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Impact of Construction Technology on Insurance Premiums

Salma Mohamed Ibrahim
The American University in Cairo AUC, salmamohamed@aucegypt.edu

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Impact of Construction Technology on Insurance Premiums

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By

Salma Mohamed Sayed Ibrahim

Under the Supervision of

Dr. Ibrahim Abotaleb
Assistant Professor
Department of Construction Engineering
The American University in Cairo

Dr. Ossama Hosny
Professor
Department of Construction Engineering
The American University in Cairo

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Impact of Construction Technology on Insurance Premiums

Abstract

The witnessed technological advancement within the construction industry affects stakeholders in connection, inclusive of the insurance industry. Construction insurance premiums resemble the quantification of risks in construction projects and signify a portion of the construction expenses in return to securing the investment in cases of claims. Accordingly, new construction technology is expected to have an impact on the insurance premiums. In other words, the insurance industry is expected to re-evaluate the insurance premiums according to the risks borne by the new construction technology utilized in construction projects and the likelihood of claims arising. Even though prior literature acknowledges the reduction in insurance premiums as a result of enhanced on-site safety measures, including construction technology, preexisting research does not quantify the relationship between construction technology and insurance premiums. Despite that insurance premiums are expected to decrease in consequence of construction technology, new kinds of risks develop with advancing the industry.

The goal of this research is to quantify the impact of construction technologies – namely building information modeling (BIM), virtual reality (VR) safety training, prefabricated and modular construction, robotic fabrication, 3D printing and construction automation, and construction site internet of things (IoT) - on accident reduction and insurance premiums. The research is conducted in two main stages. The first stage is industry research, at which interviews with construction and insurance professionals are conducted to understand the risk perception and premium evaluation criteria within the industry. The second stage is quantitative analysis, where surveys are conducted to evaluate the impact of construction technology on accident reduction and insurance premiums. This research also discusses the necessary adjustments to current insurance policies for the adoption of the above-mentioned construction technologies and provides a decision-making model to support contractors in adopting any of the above-mentioned construction technologies.

It is concluded that accidents and insurance premium decrease most for robotic fabrication, 3D printing and automated construction; followed by construction site IoT; then prefabricated and modular construction; afterwards VR safety training, and finally BIM. The results also indicated that there is a positive relationship between the reduction in accidents and the reduction in insurance premium; which is expected to encourage contractors to use such new technologies. Through mathematical modeling, an equation predicting the reduction in insurance premium as a result of accident reduction was derived; which is a unique outcome of this research. In addition, an empirical mathematical model was developed to aid contractors in the go/no-go decision for using construction technologies based on profit prediction. Finally, additional discussions were presented to aid contractors in understanding other considerations related to insurance. Insurance premium reduction is not the sole determining factor for adopting construction technology, other factors include: the size of the contractor, the scale and complexity of projects, contractual obligation, moral obligation, and sustainability of construction technology.

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Terminology and List of Acronyms

BIM	Building Information Modelling
CC	Contractors and Consultants
IB	Insurers and Insurance Brokers
IoT	Internet of Things
n	Number of Respondents
VR	Virtual Reality
3D BIM	Three-Dimensional Building Information Modelling
3D Printing	Three-Dimensional Printing
8D BIM	Eight-Dimensional Building Information Modelling

Chapter 1. Introduction

1.1 Background

1.1.1 Demand for Insurance in Construction Industry

Construction is one of the most dangerous industries in terms of injuries and fatalities per man hours (Chubb 2020). According to the U.S. Department of Labor (2019), in 2018, 21.1% of private industry worker fatalities and 47% of all fatal work injuries belong to the construction sector. Accordingly, the construction industry undergoes nonstop research and encounters advancement in digitalization day after day to improve its safety, quality, and efficiency performance standards. Such technological advancement does not only impact the industry itself, but also it impacts all the interacting businesses supplying, consuming, or interacting with the construction practices.

Companies resort to insurance as a mean of managing the business financial risks (Fadun 2013). According to Bunni (2003), the role of the insurance industry is to evaluate the risks possibly emerging within or related to the project and charge a premium in return of covering for the losses arising from those risks in case they occur. Such agreement is underwritten in details of insurance coverages and limits in an insurance policy (Bunni 2003). At the event of an accident, the insurance client (often the contractor) files a claim to the insurance company which, depending on the terms and conditions of the insurance policy, bears all the financial cover-up to the risks (Bunni 2003). Accordingly, "insurance is a mechanism through which firms can reduce negative financial consequences of an uncertain event or possible financial loss." (Fadun 2013). Influential factors determining the construction insurance premiums are widely discussed in literature but never clear enough to draw numerical conclusions since the actuarial models are highly secure and confidential. Insurance policies can be classified into three categories according to Russell (1991):

1. Required by law, such as worker's compensation; that covers for the employees' bodily injuries taking place at job related activities.
2. Required by contract, purely driven by parties' negotiations/ agreement.
3. Required due to the company's demand on transferring risk to the insurance company, and this is based on company's profile and strategic management.

1.1.2 Evolution of Construction Industry

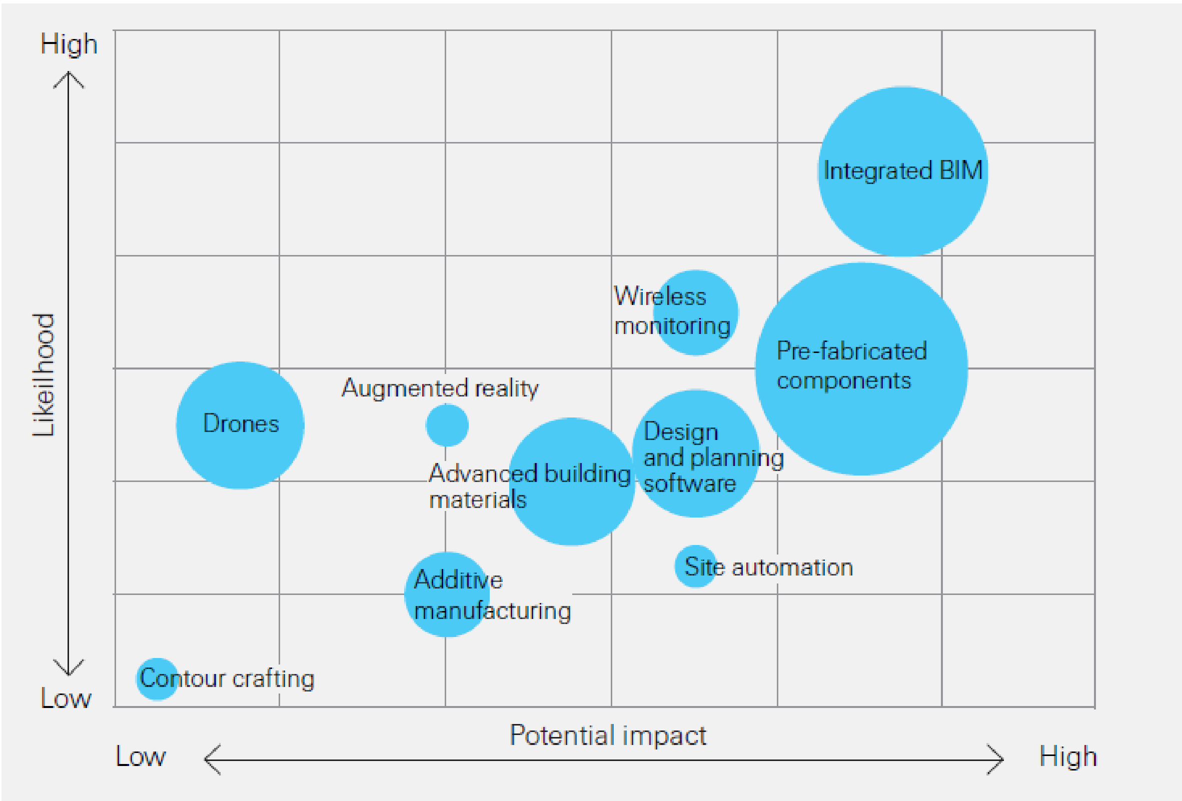
According to Duodu & Rowlinson (2021), the means of innovation in the construction industry is through involving technological advancement. In the recent times, several signs of digitalizing the construction industry started to appear and since then there is constant evolution within the construction engineering technology (Swiss Re 2018). Such digital and technological advancement within the construction industry has been happening gradually and will continue to evolve gradually until transforming the market one day to the possibility of having unmanned construction (Swiss Re 2018). Such advancement does not only improve the efficiency of the construction process in terms of time, cost, and quality, but also has a significant improvement to the safety standards of constructing the projects (Swiss Re 2018).

1.1.3 Highlight for the Necessary Adaptation of Insurance Industry

Swiss Re (2018), a leading reinsurance provider, highlighted the significance of evolving the insurance industry to meet the emerging construction technology both for the safety practices and coordination on-site and within construction method statements. Swiss Re (2018) divided the construction technological advancement that would impact engineering insurance policies and premiums into four categories: design and planning, construction management, data gathering and analytics, and new production methods and materials. The four categories start from digital designing software for project preliminary design and planning until the full coordination software between different project disciplines, the onsite safety control technology and modern digital fabrication methods. Under such umbrellas are different construction technologies discussed in literature.

Figure 1 represents the influence of different construction technologies, from the point of view of Swiss Re (2018), on the engineering insurance premiums and the advancement of utilizing such construction technologies. The diameter of the circles represents the level of advancement of each construction technology. The degree of advancement of each construction technology, its probability of impacting the insurance industry, and its actual impact are different. Yet, it is inevitable that each construction technology is unimaginatively influencing the insurance industry.

Urging the insurance industry to adapt towards the broad span of available construction technology is doubtless since construction could one day be fully automated (Swiss Re 2018) and some countries impose regulations to forcibly adopt construction technology (Mustaffa et al. 2017).



The size of the bubbles represents the technology readiness level (TRL) of the particular innovation. The TRL scale ranges from technologies that have not advanced beyond basic principles to those where applications have been widely tested and are fully operational. For details see:
https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html
Source: WEF and Swiss Re Institute calculations

Figure 1 Probability Vs impact of different construction technology on insurance market (Swiss Re 2018)

1.2 Problem Statement

Insurance companies increase premiums or may even refuse to offer insurance coverage to businesses who have significant historical record of accidents, poor safety management or highly hazardous jobs (Bunni 2003). Accordingly, the opposite is expected when improved safety management is applied leading to less hazardous environments and lower possibility of claim reporting. Reduction in construction insurance premium is not the only benefit from improving site safety rather it is the quantified benefit considered in this research due to its significance as follows.

Ikpe et al. (2011) identifies a list of direct and indirect benefits for site accident prevention. Insurance premium reduction was the primary listed benefit along with saving on accident investigation, damaged material, compensation claims costs and other factors (Ikpe et al. 2011). In addition, reduction in construction insurance premium was emphasized by Choudhry et al. (2008) in their research highlighting the safety management practices in Hong Kong along with minimizing costs of accident litigation and emergency needs, not to mention the improved productivity and moral considerations.

Even though prior acknowledgement for the reduction in insurance premiums as a result of enhanced on-site safety measures - including construction technology - is provided in literature, preexisting research does not quantify the relationship between construction technology and insurance premiums. Adding to the concern, insurance premium estimation models are confidential with no actuarial details revealed beyond the insurance companies’ research departments, inducing no room for quantifying the impact of construction technology on insurance premiums on historical statistical basis.

1.3 Research Goal and Objectives

Insurance companies are one of the main stakeholders in the construction industry. Construction insurance premiums resemble the quantification of risks in construction projects. The goal of this research is to measure the effect of new construction technologies on accident prevention/ reduction and consequently insurance premiums. Based on Swiss Re (2018), Man Li (2018), and Chubb (2020) reviewed literature, the analyzed technologies covered in this research are:

1. Building Information Modeling (BIM)
2. Virtual Reality (VR) safety training
3. Prefabricated and Modular Construction
4. Robotic Fabrication, 3D Printing and Construction Automation
5. Construction Site IoT (Internet of Things) – (Drones and Wireless monitoring)

The abovementioned technologies acquire an expected growth and utility in future projects worldwide and have a forecasted significant influence on how projects are executed (Swiss Re 2018).

The objectives of this research are:

1. Identify the factors that affect insurance premiums and qualitatively classify them according to their influence on premium estimation
2. Quantify the impact of construction technology on on-site safety and premium estimation via:
   a- Quantifying that impact of construction technology on accident reduction
   b- Quantifying the impact of accident reduction on insurance premium reduction
   c- Quantifying the impact of construction technology on insurance premium estimation from the perspectives of consultants/ contractors and insurers/ insurance brokers
3. Highlight the newly developed risks due to construction technology and accordingly identify the necessary adaptation in insurance policies
4. Propose a decision-making model for contractors' guidance in adopting construction technology based on cost savings and consequent increase in profit.
5. Measure the change in insurers' profit due to contractor's adoption of construction technology.

1.4 Research Methodology

This research is pursed in accordance with the following methodology:

1. Conduct a literature review that identifies the factors affecting insurance premiums, the influence of construction technology on construction safety and insurance premium and the newly developed risks from construction technology.
2. Conduct industry research through interviewing construction and insurance experts and analyze the different perspectives regarding construction technology
3. Conduct quantitative research to test the insurance premium sensitivity to construction technology
4. Develop a decision-making model to support contractors in adopting construction technology based on cost savings and consequent increase in profit.
5. Conclude the research with the findings from the previous steps; mainly in quantifying the impact of construction technology on insurance premiums.

1.5 Thesis Organization and Structure

This thesis is organized into seven chapters as described below:

1. Chapter 1 presents the research problem statement and the research objectives.
2. Chapter 2 consolidates the literature review for the construction technology and consequent influence on insurance.
3. Chapter 3 proposes the research methodology to meet the research objectives.
4. Chapter 4 discusses the industry research outcomes after conducting interviews with insurance and construction industry professionals.
5. Chapter 5 quantifies the relationship between construction technology, accident reduction and insurance premiums based on surveys with insurance and construction professionals.
6. Chapter 6 discusses the decision-making factors and proposes an empirical decision-making profit prediction model to guide contractors regarding adopting construction technology and measure the consequent effect on insurers’ profit and overall project cost efficiency. The model is applied on a case study for its verification and validation.
7. Chapter 7 presents the research conclusion, limitation, and recommendation for future research.

Chapter 2. Literature Review

A comprehensive literature review is conducted to serve in understanding the latest research efforts in the fields of construction insurance and construction technology. The literature review is divided into the following three main sections:

1. Factors that affect construction insurance premiums
2. Research highlighting the insurance market required adaptation to cope with construction technology
3. Construction technologies affecting on-site safety and their additional risks (insurable and uninsurable)

2.1 Factors Affecting Construction Insurance Premiums

Several research efforts exist regarding the determining factors of the insurance policies' premium, however the detailed actuarial buildup for the estimation models lack significantly in literature. Accordingly, the exact impact of the determining factors that affect insurance premiums is not available for public domain. Insurance premiums are determined based on project risks. Each research paper in literature classifies risks in a unique way depending on the chosen insurance policies and focusing on specific project parties.

A study conducted by Bou Hatoum et al. (2020) evaluated the contractor's safety performance in developing countries and formed a standard for contractor's safety evaluation. Such study attempted to guide insurance companies evaluate their premiums based on listing and evaluating the different contractor's safety practice measures through market surveys to contractors and insurance companies. Project safety policies, different methods of communicating such safety policies, investing in improving labor safety illiteracy, contractor's labor characteristics and subcontract management were the five broad categories included in the study. A further breakdown to each category, shown in Figure 2, was then identified and ranked according to the influence on construction safety (Bou Hatoum et al. 2020).

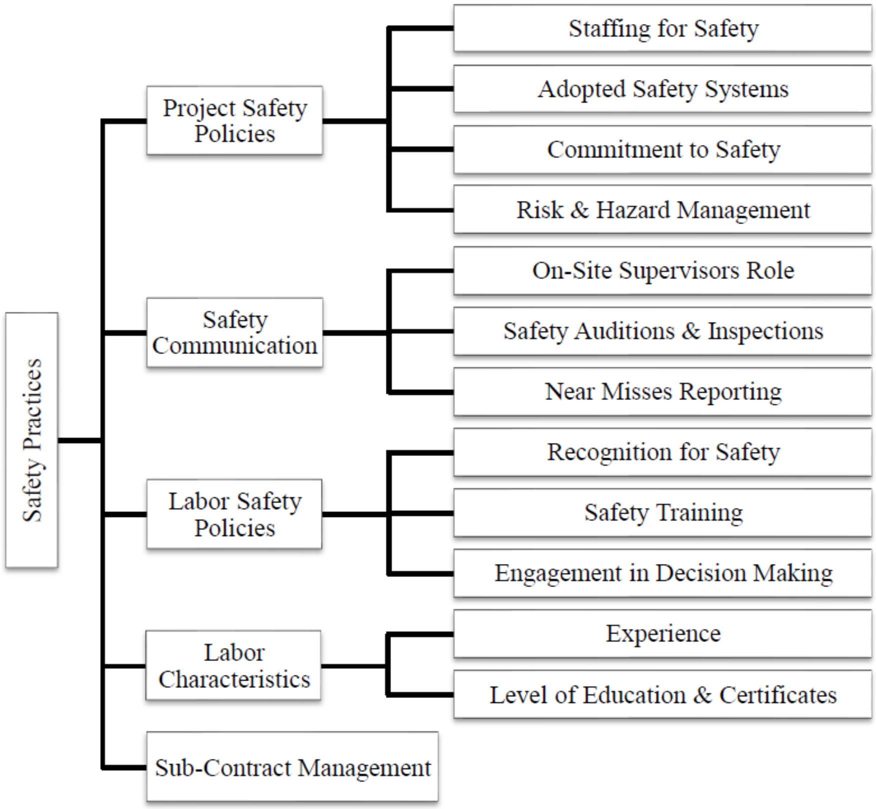


Figure 2 Different factors affecting construction safety and insurance premiums (Bou Hatoum et al. 2020).

Imriyas et al. (2007) identified the workers' compensation insurance premium determining factors for construction labor. The factors determining the insurance premium estimation were classified under the below categories: project factors, contractor factors, insurer factors and market factors. A further breakdown was similarly provided for each category and market interviews and surveys were used to classify the factors according to their impact on insurance premiums. Table 1shows the considered factors ranked in order of influence on insurance premiums. It is important to highlight that some of the mentioned factors relate to and affect only the workers' compensation insurance policy. Accordingly, this study, and similar ones, can support the current research with mostly all the factors except for the highly workers' compensation insurance related factors such as wages (Imriyas et al. 2007).

Table 1 Premium determining factors ranked in order (Imriyas et al. 2007)

Variables group	Pertinent variable
1. Important variables	Wage roll Project hazard level Effectiveness of the safety management system on site Contractor's claims history Competition Corporate objectives of the insurer Overhead costs of insurance Investment income from underwritten premiums
2. Less important variables	Profit/loss experience in WCI business Reinsurance cost Amount of outstanding claims to the insurer Project duration Placement of multiple policies by the contractor Cooperation by the contractor Volume of business in the market
3. Unimportant variables	Expectation of potential business from the contractor Contractor's size

2.2 Insurance Market Need for Adaptation

The insurance industry accommodates to the changing needs of the markets it is serving. Whenever new market trends emerge for served insured industries, the insurance market needs to follow that trend and adapt accordingly (Russell 1991). Since there is the significant flow of digitalization technology in several industries, the insurance sector does not find any alternative other than revolutionizing to tailor for the newer forms of risks (Swiss Re 2018).

Swiss Re (2018) divides the technological advancement in the construction sector shaping its risks and accordingly impacting insurance in terms of policies and premiums into four categories, all of which significantly improve on-site safety and reduce different project risks:

1- Design and planning software: VR is classified as part of the design and planning software along with AR because such tools enable visualizing the projects at an early stage. Front loading the design process of the project will clarify risks at earlier stages allowing for dealing with them.

2- Construction management: BIM is the main tool behind such category since it spans the project throughout its lifecycle. This follows the concept of front loading the design process.
3- Data gathering and analytics: all possible data gathering techniques connected to control systems are part of the data gathering and analytics category, such include IoT.
4- New production methods and materials: different forms of prefabrication and robotics using advanced materials necessary for the newer construction methods are the aim of such category.

Current examples of service providers to construction companies supporting them in blending the recent technological revolution in construction within the contractors' operations are provided in Table 2 (Swiss Re 2018).

Table 2 Examples of named companies providing services for recent technological evolution in construction (Swiss Re 2018)

Company	Key technological concept	Brief description
Daqri	Augmented Reality (AR)	The combination of AR with a security helmet can be leveraged for communication of instructions and alerts. This helps reduce both accidents on site as well as workmanship errors. See https://daqri.com/
Skycatch	UAV/drones	Camera technology is used to monitor buildings and gauge topography and soil type throughout the construction lifecycle. Software can pair with a Skycatch UAV, or drones from other manufacturers. See https://www.skycatch.com/
Cazza	Additive manufacturing	In March 2017, Dubai construction firm Cazza said it plans to build the world's first 3D-printed skyscraper by 2020. For more details on the underlying technology, see https://3dprint.com/189228/cazza-3d-print-construction-robots/
Pillar	Sensors	Wireless sensor to monitor conditions on a construction site. Various functions from air monitoring to flood or fire alarm with the aim to increase safety and security. See http://pillar.tech/
PlanGrid	BIM	Cloud-based collaboration platform for multi-user design and integration. With strict versioning and modification tracking, it enables all actors to work on a single model, reducing conflicts in design. See https://www.plangrid.com/
NCCR Meshmould	Robotics/3D printing	Robotic fabrication system that "prints" two parallel reinforcement meshes serving as a formwork between which concrete can be poured. This eliminates the need for traditional formwork allowing for higher degrees of freedom and precision of construction. See http://www.dfab.ch/portfolio/mesh-mould-2/

Source: Swiss Re Institute based on published articles and company websites

Swiss Re (2018) claim that by 2050, if the above technologies are implemented hand-in-hand the construction sector will be an “unmanned” industry possibly in the form of robotics fabricating the project using novel materials engineering under continuous progress monitoring, reporting, and controlling by different forms of IoT connected to coded control systems. Real projects, office building and a house, are fully constructed in 2016 using 3D printing technology alone, in Dubai and Beijing, respectively (Swiss Re 2018).

