, in addition to contractors, have the ability to encourage designers to implement PTD practices. The findings stressed the essential role of industry associations and regulatory bodies in actively engaging with engineers.

Institutional organizations in the Philippines hold a position of respect, authority, and proactivity in shaping codes and standards for professional practice. For instance, the Association of Structural Engineers of the Philippines (ASEP) has contributed significantly by producing the "National Structural Codes of the Philippines" (NSCP) specifically for structural engineering practice, in addition to the general "National Building Code of the Philippines" established by the national government. Consequently, professional engineering institutions in the Philippines have the capacity to exert influence by advocating or mandating the adoption of the PTD concept among their members. This emphasized the need for a collaborative effort involving regulatory bodies and professional associations to actively promote and integrate PTD principles into the professional practices of engineers in the Philippines.

Given that the concept of PTD is relatively new among designers in the Philippines, there has been little to no effort to establish PTD-specific policies to date. This study aims to enlighten both designers and regulatory authorities about the critical role of PTD in enhancing safety within the construction industry. By presenting comprehensive data and insights, the research seeks to serve as a foundational resource that advocates for the integration of PTD principles into standard practice. Hopefully, this will encourage the development of relevant policies and guidelines. This initiative could lead to greater awareness and adoption of PTD, setting a precedent for safety standards in Philippine construction projects.

7.6 THE DRIVE FOR THE PHILIPPINES' CONSTRUCTION INDUSTRY'S ADOPTION OF BIM

BIM has significantly transformed the construction industry by introducing a more integrated, collaborative, and efficient approach to project management and execution (C. M. Eastman et al., 2011; Succar, 2009). The impact of BIM spans various components of the industry, from design and planning to construction and facility management. BIM has revolutionized the construction industry by integrating these capabilities, leading to more efficient, cost-effective, and high-quality building projects (Barlish & Sullivan, 2012). Its impact continues to grow as technology advances and as the industry embraces more collaborative and integrated approaches to construction management (Azhar et al., 2012).

This research has conclusively demonstrated that the comprehensive technical features of BIM render it an exceptionally suitable instrument for implementing PTD principles. BIM's capabilities align with the core objectives of PTD, which aims to integrate safety considerations directly into the design phase of construction projects. However, by laying the foundation of the research problem, a comprehensive review of the literature was done, and this study has explored what BIM could offer in the construction industry, not only for construction safety purposes. The interview with the designers provided views on how BIM is very useful for their design work and how they can easily collaborate with other project stakeholders.

Therefore, it is considered essential to actively promote the implementation of BIM within the Philippines' construction sector. This initiative is critical in ensuring that the industry aligns with global efficiency, collaboration, and innovation standards. By embracing BIM, the Philippine construction industry can enhance project management, improve design quality, and achieve better cost and time efficiencies. The adoption of BIM is not just about keeping pace with technological advancements but also about leveraging these advancements to address the unique challenges and opportunities in the Philippine construction landscape, ultimately leading to more sustainable, safe, and successful construction projects.

Research indicates that the uptake of BIM within the Philippines' construction sector has been relatively slow (Rodriguez et al., 2019). Despite this initial slow adoption rate, there has been a noticeable shift towards embracing BIM technologies across the industry. This change is marked by a growing awareness of BIM's capabilities and an increase in its application across various construction domains within the country. The Philippines, mirroring trends observed in several other nations, has begun to acknowledge the significant advantages BIM offers in bolstering the efficiency and effectiveness of construction projects. This recognition has fueled a gradual yet consistent rise in the adoption of BIM practices (Dimaculangan, 2023).

The evolving landscape suggests a positive trajectory towards the integration of BIM into standard construction practices, driven by its potential to rationalize project management, enhance collaboration among stakeholders, and reduce costs and errors through improved accuracy and clash detection capabilities. As the construction industry in the Philippines continues to navigate the challenges of modernization and globalization, the strategic adoption of BIM is a key factor in its competitive edge and sustainability. This progressive shift towards BIM adoption is further supported by initiatives to educate and train industry professionals on BIM technologies and their applications, thereby equipping them with the necessary tools and knowledge to leverage BIM effectively in their projects.

7.7 CHAPTER’S SUMMARY

This chapter thoroughly synthesizes the research findings, examines how the outcomes relate to the defined objectives and hypotheses, and assesses their alignment or deviation from the established knowledge base. It critically evaluates the data and methodologies used to understand the study's broader academic and practical implications. The chapter emphasizes the importance of implementing proactive strategies to increase PTD adoption. It stresses the need for specific interventions to incorporate PTD practices into construction projects successfully. It also details BIM’s instrumental role in facilitating PTD adoption, particularly by enhancing safety integration in the design phase. Furthermore, it emphasizes designers' crucial role as early PTD adopters, given their capacity to incorporate safety measures from the project's inception. The discussion extends to the impact of stakeholders and policy frameworks on PTD implementation. It concludes by addressing the growing trend of BIM adoption in the

Philippines, exploring efforts to promote its use for better project outcomes and efficiency within the construction industry.

CONCLUSION

This final chapter presents a comprehensive summary of the key findings made through this research. It examines the contributions and constraints of the study and outlines directions for future inquiry. The chapter is structured as follows: Section 8.1 summarizes the significant results achieved in relation to each research objective, providing a straightforward synthesis of the study's outcomes. Section 8.2 reflects on the broader contributions of this research to the field, emphasizing its academic and practical contributions. Section 8.3 is dedicated to examining the limitations encountered during the study, offering a transparent consideration of areas of potential improvement. Building on this, Section 8.4 presents a roadmap for future research, identifying gaps in the current study that warrant further exploration and suggesting new questions that emerged from the findings. The chapter concludes in Section 8.5, which condenses the essence of the thesis and its significance within the broader discourse, bringing closure to the narrative of this scholarly endeavor.

8.1 RESEARCH OBJECTIVES AND OUTCOMES

This study's primary goal was to empirically examine how a BIM-based approach could intervene in adopting PTD in the Philippines' construction industry, specifically among structural designers. The study aimed to create phases of research with multiple views -thus with multiple but coherent objectives. A series of thorough research activities were undertaken. The following subsections (8.1.1 – 8.1.3) provide a summary of these activities and their corresponding results.

8.1.1 PHASE I: PTD AWARENESS OF STRUCTURAL DESIGNERS IN THE PHILIPPINES

This research phase concentrated on evaluating the awareness of structural designers in the Philippines about the concept of PTD. It addressed the first objective (RO1), which was to ascertain the existing awareness levels of PTD among structural designers. The findings established a baseline for efforts aimed at enhancing the comprehension and implementation of

PTD practices. The study found that a majority of structural engineers in the Philippines were not very familiar with PTD, yet they recognized its importance for the construction industry. Despite this recognition, several challenges to PTD adoption were identified, including concerns about potential liabilities, costs, and the lack of necessary design tools and guidelines. The study suggested that efforts to promote PTD among design engineers could start with providing the necessary technological tools to enhance their construction safety knowledge and awareness, thereby facilitating integration of PTD principles into their work. Additionally, the research synthesized findings on the barriers and drivers of PTD implementation in the Philippines, offering valuable insights for developing future intervention strategies. These findings has directly informed the next phase, which assessed the feasibility of using BIM for PTD.

8.1.2 PHASE II: FEASIBILITY OF BIM FOR PTD

The second phase consisted of two independent feasibility studies. The initial feasibility study presented a detailed examination of how BIM can be applied effectively in PTD. This investigation resulted in a detailed framework that outlines how PTD principles and safety management practices can be integrated into BIM workflows. Adapting BIM's functionalities to meet PTD-specific needs, the framework was substantiated by developing a PTD tool, demonstrating BIM's significant benefits in enhancing construction project safety and efficiency, particularly for structural designers. The subsequent feasibility study evaluated industry professionals' views on BIM's potential for PTD, focusing on structural designers' experiences with BIM and their perceptions of its relevance to PTD. The feedback stressed BIM's established strengths in design and its prospective utility in construction safety and PTD, suggesting a consensus on BIM's value for PTD applications. Collectively, these feasibility studies affirmed the RO2, which aimed to assess the applicability of BIM for PTD. The findings from both studies elaborated on BIM's applicability for PTD, aligning with research insights and advocating for its use in advancing PTD practices among structural designers.