In addition to the construction industry proneness to adopting the different construction technology for the much-added value, some countries are imposing regulations on contractors building projects within their borders to forcibly adopt construction technology. Examples for such regulations are in UK, Singapore, and Finland for requiring BIM in infrastructure projects (Mustaffa et al. 2017) and in Dubai for developing a 3D Printing Strategy launched in 2016 that ensure 25% of buildings to be 3D printed by 2030 (Swiss Re 2018).

To conclude, the insurance industry needs to update its underwriting strategies in managing risks to adopt for the revolutionizing construction industry. Such adaptation takes the form of developing new insurance policies to cover for the novel forms of risk developed as a byproduct for the different construction technology in addition to new actuarial models that quantify such risks and price premiums accordingly. The nature and the scope of work of the insurance company might also shape into forming mitigation plans due to the higher capability of visualizing the projects at the front-loaded design stages instead of a mere financial provider (Swiss Re 2018).

2.3 Construction Technology

Provided the above literature highlighting the insurance market need for adaptation to certain construction technologies, it is crucial to define the construction technology referred to in Figure 1, that are considered in this research.

According to Man Li (2018), traditionally, construction safety is granted via training labor and engineers/ officers and providing them the necessary PPEs for handling the jobs. In addition, hanging signs on-sites and at nearby hazardous zones is the single alarming technique for workers to avoid hazards and abide by safety regulations. In most cases, there is a safety officer that tries to reinforce the safety management plan produced for the project. However, with evolution of construction technology, such traditional means do not provide the optimum safety precautions for meeting the current construction industry advancement. Unfortunately, studies, to date, did not shed light on the impact of construction technology on construction safety, except for few studies highlighting the qualitative safety benefit of construction technology with no quantification (Man Li 2018). Man Li (2018) published a book named "An Economic Analysis on Automated Construction Safety" to guide modern construction users regarding the possible savings from adopting several construction technologies. The construction technologies discussed by Man Li (2018) are:

1. BIM and other software engineering
2. Additive Manufacturing; another term for 3D printing
3. Virtual Reality
4. Internet of Things
5. Robotics

Literature review for the use of technology and its impact on safety and premiums is discussed in the following sub-sections.

2.3.1 Building Information Modelling (BIM)

Building Information Modelling (BIM) is the process of creating 3D models during the design phase that represent the structure and/or the site and can be identified as the "virtual construction of a facility prior to its actual physical construction" (Khoshnava et al., 2012). The BIM technology reduces design uncertainty and risks helping to improve construction safety through BIM planning for hazardous site activities and site layout (Khoshnava et al., 2012). According to Man Li (2018), the use of BIM reduces design errors by 50 to 90%, accordingly decreasing reworks and improving safety exposure of the project. BIM prevents accidents through better design following the concept of "prevention through design" in supporting them safety management plan add the design and construction phases of the project (Man Li 2018). Further, BIM has the capability of reducing on-site accidents since the safety and risk management information can be added as a further dimension to BIM (Man Li 2018).

Kamardeen (2010) defines the “prevention through design” as “the input of site safety knowledge into design decisions” in possible means of identifying the different hazards in construction methods faced by labor on-site, suggesting safe design alternatives based on the identified hazards and providing on-site measures to eliminate hazards uncontrollable by design alternatives. As shown in Figure 3, the impact of controlling for the on-site safety significantly decreases overtime being the least during the construction phase (Kamardeen, 2010). Accordingly, BIM has a high opportunity and a significant contribution to lowering the on-site accidents (Kamardeen, 2010).

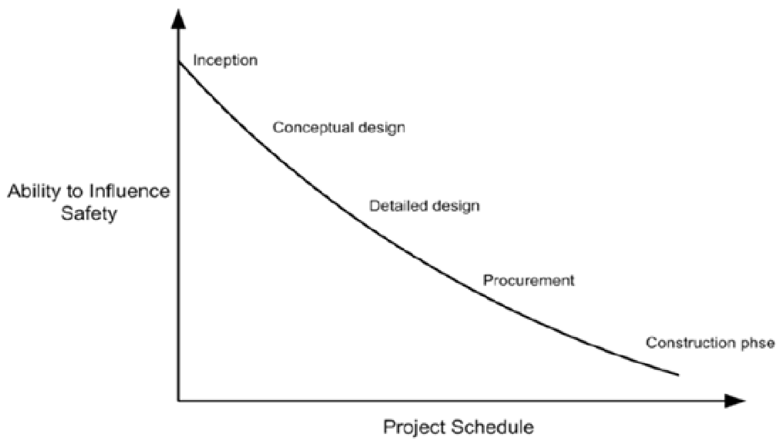


Figure 3 Possibility of impacting project safety at different projects stages (Furst 2009 and Mroszczyk 2008 from Kamardeen 2010)

BIM has several dimensions of possible inclusions to any 3D model that do not necessarily all exist simultaneously in any model (Kamardeen, 2010):

- 4D for project time schedule superimposition on construction activities. This provides a significant added value and contribution to safety management plans mainly in terms of clash detection and possible visualization of the project construction.
- 5D for project cost superimposition on construction activities to help visualize cash flow and prepare for budget allocation.
- 6D for facility management of the project during the operation phase since the model saves the data about every project element and can significantly contribute to safe and sound operation of the structure.
- 7D for sustainable project production. Such dimension supports designers to produce sustainable structures in accordance with different sustainable certifications and design criteria.

A further dimension/ advancement in BIM technology involves the introduction of 8D BIM. 8D for project safety management that accounts for the project safety on the basis of “prevention through design”. 8D BIM adds three pillars to the technology (Kamardeen, 2010):

1. Outlining hazards for model elements
2. Suggesting safer design alternatives for hazardous model elements
3. Providing on-site safety control plan for inevitable hazards; those that do not have safer design alternative.

8D BIM automatically identifies on-site safety hazards through safety-checking algorithms built within the software. 8D BIM facilitates decision making at times before the construction phase regarding the safe construction methods in order to minimize on-site hazards. In case the 8D BIM is connected to IoT (IoT will be discussed in the following sub-chapters) and/ or mobile phones of the labor on-site, it can alert users about the hazards in real time to react before the accident takes place. In addition, BIM is used to simulate hazardous construction methods and provide technical support to the safety management plans (Man Li 2018).

Man Li (2018) classified the contribution of BIM to construction safety in accordance with the following measures:

1. Data storage: BIM saves data about every element within the project and retrieves this data and simulates the physical and functional characteristics whenever activated. Such database can be used in preparing the safety management plans and controlling on-site safety by identifying the safety risks throughout the project duration and sometimes during the operational phase as well. Few research exists that uses BIM for safety training the on-site personnel. (A direct application for “prevention through design”).
2. Clash Detection: BIM allows users to identify the conflict between different disciplines and simulate the different tasks that take place on-site at the same time (provided the project schedule – 4D) showing all possible interaction and clashes between different jobs. BIM supports such criteria at the design phase helping for the safe design and time planning for different tasks on-site and throughout the construction phase in case there are any alterations to the project. (A direct application for “prevention through design”).

3. Safety Risks Identification: 8D BIM has the characteristic of identifying on-site safety hazards to the users through running the built-in algorithms and suggesting alternative means for reduced hazards. An expected reduction in risks of 40% is contributed through the use of 8D BIM. Figure 4 shows one of the developed algorithms in literature that codes for safety checking for the project risks and relating to several contractors' on-site interaction (Kim et al., 2016). Safety risk identification can take place as an add-on to 4D BIM models or even linking the 3D BIM model to other software specialized in identifying risks available in market since the BIM data is transferable and easily read by different software. The data can also be linked to other site information such as seismic in fact due to the geographical location and others. (A direct application for "prevention through design").

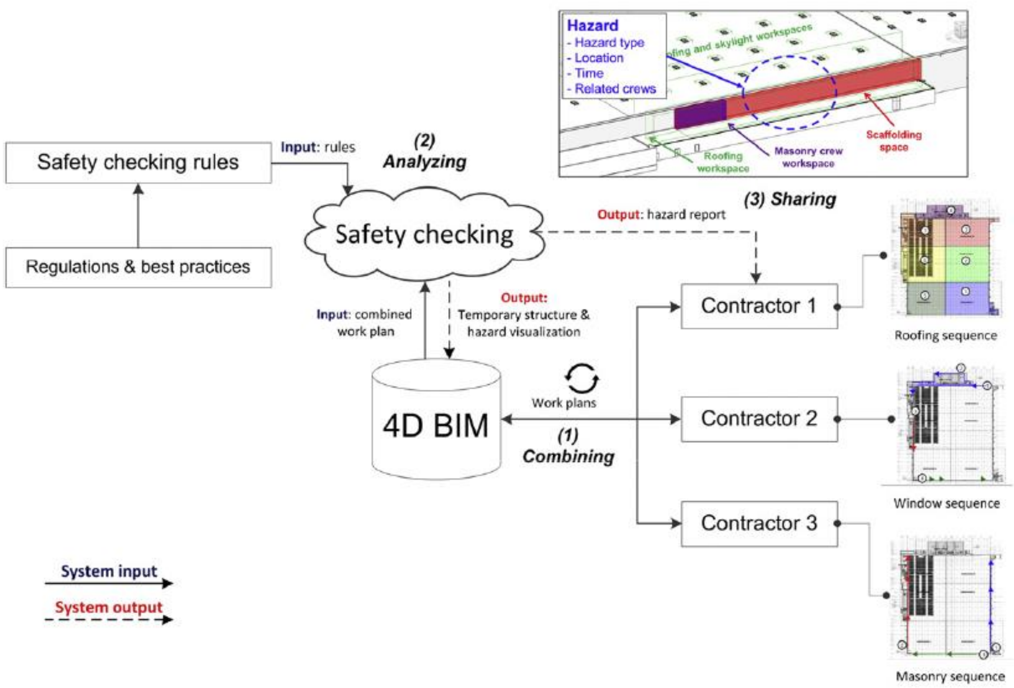


Figure 4 Developed algorithm coding for safety checks of different project risks (Kim et al., 2016)

2.3.2 Virtual Reality Safety Training

According to Sacks et al. (2013), virtual reality (VR) technology simulates fictional environment to users giving them the perception of realism and receiving user interaction to build a fictional response to it. Virtual reality has been used in several disciplines as a safety training tool. Virtual reality safety training for construction labor is expected to improve on-site construction safety through improved workers' ability to identify safety hazards better than when conventional training methods are provided. Studies show that VR safety training for specific job tasks on-site proved better recognition and dealing with safety hazards than traditional safety induction, yet not for general site safety (Sacks et al., 2013). However, according to Man Li (2018), VR safety training improves general site safety significantly since traditional means do not necessary simulate hazards in realistic manner to be understood by users as done by VR safety training and that VR safety training provides virtual tours within the site making labors practice the hazards virtually and respond to it instead of doing that in real life and encountering the fate.

According to Li et al. (2018), safety management starts at identifying the possible hazards at stake, therefore, to enhance construction safety, VR safety training shall target four main pillars:

1. Working environment; hazard recognition and intervention training, such as virtual safety assessment system (VASA).
2. Worker behavior; voluntary and involuntary response control towards a hazard, such as balance control VR training, that reduces the risk of falls at elevation, and proper use for PPEs for safety and quality assurance.
3. Working sequence; safe harmonic fusion of temporary structures design, site layouts, safe method statements and safety task scheduling.
4. High-risk equipment operation; non-immersive VR provides the safest, most cost-effective training for heavy construction equipment operators, such as Multi-User Virtual Safety Training Systems (MVSTS) game technology-based that senses user's physical acts to dismantle and operate tower cranes and respond accordingly through stored responses in a dynamic database.

Safety applications of VR in construction are not limited to VR safety training for labor. Different applications and tools for VR in construction safety in literature include (Zhou et al 2012):

1. Building Management Simulation Centre that was built in Netherlands, and others similar, to provide training for construction personnel using VR technology. This was the kick-off for VR in the safety management field.

2. The VR-based design-for-safety-process (DFSP) tool is used for identification of safety risks borne as of design implications; by relating the design criteria to possible safety hazards stored in database from previous projects or accidents.
3. Virtual Construction Laboratory (VCL) is a VR digital platform for planners to simulate construction methods and accordingly identify all possible safety hazards. This tool provides the optimal construction method for meeting safety, time, cost, and quality project requirements.
4. Computer Image Generation for Job Simulation (CIGJS) creates a virtual worker and simulates the worker's routine job according to the level of proficiency and project phase to determine the possible safety hazards the worker could be exposed to. It can also be used for training workers.

According to Ahmed (2019), application for VR currently implemented in the construction industry include:

1. Worker training; both safety and technical training. Figure 5 shows a worker training on excavator operation using VR technical training.
2. Safety Management; safety training, monitoring and control simulating real threats to users, ex: VR applications by 3M Science for worker training on Personal Protective Equipment (PPE) as shown in Figure 6.
3. Quality Control; BIM proactive defect management and VR-based mobile and digital workbench technology for defect reporting.
4. Visualization; readiness of all project data from project's cradle until operation and maintenance phase for users' virtual tour, inclusive of constructability methods.

Needless to highlight that VR technology overcomes the geographic borders between project parties in the most technical, time and cost-effective form. In general, VR has proven to provide the ultimate training experience; most knowledgeable, long-lasting memory and hands-on in the least time (Ahmed 2019).

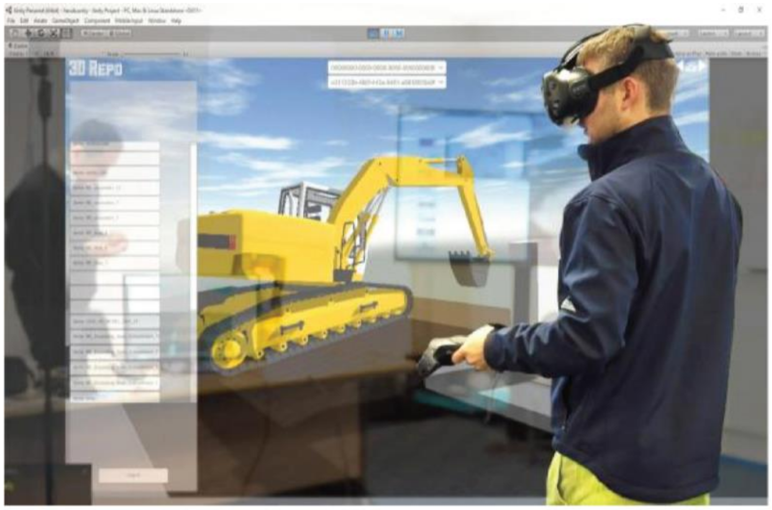


Figure 5 VR technical training on excavator operation (Knutt 2017 from Ahmed 2019)

Figure 6 VR safety training on PPE (Science 2017 from Ahmed 2019)

2.3.3 Prefabricated and Modular Construction

Modular and prefabricating technology relate to manufacturing most of the work in a factory and transporting the elements or modules to the site for erection. Manufacturing processes are more controlled in terms of quality, safety, and environment than construction works. Accordingly, on-site safety is improved due to the eliminated work being done on-site that reduces risk of the following (Chubb 2020):

1. Falling from heights; since most of the work takes place at ground level and only the final installation step is done in place.

2. Struck by accidents; due to the less heavy equipment on-site. In addition, in manufacturing zones, workers are more used to the workspace and the possibility of accidents are way below that respective accident in construction due to the dynamic nature of construction sites and continuous progress. Further, the activities in manufacturing zones are repetitive and often all labor are at the higher end of the learning curve unlike construction sites where non-skilled labor are often available.
3. Weather-related injuries; due to controlled indoor manufacturing environment. There is minimum possibility of slippery surfaces after heavy rain in manufacturing environment unlike construction sites. Also, possibilities of electrocution and hazards from overheating are more under control in manufacturing environments.
4. Labor inattention; improved focus on larger objects and lower multi-tasking. Humans tend to focus more on few things of significant sizes rather than many things of smaller sizes plus there are less tasks to be done on-site, so labor are more focused on their activities with no overworking. This saves time and improves workers productivity.
5. Reduction in project duration; due to the improved productivity and technological efficiency. It is estimated that projects depending on prefabricated or modular construction have 30% to 50% lower project durations than respective projects constructed under traditional means. This reduced project duration in its own is a factor that decreases the probability of accidents on-site.

In addition, prefabrication and modular construction minimize the need for normal construction equipment such as formworks and scaffolds and others hence saving on the project costs and reduce their related project risks. Finally, prefabrication and modular construction reduce the severity of on-site construction accidents (Chubb 2020). Construction sites have greater risks related to safety than controlled manufacturing sites. The more the prefabrication and modular construction involved within the project, the less probability of safety accidents is expected (Fard et al. 2017).

Prefabricated and modular construction reduce other project risks not related to safety. Prefabricated and modular construction improve project quality standards and reduce construction defect claims due to the controlled manufacturing processes and manufacturing quality control plans that are easier to abide with over the construction quality control plans (Chubb 2020).

2.3.4 Robotic Fabrication, 3D Printing and Construction Automation

Automation technology in construction is undergoing highly paced theoretical advancement. The level of automation may increase to the extent of substituting labor by robots or 3D printers for hazardous or critical jobs; hence improving construction safety along with all the other benefits of time, cost, quality, and productivity efficiency (Hossain et al. 2020).

There are three types of robots in construction (Man Li 2018):

1. Traditional Robots: Work up on computer coded algorithms to perform specific tasks they are designed for. Examples for such tasks in literature include climbing robots for bridge and skyscrapers, underwater robots for under water specific activities and traffic leading and controlling robots for road safety.
2. Wearable Robots: Are worn by workers on-site and have sensors that measures different aspects within the worker and the environment and respond by assisting the worker in doing the job. Such robotic activity has the capability of decreasing the worker's effort and improving the occupational health and safety for that worker. Examples for such robotics in literature include Suit AWN-03, shown in Figure 7, that senses muscular strains and supports the weights with the worker up to 15 kg.
3. Robot Arms: Similar to traditional robots but relatively have significantly smaller size and conduct activities using similar coding techniques but relative to their size and capacity. Examples for tasks performed in literature include simulating different human arm activities such as brick laying.

3D printing or additive manufacturing is the integration of advanced material science, designing software and programming codes to construct projects directly from the designer input in the form of layers; a layer above the other (Man Li 2018).

Figure 7 AWN-03 wearable robot (Man Li 2018)

The fact that robotic fabrication and 3D printing reduces construction accidents is never doubted in literature but has never been quantified. According to Man Li (2018), the use of robotic fabrication and 3D printing reduces accidents by eliminating labor on-site (fewer labor so less possibility of any gets injured) plus that human error contribute to 80% to 90% of construction accidents. With regard to activities of higher risks, robotic fabrication and 3D printing can totally replace workers. Such activities include working with toxic gases and underground activities (Man Li 2018).

Further, robotic fabrication and 3D printing increase construction productivity and reduce project durations which is a factor that decreases the possibility of encountering risks on its own (Man Li 2018).

Robotic fabrication and 3D printing are already used in real-life projects and activities; such as the full process of assembling steel beams and brick laying in a project in South Korea and installing windows and cladding panels in a project in Hong Kong (Man Li 2018).

2.3.5 Construction Site Internet of Things (IoT)

Internet of things or sensor-based technology is an emerging technology in the construction industry that does not have vast range of construction applications except that it invaded the safety applications in construction (Zhang et al. 2017). Internet of things or sensor-based technology refers to exchanging data between environment and humans through computers and networking in real-time for monitoring and controlling of on-site activities and environment (Man Li 2018). As described by Man Li (2018), "IoT will result in a paradigm shift: from a reactive manual approach to proactive automated methods".

Internet of things or sensor-based technology is divided into (Zhang et al. 2017):

1. Location sensor-based technology: These are sensors that measure the location of whatever connected to them; worker, material, or equipment, using several technologies currently and cheaply available such as GPS (Global Positioning System), radio frequency, WLAN (Wireless Local Area Network), UWB (Ultra-wideband), Zigbee (a two-way low complexity and performance wireless communication technique for short distances) and ultrasound.

2. Vision-based sensing technology: These are sensors that collect photos and videos, analyze the collected data algorithmically and refine for the coded input. Such sensors are easily distracted by light conditions and background color. They are used for surveillance both manually and automated as coded for. They might be connected to image-based recognition technology for image processing and interpretation; however, this does not necessarily indicate high precision levels.

3. Wireless sensor network: These are sensors used by workers or placed on materials to measure different conditions based on the type of sensor used:
   - Temperature sensors
   - Displacement sensors
   - Light sensors
   - Optical fiber sensors: for structural integrity
   - Pressure sensors

For real time monitoring, the sensors are connected to a control unit that analyses and processes the input from the sensors and outputs the ideal response to the condition is coded for. Figure 8 shows the typical IoT architecture.

IoT does not only record the location for workers and materials on-site but rather provides dynamic safety warning system when connected to computers and networks to sense the hazards before the accident takes place (Man Li 2018). As shown in Figure 9, Ding et al. (2013) demonstrated visually the different dynamic safety warning information layers for developing an instantaneous warning procedure for accident prevention.

Sensor-based technology can be used for other safety applications than accident warning, such as safety route prediction and planning, structure health monitoring and other applications. It is important to consider that a single sensor-based technology does not signify an impact on construction safety and that multitude sensing technologies need to work in integration to provide promising safety results. The initial investment cost in this technology is not expected to be high because the hardware and the software requirement are readily handy to almost all labor on-site; smartphones (Zhang et al. 2017).

An example of vision-based sensing technology already exists in the construction industry. OnSiteIQ (2020) is a company that provides vision-based sensing technology support to contractors. They collect visual data from the sites, export and apply the collected site 360^{o} site scenes on the project documents or BIM. This enables users to access and monitor the site online. It can also be connected to artificial intelligence platforms that recognize and report safety hazards (OnSiteIQ 2020).

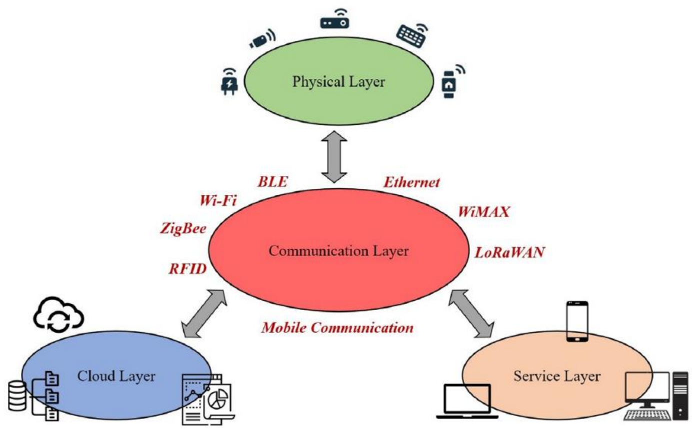


Figure 8 Typical IoT architecture (Lawal et al. 2021)

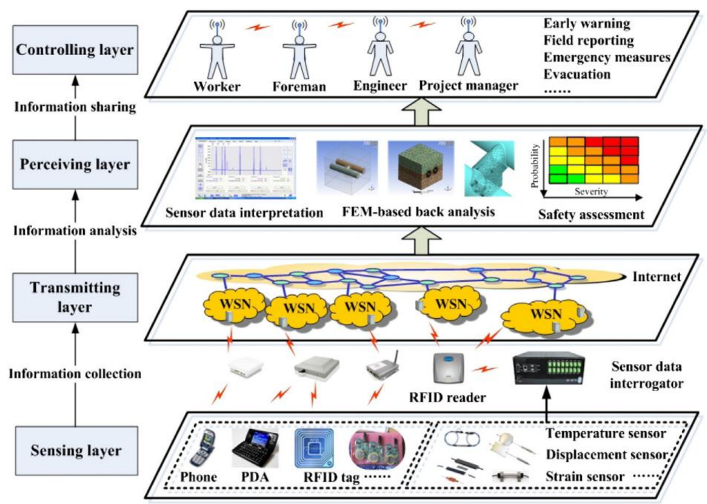


Figure 9 Dynamic safety warning information layers (Ding et al. 2013)

2.4 Insurable and Uninsurable Risks of Construction Technology

There is another edge to the weapon of construction technology. Since construction technology is not highly adopted within the construction industry, not all its drawbacks are known yet. However, literature discussed some problems related to the construction technology; of which some might be insurable, and others might not.

2.4.1 Building Information Modelling (BIM)

Even though Swiss Re (2018) urged for the advancement of the insurance industry to meet the construction technological evolution, Swiss Re (2018) highlighted new threats to digitalizing the construction sector. Among the primary risks of construct ion digitalization is the cyber security

(Swiss Re 2018). Cyber security breaches can take place in different forms such as viruses, malware, ransomware attacks, criminal cyber activity, etc. … and might lead to business interruption and loss of confidential information (Allianz 2021). Research conducted by Allianz (2021), a world-wide insurance provider, discussed the main causes of cyber security incidents and the results are provided in Figure 10. Cyber security breaches are of high impact on the following construction technology (Swiss Re 2018):

1. BIM and other project management software
2. VR
3. Robotics, 3D printing and construction automation
4. IoT

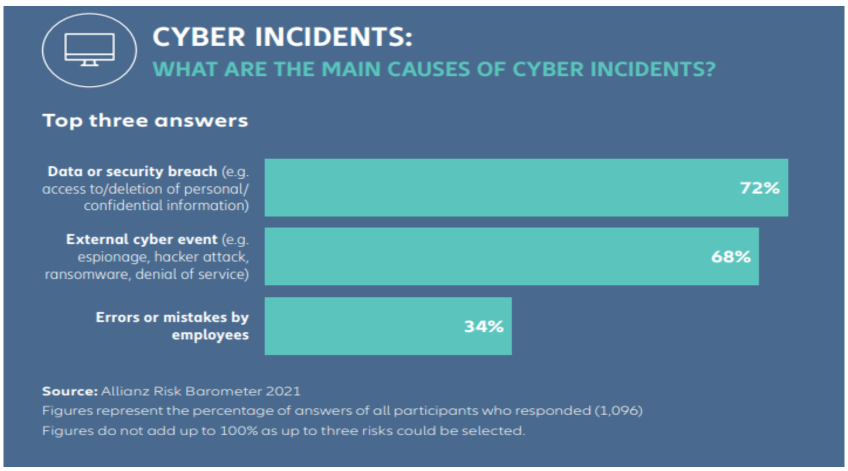


Figure 10 The main causes of cyber security incidents (Allianz 2021)

NorthBridge (2018) insurance, an insurance provider, states that the higher the digitalization, the more are weak points vulnerable to cybercrimes and cybercrimes can take place to several information/ assets within the company such as:

- Designs
- Intellectual property: know-how for designs or Research and Development (R&D)
- Technological infrastructure assets
- Financial information
- Employee personal information, etc. …

Cyber security breaches do not only impact the company directly affected by the bridge, but due to the interconnectivity of industries in the modern world, all related companies dealing with the company under breach could possibly be taken by the storm. This factor on its own increases the impact of any cyber security breach claim (Swiss Re 2018).

Other factors need to be considered when using BIM. These factors include the capacity of the IT within the company, the means of technological management for BIM, the confidentiality the information and the credibility over the editors (Man Li 2018).

2.4.2 Virtual Reality Safety Training

As previously mentioned, VR is vulnerable to cyber security breaches (Swiss Re 2018).

Another factor is that the effectiveness of VR safety training will not be recognizable except when the vast majority of the workers on-site are trained, not only few of them, for the general site safety which for some construction companies might be of a significant cost (Man Li 2018).

In addition, the resistance to change by elder workers, generation illiteracy and unacceptance to technological evolution are factors that hinder the adoption of VR. Companies need to convince such workers to understand and use the VR safety training. However, sometimes the problem is that the higher managerial level within the company itself is unaware of the technology benefits as they already exhibit the generation illiteracy (Man Li 2018).

2.4.3 Prefabricated and Modular Construction

The use of prefabricated and modular construction emerges some associated safety hazards, such as (Chubb 2020):

1. The need for often higher capacity cranes to sustain the loads of the heavier components/ modules. It is advised to resort to specialized companies in calculating the required crane capacities and preplan for the hoisting operations.
2. Similarly for the rigging of the prefabricated elements or modules, extreme precautions need to take place on-site and highly experienced safety officers for activities that are to be done on-site using prefabricated or modular construction need to be provided.
3. Temporary connections for modular elements that stabilized their transportation need to be done precisely to avoid any accidents.

4. Safety management plans shall ensure that no workers exist below any of the moving prefabricated elements or modules when they are lifted or transported within the site and that only required skilled labor working on search operation exist.
5. Most contractors will not have the transportation capacity in meeting the modular elements and ensuring safety precautions for their transportation. Accordingly, it is advised to procure companies specialized in oversized load transportation to do the job.

Other logistical challenges from the use of prefabricated and modular construction stem in the storage of such elements or modules in terms of creating the suitable storage environment to ensure minimal deterioration in the quality of the elements or modules and minimal harm from the environment, for example in case of fire, flooding or other natural disasters or risks (Swiss Re 2018).

2.4.4 Robotic Fabrication, 3D Printing and Construction Automation

As previously mentioned, robotics, 3D printing and construction automation are vulnerable to cyber security breaches (Swiss Re 2018).

In addition, this construction technology has a significant and direct impact on the labor market in several means:

1. The substitution of labor by machinery in such a labor-intensive market would lead to technological unemployment plus its effect on the economy is still questionable (Hossain et al. 2020). A possible solution is to have high-risk activities only to be done using robots, however contractor’s preference for that might change over time as the price of robotics develop (Man Li 2018).
2. Another perspective is that there can never be full replacement of labor by robotics. Robots and 3D printers themselves are operated by labor but of different criteria. Accordingly, there is the need for labor with specialized training and expertise to supervise and control the robotics (Man Li 2018)
3. Industry professionals considered in previous research in literature are questioning the safety prospects of labor working next to robotics and 3D printers. This issue is similar to the use of robotics in industries other than construction, where there are specific ISO standards developed to dealing with robots in order to decrease the hazardous risks born

from adopting robotics and 3D printing. This investigated consideration has been targeted by the American National Institute of Standards and Technology which identifies three safety working zones for robots, each has its own safety precautions (Man Li 2018):

- the closest vicinity to the robotic
- the accessible work area by the robotic
- the areas out of reach of the robotic

Equally important, the initial investment cost for robotics or 3D printers is extremely high that only large-scale construction companies would have the financial capacity to adopt robotics or 3D printers within their operations. The cost of the robots and 3D printers is not affected by the building components within the robotic rather by the investment in the R&D since such area of knowledge is still novel. However, the investment cost is expected to decrease once R&D is developed and robotics are up for mass production. The concerning factor is that is it worth to invest in robotics while being still under R&D or to wait until they are up for mass production at the lower cost. Moreover, there is the cost of maintaining the robotics. Yet such high investment is still worth saving lives (Man Li 2018).

Further, some contractors exercise resistance to change but in another format. Their higher-level management fear different labor response towards technological unemployment and being released. It might cause instability in the company's reputation within the labor market for some time until the market adapts to robotic technology. On the other hand, this can be an opportunity to keep on the talented calibers and higher expertise for more labor cost effectiveness (Man Li 2018).

Finally, the use of robots or 3D printers on construction sites even though it does significantly reduce the probability of accidents, there is a significant increase in the impact of such accidents for not only replacing that the loss that occurs to the project and its relatively cheap equipment, but for much more expensive ones; robots and 3D printers (Swiss Re 2018).

2.4.5 Construction Site IoT (Internet of Things)

As previously mentioned, IoT is vulnerable to cyber security breaches (Swiss Re 2018). IoT must be secured against loss of data, personal information and users need to trust in its technical capability to be of value (Miorandi et al. 2012).

2.5 Research Gap

Several trials have been attained aiming to find whether the impact of construction technology on accident reduction and insurance premiums has been studied before and if there are any quantifiable results previously provided whether by academic research or market outcomes, yet in vain. There is minimal literature, however, providing some cost benefit analysis in a qualitative regard for the construction technology without any quantification and no single relation to insurance premiums. Such literature relates the cost of construction technology to the savings expected in the projects using the construction technology, with insurance unconsidered. Certainly, and absolutely, literature is bare of relating the impact of construction technology on accident reduction and premium reduction in a quantifiable manner. As seen and concluded from the above latest literature available, the topic is still novel, and literature falls short in covering such studies. Accordingly, the focus of this research is to fill in the literature gap regarding this concept. This research does not aim to provide a cost benefit analysis to the construction technology but rather quantify the impact of construction technology on accident reduction and premium reduction.

Chapter 3. Research Methodology

To achieve the research objectives previously mentioned in Chapter 1, the utilized research methodology, as presented in Figure 11, consists of five main stages:

1. Literature Review
   a- Identifying and consolidating the factors that affect insurance premiums.
   b- Identifying and consolidating the mechanism and influence of construction technology on construction safety.
   c- Identifying and consolidating the mechanism and influence of construction technology on insurance premium.

2. Data Collection
   a- Industry Research: Interviewing industry experts to mainly understand:
      - The interaction between insurance and construction industries
      - The governing factors that affect insurance premiums
      - Their opinion about construction technology
   b- Quantitative Research: Sending surveys to industry experts for the purpose of:
      - Categorizing the insurance premium indicators according to their significance in insurance premium estimation
      - Testing the insurance premium sensitivity to the construction technology

3. Data Analysis
   a- Qualitative analysis
   b- Quantitative analysis for investigating the relationship between the construction technologies, safety performance, and insurance premiums.

4. Decision-Making Model
   a- Highlight the decision-making factors
   b- Provide a decision-making tool for contractors based on profit
   c- Measure the impact of contractor’s decision on insurance companies
   d- Calculate the cost effectiveness of the construction technology

5. Conclusion

   This section presents the summary of the research findings and maps the outcomes to the objectives.

A further elaboration is provided in the following sub-chapters.

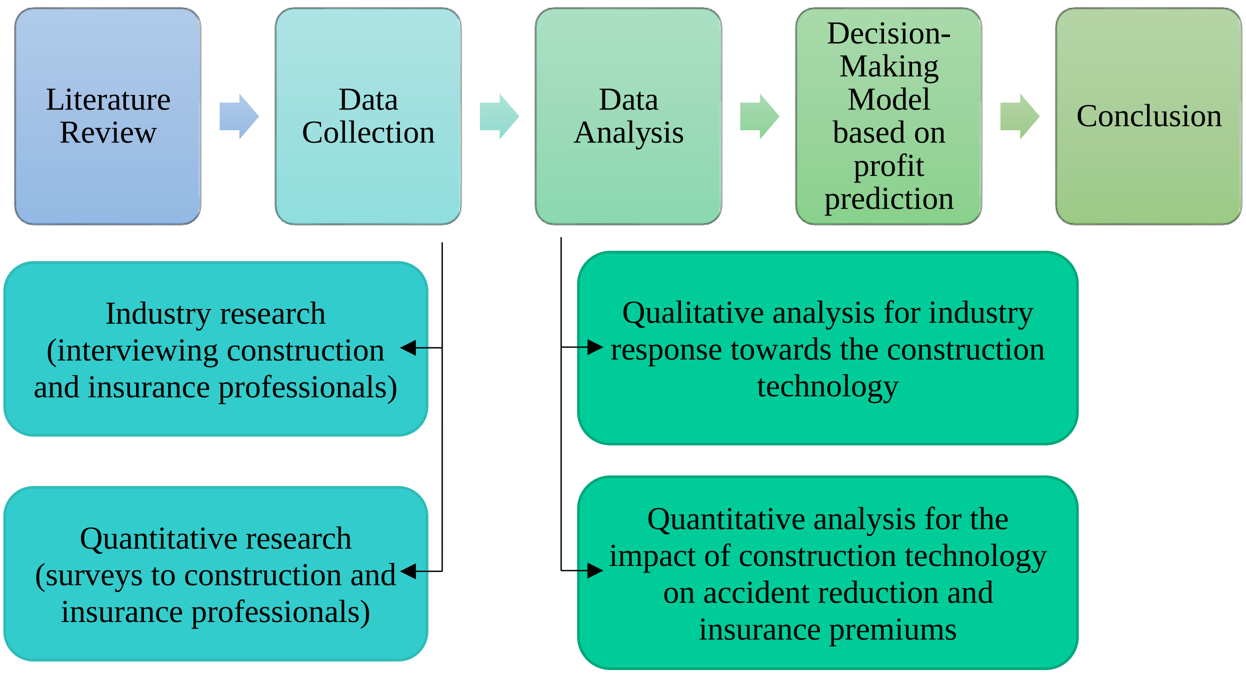


Figure 11 High level research methodology

3.1 Literature Review Methodology

A comprehensive literature review is conducted that provides an overview about the insurance industry and its relation to construction projects, as well as the latest research efforts in such area (Figure 12). The literature review also serves to prepare for data collection strategies and enhance data analysis techniques. Literature review mainly focuses on:

1. Identifying the factors that influence construction insurance premiums in previous research
2. Identifying the gaps in the insurance market highlighting the need for adaptation to meet the evolving construction industry
3. Identifying which construction technologies are to cause significant impact on the insurance industry
4. Find the possible impact of construction technology on construction safety and insurance premiums if provided in literature
5. Discuss the possible drawbacks and additional risks from adopting construction technology

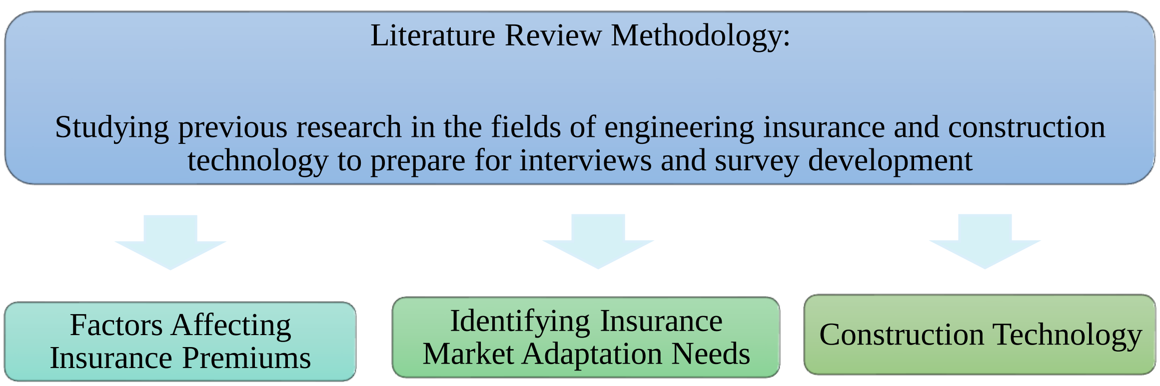


Figure 12 Literature Review Methodology

3.2 Industry Research Methodology and Qualitative Interview Analysis

Industry research is conducted through interviewing construction and insurance professionals to fully grasp how both industries function hand-in-hand and understand the different risk factors considered when both parties are up for an insurance contract negotiation. The main purpose of the interviews is to set sound and stable ground for the participants in the quantitative research to fairly evaluate the different types of risks and relate construction technology to insurance premiums. Figure 13 explains the detailed methodology used for developing the industry research.

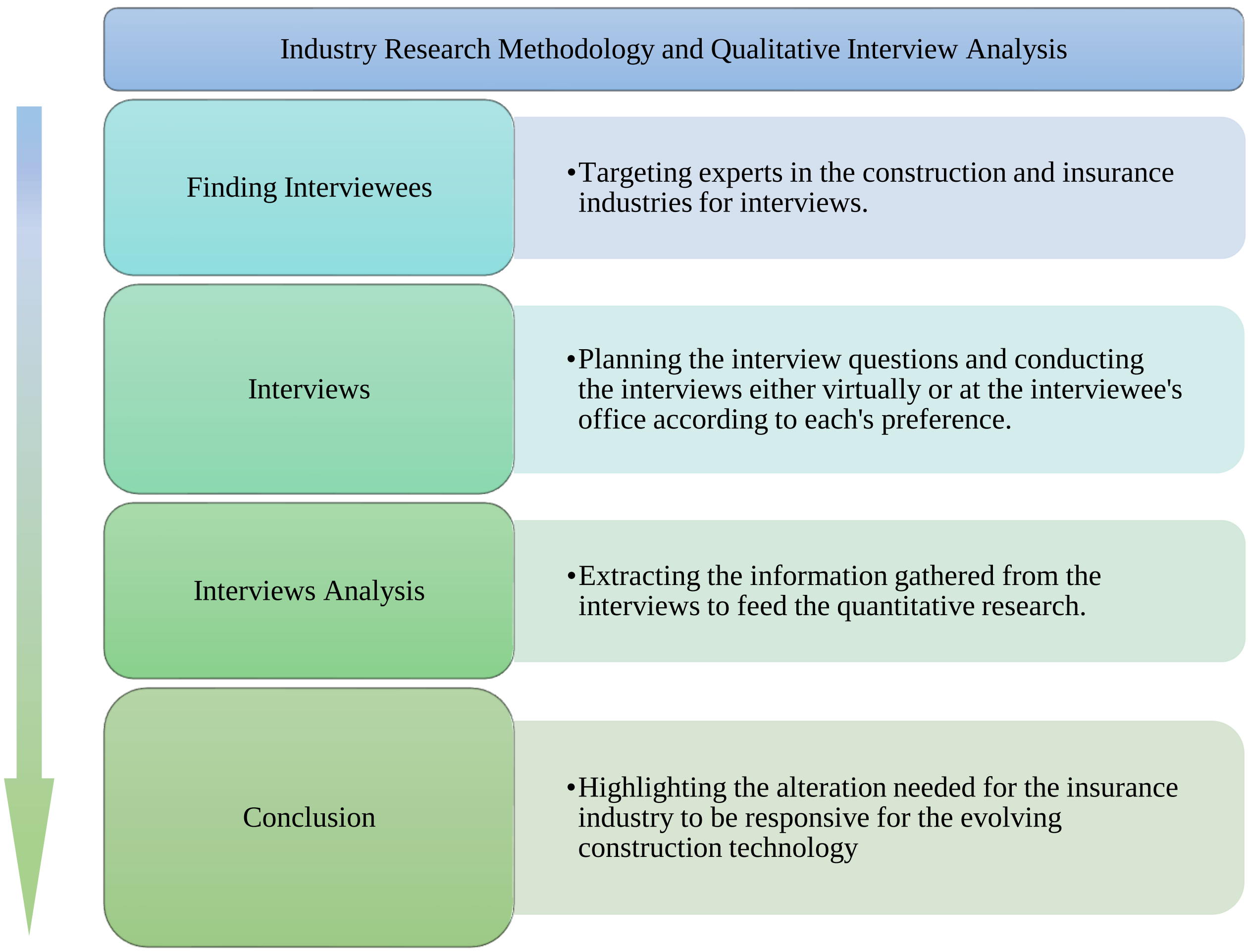


Figure 13 Industry Research Methodology and Qualitative Interview Analysis

In parallel to getting in connection with experts from both construction and insurance industries for participation in interviews, the interview questions are planned based on the literature review to serve for the research objectives in terms of understanding the following items:

1. The interaction between both industries
2. Factors that affect insurance premium estimation
3. Statistical models for risk evaluation and insurance premium estimation
4. Possible impact of construction technology on on-site accidents and insurance premiums
5. Testing the insurance industry responsiveness to the evolution in construction technology
6. Different types of insurance policies for construction projects; different coverages, deductibles, and exclusions
7. Effect of construction parties on insurance premiums
8. Profit generation cycles and corporate strategies for insurance companies in the construction sector
9. Market forces in insurance industry relating to the construction sector

The interviews are to assist in understanding the overall insurance cycle for construction projects in order to develop competent, sound, and unbiased survey questions for the quantitative research, to attain fair and credible results regarding the research objectives. Accordingly, it is essential to maintain diversity of interviewees in order to make sure that there is no patronage of the project parties nor a specific project type nor any construction technology.