8.1.3 PHASE III: SOCIO-TECHNICAL QUALITIES OF BIM FOR PTD

This study argues that technology adoption is shaped not only by its technical capabilities but also by the complex socio-technical dynamics that encompass it. This view highlights the interaction between technological features and the social context in which the technology operates.With the confirmed potential of BIM to enhance PTD through its technical capabilities, this phase of the study further investigated the socio-technical attributes of BIM that could encourage designers to utilize it for PTD applications. The study developed a model that provides empirical insights into how BIM’s socio-technical quality aspects influence the adoption of BIM for PTD practices in the construction sector (RO3). It also focused on structural engineers within the Philippine construction industry. With participation from 131 individuals who completed the questionnaires, the research utilized SEM to validate the model's components. The findings stressed that BIM's perceived usefulness and relative advantage for PTD are crucial factors driving designers' intentions to adopt BIM for PTD, underscoring the significance of recognizing BIM's benefits for PTD practices. These two factors emerge as key determinants, emphasizing the importance of recognizing BIM's usefulness and advantages to PTD practices. The ease of using BIM indirectly influences the formation of these intentions, underlining the significance of user-friendliness and accessibility in facilitating technology adoption. The study's insights hold substantial value, particularly in the construction industry context and the challenges designers face in embracing PTD practices.

8.2 RESEARCH CONTRIBUTIONS

Construction safety remains a persistent challenge in the industry, continuously evolving with new technologies, methodologies, and regulations. Within this landscape, PTD emerges as a relatively new paradigm that embeds safety considerations directly into the design phase of construction projects. Recognizing the critical need for innovative approaches to enhance construction safety, this research was undertaken with the following academic goal: to advance theoretical understanding in the field of PTD research and to offer tangible contributions to construction safety within the construction sector, specifically in the Philippines.

Furthermore, the study's focus on PTD within the construction industry addresses a significant gap in safety management research, which has often overlooked the unique challenges and opportunities the construction sector presents. By situating PTD within the safety management framework, the research sheds light on how safety innovations can be diffused and adopted in construction. A detailed elaboration of these contributions is provided in the following subsections, summarizing both the academic advancements made to the existing body of knowledge and the practical benefits extended to the construction industry through this research.

8.2.1 THEORETICAL CONTRIBUTION TO THE BODY OF KNOWLEDGE

PTD concept holds significant potential for revolutionizing safety protocols by shifting the focus toward eliminating risks during the earliest phases of project development. Despite its promising advantages, the adoption of PTD has been relatively slow, hindered by substantial barriers such as a general lack of safety-centric awareness among designers, the inherent complexities of construction projects, and a pervasive reluctance within the industry to shift away from traditional practices. These challenges underscore the critical knowledge gaps that persist in effectively integrating and applying PTD principles broadly.

In response to these challenges, this research contributed to the body of scientific knowledge by attempting to meet these challenges. This dissertation explored the integration of BIM technologies with PTD practices as a pathway to facilitate the more widespread adoption of PTD. BIM offers sophisticated tools that allow for detailed visualization, simulation, and analysis of safety measures during the design phase, potentially transforming how designers approach project safety. By leveraging BIM’s capabilities, this study explored theoretical solutions to embed safety considerations directly into the design process, addressing the critical need to promote PTD adoption among structural designers.

Furthermore, the theoretical contributions of this research provide the foundation for future studies and practical applications of PTD in the Philippines and other countries. It empirically demonstrated the feasibility of a BIM-based PTD approach, thus offering new insights into how digital technologies can be studied to promote PTD. This study also contributes to the ongoing discourse on improving OSH standards in the construction industry through technological advancements. Showcasing how BIM can be harnessed to support PTD practices paves the way for more informed, proactive, and safety-oriented design practices.

Specifically, by investigating the current level of awareness and adoption of PTD among structural engineers, particularly within the context of the Philippine construction industry, this study fills a gap in the existing literature regarding specific stakeholders, which are designers, to adopt PTD practices primarily. The study offered empirical evidence regarding the present level of understanding and application of PTD, emphasizing areas that need enhancement and the possibility of wider adoption in the industry. The study advanced the understanding of how BIM can be effectively utilized to facilitate PTD principles. By demonstrating the applicability of BIM in PTD through the development and validation of a BIM-based PTD tool, the research exemplifies the technical collaborations between BIM and PTD. It offers a novel perspective on leveraging technology for PTD. This study enriches the PTD literature by contributing comprehensive insights into the integration of PTD and BIM, identifying factors influencing PTD adoption, and proposing actionable frameworks and strategies to enhance safety through design in the construction industry.

Additionally, this study establishes a baseline for future research activities in PTD, suggesting areas for further exploration and providing a methodological approach that can be replicated or adapted in other contexts. This contribution is vital for the continuous evolution of PTD as a field of study, encouraging subsequent investigations that can build on the foundational knowledge this research provides.

8.2.2 PRACTICAL CONTRIBUTION TO THE CONSTRUCTION INDUSTRY

This study promotes the enhancement of safety through early intervention. It illustrates how BIM can be utilized to embed safety considerations into design processes, allowing for the identification and mitigation of hazards before construction begins. By integrating PTD principles through BIM technologies, designers are equipped with the tools necessary to visualize and provide them with awareness of construction site risks, leading to more informed decision-making and safer design practices. Construction companies should prioritize investments in BIM software and training to harness its full potential for safety management. Ensuring that staff are well-trained in both BIM and PTD principles can maximize the benefits of this integration. As new technologies and standards emerge, it is vital for companies to remain adaptive and update their safety protocols accordingly. This includes staying beside advancements in BIM applications and integrating these innovations into existing safety practices.

The study asserted safety compliance and risk management. The adoption of a BIM-based PTD approach can help companies adhere more easily to safety regulations and standards. BIM's capability to document and track compliance through every phase of a project ensures that safety is not only an initial design feature but a continuous priority throughout the construction lifecycle. Companies should establish protocols that integrate PTD principles as a standard part of the design process. By making safety a fundamental design criterion, firms can ensure it is consistently prioritized across all projects.

Furthermore, the study encourages improved stakeholder communication. BIM facilitates better communication and collaboration among all project stakeholders by providing a shared, real-time view of project details. This transparency helps in aligning all parties on safety protocols and design modifications, fostering a collective responsibility towards safety. Promoting a culture of collaboration and open communication between designers, engineers, and construction managers can enhance the effectiveness of safety implementations. Regular meetings and updates regarding OSH matters should be institutionalized to keep all stakeholders informed and engaged. Utilize the data capabilities of BIM to monitor safety outcomes and continuously improve safety strategies. Analyzing data from past projects can help identify recurring issues and success factors, informing better safety practices for future projects.

8.3 STUDY LIMITATIONS

This study faced certain constraints that narrowed its scope and focus, which are outlined as follows:

- This study was primarily conducted within the Philippine construction industry, which may limit the generalizability of the findings to other countries with different regulatory, cultural, and economic contexts. Future research could benefit from a comparative analysis across various countries to enhance the conclusions' applicability.

- The research relied on a sample of structural engineers, which may not fully represent the wide array of professionals involved in the construction industry. Expanding the sample to include architects, project managers, safety professionals, and other stakeholders could provide a more holistic understanding of PTD adoption.

- While the study focused on BIM as a tool for facilitating PTD, the rapidly evolving nature of construction technologies suggests that future research should explore the potential of new and emerging digital tools and platforms in enhancing PTD.

- The research provides a snapshot of the current state of PTD adoption and BIM integration. A longitudinal study tracking the evolution of these practices over time could offer valuable insights into the long-term effectiveness and adoption patterns of PTD in the construction industry.

8.4 FUTURE RESEARCH DIRECTIONS

Future research directions arising from this study point toward several avenues for further investigation and exploration. These directions aim to build upon the findings, address the limitations, and expand the knowledge base in the relevant field. Potential areas for future research include:

- Investigating the perspectives of a broader range of construction industry stakeholders, including clients, regulatory bodies, and end-users, could provide a more comprehensive understanding of the barriers and facilitators to PTD adoption.

- Assessing the impact of emerging technologies, such as virtual reality, augmented reality, and artificial intelligence, on PTD practices could provide insights into future directions for safety innovation in construction.

- Conducting studies that focus on implementing PTD practices and their tangible impact on project outcomes, safety performance, and cost-effectiveness could provide empirical evidence to support broader adoption.

8.5 RESEARCH CLOSURE

In conclusion, this research has provided valuable insights into the current state and potential future directions of PTD practices within the construction industry, focusing on integrating BIM. Through a detailed examination of the awareness, adoption, and implementation challenges associated with PTD and the exploration of BIM's role in facilitating these practices, this study has contributed significantly to both the academic literature and practical methodologies in construction safety management. The findings explain the importance of enhancing awareness and understanding of PTD among industry professionals and focus on the transformative potential of BIM technologies in embedding safety considerations into the design phase. Moreover, by identifying barriers to PTD adoption and proposing a comprehensive framework for its integration, the research offers actionable strategies for industry stakeholders to improve safety outcomes in construction projects.