3.3 Quantitative Research Methodology

To ensure that the survey exactly functions for the required research objectives, is businesslike, comprehensive, and well grasped by the participants, the survey is developed from both data gathered from literature and from the interviews and is issued for pilot testing and fine adjustment first before mass distribution. Figure 14 explains the detailed methodology used for developing the quantitative research methodology.

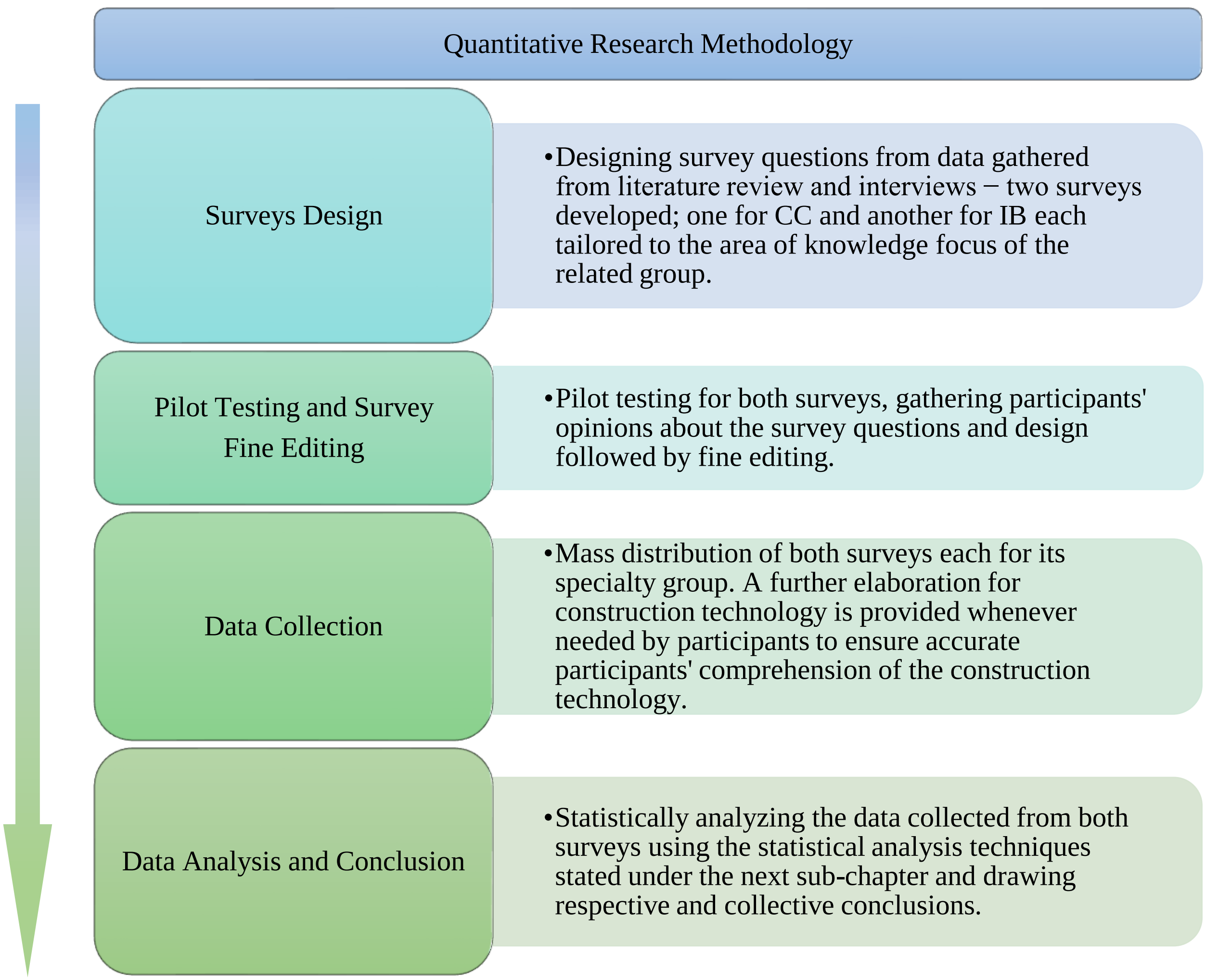


Figure 14 Quantitative Research Methodology

Once the literature review is complete and all interviews are conducted and analyzed, the survey is designed to incorporate all the factors provided in literature and mentioned by the interviewed construction and insurance professionals to meet the research objectives. Accordingly, the objectives of survey are:

1- Categorizing project types according to frequency and impact of accidents
2- Ranking the factors compiled from literature and interviews that impact premium estimation
3- Quantifying the impact of construction technology on accident reduction
4- Quantifying the impact of accident reduction on insurance premiums and developing a prediction equation
5- Quantifying the impact of construction technology on insurance premiums
6- Measure how the different parties (insurance brokers, insurance companies, contractors, and consultants) view the impact of construction technology on insurance premiums
7- Study the responsiveness of the insurance industry to the changes in construction technology

The target participants for the quantitative research are:

- Insurance Brokers
- Insurance Companies
- Contractors
- Engineers/ Consultants

Accordingly, two surveys are designed; one for contractors and consultants (CC) and another for insurers and insurance brokers (IB) each tailored to the area of knowledge focus of the related group. As shown in Figure 15, the survey incorporated questioning the participants about the following:

1. Evaluating the risk for different construction projects according to severity and frequency
2. Evaluating the impact of different factors (from literature and interviews) on insurance premiums
3. Evaluating the impact of construction technology on accident reduction
4. Evaluating the impact of accident reduction on premium reduction
5. Evaluating the impact of construction technology on premium reduction

Figure 15 is divided into two zones; blue and green for IB and CC surveys respectively. Each circle represents a question within its respective survey while the arrow represents the link between questions in order to meet the research objectives.

Both surveys are subject to pilot testing and gathering participants' opinions regarding the survey questions and design. The results from the pilot testing are used to fine tune edit the surveys before the mass distribution to both industries' professionals. Whenever needed, a further elaboration for the construction technology is provided to participants to ensure accurate participants' evaluation.

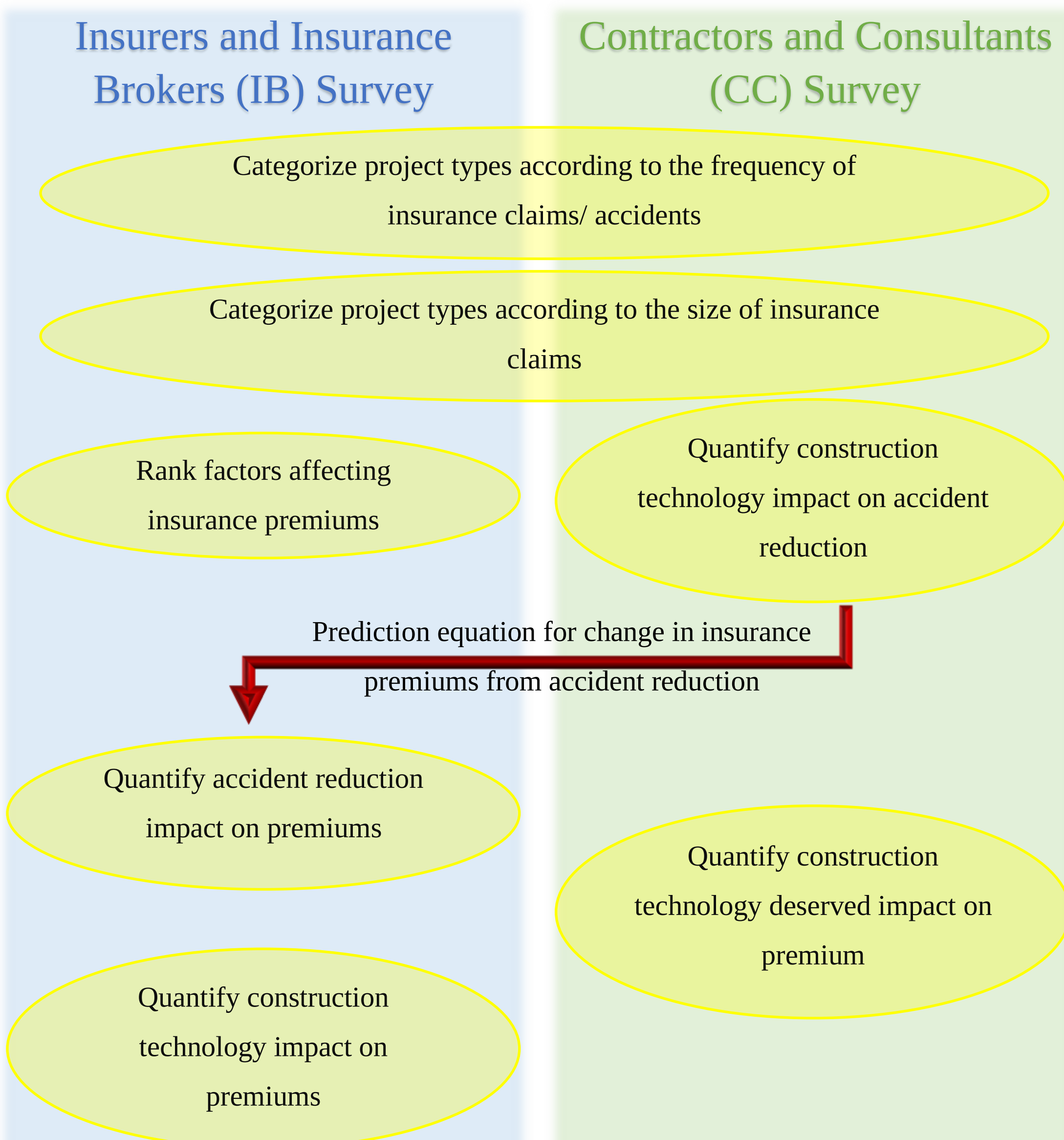


Figure 15 Survey Design

3.4 Statistical Analysis Methodology

Provided that data is collected from the CC and IB surveys, each of the different data sets is subjected to its relevant statistical analysis techniques depending on the characteristics of the data. The below sections represent the different statistical analysis techniques used for each data set. The statistical analysis techniques are selected to ensure logical analysis for the information and consequently sound, realistic, and credible conclusions.

3.4.1 Frequency of Filing Insurance Claims and Size of Claimed Costs Vs Project Type

Respondents classify different project types according to the frequency of filing insurance claims, i.e., reporting safety accidents; and the size of claimed costs into low, medium, or high. Simple weighted average technique is used to calculate the collective frequency of filing an insurance claim and the possible size for claimed cost for each project type using the weights assigned in Table 3 and accordingly classify each project type according to its frequency of filing insurance claims and the size of claimed costs. The considered project types are residential & commercial buildings, road and bridge construction, tunneling construction and high-rise construction. In addition, the percentage of respondents choosing each frequency for filing insurance claims and for the size of claimed costs for every project type is calculated.

Table 3 Assigned Weights for Frequency of Claims and Size of Claimed Costs

Frequency of Claims or Size of Claimed Cost	Assigned weights
Low	1
Medium	2
High	3

Since this data is collected from both CC and IB groups and that each group is statistically independent, it is inviting to test whether both groups have same or different perspectives regarding the frequency of filing insurance claims and the size of claimed costs for each project type. Accordingly, the statistical t-test is implemented to compare the means of both CC and IB groups with respect to the frequency and size of insurance claims for each project type.

Since the data is not paired (meaning unique participants in each dataset), to decide how the t-test is to be conducted, it is essential to first test the variance of the statistically independent CC and

IB groups results. Accordingly, the statistical Levene's test of Equality of Variances is implemented to determine whether there is equal variance among the statistically independent CC and IB groups results. As shown in Figure 16, a Levene's test P-value result of less than 0.05 reflects data that has non-equal variance, and a t-test of P-value less than 0.05 reflects that there is significant statistical difference between the means of the two compared groups (Abotaleb et al. 2019).

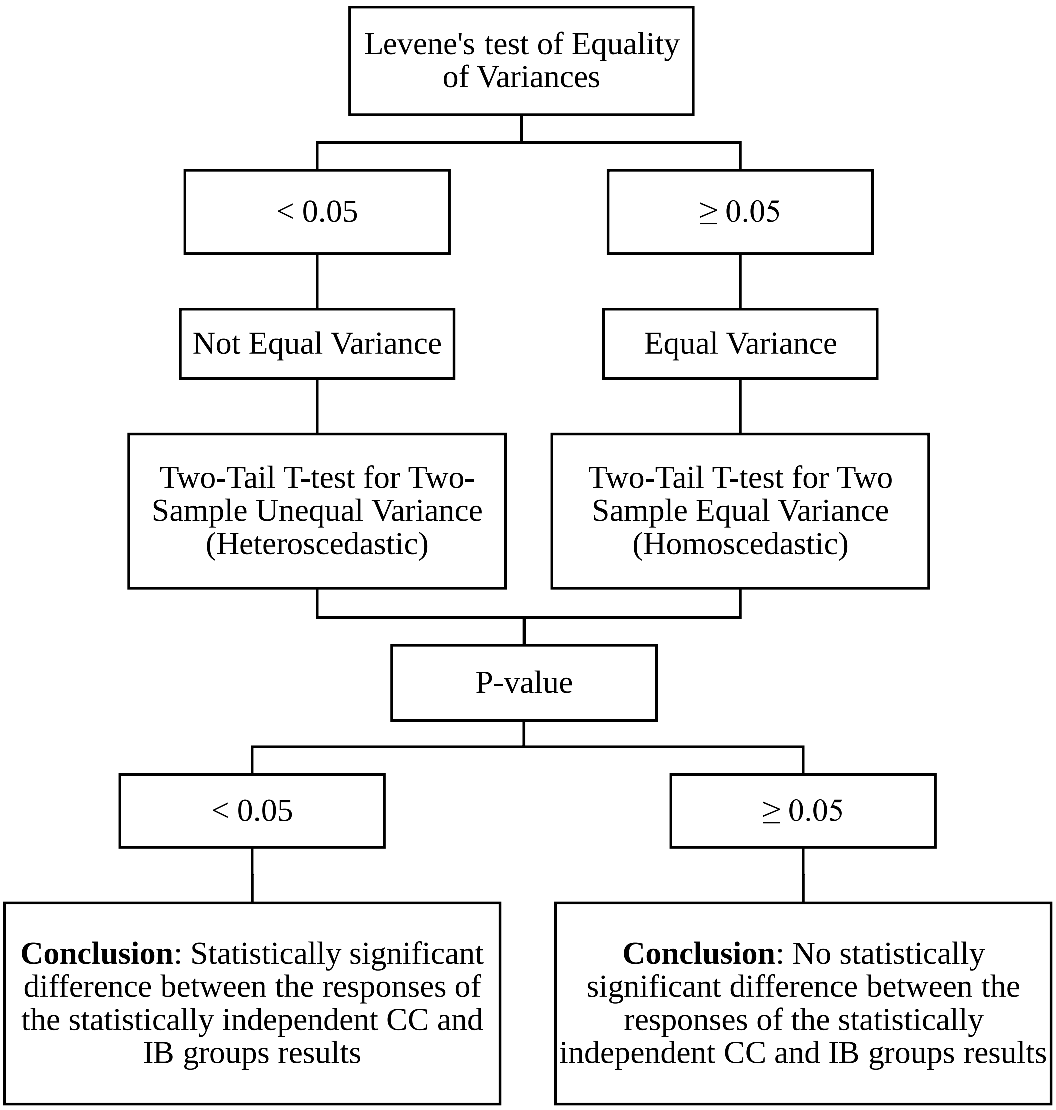


Figure 16 Statistical Testing Procedure for Comparing the Means of CC and IB Groups Results (modified from Abotaleb et al. 2019)

3.4.2 Factors Affecting Insurance Premium

In the IB survey, the respondents are asked to evaluate the premium influencing factors collected from literature and interviews, provided in Table 11 in Chapter 5, according to their impact on construction insurance premium as either each factor has no, low, moderate, or high impact on insurance premium. Weighted average is used to calculate the relative impact of each factor on insurance premium using the weights assigned in Table 4 and accordingly classify each factor according to its relative impact on construction insurance premium into either no, low, moderate, or high impact. In addition, the factors are ranked according to their relative impact on insurance premium and the percentage of respondents choosing each impact category on insurance premium for each factor is calculated. Finally, for each category of factors, the collective relative impact is calculated as the average of the relative impacts of the constituting factors.

Table 4 Assigned Weights for Impact on Premium

Impact on Premium	Assigned weights
No	0
Low	1
Medium	2
High	3

3.4.3 Impact of Construction Technology on Accidents Reduction

CC respondents evaluate the expected impact of each construction technology on on-site accident reduction. The five construction technologies are categorized according to the expected reduction in accidents on a scale of no, low, moderate, high, and very high corresponding to certain percentage ranges in accident reduction as shown in Figure 17, where the maximum assumed reduction in accidents is 80%. Figure 17 reflects the conceptual frame for designing this survey question, where participants choose the category for percentage decrease in accidents for each construction technology. Weighted average is used to calculate the expected percentage reduction in accidents for each construction technology using the midpoints assigned in Table 5 and accordingly classify each construction technology according to its impact on accident reduction on a scale of no, low, moderate, high, or very high reduction in accidents.

Table 5 Scale for reduction in accidents

Impact category for reduction in Accidents	Percentage Reduction in Accidents	Midpoint
No reduction in accidents	0%	0.0%
Low reduction in accidents	1% – 10%	5.5%
Moderate reduction in accidents	10% - 25%	17.5%
High reduction in accidents	25% - 50%	37.5%
Very High reduction in accidents	50% - 80%	65.0%

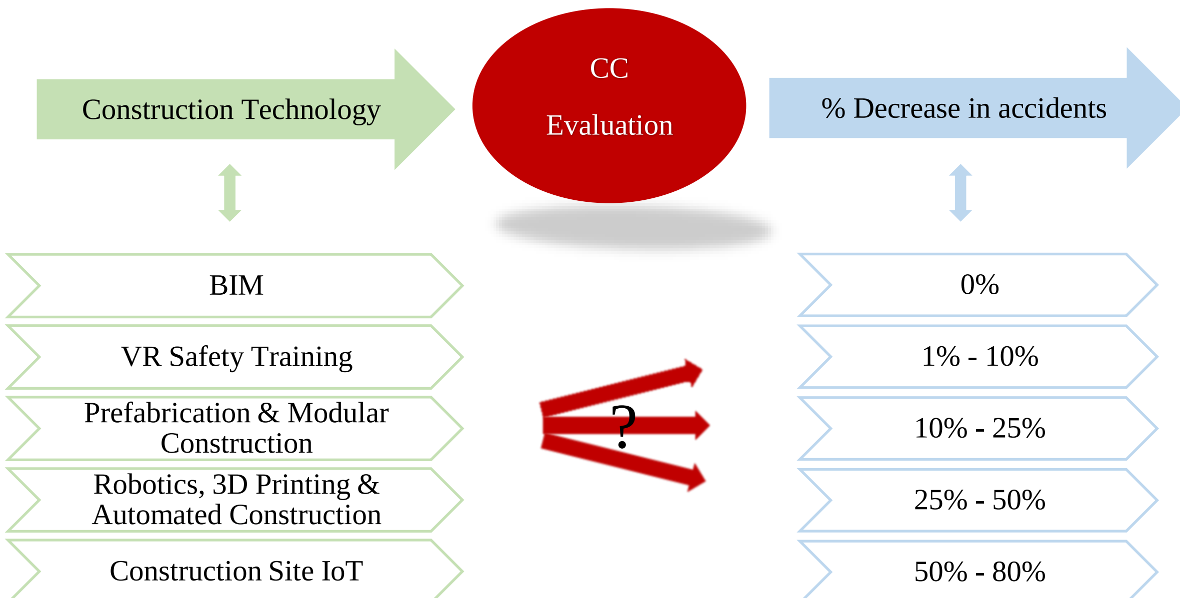


Figure 17 Concept for impact of construction technology on accident reduction

Finally, the percentage of respondents choosing each category for reduction in accidents for each construction technology is calculated and presented in a chart.

3.4.4 Effect of Accident Reduction on Insurance Premiums

Based on the conceptual frame for designing this survey question reflected in Figure 18, IB respondents evaluate the percentage reduction in insurance premiums for each category of percentage reduction in on-site accidents. Accordingly, the percentage of respondents choosing each reduction in premiums category for each reduction in accidents percentage category is calculated and presented in a chart.