As the construction industry continues to evolve, driven by technological advancements and changing regulatory landscapes, the insights garnered from this study provide a foundation for future research and practice. Hopefully, the recommendations and frameworks developed through this research will serve as valuable resources for construction professionals, policymakers, and researchers alike, guiding efforts to promote safer, more efficient, and sustainable construction practices.

In moving forward, it is essential for the industry to embrace the principles of PTD and leverage the capabilities of BIM, addressing the identified challenges and capitalizing on the opportunities for innovation in construction safety management. This research represents a step toward realizing that goal, encouraging continued exploration, adaptation, and improvement in construction safety practices for the benefit of all stakeholders involved.

Ultimately, the journey towards safer construction environments is ongoing, and this research contributes to that journey by providing a clearer path forward. Through collaborative efforts, informed by empirical research and grounded in practical application, the construction industry can achieve significant strides in safety and efficiency, ensuring a safer future for all those involved in the construction industry.

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APPENDIX A

APPENDIX A PRELIMINARY STUDY QUESTIONNAIRE

March 15, 2021

Dear Participant:

My name is Rimmon Salvacion Labadan from the Philippines, and I am a Double Degree Ph.D. student at Sirindhorn International Institute of Technology – Thammasat University Thailand, and the Hokkaido University Japan. As part of my doctoral dissertation, I am examining the the awareness of civil engineers who practice structural engineering design in the Philippines about the concept of "Prevention through Design(PtD)" for building constructions. I invite you to participate in this research study by completing the attached surveys.

The following questionnaire will require approximately 10 minutes to complete. There is no compensation for responding, nor is there any known risk. Please answer all questions as honestly as possible and promptly submit the completed questionnaires. Please use Adobe Reader in answering the questionnaire. Go to the the link if you want to download the free version. (https://get.adobe.com/reader/)

Thank you for taking the time to assist me in my educational endeavors. If you require additional information or have questions, please contact me at the email listed below.

Sincerely,

Rimmon Labadan
PhD Student
rimmon.sal@dome.tu.ac.th
rimmonlabs@gmail.com

Recommended by:

Assoc. Prof. Dr. Kriengsak Panuwatwanich
Supervisor (SIIT-Thammasat University)
kriengsak@siit.tu.ac.th

Assoc. Prof. Dr. Sho Takahashi
Supervisor (Hokkaido University)
stakahashi@eng.hokudai.ac.jp

*Note: Please open this pdf file using **Adobe Reader** to be able to answer and save the form properly. (Free version is OK) Go to the link if you want to download free version: https://get.adobe.com/reader/*

A brief definition of Prevention through Design (PtD)

The concept of PtD, also called Design for Safety (DfS), is the consideration of safety during the design phase of a project and conscious of making design decisions for the constructors' possible risk. It includes the insertion of safety awareness during the plans and specifications preparations. It also includes safety considerations in the constructability review process. It provides a guide on incorporating occupational risks into the design and redesign processes to eliminate, reduce, and control occupational risks that must be done before the construction.

General Information:

1. Name (Optional)
2. Age:
3. Years of Experience as a Structural Engineer:
4. Work Sector: ○ Public ○ Private
5. Position:
6. Are you willing for a further interview if we have a further study based on this questionnaire's outcome?

   ○ Yes ○ No ○ Maybe
7. If yes or maybe, please provide us your email:

Questions

Section 1. Knowledge about PtD

1.1 When did you first learn about the concept of "Prevention through Design (PtD)" or "Design for Safety (DfS)"?

- ○ Just now, after reading this questionnaire.
- ○ After I started my profession.
- ○ Before I started my profession.
- ○ Others (Please specify).

1.2 How did you first learn about PtD?

- ○ Just by this questionnaire.
- ○ Through my company.
- ○ Tertiary education.
- ○ Scholarly published papers or conferences
- ○ Seminars or training courses.
- ○ Others (Please specify):

1.3 Have you attended any PtD training course?

◯ Yes ◯ No

1.4 Rate your understanding of the concept of PtD.

Very Poor		Average		Excellent
1	2	3	4	5
◯	◯	◯	◯	◯

1.5 Rank your level of familiarity with implementing construction safety assessment during concept, detailed, and pre-construction design stages.

Not at all Familiar		Somewhat		Very Familiar
1	2	3	4	5
◯	◯	◯	◯	◯

1.6 Listed below are examples of PtD guidelines. In your insight, please rate each guideline's effectiveness to decrease construction accidents and rate the practicality to apply these guidelines in your design.

	PtD Guidelines	Effectiveness					Practicality				
		Not Effective At All		Somewhat Effective		Very Effective	Not Practical At All		Somewhat Practical		Very Practical
No.		1	2	3	4	5	1	2	3	4	5
1	Design the structural members to withstand all anticipated construction loading during fabrication, storage, erection, and final connection.	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
2	Design member depths to allow adequate head room clearance around stairs, platforms, valves, and all areas of egress.	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
3	Design members which are consistent size, light, weight, and easy to handle.	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

	PtD Guidelines	Effectiveness					Practicality				
		Not Effective At All		Somewhat Effective		Very Effective	Not Practical At All		Somewhat Practical		Very Practical
		1	2	3	4	5	1	2	3	4	5
4	Design columns with holes at 21 and 41 inches above the floor level to provide support locations for lifelines and guardrails.	○	○	○	○	○	○	○	○	○	○
5	Locate column splices between 2 and 3 feet above the finished floor level, and two-story intervals	○	○	○	○	○	○	○	○	○	○
6	In order to allow sufficient walking surface, use a minimum beam width of 6 inches.	○	○	○	○	○	○	○	○	○	○
7	Consider alternative steel framing systems which reduce the number of elements and where beams are landed on supports rather than suspended between them.	○	○	○	○	○	○	○	○	○	○
8	Design welded connections such that weld locations can be safely accessed.	○	○	○	○	○	○	○	○	○	○
9	Limit the lift heights of steel erection.	○	○	○	○	○	○	○	○	○	○
10	Use a metal deck and concrete fill rather than a slab that requires temporary formwork.	○	○	○	○	○	○	○	○	○	○

Section 2. Attitude about PtD

2.1 Do you think the implementation of PtD is important?

Not Important — Somewhat Important — Very Important

1 ○ 2 ○ 3 ○ 4 ○ 5 ○

2.2 In your opinion who among the construction stakeholders, other than the designers, should push you to apply PtD?

○ Owners/Client

○ Contractors

○ Project Managers

○ Regulators

Others:

2.3 To what extent do you agree or disagree that your professional duty should involve design for safety?

Strongly Disagree — Neutral — Strongly Agree

1 ○ 2 ○ 3 ○ 4 ○ 5 ○

2.4 In your opinion, rank the known factors contributing to the success of PtD. (Please rank your choices by marking 1 to 5 in the following items with 1 as the highest factor)

- Designer's mindset toward safety.
- Legislative force promoting PtD (ex. Policies, Regulations).
- Designer's necessary support from industry, organization and stakeholders.
- Software extensions for existing Building Information Modelling(BIM) and analysis softwares with PtD guidance available for use and reference.
- Third party consultant for PtD.

Please specify others factors:

2.5 Do you agree that PtD will decrease the construction industry's injuries and fatalities rate?

Strongly Disagree — Neutral — Strongly Agree

1 ○ 2 ○ 3 ○ 4 ○ 5 ○

Section 3. Practice of PtD

3.1 Have you been involved in a construction safety assessment during construction?

Never — Sometimes — Always

1	2	3	4	5
○	○	○	○	○

3.2 Have you ever been asked to address construction worker health and safety in the design phase?

Never — Sometimes — Always

1	2	3	4	5
○	○	○	○	○

3.3 Would you agree or disagree that a PtD Coordinator's role is essential in facilitating PtD?

Strongly Disagree — Neutral — Strongly Agree

1	2	3	4	5
○	○	○	○	○

3.4 What are the problems you will face or have faced when practicing PtD? (You can select more than one item.)

- ☐ Quality/Creativity of design is compromised.
- ☐ Lack of design guides for a design safe for construction.
- ☐ Lack of design tools or software.
- ☐ Interference with the contractors' means and methods
- ☐ Lack of organizational support.
- ☐ No mechanism in place to check for consistency in DfS.
- ☐ Lack of early involvement (design phase) of the contractor.
- ☐ Cost consideration from client or company.

Others: ______

3.5 Rank the following concerns in PtD implementation? (Rank the follwing items 1-4 with 1 as the highest concern)

- [-] It will compromise my design creativity.
- [-] It will give me liabilities on accidents that may occur during the construction.
- [-] I have to do it voluntarily.
- [-] It will result in complications in the procurement process.

Please write other concerns you have if you will implement PtD:

______

3.6 Are there sufficient PtD guidelines, manuals, online resources, or other material to facilitate construction safety planning in your country?

None — Average — Many

1 ○ 2 ○ 3 ○ 4 ○ 5 ○

3.7 What are the types of design guidelines that you use to facilitate your design work in general? (You can check more than 1 item.)

- ☐ Structural Analysis Codes (NSCP, ACI, etc.)
- ☐ Material Codes (ASTM, DPWH Bluebook for material specifications, etc.)
- ☐ National Building Codes
- ☐ Occupational Safety and Health Standard(OSHA) Guidelines

Others (Please specify):

Section 4. Building Information Modelling for PtD

A brief definition of Building Information Modelling (BIM)

BIM is the virtual representation of a facility's physical and functional characteristics from inception onward that serves as a shared information repository for collaboration throughout a facility's life cycle. It is a virtual model of a building that includes a 3D geometry with incorporated physical and functional information on its elements. It is also a development and use of a computer software model to analyze or simulate facilities' construction activities and operations.

4.1 Are you using Building Information Modelling (BIM) software for detailing works?

Never — Sometimes — Every time

1 ○ 2 ○ 3 ○ 4 ○ 5 ○

4.2 Which BIM software for detailing are you using? (You can select more than one, including others.)

- ☐ TEKLA
- ☐ REVIT
- ☐ ARCHICAD
- ☐ 3D AUTOCAD

Others. Please specify:

4.3 To what extent do you agree or disagree that structural design codes' embedment in structural analysis or BIM software increases your awareness of structural design criteria?

Strongly Disagree		Neutral		Strongly Agree
1	2	3	4	5
○	○	○	○	○

4.4 How do you like the idea of incorporating PtD analysis on structural analysis or detailing software?

Not at all		Neutral		Very
1	2	3	4	5
○	○	○	○	○

4.5 In your opinion, what is the ideal software capability for PtD analysis?

☐ Risk identification capability

☐ Risk quantification capability

☐ Design for safety guide availability

Other software capability you can suggest:

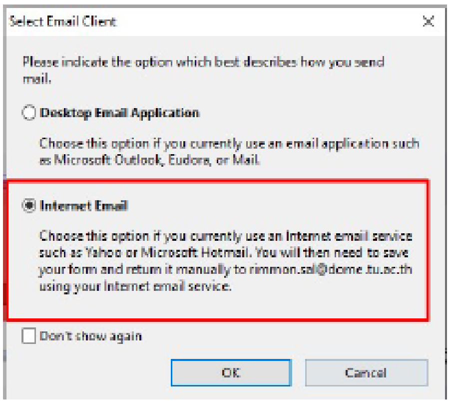
4.6 Please leave other feedback here.

Note for submiting your response:
After finishing the form please click the "Submit" button 

located in the upper right corner. Fill the necessary information.

You have an option to send your response:

a. Desktop Email Application - to directly send the form using email application softwares.
b. Internet email - this will ask you to save the form/questionnaire and manually send the file to rimmon.sal@dome.tu.ac.th (This option is more preferred)



I will notify you once I received the email. Thank you very much!!!

APPENDIX B

CASE STUDY INTERVIEW QUESTIONS

Information:

1. Position:
2. Type of Company:
3. Years of experience as a structural engineer:
4. Type of projects involved:
5. BIM software used: (aside from structural analysis 3D software)

Part 1. Evaluate the technical capabilities of BIM software for designing.

A. 3D Modeling: Think about how well BIM supports the creation of detailed 3D models of your design, including building elements, systems, and components.

   1. *Can you describe your experience with using BIM to create detailed 3D models of a project's building elements, systems, and components?*
   2. *What tools or features within BIM software do you find most effective for representing building components in 3D?*

B. Visualization: Consider how well BIM can help visualize your design concepts.

   1. *How does BIM enhance the visualization of a designer's work?*
   2. *Can you provide examples of specific BIM visualization features or techniques you've used in your design?*

C. Data Integration: Evaluate the ability of BIM to integrate related design data, such as information, material specifications, and construction methods.

   1. *Can you describe your experience with using BIM to integrate data types, such as project information, material specifications, and construction methods?*

   2. *In designing, how would you ensure that various data are effectively integrated and synchronized within a BIM environment?*

D. Collaboration: Think of the collaboration features of your BIM software, which allow various stakeholders to work together seamlessly.

   1. *Could you describe your experience using BIM collaboration features to facilitate teamwork among project stakeholders, such as architects, engineers, contractors, and clients?*
   2. *Can you provide an example of a project where BIM collaboration features significantly enhanced communication and coordination among stakeholders?*

Part 2. Assess the applicability of BIM's technical capabilities for PTD.

A. 3D Modeling: Assess how well BIM will support the creation of detailed 3D models of the project, including building elements, systems, and components for prevention through design (PTD).

    1. *How do you think BIM can also create 3D models that can proactively identify and address safety hazards during the design phase?*
    2. *Could you provide examples of specific safety-related elements or features you would include in these BIM models?*

B. Visualization: Consider how BIM can help visualize potential safety hazards and design alternatives.

    1. *What do you think about using BIM to visualize and identify safety hazards during the design phase of a construction project?*
    2. *In your opinion, How should a designer like you visually integrate design alternatives and safety measures into 3D models?*

C. Data Integration: Think of the ability to integrate safety-related data, such as hazard information, material specifications, and construction methods.

    1. *Is it feasible to integrate safety-related data into BIM models for a project?*
    2. *Can you suggest how to integrate construction safety-related data in a BIM model?*

D. Collaboration: Think of the collaboration features of your BIM software for construction safety assessments with other designers or stakeholders.

    1. *How can the collaboration features within BIM software enhance the coordination of safety-related information among project stakeholders to support Prevention through Design (PTD)?*
    2. *Can you share a possible example of a project where BIM's collaboration features will be crucial in improving safety-related decision-making?*

Part 3. Concluding questions.

1. *Based on our discussion today, do you believe that adopting BIM technology will likely lead to increased implementation of PTD practices in the construction industry? If so, can you give some factors contributing to this belief?*

2. *Are there specific features or applications within BIM that will play a key role in promoting PtD in the construction industry?*

3. *Do you see BIM as a catalyst for a broader industry shift toward prioritizing PtD practices, and what, in your view, are the critical steps that should be taken to facilitate this transition?*