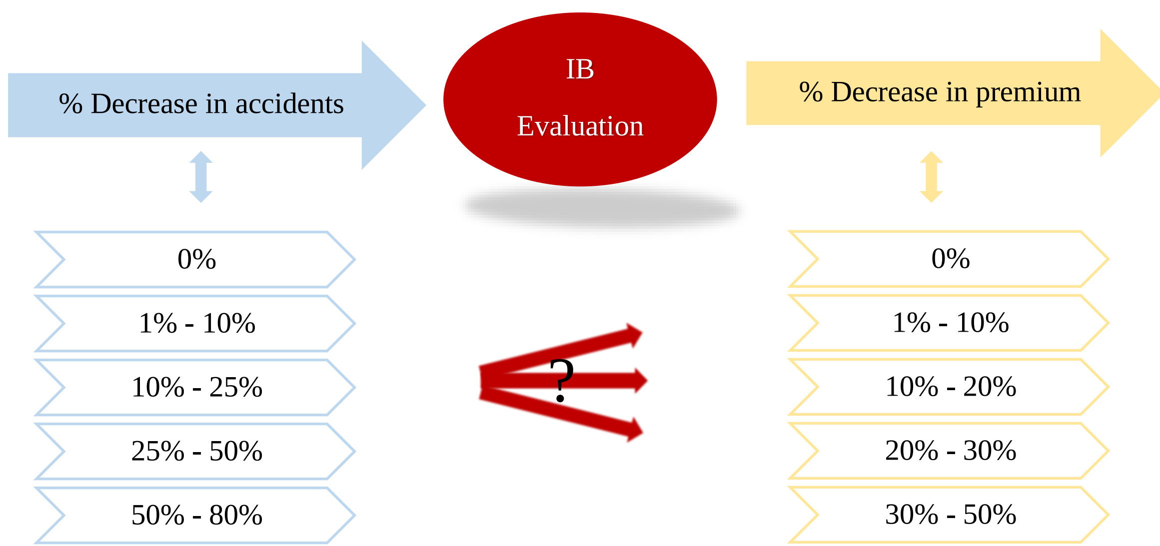


Figure 18 Concept for impact of accident reduction on insurance premiums

Since both, the input (percentage decrease in accidents) and the output (percentage decrease in premium) are in the forms of a range, both data types are represented using the midpoints for the ranges assigned in Table 5 and Table 6, respectively.

Table 6 Scale for reduction in premium

Impact category for reduction in Premium	Percentage Reduction in Premium	Midpoint
No impact on premium	0%	0.0%
Low reduction in premium	1% – 10%	5.5%
Moderate reduction in premium	10% - 20%	15.0%
High reduction in premium	20% - 30%	25.0%
Very High reduction in premium	30% to 50%	40.0%

In order to measure the ordinal association between the percentage decrease in accidents and the percentage decrease in premiums, Kendall's tau-b (τ_b) correlation test is conducted to the survey results. Kendall's tau-b (τ_b) correlation test provides lower mean square error for small sample sizes than Spearman's rho (Xu et al. 2013), and as such it will be more comprehensive in our case. In concept, Kendall's tau-b (τ_b) is a normalized factor, where a value of 0 indicates no association between variables, and as the value tends to 1 or -1, a correlation is indicated to either for a positive or a negative association, respectively (Ghalibaf 2020). The Kendall's tau-b (τ_b) correlation test null hypothesis is: $\tau_b = 0$ (Ghalibaf 2020). For any chosen significance level, if *p*-value is less than the significance level, the null hypothesis is rejected indicating a correlation between variables (Ghalibaf 2020). Figure 19 represents the statistical testing procedure for Kendall's tau-b (τ_b) correlation test. In this research, the chosen significance level is 5% corresponding to a confidence level of 95%.

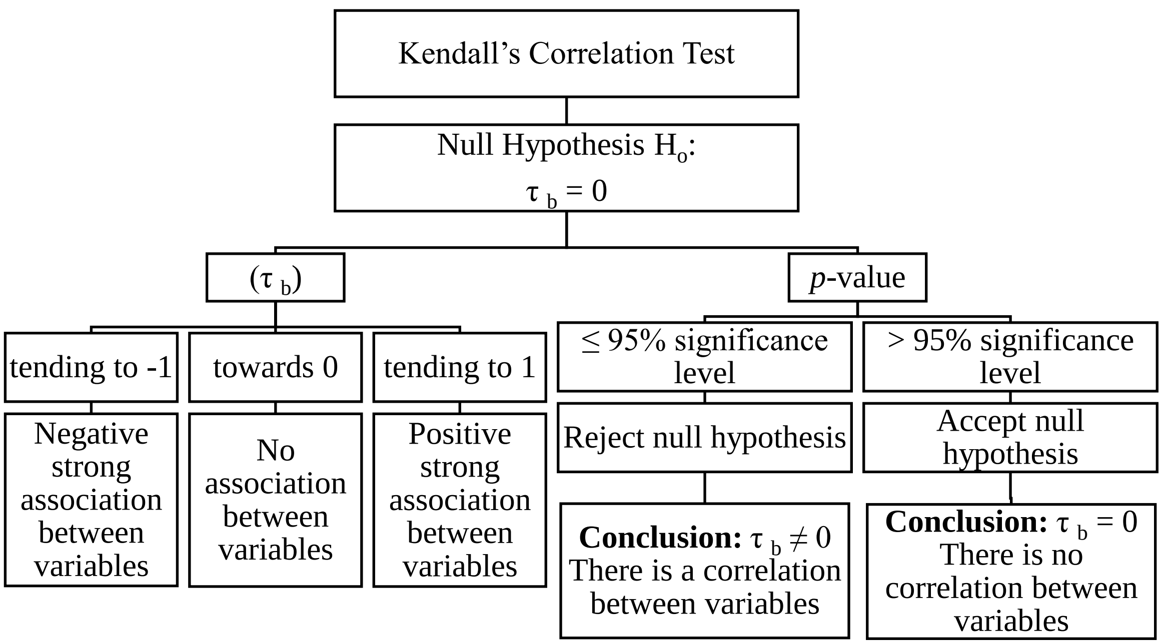


Figure 19 Statistical Testing Procedure for Kendall's Correlation Test

3.4.5 Direct Evaluation for Reduction in Insurance Premiums Due to Construction Technology – Between Contractor's Opinion and Insurance Estimation

Based on the conceptual frame for designing this survey question presented in Figure 20, CC and IB respondents directly evaluate the reduction in insurance premiums due to adopting construction technology. For each group, the percentage of respondents choosing each reduction in premiums category for each construction technology is calculated and presented in a chart.

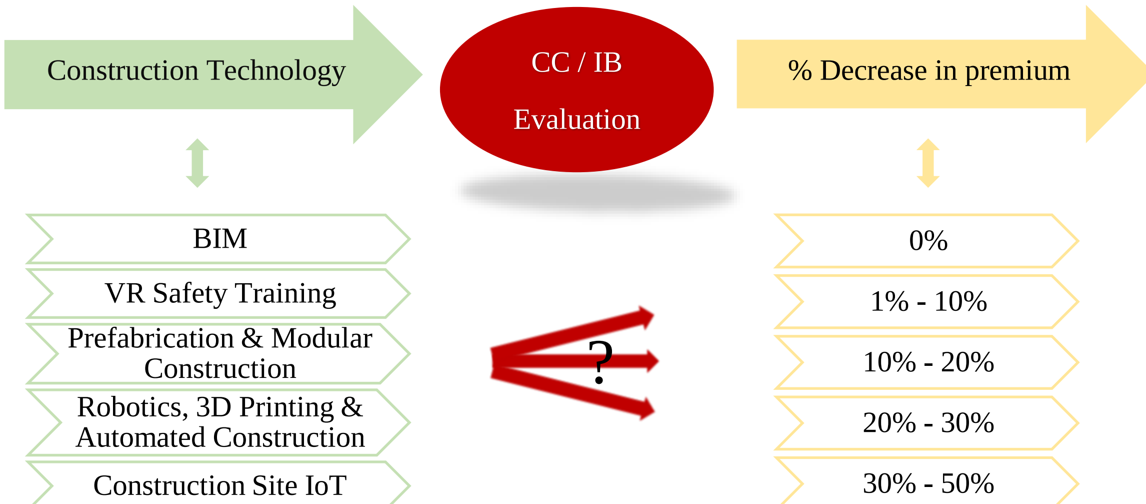


Figure 20 Concept for impact of construction technology on premium reduction

Weighted average is used to calculate the percentage reduction in premium for each construction technology using the midpoints assigned in Table 6 and accordingly classify each construction technology according to its impact on premium reduction on a scale of no, low, moderate, high, or very high reduction in premium.

The statistical t-test is conducted to compare the means of the CC and IB responses with respect to the evaluated reduction in premium as detailed in Table 7.

Table 7 Statistical testing procedure for comparing the means of premium reduction estimation by CC and IB groups results

Variable 1	Variable 2	T-test Methodology
CC evaluation for the deserved reduction in insurance premiums due to adopting construction technology	IB evaluation for the reduction in insurance premiums after understanding the construction technology	Data is not paired (not equal in the number of entries). Accordingly, Figure 16 applies.

3.5 Empirical Profit Prediction Decision-Making Model Methodology

Given that the impact of construction technology on premium reduction is quantified, contractors need to know the worth of their investment in the construction technology and the factors that affect the decision-making process for implementing the construction technology. Accordingly, a decision-making model based on profit generation is proposed to support contractors in their decision-making process. The model also discusses the possible impact on insurers as a result of the contractors adopting construction technology. In addition, the model measures the cost effectiveness of the construction technology for construction projects. Figure 21 explains the detailed methodology used for developing the industry research.

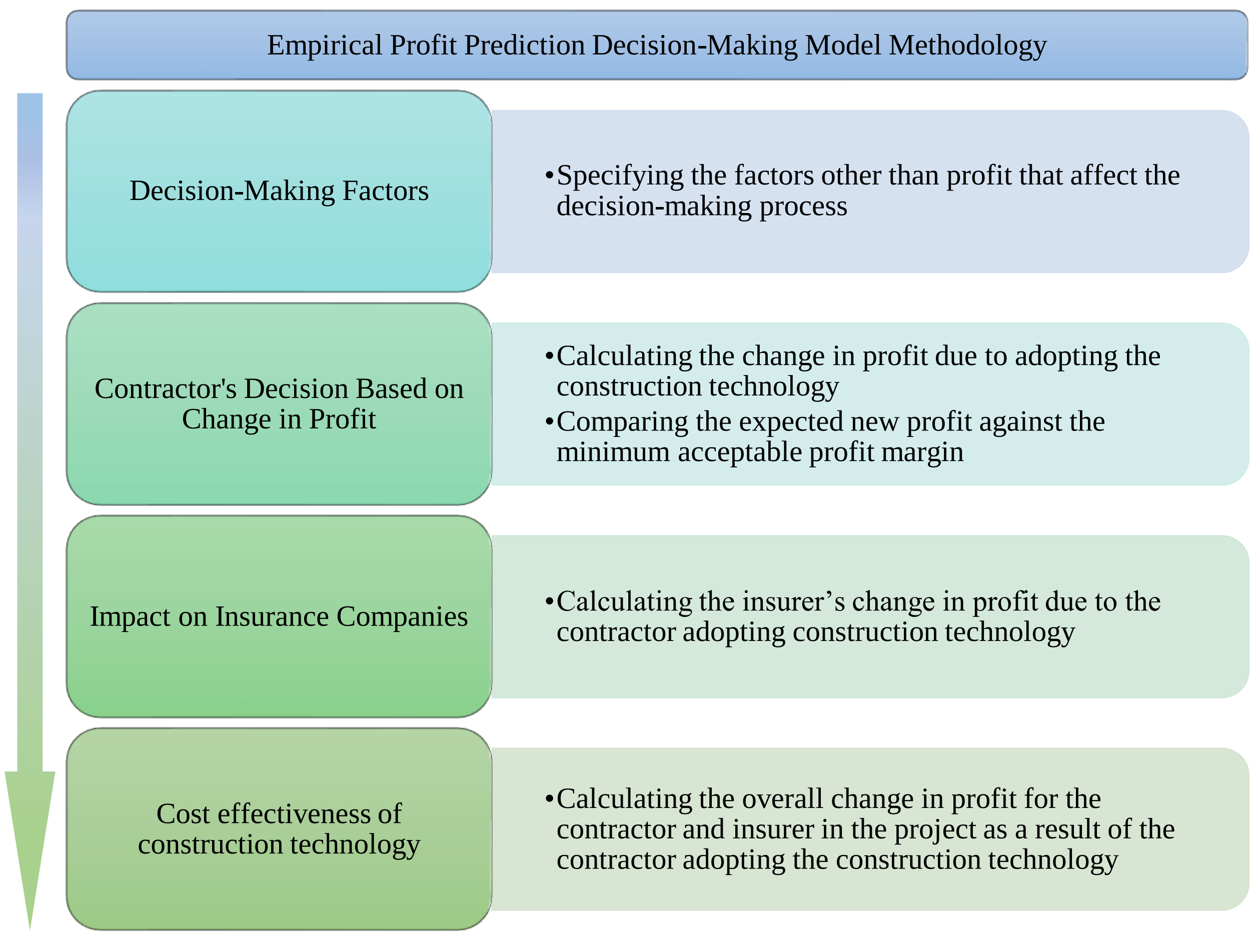


Figure 21 Empirical Profit Prediction Decision-Making Model Methodology

Chapter 4. Industry Research Formulation and Outcomes – Qualitative Analysis

Industry research is conducted through interviewing construction and insurance professionals. The main aim of such research is to understand the interaction between construction and insurance industries at the times of construction technology implementation and the expected alteration to the construction insurance field. The interviews were planned to serve in understanding the overall insurance cycle for construction projects and prepare for unbiased quantitative research in order to meet the research objectives.

The interviews were conducted with "key players" in the Egyptian construction insurance market, hence the limited number of interviews. Some interviews were conducted at the interviewees offices while others took place virtually over online platforms according to the preference of the interviewees and their availability. In respect to the interviewees interest and the sensitivity of their positions and to persuade them to participate in the research while making sure there is no room for partiality in their responses, the interviewees desire of not mentioning their names and their companies' names is considered in this research and accordingly applied to the following section.

The following sections are to discuss the industry research outcomes for the five interviews that are conducted under this research. The diversity of interviewees is maintained to make sure there is no bias towards an industry over the other. The interviewees are experts from:

1. Insurance company with the title of Chief Executive of Engineering Insurance
2. Insurance broker with the title of Client Service Advisor
3. Contractor with the title of Risk Evaluation and Insurance Contracts Manager

   The expert is working on developing a model that predicts insurance premiums based on previous updated premiums from projects, given that all the projects' data is available such as location, type, terms and conditions, etc.…
4. Contractor with the current title of Contracts and Procurement Manager and a previous title of Project Manager
5. Ex-insurance broker with a title of Client Service Advisor and current contractor with the title of Procurement Manager

4.1 Construction Insurance Industry

Insurance is a mechanism for risk transfer with four main players in market:

1. The buyer: Whoever party representing the project; owner or contractor. In mega projects, sometimes the owner is the one responsible for insuring the project.
2. The insurance company: The party willing to hold the risk and pay for any claims.
3. The intermediatory (broker): Not necessarily existing in all projects, however, its existence provides some benefit for the buyer and the insurance company as stipulated below.
4. The reinsurance company: A party sharing the risk with the insurance company in return of a portion from the premium.

Insurance brokers understand the project from the buyer, identify the risks, and issue a tender for insurance companies providing keys documents that affect insurance premium estimation such as:

1. Key drawings, specification and BOQ
2. Construction method statements for severe jobs
3. Level 1 project schedule (summary for primavera schedule)
4. Project financial structure: lenders, banks, etc.…
5. Any other document showing possible unique project risks

Then comes the role of insurance companies to study the tender documents and quantify the documents into a value that covers for that transferred risks in terms of the probability and impact of all possible risks in the project. Such value is the premium.

The advantage of the insurance broker doing the tender is not limited to receiving offers with different premiums, but rather the different coverages provided by each insurance company. Insurance brokers compare the premium and all other technicalities; namely policy coverages and exclusions, limitation of liability, deductibles, etc... and negotiate with bidders (insurance companies) to provide the buyer with the optimum premium for the corresponding insurance coverage. Insurance brokers are more aware and experienced in the insurance market over the buyers as they can provide local and international tenders for the projects and are more aware of any insurance legalities in the country of the project. For example, in Egypt, the Financial

Regulatory Authority (FRA) regulates that if the project is on Egyptian soil, there shall be a local insurance policy for the project. Accordingly, in this case if the main insurance company is from abroad, the broker orients the legalities to follow the regulations of the FRA for all insurance policies, except for marine insurance, there is no need for a local insurance policy because often waters is an international commodity (not all of it is on Egyptian soil).

In return to the insurance brokerage services provided, is the brokerage commission. Brokers receive their commission percentage from the insurance company not from the buyer. Brokerage commission is often a fixed percentage from the premium. Brokerage commission if any is included in the premium offered to the client and the insurance broker determines the commission percentage based on market factors and market relation with buyer. Brokerage commission does not significantly impact premiums.

Some insurers are reinsured by reinsurance companies as a mean of transferring risk. Reinsurance companies share the premium and claim compensation with insurance companies in a certain pre-agreed upon ratio. Sometimes, insurance brokers exist to facilitate contract agreements between insurers and reinsurers.

4.1.1 Construction Insurance Policies

There are several types of engineering insurance, of which most important and on-demand are:

1. EAR or CAR: Erection All Risk (EAR) for projects with significant mechanical and electrical scope; such as power plants, while Construction All Risk (CAR) for projects with significant civil scope.

   This policy covers for all contract works, all material included in storage zones and often all supporting structures such as caravans. It is advised to include all permanent and temporary works under this policy in addition to loss of documents that might take place due to fire, theft, natural hazards, burglary, labor error, etc.…
2. CPM: Construction Plant and Material policy covers for any risk related to any plant or material belonging to the contractor such as loaders, forklifts, cranes, power tools, surveying tools, etc.…

The frequency of accidents/ claims is higher under CPM than EAR/ CAR while the severity of accident and the claimed amount are higher under EAR/ CAR than CPM.

Meanwhile it is advised to procure the following policies and transfer their high risk to insurers:

1. Employer liability: An insurance policy that covers for the employees/ labor registered under the company's payroll against project related injuries. The term "Employer" refers to the contractor/ buyer of the policy. It is highly recommended to cover the subcontractors' and sub-service-providers' labor under this policy. This is other than workman's compensation insurance required by law to non-registered labor in the company's payroll and irregular workforce. The Egyptian workman's compensation law issued early 2020 divides activities and BOQ items according to their labor intensiveness and specifies certain percentage of the contract price (BOQ contract price for each item) as a premium according to the intensiveness of labor in the activity, for example, traditionally mixing concrete for foundation has a certain percentage of the contract price for that BOQ item that is almost double the same item if performed using ready-mix concrete. The premium for the mandatory workman's compensation insurance is paid to the related government authority with the certification of each invoice. In case owners require extra coverage for the workman's compensation insurance beyond that required by law, insurance companies provide a workman's compensation insurance policy.
2. Auto-liability: A policy covering for any car belonging to the contractor.
3. Third Party liability: A policy covering for any loss or damage that takes place to any third party, including other contractors on-site, due to the construction of the project.
4. Credit insurance policy: This is a new insurance policy of a raising essence. The credit insurance policy deals with compensating the contractor for certain risks affecting its cash flow; such as delayed payments by the owner for reasons not attributable to the contractor. In this case, the insurance company will pay the invoice to the contractor until being reimbursed by the owner. In case the owner does not allow the contractor to procure such policy for the project, the contractor, as a company, is advised to procure "Loss of Profit" insurance policy that covers the contractor if the owner did not pay the invoices due to the owner's financial instability.

5. Professional Indemnity insurance policy: This is an insurance policy that covers for design errors. It is necessary for contractors working on design-build or EPC projects.
6. Wrap-up insurance policy: A policy that covers for all the insurance coverages previously mentioned (CAR, Employer liability, CPM, Third Party, Automobile, etc. …) in a single insurance policy. This helps in avoiding any risk gaps that might take place due to the several exclusions for each insurance policy independently, especially whenever the procured policies are from different insurers. Such policy is often at a lower premium than the combined total of all premiums from each policy on its own.

4.2 Pricing Strategy for Construction Insurance Premiums

Pricing premiums in insurance industry is completely different from pricing projects by contractors since contractors know their expected project cost and specify a certain profit margin beyond such estimated cost to calculate the contract price. In insurance, insurers do not depend on the expected project cost. Instead, they evaluate risks for every project based on different project criteria and contractor criteria. Hence, if pricing the premium is to be expressed in an equation, it will be as follows:

$$\text{Premium} = \begin{array}{c}\text{Evaluation of Risks}\\ \text{(Cost of Risk Based Theory of Large}\\ \text{Numbers)}\end{array} + \begin{array}{c}\text{Insurer's}\\ \text{Indirect}\\ \text{Costs}\end{array} + \begin{array}{c}\text{Insurer's}\\ \text{Profit}\\ \text{Margin}\end{array}$$

Regarding the first term (Evaluation of Risks), there are already developed models that estimate and quantify the value of each risk in the project. Such statistical algorithms are based on historical records of previous projects. Premium estimation models are confidential and differ from one company to the other. They are the know-how of insurance companies and the main reason behind the successful existence of insurance companies in business.

Every detail about the project and the contractor affects the insurance premium, of which are:

1. Project type: Often tunneling and any underground works are assigned the highest insurance premiums since no matter how many boreholes investigation work takes place, there is no guarantee ever what will take please once excavation starts and no guarantee

preventing the collapse of the work on the people and equipment inside even for the best soil supporting systems.

2. Project size: The scale of the project affects the interaction and interconnection of risks
3. Construction methods: If the contractor will be following traditional construction methods, models can easily quantify the risks however for new prototypes where there are minimum historical records, higher premiums are estimated.
4. Project location, nearby geography, and surrounding property: Having the project near water structures, industrial zones, and flammable material such as gas stations, or in zones subject to natural hazards definitely affect the project risks
5. Contractor experience and history of claims: The bigger and more reputable the contractor is, the less expected risks for that project are
6. Contractor's safety standards: The safety measures and fire protection undertaken on-site provided in the safety control plan significantly lowered the expected risks from the project. They can help control the accident before the damage is severe.
7. Any unique uncommon project criteria
8. Key drawings, specification and BOQ
9. Construction method statements for severe jobs
10. Advanced construction technology
11. Level 1 project schedule (summary for primavera schedule)
12. Project financial structure: how trustworthy the lenders are

The risk increases by the end of the project. An accident at the early stages of the construction has a lower impact in comparison to the impact of the same accident if occurred at later construction stages. However, the premium rate is a fixed rate throughout the project duration. Insurance companies quantify the value of the risks for the project throughout the project duration and linearly distribute such value over the project duration. In case there is an extension of time in the project, the premium rate increases according to the preset agreement in the insurance policy since the risk will be at its highest possible levels by then.