4. *Anything to add?*

-End of the interview-

APPENDIX C

AUTOMATED GUARDRAIL MODELING ALGORITHM

```
using System;
using Tekla.Structures.Dialog;
using System.Windows.Forms;
using Tekla.Structures;
using Tekla.Structures.Model;
using Tekla.Structures.Geometry3d;
using System.Linq;
using System.Collections;
using System.Collections.Generic;
using System.IO;
using Tekla.Structures.Solid;

namespace Prevention_Through_Design
{
  public partial class PTDPluginForm : PluginFormBase
  {
    public PTDPluginForm()
    {
      InitializeComponent();
     }

       //Use default values for plugins in models without a standard attribute file
    protected override string LoadValuesPath(string fileName)
    {
      SetAttributeValue(textBoxLengthFactor, 2d);  // One line for each plugin attribute
      SetAttributeValue(textBoxProfile, "");
      string Result = base.LoadValuesPath(fileName);
      Apply();
      return Result;
    }

    //Remember to assign these events to the buttons.
    private void okApplyModifyGetOnOffCancel1_ApplyClicked(object sender, EventArgs e)
    {
      this.Apply();
    }

    private void okApplyModifyGetOnOffCancel1_CancelClicked(object sender, EventArgs e)
    {
      this.Close();
    }

    private void okApplyModifyGetOnOffCancel1_GetClicked(object sender, EventArgs e)
    {
      this.Get();
    }
```

```
        private void okApplyModifyGetOnOffCancel1_ModifyClicked(object sender, EventArgs e)
        {
            this.Modify();
        }

        private void okApplyModifyGetOnOffCancel1_OkClicked(object sender, EventArgs e)
        {
            this.Apply();
            this.Close();
        }

        private void okApplyModifyGetOnOffCancel1_OnOffClicked(object sender, EventArgs e)
        {
            this.ToggleSelection();
        }

        private void listBox1_Click(object sender, EventArgs e)
        {
            var x = listBox1.GetItemText(listBox1.SelectedItem);


            if (x == "Consider pre-fabricated design.")
            {
                pictureBox1.Image = Prevention_Through_Design.Properties.Resources.PTD_Prefabricated;
                label4.Text = "Less work on site, and jobs can be completed faster. \r\n Thus, less accident
could happen";
            }
            else if (x == "Consider modularized design.")
            {
                pictureBox1.Image = Prevention_Through_Design.Properties.Resources.PTD_Modularized;
                label4.Text = "Less work on site, and jobs can be completed faster. \r\n Thus, less accident
could happen";
            }
            else if (x == "Use metal deck and concrete fill rather than a slab.")
            {
                pictureBox1.Image = Prevention_Through_Design.Properties.Resources.PTD_Steel_Deck;
                label4.Text = "Use metal deck and concrete fill rather than a slab. \r\n Slab requires more
temporary works";
            }
            else
            {
                pictureBox1.Image = Prevention_Through_Design.Properties.Resources.PTD_Consistent;
                label4.Text = "The simplier the work, the less the risk";
            }


        }


        private void listBox2_Click_1(object sender, EventArgs e)
```

```
    {
        var x = listBox2.GetItemText(listBox2.SelectedItem);


        if (x == "Provide column holes at 21 and 42 inches above the floor level.")
        {
            pictureBox1.Image = Prevention_Through_Design.Properties.Resources.PTD_Column_Hole;
            label4.Text = "Column holes at 21 and 42 inches above the floor level \r\n provides support
loacations for lifelines and guardrails.";
        }
        else if (x == "Locate column splices between 2 and 3 feet above the finished floor level.")
        {
            pictureBox1.Image = Prevention_Through_Design.Properties.Resources.PTD_Column_Splice;
            label4.Text = "Column splice will serve as post guardrails and lifelines \r\n while the
succeding story is not yet set up.";
        }
        else if (x == "Design connection points along the beams for the lifelines.")
        {
            pictureBox1.Image = Prevention_Through_Design.Properties.Resources.PTD_Beam_Hole;
            label4.Text = "Provide beam holes or additional beam details \r\n for worker's lifeline
attachment";
        }
        else if (x == "Use a minimum beam width of 6 inches.")
        {
            pictureBox1.Image = Prevention_Through_Design.Properties.Resources.PTD_BEAM_6;
            label4.Text = "Use a minimum beam width of 6 inches to allow a sufficient walking surface.";
        }
        else if (x == "Design the footing's top layer of reinforcing steel to be spaced at no more than 6
inches on center, each way.")
        {
            pictureBox1.Image =
Prevention_Through_Design.Properties.Resources.PTD_Footing_Reincforcement;
            label4.Text = "Design the footing's top layer of reinforcing steel to be spaced \r\n at no more
than 6 inches on center, each way, to provide a continuous, stable walking surface \r\n before the
concrete is poured.";
        }

        else
        {
            pictureBox1.Image = Prevention_Through_Design.Properties.Resources.PTD_Roof_Parapet;
            label4.Text = "Roof parapet will serve as fall prevention guardrail \r\n  on roof work and
maintenance works";
        }
    }


    private void listBox3_Click(object sender, EventArgs e)
    {
        listBox2.Items.Clear();
        var y = listBox3.GetItemText(listBox3.SelectedItem);
```

```
            if (y == "Column")
            {
                listBox2.Items.Add("Provide column holes at 21 and 42 inches above the floor level.");
                listBox2.Items.Add("Locate column splices between 2 and 3 feet above the finished floor
level.");

            }
            else if (y == "Beam")
            {
                listBox2.Items.Add("Design connection points along the beams for the lifelines.");
                listBox2.Items.Add("Use a minimum beam width of 6 inches.");
            }
            else if (y == "Foundation")
            {
                listBox2.Items.Add("Design the footing's top layer of reinforcing steel to be spaced at no
more than 6 inches on center, each way.");

            }
            else if (y == "Connections")
            {
                listBox2.Items.Add("Use a single size, or a minimum number of sizes possible, of bolts, nails,
and screws.");
                listBox2.Items.Add("Use a minimum of two bolts, nails, or screws per connection.");

            }
            else
            {
                listBox2.Items.Add("Provide enough height of roof parapet.");
                listBox2.Items.Add("Minimize the use of cantilevers.");
            }

        }

        private void DrawBeam_Click(object sender, EventArgs e)
        {
            //const string PartPath = @"E:\Documents\partproperties.csv";
            //var part = TeklaStructures.Model.PickObject(string.Empty) as Part;
            //var pProperties = GetPartContentAttribute(part);
            //pProperties.SaveAsCsv(PartPath);
            listBox4.Items.Clear();

            Model Model = new Model();

            ArrayList SlabOject = new ArrayList();
            ArrayList MyList = new ArrayList();
            ArrayList MyListX = new ArrayList();
            ArrayList MyListY = new ArrayList();
            ArrayList MyListZ = new ArrayList();
            ArrayList MyFaceNormalList = new ArrayList();
            ArrayList TotalObject = new ArrayList();
            ArrayList coordinate = new ArrayList();
```

```
ModelObjectEnumerator Enum = Model.GetModelObjectSelector().GetAllObjects();
while (Enum.MoveNext())
{
   ContourPlate Slabs = Enum.Current as ContourPlate;

   if (Slabs != null)
   {
      if (Slabs.Name == "SLAB")
      {
         SlabOject.Add(Slabs);

         Solid Solid = Slabs.GetSolid();
         FaceEnumerator MyFaceEnum = Solid.GetFaceEnumerator();
         while (MyFaceEnum.MoveNext())
         {

            Face MyFace = MyFaceEnum.Current as Face;
            if (MyFace != null)
            {
               MyFaceNormalList.Add(MyFace.Normal);


               LoopEnumerator MyLoopEnum = MyFace.GetLoopEnumerator();
               while (MyLoopEnum.MoveNext())
               {
                  Loop MyLoop = MyLoopEnum.Current as Loop;
                  if (MyLoop != null)
                  {

                     VertexEnumerator MyVertexEnum = MyLoop.GetVertexEnumerator() as
VertexEnumerator;
                     while (MyVertexEnum.MoveNext())
                     {

                        Point MyVertex = MyVertexEnum.Current as Point;
                        if (MyVertex != null)
                        {

                           MyList.Add(MyVertex);
                           MyListX.Add(Decimal.Round(Convert.ToDecimal(MyVertex.X),2));
                           MyListY.Add(Decimal.Round(Convert.ToDecimal(MyVertex.Y), 2));
                           MyListZ.Add(Decimal.Round(Convert.ToDecimal(MyVertex.Z), 2));
                        }
                     }
                  }
               }
            }
         }

      }
```

```
    }
}

int Slabcount = SlabOject.Count;
int FaceCount = MyFaceNormalList.Count;
int VertexCount = MyList.Count;

for (int xi = 0; xi <MyListX.Count; xi += 1)
{
    listBox4.Items.Add(MyList[xi]);
    listBox4.Items.Add(MyListX[xi]);
    listBox4.Items.Add(MyListY[xi]);
    listBox4.Items.Add(MyListZ[xi]);

}
listBox4.Items.Add(Slabcount);
listBox4.Items.Add(FaceCount);
listBox4.Items.Add(VertexCount);


ArrayList Shapes = new ArrayList();
int ii = 0;
for (int si = 0; si < Slabcount ; si = +1)
{

    if (MyList[ii].ToString() == MyList[ii + 9].ToString())     //3 sides polygon
    {
        Shapes.Add("3Sides");
        for (int xi = 0; xi <= 9; xi += 4)
        {

            double PositionX = Convert.ToDouble(MyListX[ii + xi]);
            double PositionY = Convert.ToDouble(MyListY[ii + xi]);
            double PositionZ = Convert.ToDouble(MyListZ[ii + xi]);
            double PositionX2 = Convert.ToDouble(MyListX[ii + xi + 1]);
            double PositionY2 = Convert.ToDouble(MyListY[ii + xi + 1]);
            double PositionZ2 = Convert.ToDouble(MyListZ[ii + xi + 1]);

            if (radioButton1.Checked)
            {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2, 
"50x150");
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2, 
"50x150");
            }
            else
            {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2, 
"ROD16");
```

```
                    CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                }

                Model.CommitChanges();
            }
            ii = ii + 18;
        }
        else if (MyList[ii].ToString() == MyList[ii + 13].ToString())   //4 sides polygon
        {
            Shapes.Add("4Sides");

            for (int xi = 0; xi <= 13; xi += 4)
            {

                    double PositionX = Convert.ToDouble(MyListX[ii + xi]);
                    double PositionY = Convert.ToDouble(MyListY[ii + xi]);
                    double PositionZ = Convert.ToDouble(MyListZ[ii + xi]);
                    double PositionX2 = Convert.ToDouble(MyListX[ii + xi + 1]);
                    double PositionY2 = Convert.ToDouble(MyListY[ii + xi + 1]);
                    double PositionZ2 = Convert.ToDouble(MyListZ[ii + xi + 1]);
                if (radioButton1.Checked)
                {
                    CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                    CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                }