Regarding the second term (Insurer's Indirect Costs), the bigger the insurance company is and the more projects the insurance company insures, the more the indirect costs are, accordingly the higher the premium will be.

Regarding the third term (Insurer's Profit Margin), for insurance companies, the main source of generating profit is not from premiums received Vs the collective claimed costs paid; since it is often that the collective claim costs are greater than the premiums received. This is often known as "Loss Ratio" where the loss ratio is defined as the ratio of the total claims paid by the insurer to the total premiums received by the insurer. Rather the main source of generating profit is from the reinvestment of premiums. The concept of reinvestment is highly utilized in the insurance industry and all insurance parties reinvest far from the multinational insurance brokers to insurers and reinsurers.

In addition, since the pricing block for insurance companies is the risk, if any one project made loss for the insurance company; that is the claimed and compensated for costs exceed the premium, this does not indicate that the insurance company is losing profit in the overall. Getting back to the basics of insurance since the times of Lloyds insurance, insurance is based on the theory of large numbers; that is, the more the insured projects are, the less the accidents ratio is and the more the profit is generated; where accidents ratio is the ratio of insured projects that develop accidents to the total projects insured.

Finally, the profit margin of the insurance companies is affected by:

1. Corporate strategy: Depending on the corporate strategy, entering new markets may lead to premiums being underestimated in parallel to the added indirect cost of providing business support to the job demand. To compensate for such loss, the company might increase the profit margin within the current markets being served.
2. Market forces: The volume of business in the insurance industry affects the profit margin significantly.
3. Competition: As the number of insurance companies serving a certain industry increase, the competition increases between insurers leading to premium reduction.

In normal conditions, whenever the risk in a project gets higher, the premium increases and the profit margin for that project also increases.

4.3 Insurance Premium Estimate

Insurance premium is expressed as a value per thousand (‰) of the construction contract price. Current fair estimates within the Egyptian market range between 0.3‰ and 1.5‰ (0.03% and 0.15%) with an average of 0.55‰ (0.055%). However, such rate might increase for exceptionally risky projects reaching up to 5‰ (0.5%) or higher.

4.4 Construction Technology

The relationship between construction technology and insurance premiums can be expressed in the following precise conclusions:

1. If the construction technology is a new prototype not subjected to insurance before, premiums will be extremely high. Once the history builds up, actuarial models are to decide on the fair judgement for the insurance premiums.
2. If the construction technology is related to the supervision of work, such as construction site IoT, instantaneous significant reduction to premiums will take place due to the early warning and prevention of accidents.
3. If the construction technology reduces labor involvement and human error, such as robots, 3D printing or prefabrication and modular construction, the enhanced on-site safety will reflect in reduced insurance premiums. This is reinforced by the Egyptian workman's compensation insurance law issued early 2020 that bases premium on labor intensiveness in each project activity/ BOQ item.
4. If the construction technology improves on-site labor performance and their understanding of construction methods and different safety incidents, such as VR safety training, the enhanced on-site safety will reflect in reduced insurance premiums.
5. Construction technology may not necessarily contribute to premiums only but to other policy factors such as deductibles or limitation of liability.
6. Only time and history can conclude the actual impact of construction technologies on insurance premiums since other risks emerge against the reduced risks.

7. Some insurance policies outdate, require modification or complete alteration and tailoring to fit for construction technologies, such as:
   - No more need for the loss of paper insurance policy (against theft, fire, natural hazards, etc.…) in case BIM is fully adopted.
   - For BIM, professional indemnity insurance is to be tailored against any high dimension design and software errors.
   - A new BIM insurance policy is required to cover for the credibility of editors (authorized users). Some standard construction contracts are adapting to involve BIM insurance policies, such as:
     a. American Institute of Architects (AIA) – BIM addendum insurance clauses
     b. Institution of Civil Engineers (ICE) – BIM module insurance clauses
   - A new electronic equipment policy or modification to existing electronic policies is needed to account for robotic fabrication, 3D printing and automated construction on-site equipment.
   - Cyber liability insurance policy is needed to cover against cybersecurity breaches.

Previous real-life confidential market cases negotiated for construction technology and premium sensitivity where the contractor presented the project details and the modified method statements using the construction technology. After brainstorming and negotiating with insurance companies, premium prices fluctuated significantly. Even though such experts were aware of the newer risks emerging within the project; such as: untrained workmanship dealing with the construction technology upgrade, such added risks are significantly lower than the improved on-site safety measures induced by the construction technology upgrade and can be solved by simple means of providing training programs.

Chapter 5. Quantitative Analysis for the Relationship of Construction Technology with Safety and Insurance Premiums

A quantitative analysis is conducted based on the outcomes of the literature review and industry research. The main aim of such research is to categorize insurance premium indicators according to their significance in insurance premium estimation and test the insurance premium sensitivity to construction technology. The below sections present the survey outcomes based on the statistical methodology previously discussed under Chapter 3.

The survey is forwarded to 300 field professionals and completed by 57 as shown in Table 8. All incomplete or ignored surveys are removed from the statistics developed in this research and discussed in the following chapter subdivision.

Table 8 Survey Participants

	Insurers and Brokers (IB)	**Contractors and Consultants (CC)**	**Total**
Survey forwarded to	44	256	300
Survey opened by	27	40	67
Survey completed by	21	36	57
Response rate = $\frac{\boldsymbol{Completed\ surveys}}{\boldsymbol{Targeted\ participants}}$	48%	14%	19%
Participants	Insurance risk analysts and insurance brokers client advisors	Safety officers, risk analysts, project managers and construction managers working at contractors and consulting firms	

5.1 Frequency of Filing Insurance Claims Vs Project Type

Both CC and IB groups are asked to classify the frequency of having a safety accident and filing an insurance claim for different project types; residential & commercial buildings, road and bridge construction, tunneling construction and high-rise construction; into either low, medium, or high probabilities of claims. Figure 22 shows the percentage of participants choosing each category of frequency for each project type.

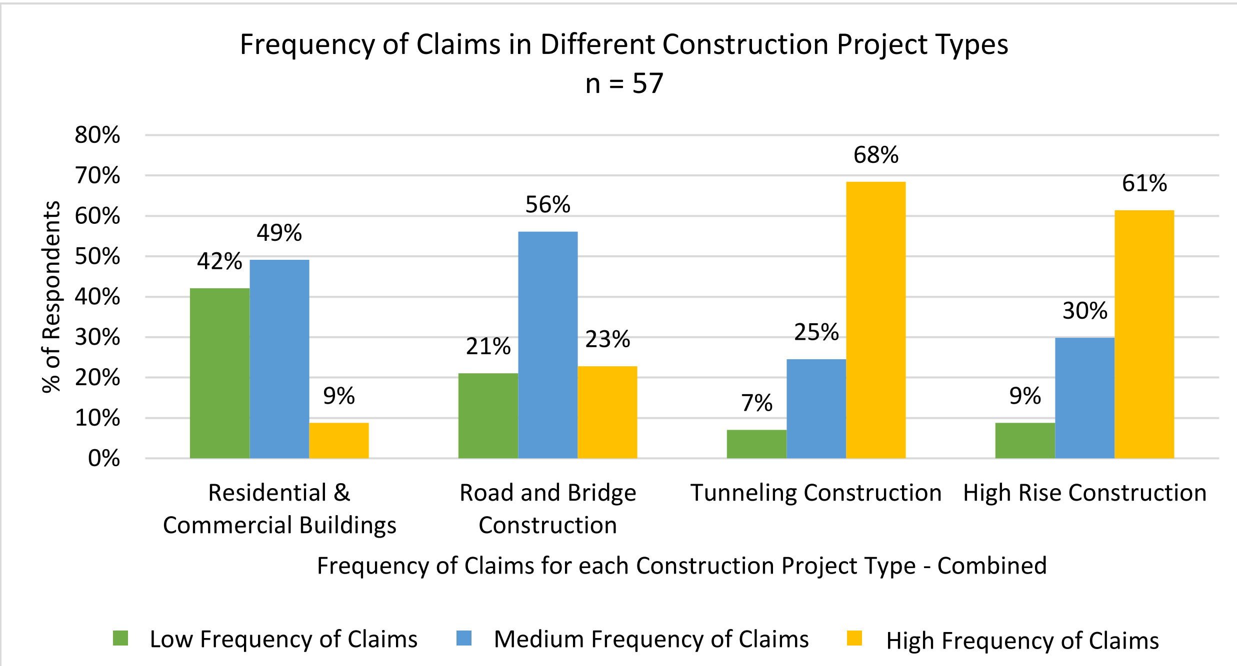


Figure 22 Percentage of participants classifying each project type according to low, medium, or high frequency of filing insurance claims

As shown in Figure 23, the frequency of claims is high in tunneling construction and high-rise construction, medium in road and bridge construction and low in residential & commercial buildings. Tunneling construction exceeds high-rise construction in the frequency of claims.

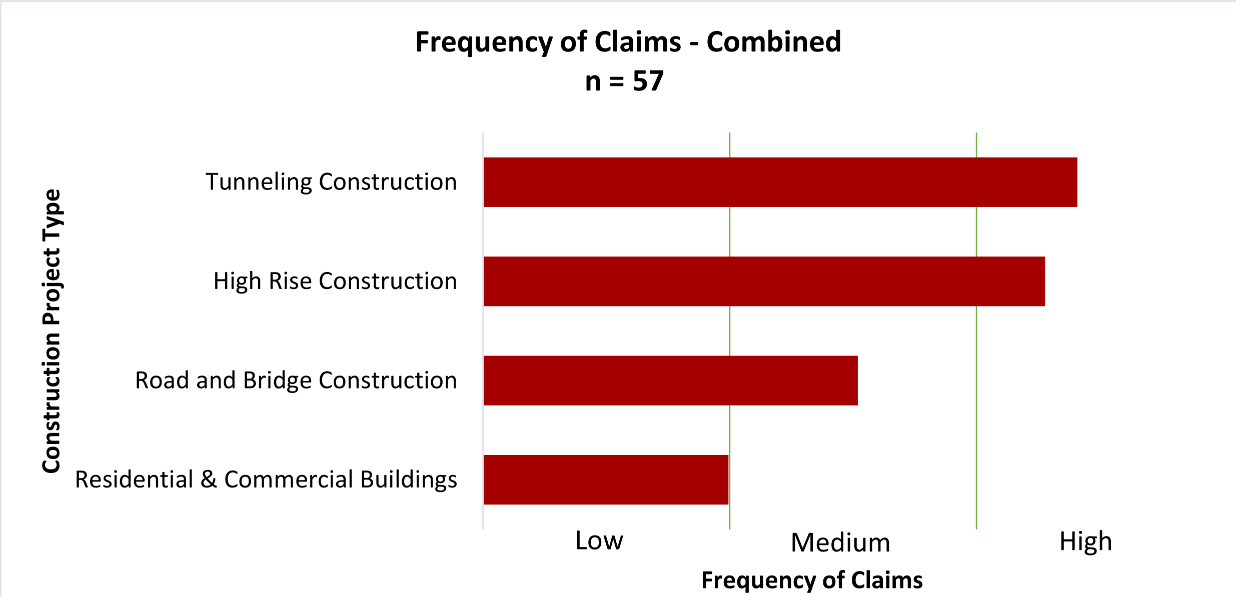


Figure 23 Project types categorized according to low, medium, or high frequency of filing insurance claims

As represented in Table 9, Levene's test shows equal variance for all project types and the P-value for the T-test is greater than 0.05 for all project types indicating that there is no statistically significant difference between the frequency of safety accidents and reporting insurance claims for all project types provided by CC and those provided by IB.

Table 9 Levene's test and T-test results for the means of both CC and IB groups with respect to the frequency of reporting insurance claims for each project type.

Project Type	Levene's test of Equality of Variances		T-test	
			P-value	Conclusion at 95% Confidence Level
Residential & Commercial Buildings	0.18	Equal Variance	0.08	No statistically significant difference between the response of CC and IB
Road and Bridge Construction	0.96	Equal Variance	0.17	No statistically significant difference between the response of CC and IB
Tunneling Construction	0.43	Equal Variance	0.41	No statistically significant difference between the response of CC and IB
High-Rise Construction	0.81	Equal Variance	0.40	No statistically significant difference between the response of CC and IB

5.2 Size of Insurance Claims Vs Project Type

Both CC and IB groups are asked to classify the size of insurance claims or claimed costs for different project types; residential & commercial buildings, road and bridge construction, tunneling construction and high-rise construction; into either low, medium, or high claimed costs. Figure 24 shows the percentage of participants choosing each category of claimed costs for each project type.

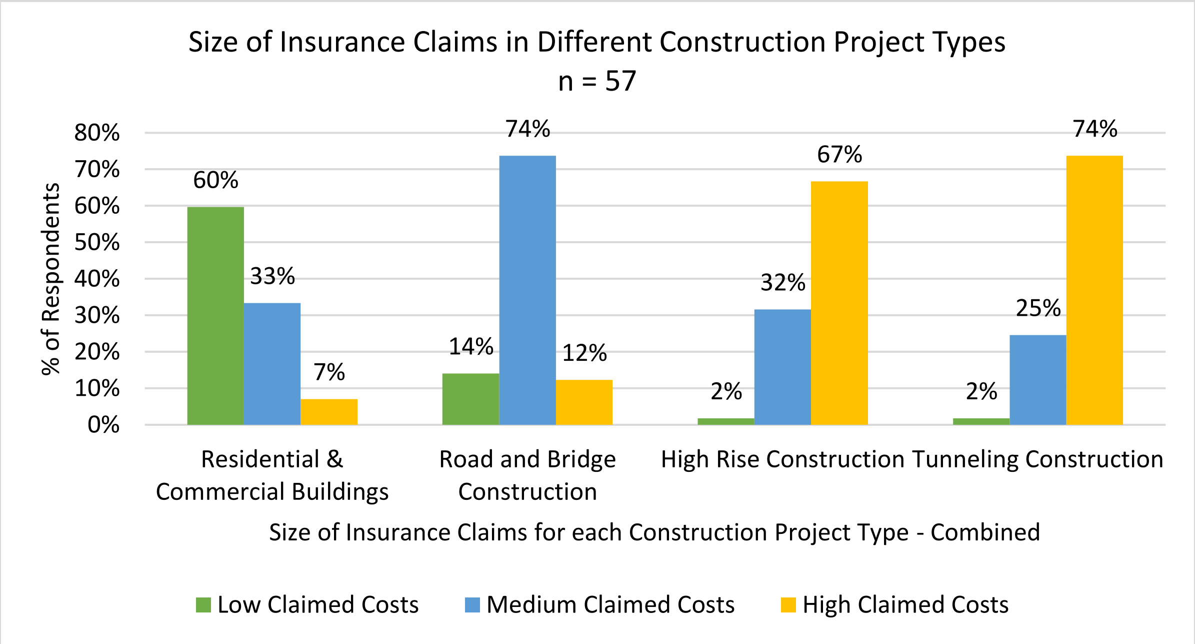


Figure 24 Percentage of participants classifying each project type according to low, medium, or high size of insurance claims

As shown in Figure 25, the sizes of insurance claims/ claimed costs are high in tunneling construction and high-rise construction, medium in road and bridge construction and low in residential & commercial buildings. Tunneling construction exceeds high-rise construction in the size of insurance claims.

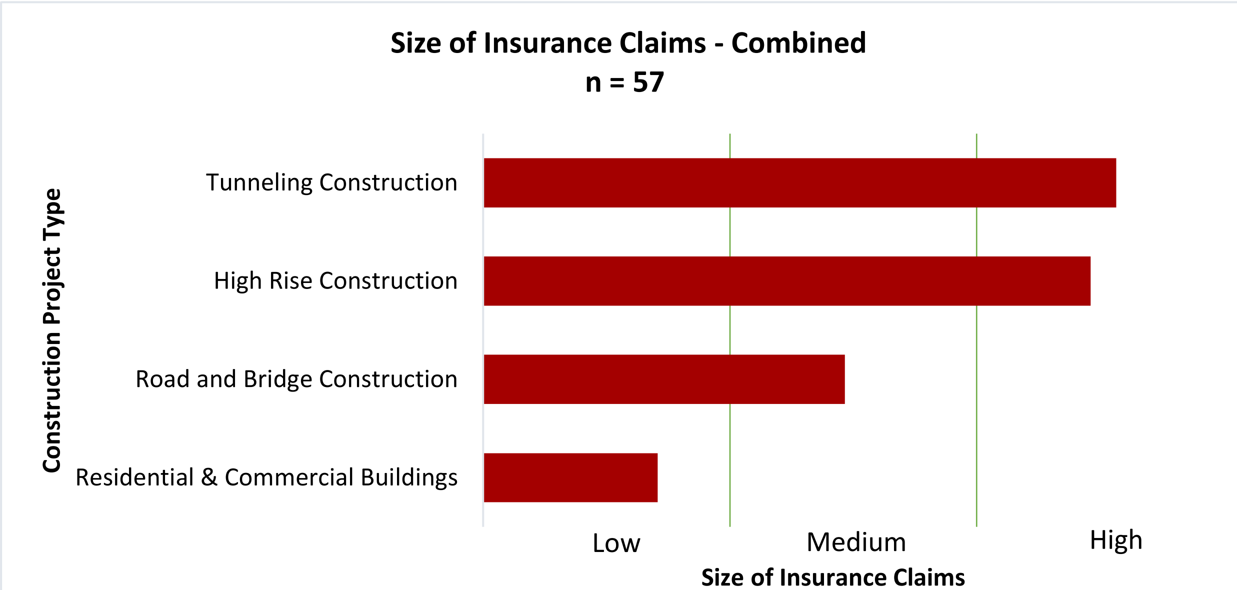


Figure 25 Project types categorized according to low, medium, or high sizes of insurance claims

As represented in Table 10, Levene's test shows equal variance for all project types and the P-value for the T-test is greater than 0.05 for all project types indicating that there is no statistically significant difference between the size of insurance claims or claimed costs for all project types provided by CC and those provided by IB.

Table 10 Levene's test and T-test results for the means of both CC and IB groups with respect to the size of insurance claims/ claimed cost for each project type.

Project Type	**Levene's test of Equality of Variances**		**T-test**	
			P-value	**Conclusion at 95% Confidence Level**
Residential & Commercial Buildings	0.13	Equal Variance	0.98	No statistically significant difference between the response of CC and IB
Road and Bridge Construction	0.24	Equal Variance	0.39	No statistically significant difference between the response of CC and IB
Tunneling Construction	0.63	Equal Variance	0.95	No statistically significant difference between the response of CC and IB
High-Rise Construction	0.14	Equal Variance	0.16	No statistically significant difference between the response of CC and IB

In brief, tunneling construction followed by high-rise construction account to both high frequency of insurance claims and high claimed costs, then road and bridge construction has medium frequency of insurance claims and medium claimed costs while residential & commercial buildings construction account to the least frequency of insurance claims and claimed costs. Finally, there is no statistically significant difference between the response of CC and IB with respect to the frequency of insurance claims and claimed costs.

5.3 Factors Affecting Insurance Premiums

33 factors affecting insurance premiums are compiled from literature and interviews as provided in Table 11. The factors are classified according to either a project factor, a parties' factor (both contractor and owner/engineer) and an insurer factor. Table 11 shows a description to some of the factors in brackets next to the factor and the sources for each of the 33 factors.

Table 11 Classification of factors affecting construction insurance premiums.

Factor No.	Safety Factors	Source
Project Factors		
1	Project type/ nature (tunnel, high-rise, etc.…)	(Interviews), (Imriyas et al.2007), (SecureNow 2021)
2	Project size (mega-project, mid-sized, etc.…)	(Interviews), (Stromberg 2021)
3	Project Contract price	(Interviews), (SecureNow 2021)
4	Project location and surrounding environment (located in earthquake zones or next to water structures, gas stations, etc.…)	(Interviews), (Imriyas et al. 2007), (Stromberg 2021), (SecureNow 2021)
5	Project weather conditions	(Interviews), (Imriyas et al. 2007)
6	Project duration	(Interviews), (Imriyas et al. 2007), (SecureNow 2021)
7	Drawings, Specifications, Construction time schedule & BOQ	(Interviews), (Imriyas et al. 2007), (SecureNow 2021)
8	Project financial structure/ lenders (development banks, NGOs, privately financed, etc.…)	(Interviews)
9	Project procurement method (traditional, design-build, etc...)	(Interviews)
10	Number of contractors on-site	(Imriyas et al. 2007)
11	Number of insured participants (Namely, several sub-contractors are on-site)	(Imriyas et al. 2007), (Stromberg 2021)
12	Project sum insured (In case not all the contract price is insured)	(Interviews), (SecureNow 2021)

13	Building materials for use	(Interviews), (SecureNow 2021)
14	Unique project complexities	(Interviews)
15	Construction contract terms and conditions	(Interviews), (SecureNow 2021)
16	Insurance coverage limits, exclusions, and deductibles	(Interviews), (Stromberg 2021), (SecureNow 2021)
	Parties' Factors (Construction Company)	
17	Contractor's size	(Interviews), (Imriyas et al. 2007)
18	Contractor's experience in similar projects/ method statement	(4.2.1), (Stromberg, 2021), (SecureNow 2021)
19	Contractor's construction technology and building techniques (traditional Vs advanced)	(Interviews), (SecureNow 2021)
20	Contractor's method statements for severe jobs	(Interviews)
21	Contractor's Safety Claim history (previous accidents reported by the contractor)	(Interviews), (Bou Hatoum et al. 2020), (Imriyas et al. 2007)
22	Contractor's Sub-Contract Management (control over safety practices of the sub-contractors)	(Bou Hatoum et al. 2020)
	Parties' Factors (Contractor's Safety Practices)	
23	Contractor's Safety Policies/ Hazard Management Policies (The level of detail in the safety assurance policies)	(Interviews), (Bou Hatoum et al. 2020), (SecureNow 2021)
24	Contractor's Safety technology (Actual technology used to improve on-site safety standards)	(Interviews), (Bou Hatoum et al. 2020), (SecureNow 2021)
25	Contractor's Safety Training (Training provided to the employees and labor)	(Interviews), (Bou Hatoum et al. 2020), (SecureNow 2021)
	Parties' Factors (Contractor's Labor)	
26	Contractor's Labor Experience	(Bou Hatoum et al. 2020)
27	Contractor's Labor Level of Education	(Bou Hatoum et al. 2020)
	Parties' Factors (Engineer Factor)	
28	Owner/ Engineer influence on committing to safety standards (Owner/ Engineer participation in controlling safety on-site)	(Huang et al. 2006)
	Insurer Factors	
29	Insurer's Direct Cost: Reinsurance cost and insurance broker commission	(Interviews), (Imriyas et al. 2007)
30	Insurer's Indirect Cost: Insurance company overhead cost	(Interviews), (Imriyas et al. 2007)
31	Insurer's Strategy of Profit Generation and Potential Future Business	(Interviews), (Imriyas et al. 2007)
32	Volume of business in insurance market (Number of construction projects)	(Interviews), (Imriyas et al. 2007)
33	Insurance Market Competition (number of insurers/ competitors in the insurance market)	(Interviews), (Imriyas et al. 2007)

The above-described factors are provided for IB participants to evaluate their impact on construction projects' premium according to a scale of no, low, moderate, and high impact. After following the statistical methodology previously described above, Figure 26 represents the 33 factors ranked and classified according to their respective relative impact.