                else
                {
                    CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                    CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                }
                Model.CommitChanges();
            }
            ii = ii + 24;

        }
        else if (MyList[ii].ToString() == MyList[ii + 17].ToString()) //5 sides polygon
        {
            Shapes.Add("5Sides");
            for (int xi = 0; xi <= 17; xi += 4)
            {

                double PositionX = Convert.ToDouble(MyListX[ii + xi]);
                double PositionY = Convert.ToDouble(MyListY[ii + xi]);
                double PositionZ = Convert.ToDouble(MyListZ[ii + xi]);
                double PositionX2 = Convert.ToDouble(MyListX[ii + xi + 1]);
                double PositionY2 = Convert.ToDouble(MyListY[ii + xi + 1]);
```

```
                double PositionZ2 = Convert.ToDouble(MyListZ[ii + xi + 1]);
                if (radioButton1.Checked)
                {
                    CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                    CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                }
                else
                {
                    CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                    CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                }
                Model.CommitChanges();
            }
            ii = ii + 30;
        }
        else if (MyList[ii].ToString() == MyList[ii + 21].ToString())  //6 sides polygon
        {
            Shapes.Add("6Sides");
            for (int xi = 0; xi <= 21; xi += 4)
            {

                double PositionX = Convert.ToDouble(MyListX[ii + xi]);
                double PositionY = Convert.ToDouble(MyListY[ii + xi]);
                double PositionZ = Convert.ToDouble(MyListZ[ii + xi]);
                double PositionX2 = Convert.ToDouble(MyListX[ii + xi + 1]);
                double PositionY2 = Convert.ToDouble(MyListY[ii + xi + 1]);
                double PositionZ2 = Convert.ToDouble(MyListZ[ii + xi + 1]);
                if (radioButton1.Checked)
                {
                    CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                    CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                }
                else
                {
                    CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                    CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                }
                Model.CommitChanges();
            }
            ii = ii + 36;
        }
        else if (MyList[ii].ToString() == MyList[ii + 25].ToString()) //7 sides polygon
        {
```

```
            Shapes.Add("7Sides");
            for (int xi = 0; xi <= 25; xi += 4)
            {

              double PositionX = Convert.ToDouble(MyListX[ii + xi]);
              double PositionY = Convert.ToDouble(MyListY[ii + xi]);
              double PositionZ = Convert.ToDouble(MyListZ[ii + xi]);
              double PositionX2 = Convert.ToDouble(MyListX[ii + xi + 1]);
              double PositionY2 = Convert.ToDouble(MyListY[ii + xi + 1]);
              double PositionZ2 = Convert.ToDouble(MyListZ[ii + xi + 1]);
              if (radioButton1.Checked)
              {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
              }
              else
              {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
              }
              Model.CommitChanges();
            }
            ii = ii + 42;
          }
          else if (MyList[ii].ToString() == MyList[ii + 29].ToString()) //8 sides polygon
          {
            Shapes.Add("8Sides");
            for (int xi = 0; xi <= 29; xi += 4)
            {

              double PositionX = Convert.ToDouble(MyListX[ii + xi]);
              double PositionY = Convert.ToDouble(MyListY[ii + xi]);
              double PositionZ = Convert.ToDouble(MyListZ[ii + xi]);
              double PositionX2 = Convert.ToDouble(MyListX[ii + xi + 1]);
              double PositionY2 = Convert.ToDouble(MyListY[ii + xi + 1]);
              double PositionZ2 = Convert.ToDouble(MyListZ[ii + xi + 1]);
              if (radioButton1.Checked)
              {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
              }
              else
              {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
```

```
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
              }
              Model.CommitChanges();
            }
            ii = ii + 48;
          }
          else if (MyList[ii].ToString() == MyList[ii + 33].ToString()) //9 sides polygon
          {
            Shapes.Add("9Sides");
            for (int xi = 0; xi <= 33; xi += 4)
            {

              double PositionX = Convert.ToDouble(MyListX[ii + xi]);
              double PositionY = Convert.ToDouble(MyListY[ii + xi]);
              double PositionZ = Convert.ToDouble(MyListZ[ii + xi]);
              double PositionX2 = Convert.ToDouble(MyListX[ii + xi + 1]);
              double PositionY2 = Convert.ToDouble(MyListY[ii + xi + 1]);
              double PositionZ2 = Convert.ToDouble(MyListZ[ii + xi + 1]);
              if (radioButton1.Checked)
              {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
              }
              else
              {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
              }
              Model.CommitChanges();
            }
            ii = ii + 54;
          }
          else if (MyList[ii].ToString() == MyList[ii + 37].ToString()) //10 sides polygon
          {
            Shapes.Add("10Sides");
            for (int xi = 0; xi <= 37; xi += 4)
            {

              double PositionX = Convert.ToDouble(MyListX[ii + xi]);
              double PositionY = Convert.ToDouble(MyListY[ii + xi]);
              double PositionZ = Convert.ToDouble(MyListZ[ii + xi]);
              double PositionX2 = Convert.ToDouble(MyListX[ii + xi + 1]);
              double PositionY2 = Convert.ToDouble(MyListY[ii + xi + 1]);
              double PositionZ2 = Convert.ToDouble(MyListZ[ii + xi + 1]);
              if (radioButton1.Checked)
              {
```

```
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
            }
            else
            {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
            }
            Model.CommitChanges();
        }
        ii = ii + 60;
    }
    else if (MyList[ii].ToString() == MyList[ii + 41].ToString()) //11 sides polygon
    {
        Shapes.Add("11Sides");
        for (int xi = 0; xi <= 41; xi += 4)
        {

            double PositionX = Convert.ToDouble(MyListX[ii + xi]);
            double PositionY = Convert.ToDouble(MyListY[ii + xi]);
            double PositionZ = Convert.ToDouble(MyListZ[ii + xi]);
            double PositionX2 = Convert.ToDouble(MyListX[ii + xi + 1]);
            double PositionY2 = Convert.ToDouble(MyListY[ii + xi + 1]);
            double PositionZ2 = Convert.ToDouble(MyListZ[ii + xi + 1]);
            if (radioButton1.Checked)
            {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
            }
            else
            {
                CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
            }
            Model.CommitChanges();
        }
        ii = ii + 66;
    }
    else if (MyList[ii].ToString() == MyList[ii + 45].ToString()) //12 sides polygon
    {
        Shapes.Add("12Sides");
        for (int xi = 0; xi <= 45; xi += 4)
        {
```

```
                double PositionX = Convert.ToDouble(MyListX[ii + xi]);
                double PositionY = Convert.ToDouble(MyListY[ii + xi]);
                double PositionZ = Convert.ToDouble(MyListZ[ii + xi]);
                double PositionX2 = Convert.ToDouble(MyListX[ii + xi + 1]);
                double PositionY2 = Convert.ToDouble(MyListY[ii + xi + 1]);
                double PositionZ2 = Convert.ToDouble(MyListZ[ii + xi + 1]);
                if (radioButton1.Checked)
                {
                  CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                  CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"50x150");
                }
                else
                {
                  CreateBarrier(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                  CreateBarrier2(PositionX, PositionY, PositionZ, PositionX2, PositionY2, PositionZ2,
"ROD16");
                }
                Model.CommitChanges();
              }
              ii = ii + 72;
            }
            listBox4.Items.Add(Shapes[si]);

          }

        }

        private static ModelObject CreateBarrier(double PositionX, double PositionY, double PositionZ,
double PositionX2, double PositionY2, double PositionZ2, string grtype)
        {
          Beam Guardrail = new Beam();

          Guardrail.Name = "GUARDRAIL";

          Guardrail.Profile.ProfileString = grtype;

          Guardrail.Material.MaterialString = "Conceptual";
          Guardrail.Class = "40";
          Guardrail.StartPoint.X = PositionX;
          Guardrail.StartPoint.Y = PositionY;
          Guardrail.StartPoint.Z = PositionZ+600.0;

          Guardrail.EndPoint.X = PositionX2;
          Guardrail.EndPoint.Y = PositionY2;
          Guardrail.EndPoint.Z = PositionZ2 + 600.0;
          Guardrail.Position.Rotation = Position.RotationEnum.FRONT;
          Guardrail.Position.Plane = Position.PlaneEnum.MIDDLE;
```

```
            Guardrail.Position.Depth = Position.DepthEnum.MIDDLE;

            if (!Guardrail.Insert())
            {
                Console.WriteLine("Insertion of guardrail failed.");
            }

            return Guardrail;
        }
        private static ModelObject CreateBarrier2(double PositionX, double PositionY, double PositionZ,
double PositionX2, double PositionY2, double PositionZ2, string grtype)
        {
            Beam Guardrail2 = new Beam();

            Guardrail2.Name = "GUARDRAIL";
            Guardrail2.Profile.ProfileString = grtype;
            Guardrail2.Material.MaterialString = "Conceptual";
            Guardrail2.Class = "40";
            Guardrail2.StartPoint.X = PositionX;
            Guardrail2.StartPoint.Y = PositionY;
            Guardrail2.StartPoint.Z = PositionZ + 1200.0;

            Guardrail2.EndPoint.X = PositionX2;
            Guardrail2.EndPoint.Y = PositionY2;
            Guardrail2.EndPoint.Z = PositionZ2 + 1200.0;
            Guardrail2.Position.Rotation = Position.RotationEnum.FRONT;
            Guardrail2.Position.Plane = Position.PlaneEnum.MIDDLE;
            Guardrail2.Position.Depth = Position.DepthEnum.MIDDLE;

            if (!Guardrail2.Insert())
            {
                Console.WriteLine("Insertion of guardrail failed.");
            }

            return Guardrail2;
        }

        private void RemoveGuardrail_Click(object sender, EventArgs e)
        {
            Model Model = new Model();

            ArrayList GuardrailOject = new ArrayList();
            ModelObjectEnumerator Enum = Model.GetModelObjectSelector().GetAllObjects();
            while (Enum.MoveNext())
            {

                Beam guardrailsmodel = Enum.Current as Beam;

                if (guardrailsmodel != null)
                {
                    if (guardrailsmodel.Name == "GUARDRAIL")
```

```
                {
                    guardrailsmodel.Delete();
                    Model.CommitChanges();
                }
            }
        }


    }
  }
}
```

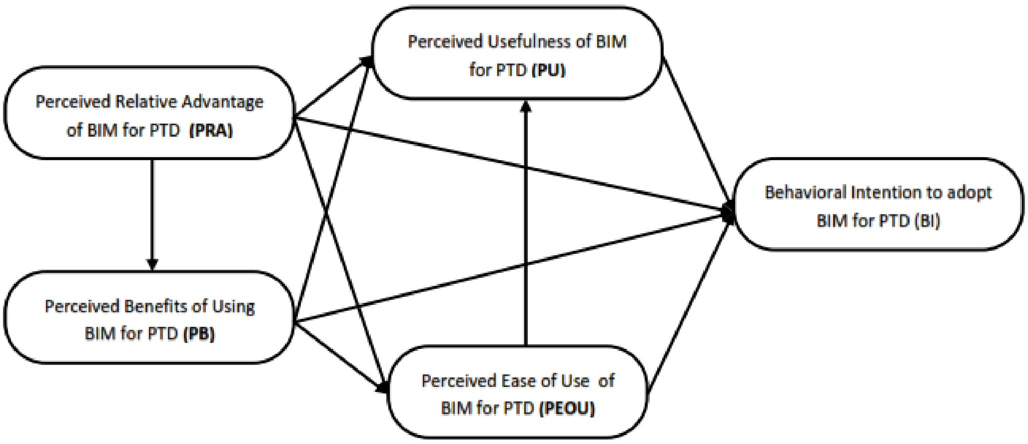
APPENDIX D

EXPERT REVIEW BRIEFING FORM AND QUESTIONNAIRE ASSESSMENT FORM

EXPERT REVIEW BRIEFING SHEET

Purpose: This expert review process is conducted to assess the draft questionnaire by seeking comments from independent experts with experience in structural design.

Questionnaire's objective: The draft questionnaire was developed to determine the intervening qualities of Building Information Modeling (BIM) technology to the adoption of Prevention Through Design(PTD) among design engineers by measuring each construct of the following model:



Target groups of respondents: Philippine-based structural designers.

Structure of the questionnaire: The draft questionnaire consists of three main parts:

• **Part A** aims to measure the survey respondents' perceptions of the qualities or attributes of BIM technology for PTD. Most of the questions in this part were adapted from published survey instruments. This part consists of 5 sections:

- **Section A-1:** Perceived Usefulness (PU) of BIM for PTD
- **Section A-2:** Perceived Ease of Use (PEOU) of BIM for PTD
- **Section A-3:** Perceived Relative Advantage (PRA) of BIM for PTD
- **Section A-4:** Perceived Benefits (PB) of using BIM for PTD
- **Section A-5:** Behavioral Intention (BI) to Adopt BIM for PTD

• **Part B** enquires background information of the respondents.

QUESTIONNAIRE ASSESSMENT RECORD FORM

REVEIWER'S NAME: ____________________________

INSTRUCTIONS

(1) Please use the following criteria to review the questions.
(2) For each criterion, please list (if any) affected question numbers and briefly write remedial suggestions.

1. Questionnaire Instructions: Look for problems with any introductions, instructions, or explanations from the respondent's point of view.
1a. Conflicting or inaccurate instructions, introductions, or explanations.
1b. Complicated instructions, introductions, or explanations.

2. Clarity: Identify problems related to communicating the intent or meaning of the question to the respondent.
2a. Wording: The question is lengthy, awkward, ungrammatical, or contains complicated syntax.
2b. Technical term(s) are undefined, unclear, or complex.
2c. Vague: There are multiple ways to interpret the question or to decide what is to be included or excluded.

2d. Reference periods are missing, not well specified, or in conflict.

3. Assumptions: Determine if there are problems with the assumptions made or the underlying logic.
3a. Inappropriate assumptions are made about the respondent or about her/his situation.
3b. Assumes constant behavior or experience for situations that vary.
3c. Double-barrelled: Contains more than one implicit question.

4. Knowledge/Memory: Check whether respondents are likely to not know or have trouble remembering information.
4a. Knowledge may not exist: Respondent is unlikely to know the answer to a factual question.
4b. Attitude may not exist: Respondent is unlikely to have formed the attitude being asked about.
4c. Recall failure: Respondent may not remember the information asked for.

4d. Computation problem: The question requires a difficult mental calculation.

5. Sensitivity/Bias: Assess questions for sensitive nature or wording and for bias.
5a. Sensitivity: The question asks about an embarrassing, very private topic or can lead to the individual respondent being identified.
5b. Desirability response is implied by the question.

6. Response Categories: Assess the adequacy of the range of responses to be recorded.
6a. Mismatch between question and response categories.
6b. Technical term(s) are undefined, unclear, or complex.
6c. Vague response categories are subject to multiple interpretations.
6d. Overlapping response categories.

6e. Missing eligible responses in response categories.
6f. Illogical order of response categories.
7. Other Problems: Look for problems not identified in the above criteria.
7. Other problems not previously identified.

This form can be returned by email to: rimmonlabs@gmail.com or d6222300235@g.siit.tu.ac.th

APPENDIX E

SURVEY QUESTIONNAIRE

February 27, 2023

Dear Engr.,

I am currently undertaking research into the adoption of Prevention Through Design (PTD) among structural designers in the Philippines. The research seeks to determine the intervening qualities of Building Information Modeling (BIM) to PTD adoption.

As part of my research, I am administering a questionnaire to Philippine-based structural designers for input. Due to the small sample size of professionals, **your experiences and perceptions on the subject are very important to this study**.

The questionnaire will require roughly 5-10 minutes to complete. Your response will be held in the **strictest confidence**. The data will only be used for academic reasons. Just a summarized overview of the results, not the names of the participants, may be published and made available. Also, if you complete the questionnaire by **April 27, 2023**, you will have a chance to **win 1 of 5 1000-worth Gcash Loads**.

The questionnaire is also available online at the following link:
https://docs.google.com/forms/d/e/1FAIpQLSfmbGhlyWe6l_n_O4_UzNTvGLRScvThDPH_ttVBoUaQEmlXhQ/viewform?usp=sf_link

Should you have any questions, please contact me by phone at 09978838517 or by email at rimmonlabs@gmail.com.

Thank you for taking the time to assist me in my educational endeavors.