Unsurprisingly, the project characteristics; project type, location, unique complexities, exhibit the highest influence on the premium evaluation followed by contractor's safety management strategies and safety claim history.

Only 3 factors (out of 33) have a low impact on insurance premiums. These factors are "Contractor's Labor Level of Education", "Project financial structure/ lenders" and "Project procurement method" where insurers believe that any change in such factors does not significantly influence their premium estimation. A possible interpretation for such conclusion is that the contractor's labor level of education does not necessarily indicate the level of skill in performing the task safely. In addition, the project financial structure and procurement methods do not relate to the on-site safety conditions rather to the commercial project management field. Insurance companies focus on the risk of accidents and do not consider these factors of significant cause for accidents.

All other factors have significant impact on insurance premium estimation; either moderate or high, with relative percentages.

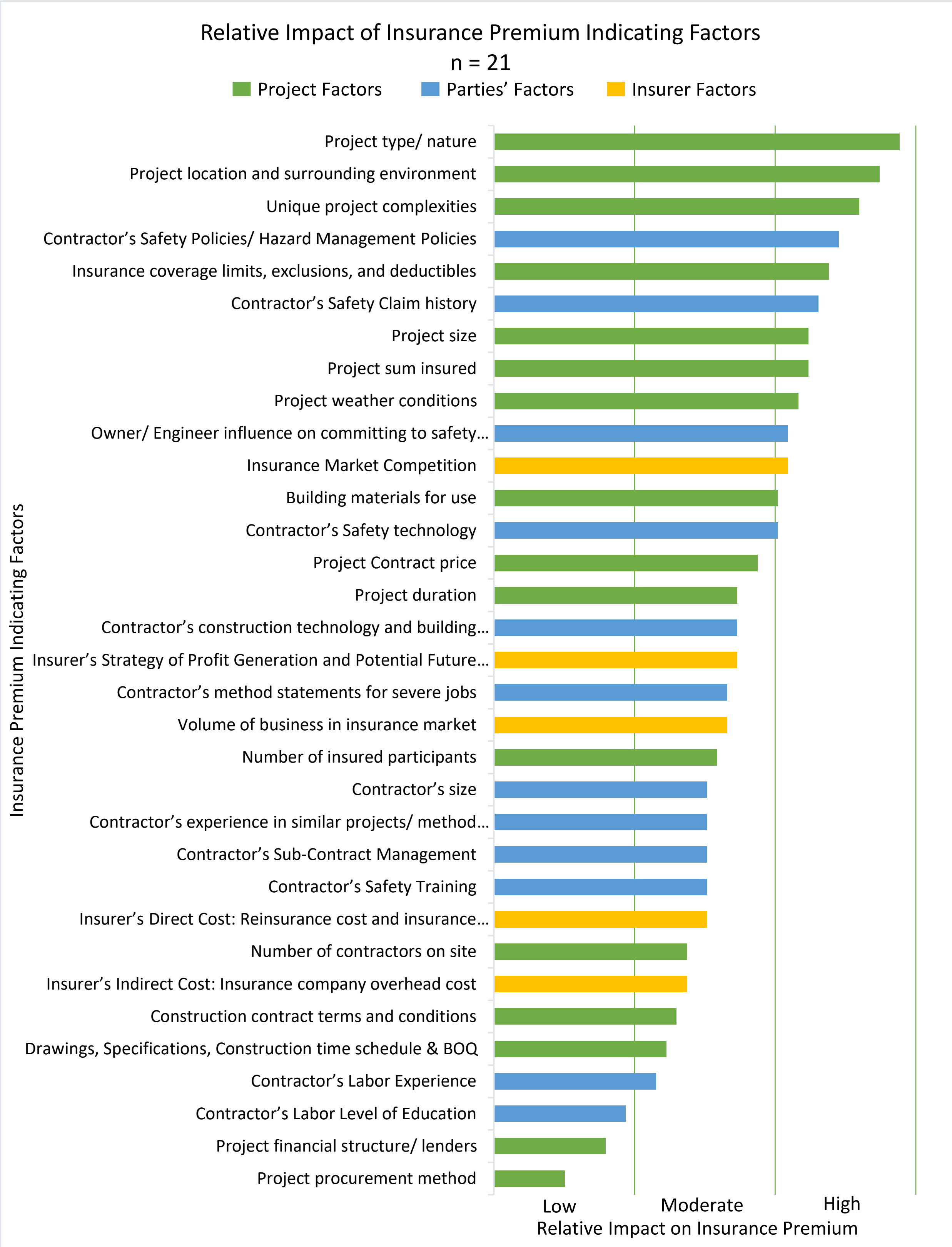


Figure 26 Relative impact of insurance premium indicating factors

Table 12 shows the details of responses leading to the summary demonstration in Figure 26. The table shows the percentage of responses mapping each factor to its relative impact on (or correlation with) insurance premium.

Table 12 Relative impact of insurance premium indicating factors and categories.

Category	**Safety Factors**	**Factor Impact on (or correlation with) Premium (The numbers represent the % of responses)**			
		No	Low	Moderate	High
Project factors	1. Project type/ nature	0	0	10	90
	2. Project size	0	19	14	67
	3. Project Contract price	5	10	43	43
	4. Project location and surrounding environment	0	0	19	81
	5. Project weather conditions	10	10	10	71
	6. Project duration	5	29	14	52
	7. Drawings, Specifications, Construction time schedule & BOQ	14	14	48	24
	8. Project financial structure/ lenders	24	29	19	29
	9. Project procurement method (traditional, design-build, ...)	38	10	33	19
	10. Number of contractors on-site	19	5	43	33
	11. Number of insured participants	0	33	29	38
	12. Project sum insured	0	5	43	52
	13. Building materials for use	5	14	24	57
	14. Unique project complexities	0	10	10	81
	15. Construction contract terms and conditions	5	33	33	29
	16. Insurance coverage limits and deductibles	5	10	10	76
Parties' factors	1. Contractor's size	14	14	29	43
	2. Contractor's experience in similar projects/ method statement	19	10	24	48

	3. Contractor’s construction technology and building techniques	10	24	10	57
	4. Contractor’s method statements for severe jobs	0	29	33	38
	5. Contractor’s Safety Claim history	0	14	19	67
	6. Contractor’s Sub-Contract Management	14	10	38	38
	7. Contractor’s Safety Policies/ Hazard Management Policies	0	0	38	62
	8. Contractor’s Safety technology	5	5	43	48
	9. Contractor’s Safety Training	5	24	38	33
	10. Contractor’s Labor Experience	19	14	38	29
	11. Contractor’s Labor Level of Education	33	5	29	33
	12. Owner/ Engineer influence on committing to safety standards	5	10	29	57
Insurer factors	1. Insurer’s Direct Cost: Reinsurance cost and insurance broker commission	5	29	29	38
	2. Insurer’s Indirect Cost: Insurance company overhead cost	0	33	43	24
	3. Insurer’s Strategy of Profit Generation and Potential Future Business	5	24	24	48
	4. Volume of business in insurance market	0	10	71	19
	5. Insurance Market Competition	5	5	38	52

The three categories provide medium impact on insurance premiums with no category of factors having more impact on the premium over the other.

Having a deeper look at the factors grouped in their categories, considering the project factors, any factor that has direct relation to the site conditions highly impacts the insurance premium while the moderately influential factors are all related to contractual obligation between parties.

Considering the parties' factors, all the safety practices from any party and the historical record of claims are those that account for the higher contribution to premium estimation over the other factors related to contractors' size or experience or other factors of similar nature.

Finally considering the insurer's factors, the only factor that significantly impacts the insurance premium estimation is the market competition in the insurance industry. This has been previously reflected in the interview with the insurance company representative stating that more insurance companies are entering the market and accordingly insurers decide their premiums based on market competition which might lead to unfair quantification of risk to premium. Same concept is discussed in the interview with the mid-sized contractor representative that already practices pressure on insurers to reduce their premiums knowing that there is high market competition.

5.4 Impact of Construction Technology on Accidents Reduction

CC respondents evaluated the expected impact of each construction technology on on-site accident reduction into a scale of no, low, moderate, high, and very high corresponding to certain percentage ranges provided in the survey question. Using the statistical methodology previously described above, Figure 27 shows the percentage of participants choosing each of the reduction in accidents categories for each construction technology.

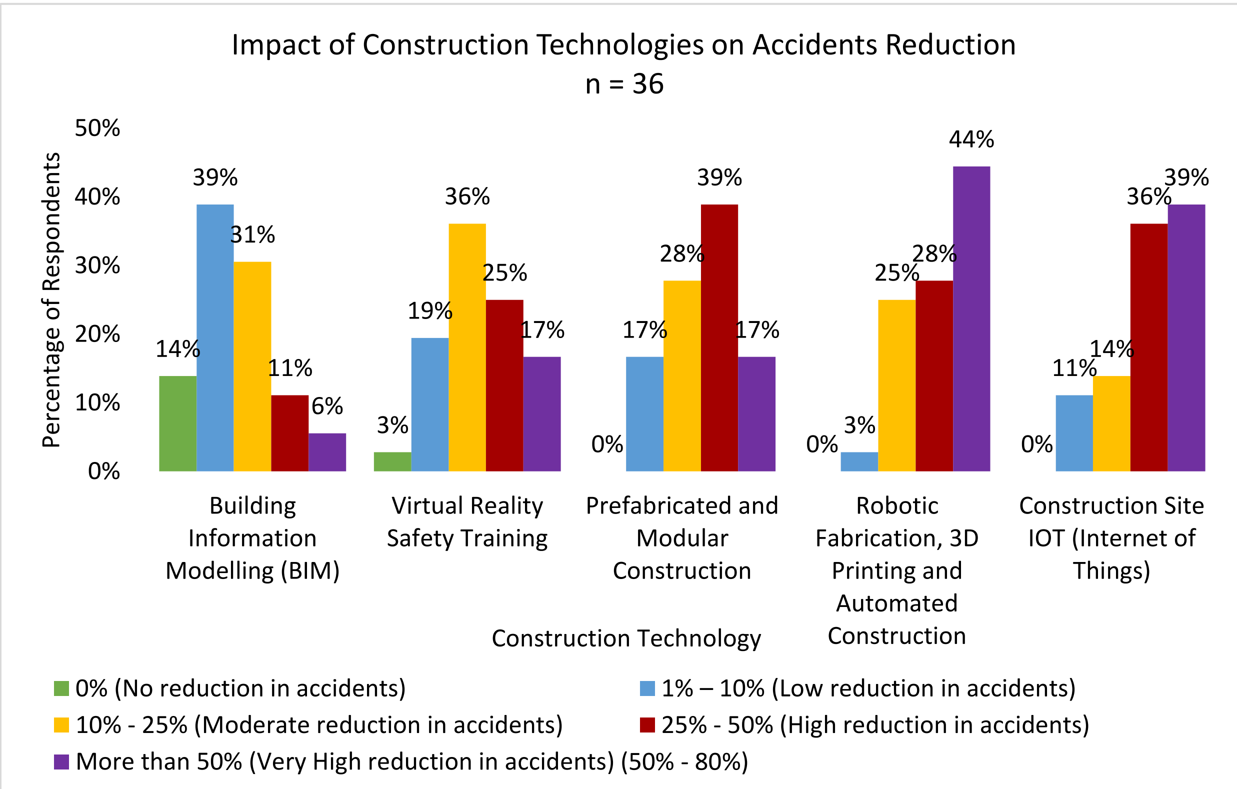


Figure 27 Percentage of respondents choosing each category of accident reduction for each construction technology

Figure 28 shows the evaluated effect of each construction technology on accident reduction.

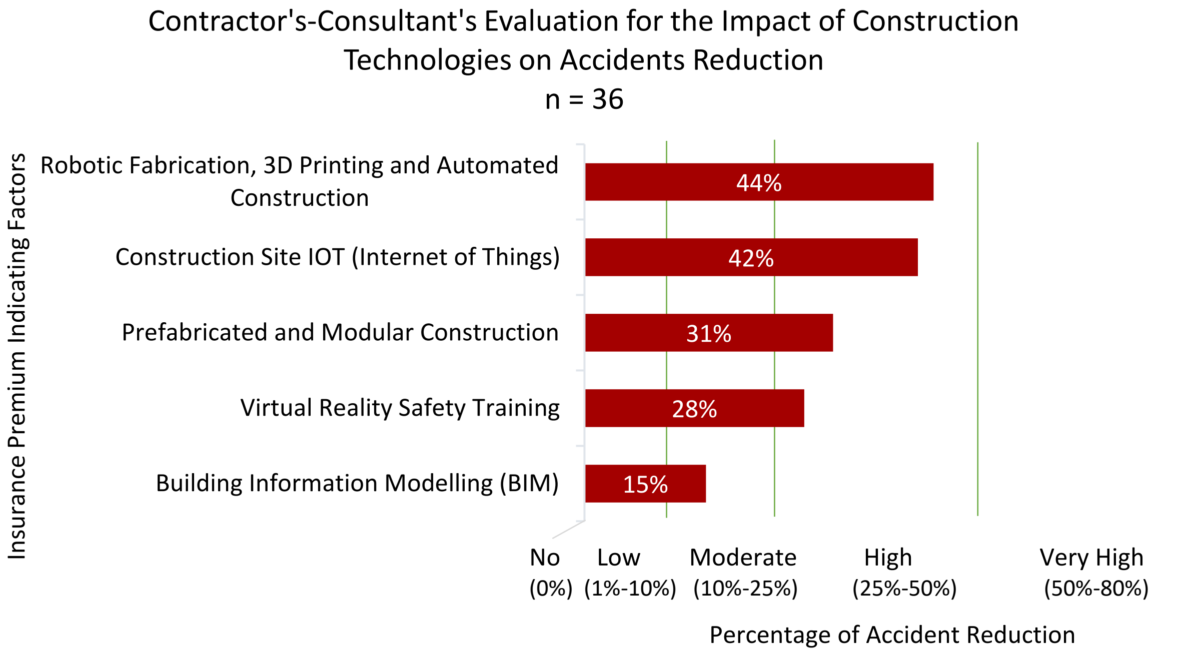


Figure 28 Construction technologies classified according to the impact on accident reduction

All construction technologies have a high percentage reduction in accidents; ranging from 25% to 50%, except BIM that has a moderate impact on accident reduction. Exact percentage reduction in accidents for each construction technology is provided in Figure 28 on the bar for each construction technology. Robotic fabrication, 3D printing and automated construction exhibit the highest percentage reduction in accidents followed by construction site IoT then prefabrication and modular construction and finally virtual reality safety training.

This indicates that the more the site is automated with less labor, the higher the precision is and the less the accidents recorded are. In case labor is available on-site, notifying them with any harm in the surrounding will highly reduce the reported accidents. If robotic fabrication, 3D printing and automated construction or construction site IoT cannot be easily implemented, simplifying the construction method for labor in terms of providing more of prefabrication and modular construction, if possible, and investing in labor safety training through VR will still provide high reduction in accidents. Finally, the use of BIM moderately reduces accidents on-site. This might be due to the less reworks gained from using BIM. Such percentage is expected to increase significantly in case 8D BIM, once commercially developed, is implemented to the projects.

5.5 Effect of Accident Reduction on Insurance Premiums

After CC's evaluation for the reduction effect of construction technology on accidents, IB participants analyze the impact of accident reduction on insurance premiums. Accordingly, Figure 29 shows the percentage of the respondents choosing each impact category on premiums for each percentage reduction in accidents.

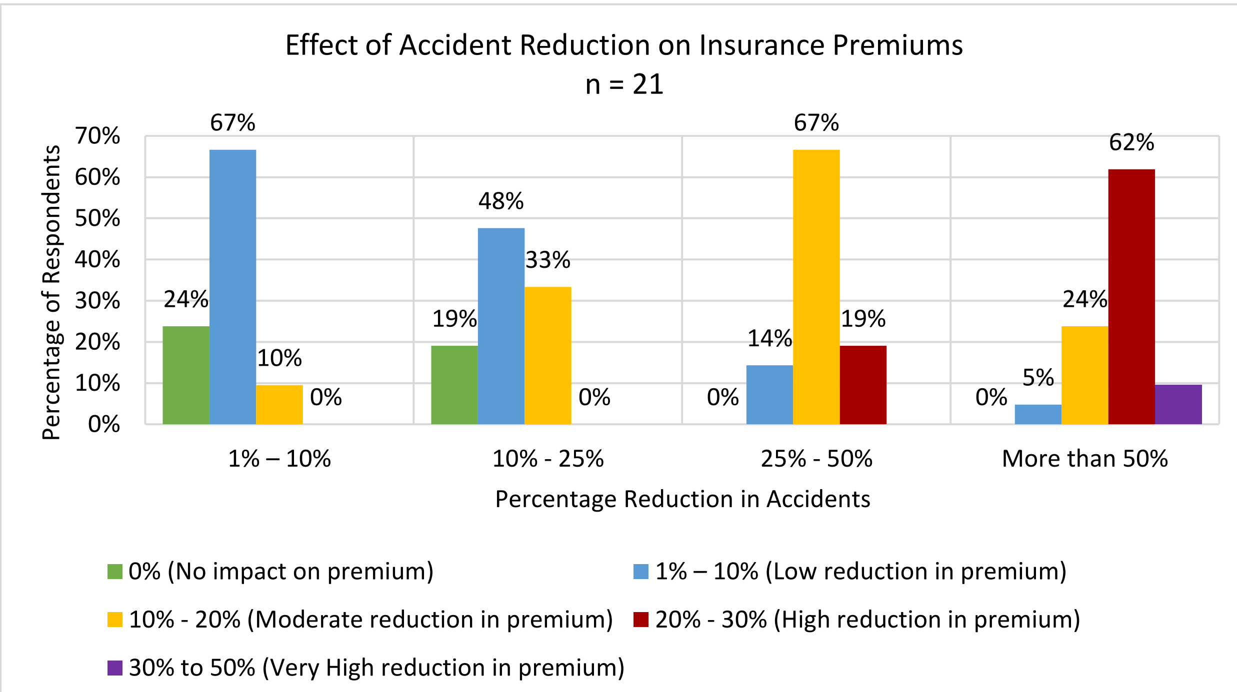


Figure 29 Percentage of respondents choosing each category of reduction in premium for each category of reduction in accidents

The participants' results based on the midpoints of ranges are used to plot the line of best fit calculated for the highest coefficient of determination (R^2). This is to provide a prediction equation for the change in insurance premiums from the change in accident reduction. A box-and-whisker plot is schemed to graphically represent the variation in and dispersion of the results among all categories for percentage decrease in accidents and premiums. The line of best fit is superimposed on the box-and-whisker plot to graphically illustrate the expression of data through the derived equation as presented in Figure 30.

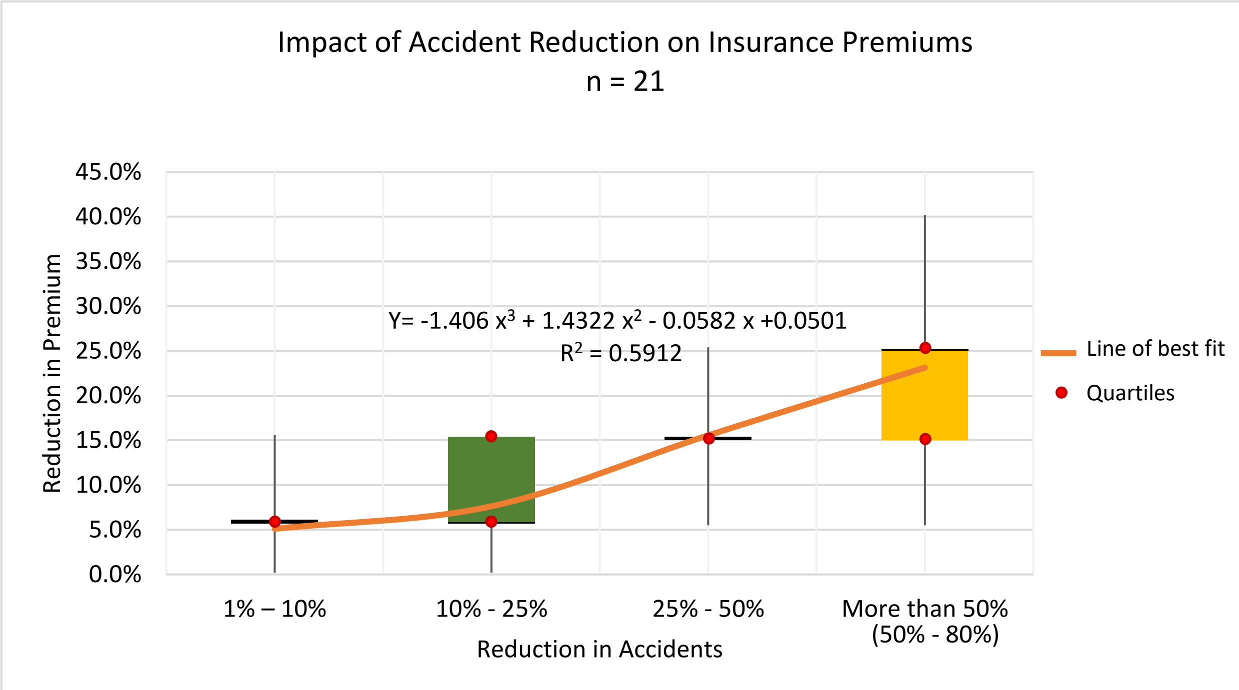


Figure 30 Impact of accident reduction on insurance premiums

The box-and-whisker plot is derived from Table 13 representing the distribution and dispersion of the quantitative research results.