Sincerely,

Rimmon Labadan
Ph.D. Candidate
SIIT Thammasat University, Thailand &
Graduate School of Engineering,
Hokkaido University, Japan

Recommended by:

Assoc. Prof. Dr. Kriengsak Panuwatwanich
Supervisor (SIIT-Thammasat University)
kriengsak@siit.tu.ac.th

Assoc. Prof. Dr. Sho Takahashi
Supervisor (Hokkaido University)
stakahashi@eng.hokudai.ac.jp

SINCE 1992

Questionnaire Survey

Purpose of the survey: This survey aims to gather data for developing a model for evaluating the intervening qualities of Building Information Modeling (BIM) for Prevention Through Design (PTD) adoption among structural designers in the Philippines. Your response will measure BIM's perceived characteristics/qualities and how they affect the designer's behavioral intention to adopt PTD.

Confidentiality: The information will be used for academic purposes only. Your answers will be kept completely confidential. Results will be aggregated and presented as summaries only, and individual respondents will not be identified.

Questionnaire structure: This questionnaire contains 3 pages consisting of 2 main parts. Part A requests information regarding perceived characteristics/qualities of BIM for PTD, and Part B solicits background information.

The questionnaire is available online at the following link:

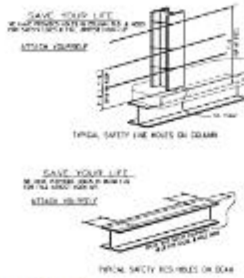
https://docs.google.com/forms/d/e/1FAIpQLSfmbGhlyWe6l_n_O4_UzNTvGLRScvThDPH_ttVBoUaQEmIXhQ/viewform?usp=share_link

List of Definitions & Illustrations

Prevention through Design (PTD)

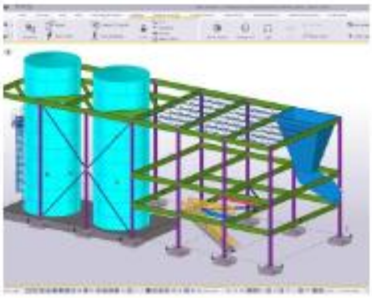
The concept of PtD, also called Design for Safety (DfS), is the consideration of safety during the design phase of a project and consciously making design decisions for the construction workers' possible risk. It includes the insertion of safety awareness during the plans and specifications preparations.
Examples of PTD:

Adding holes in structural members in preparation for guardrails and lifeline supports.



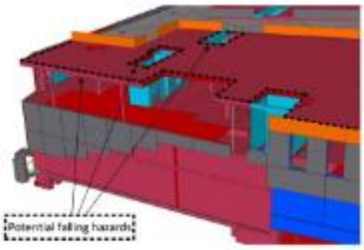
Building Information Modeling (BIM)

BIM is the virtual representation of a building's physical and functional characteristics that includes a 3D geometry with incorporated physical and functional information on its elements. It also develops and uses a computer software model to analyze or simulate facilities' construction activities and operations. Some examples of BIM software are Tekla Structures, Autodesk Revit, Archicad, BIMcollab, and Solibri Model Checker.



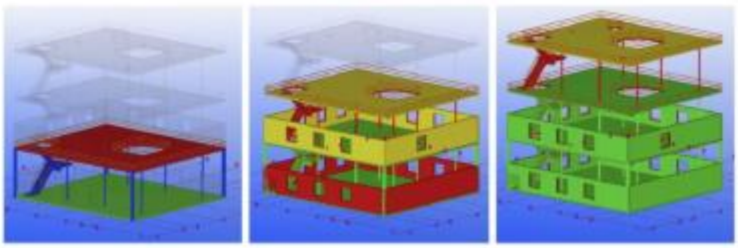
Some examples of BIM usage for construction safety:

1. **Visualization of construction risks:**



2. **Animation of construction sequences:**

3. **Automation of safety guardrails:**



Part A

This part consists of 6 sections (A-1 to A-6). When rating a statement, please use the rating scale provided in each section.

Section A-1: Perceived Usefulness (PU) of BIM for PTD

Please rate (✓) your opinion on the following statements.

		STRONGLY DISAGREE ▼	DISAGREE ▼	NEUTRAL ▼	AGREE ▼	STRONGLY AGREE ▼
PU1	Using BIM will improve my ability for construction safety analysis.	(1)	(2)	(3)	(4)	(5)
PU2	Using BIM will improve my effectiveness in conducting PTD.	(1)	(2)	(3)	(4)	(5)
PU3	I find BIM useful in the construction safety analysis.	(1)	(2)	(3)	(4)	(5)

Section A-2: Perceived Ease of Use (PEOU) of BIM for PTD

Please rate (✓) your opinion on the following statements.

		STRONGLY DISAGREE ▼	DISAGREE ▼	NEUTRAL ▼	AGREE ▼	STRONGLY AGREE ▼
PEOU1	My interaction with BIM is clear and understandable for construction safety analysis.	(1)	(2)	(3)	(4)	(5)
PEOU2	I find the BIM-based approach for PTD interesting.	(1)	(2)	(3)	(4)	(5)
PEOU3	Learning to use BIM for PTD will be easy for me.	(1)	(2)	(3)	(4)	(5)

Section A-3: Perceived Relative Advantage (PRA) of BIM for PTD

Please rate (✓) your opinion on the following statements.

		STRONGLY DISAGREE ▼	DISAGREE ▼	NEUTRAL ▼	AGREE ▼	STRONGLY AGREE ▼
PRA1	A BIM-based approach will enable me to optimize construction safety in my design.	(1)	(2)	(3)	(4)	(5)
PRA2	Using BIM for PtD will improve the quality of my involvement in construction safety concerns.	(1)	(2)	(3)	(4)	(5)
PRA3	A BIM-based approach for PTD is convenient for designers.	(1)	(2)	(3)	(4)	(5)

Section A-4: Perceived Benefits (PB) of using BIM for PTD

Please rate (✓) your opinion on the following statements.

		STRONGLY DISAGREE ▼	DISAGREE ▼	NEUTRAL ▼	AGREE ▼	STRONGLY AGREE ▼
PB1	BIM can facilitate the integration of construction safety aspects.	(1)	(2)	(3)	(4)	(5)
PB2	BIM can increase my construction OSH knowledge and awareness.	(1)	(2)	(3)	(4)	(5)
PB3	The 3D model of BIM will enable me to visualize construction hazards.	(1)	(2)	(3)	(4)	(5)

Section A-5: Behavioral Intention (BI) to Adopt PTD
Please rate (✓) your opinion on the following statements.

		STRONGLY DISAGREE ▼	DISAGREE ▼	NEUTRAL ▼	AGREE ▼	STRONGLY AGREE ▼
BI1	I will likely adopt PTD.	(1)	(2)	(3)	(4)	(5)
BI2	I intend to perform PTD.	(1)	(2)	(3)	(4)	(5)
BI3	If I am asked to include construction safety analysis in my work, I will perform it.	(1)	(2)	(3)	(4)	(5)

END OF PART A -------------------------- PLEASE CONTINUE TO PART B → →

Part B: Background Information

1. What is your current level of position as a designer?
   - ☐ Principal ☐ Associate ☐ Senior ☐ New entry
   - ☐ Freelancer ☐ Others: ________________

2. Years of experience in structural designing:
   - ☐ 0-5 ☐ 6-10 ☐ 11-20 ☐ 21-40 ☐ Over 41

3. How old are you?
   - ☐ 20-25 ☐ 26-30 ☐ 31-40 ☐ 41-50 ☐ Over 51

4. What is your highest level of education?
   - ☐ Bachelor Degree ☐ Master Degree ☐ Doctorate Degree
   - ☐ Other____________

5. Which part of structural designing do you do?
   - ☐ Structural analysis
   - ☐ Detailing
   - ☐ Both analysis and detailing
   - ☐ Other (please specify) ____________________

6. Have you used any BIM software on your design?
   - ☐ Yes ☐ None so far

7. How do you use BIM software? (Please check all applicable items.)
   - ☐ Structural analysis
   - ☐ Structural plan detailing
   - ☐ Structural manufacturing
   - ☐ Collaboration with the architect
   - ☐ Collaboration with the contractor
   - ☐ Collaboration with other designers
   - ☐ Collaboration with the owner or general project manager
   - ☐ Other _____________________

8. How do you share or collaborate your designs with other designers or project stakeholders? (Please check all applicable items.)
   - ☐ Paper-based
   - ☐ Software file sharing
   - ☐ IFC file sharing
   - ☐ Cloud-based
   - ☐ Other____________

If you would like to enter the prize draw, please provide your contact details below.

First name:____________________ Last name:__________________
Cell Number: __________________ Email address: ________________

--------------------------------------END OF QUESTIONNAIRE---------------------------------

Thank you very much for your time and effort!