Table 13 Box-and-whisker plot details for reduction in premium Vs reduction in accidents

Category for reduction in accidents	**Low**	**Moderate**	**High**	**Very High**
Percentage reduction in accidents	1% – 10%	10% - 25%	25% - 50%	50% - 80%
Range Midpoint	5.50%	17.50%	37.50%	65.00%
Minimum value (reduction in premium)	0.00%	0.00%	5.50%	5.50%
First quartile (reduction in premium)	5.50%	5.50%	15.00%	15.00%
Median value (reduction in premium)	5.50%	5.50%	15.00%	25.00%
Third quartile (reduction in premium)	5.50%	15.00%	15.00%	25.00%
Maximum value (reduction in premium)	15.00%	15.00%	25.00%	40.00%
Line of Best Fit (reduction in premium)	5.10%	7.62%	15.55%	23.13%

As the percentage decrease in accidents increases, the percentage decrease in premium increases.

Based on these results, an empirical equation was derived to grasp the relationship between reduction in accidents and reduction in insurance premiums. This equation is derived from the line of best fit is presented in Figure 30 is as follows:

Let z represent the percentage reduction in accidents and $\Delta\ \varepsilon$ represent the percentage reduction in insurance premium, where;

Equation 1 Percentage reduction in insurance premium as a function of percentage reduction in accidents

$$\Delta\ \varepsilon = -1.406\, z^3 + 1.4322\, z^2 - 0.0582\, z + 0.0501; \quad (1)$$

$$\text{Condition: } 0.05 \leq z \leq 0.65$$

This function moderately represents the data available since the R^2 is 0.5912 yet it is the most representable function developed for the data. This function is only valid within the limitation of the available data; starting 5% and until 65% reduction in accidents the function can predict the reduction in premium. No data is available from 65% to 100% reduction in accidents. Therefore, in this study, the reduction in premium is assumed constant at 23% for reduction in accidents exceeding 65%. (*65% is the midpoint for the range 50% to 80%. 80% is assumed the maximum reduction in accidents in this study). For 0% reduction in accidents, it is assumed that there will be 0% reduction in premium.

For the low reduction in accidents category, responses provided are convergent towards 5.5% reduction in premium with minimum outliers above and below. Similarly for the high reduction in accidents, results are convergent towards 15% reduction in premium with minimum outliers above and below. However, for the moderate and very high reduction in accidents, results diverge far from 5.5% to 15% reduction in premium with few outliers below and far from 15% to 25% reduction in premium, respectively.

Kendal's tau b test resulted in $\tau_b = 0.678$, and *p*-value = 0.000. Since for H_o (null hypothesis): $\tau_b = 0$; for H_1: $\tau_b \neq 0$; and for a confidence level of 95% and significance level of 5%; Z-score for standard normal distribution = 7.368 and z = 1.96 falls in the rejection region (RR); hence reject H_o and accept H_1. This provides sufficient evidence to reject the null hypothesis at 5% significance level corresponding to 95% confidence level. Accordingly, τ_b is not equal to 0. Having a positive τ_b indicates a **statistically significant positive relationship between the reduction in accidents and the reduction in insurance premium**.

5.6 Direct Evaluation for Reduction in Insurance Premiums Due to Construction Technology – Assessing the Alignment between Contractors and Insurers

IB and CC groups evaluated the deserved impact of construction technology on insurance premiums. For each evaluation, Figure 31 reflects the percentage of respondents choosing each reduction in premiums category for each construction technology.

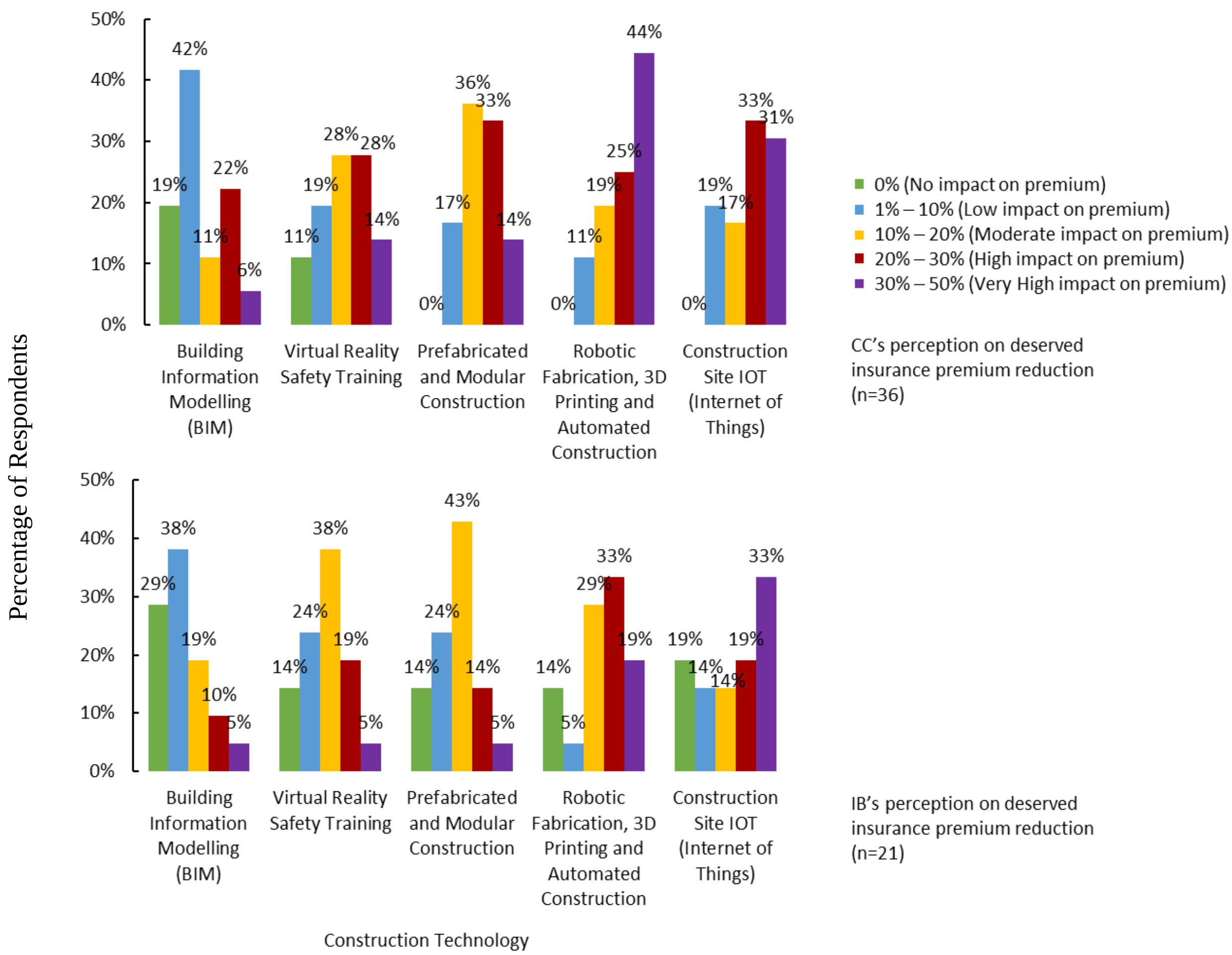


Figure 31 Percentage of respondents evaluating the reduction in insurance premiums from different perspectives

Using weighted average, construction technologies are classified according to the impact on premium reduction on a scale of no, low, moderate, high, or very high reduction in premium for each form of estimate. Figure 32 shows the different estimates for the impact of construction technology on premium reduction.

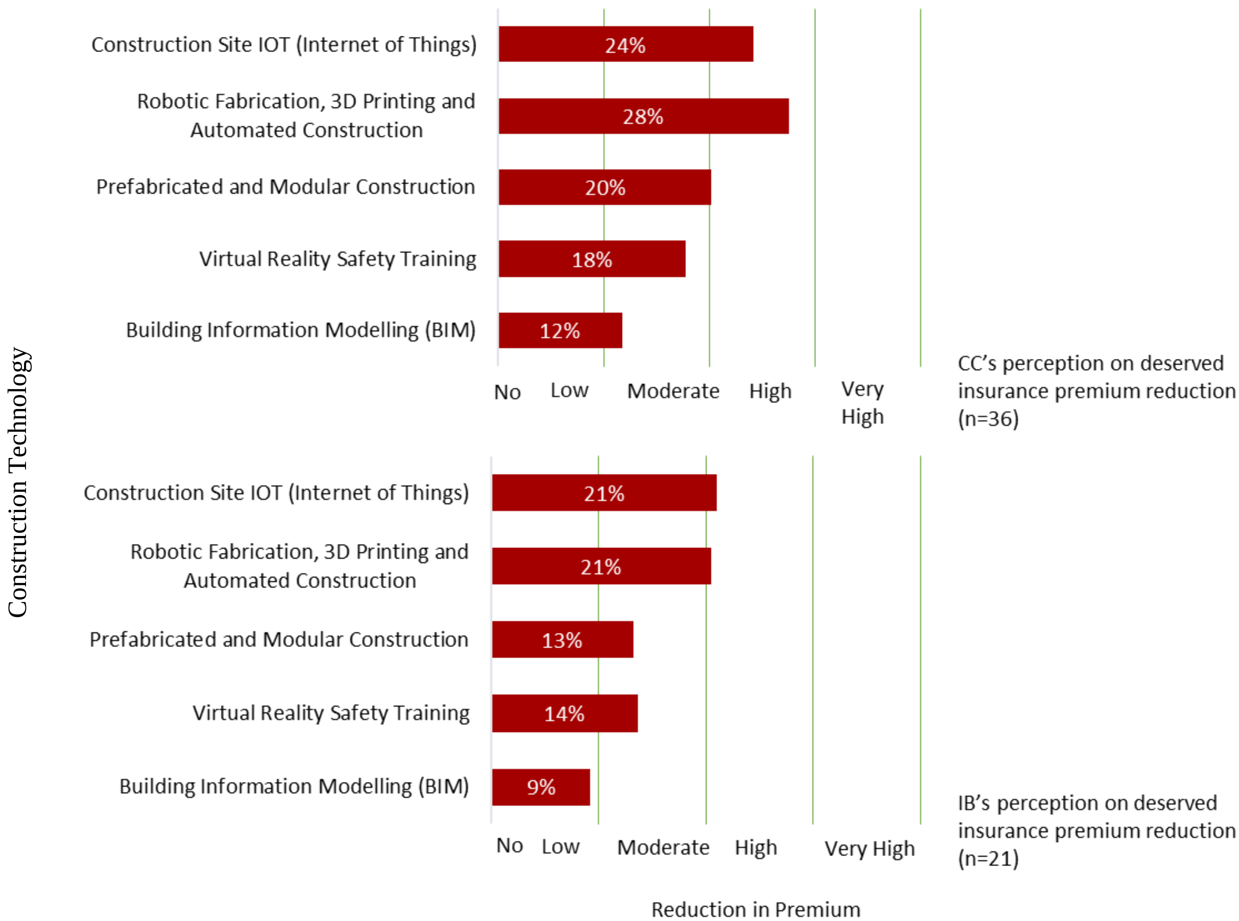


Figure 32 Expected reduction in insurance premiums from different perspectives

It is evident that regardless of the perspective, none of the construction technologies have a very high impact on premium reduction, while all estimates agree that robotic fabrication, 3D printing and automated construction and construction site IoT will have a high impact on premium reduction and virtual reality safety training will have moderate impact on premium reduction.

To provide a comparison for the respondents' different perspectives regarding premium reduction for each construction technology in a statistical manner, the results for the statistical t-test are concluded below.

CC's deserved reduction in premiums is compared with IB evaluation for actual reduction in premiums in Table 14. Levene's test shows equal variances for all construction technologies. There is alignment between contractors and insurers when it comes to their view on the deserved and actual reduction in premium corresponding to some technologies such as building information modelling (BIM), virtual reality safety training and construction site IoT. However, there is a lack of alignment when it comes to prefabricated and modular construction, and robotic fabrication, 3D printing and automated construction. The contractors estimate that such technologies deserve higher reduction in premium than what the insurers estimate. This highlights the fact that more communication should be made between contractors and insurers with respect to these technologies and more studies need to be made to minimize this gap between both parties.

Table 14 Comparing CC's deserved reduction in premiums Vs IB evaluation for actual reduction in premiums

Construction Technology	Average reduction in premiums		Levene's test of Equality of Variances		Two-tailed T-test between CC's deserved and IB's evaluation for reduction in premiums		
	What Contractors View as Deserved Reduction	What Insurers View as Deserved Reduction			t-statistic	P-value	Conclusion at 95% Confidence Level
Building Information Modelling (BIM)	12%	9%	0.688	Equal Variance	0.82	0.417	No statistically significant difference between what CC evaluate as a deserved reduction in premium and what IB evaluate as actual reduction in premiums.
Virtual Reality Safety Training	18%	14%	0.377	Equal Variance	1.26	0.212	No statistically significant difference between what CC evaluate as a deserved reduction in premium and what IB evaluate as actual reduction in premiums.
Prefabricated and Modular Construction	20%	13%	0.808	Equal Variance	2.47	**0.017**	Statistically significant difference between what CC evaluate as a deserved reduction in premium and what IB evaluate as actual reduction in premiums.
Robotic Fabrication, 3D Printing and Automated Construction	28%	21%	0.887	Equal Variance	2.02	**0.048**	Statistically significant difference between what CC evaluate as a deserved reduction in premium and what IB evaluate as actual reduction in premiums.
Construction Site IoT	24%	21%	0.225	Equal Variance	0.80	0.426	No statistically significant difference between what CC evaluate as a deserved reduction in premium and what IB evaluate as actual reduction in premiums.

5.7 Summary for The Impact of Construction Technology on Accident and Premium Reduction

Based on gathered data, an empirical equation is derived to predict the decrease in insurance premium as a result of the decrease in accidents. To sum up, there are three different percentages for premium reduction for each construction technology developed from the quantitative research, in addition to the accident reduction. The three different estimates for the premium reduction are presented in Table 15 and account for:

1. Premium reduction calculated from accident reduction for each construction technology
2. Expected premium reduction by IB for each construction technology
3. Deserved premium reduction as estimated by CC

Table 15 Summary for the impact of construction technology on accident and premium reduction

Construction Technology	Average Accident Reduction	Average Premium Reduction Calculated from Average Accident Reduction	Average Expected Premium Reduction by IB	Average Deserved Premium Reduction by CC
Robotic Fabrication, 3D Printing and Automated Construction	44%	18%	21%	28%
Construction Site IoT	42%	17%	21%	24%
Prefabricated and Modular Construction	31%	13%	13%	20%
Virtual Reality Safety Training	28%	11%	14%	18%
Building Information Modelling (BIM)	15%	7%	9%	12%

Figure 33 represents the same data in a graphical illustration. It can be concluded that:

1. Regardless of the perspective for premium reduction, the reduction in premium decreases in the following order of construction technology:

    a- Robotic Fabrication, 3D Printing and Automated Construction

    b- Construction Site IoT

    c- Prefabricated and Modular Construction

    d- Virtual Reality Safety Training

e- Building Information Modelling (BIM)

2. Regardless of the perspective for premium reduction, the reduction in premium is always below the reduction in accidents.
3. Regardless of the construction technology, the premium reduction calculated from accident reduction is the lowest insurance premium reduction percentage.
4. Regardless of the construction technology, CC's evaluation for the deserved reduction in insurance premium is higher than IB's evaluation.

The most reliable percentage reduction in premium is the one calculated from the prediction equation using the accident reduction since each party CC and IB made its professional evaluation and judgment regarding its field of expertise where CC are more competent to evaluate the impact of construction technology on accident reduction while IB are more competent to evaluate the impact of accident reduction on insurance premiums. Accordingly, the prediction equation is the most reliable of all three and will be used in the coming chapter in this research. While this is the case, it is important to notice that there is not such a great difference between the three values of premium reduction for each construction technology. Given that all values are close to each other, this is an indication that the quantitative research excelled in making each participant understand the required objectives from the questions and answer accordingly targeting the research objectives.

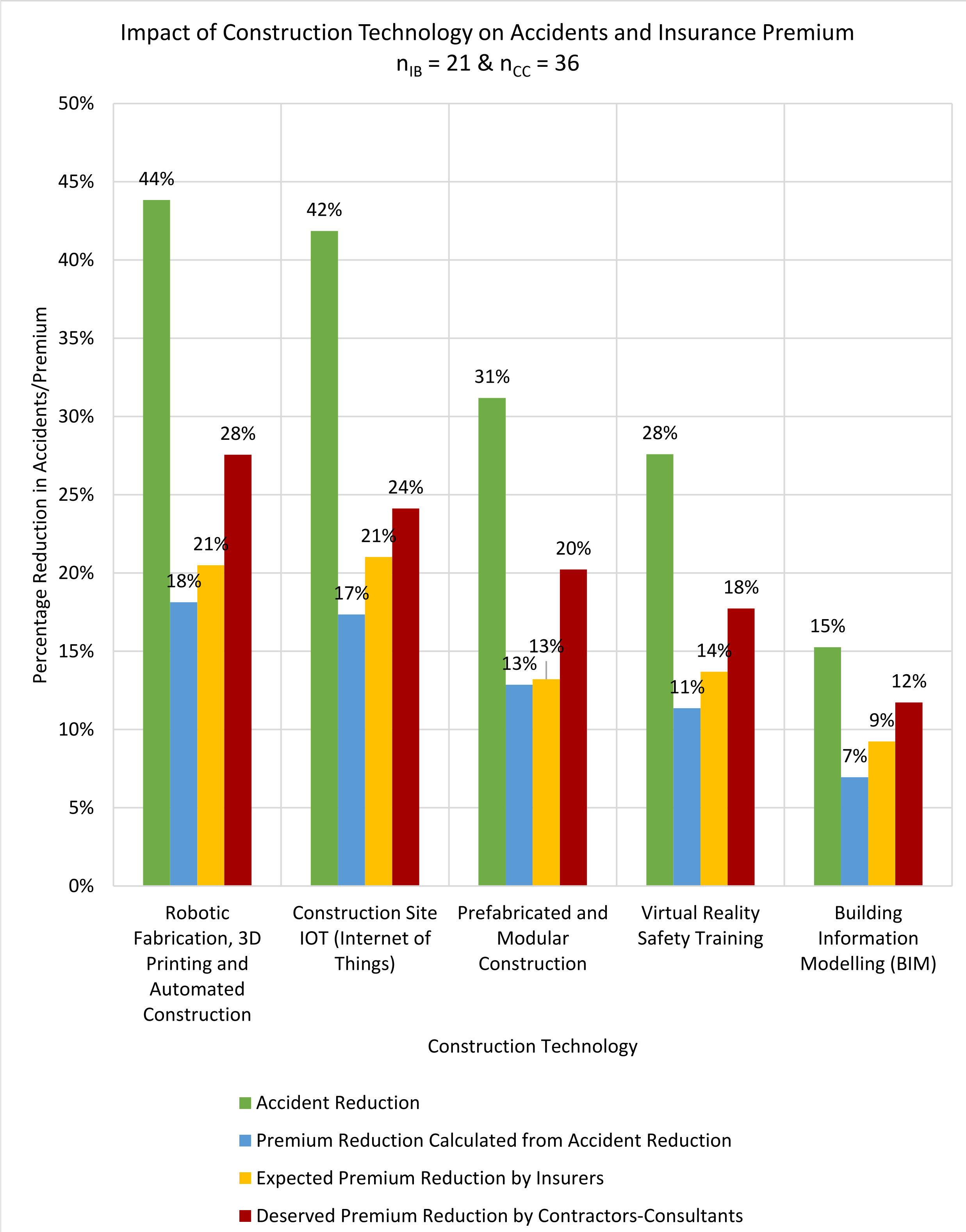


Figure 33 Effect of construction technology on accident reduction and premium reduction from different perspective

Chapter 6. Decision-Making Model

The previous chapters presented in-depth insights about the impact of construction technology on the on-site accident reduction followed by the expected reduction in insurance premiums, contractors are left to determine whether to go for the construction technology or not. In other words, ***which factors are to be considered during the decision-making process for the implementation of the construction technology?*** and ***is such reduction in insurance premiums worth the investment in the construction technology?***

This chapter discusses some factors that affect the contractor's decision; and highlights the overall added value of the construction technology on the contractor's company and for its employees. Further, a decision-making model is developed for the contractors to choose whether to adopt the construction technology based on the expected profit. The model also calculates the consequent financial impact on the insurers and the overall cost effectiveness of the technology. An illustrative case study from an actual construction project is implemented for the developed decision-making model and is concluded with some recommendations to the contractor.

6.1 Decision-Making Factors

The contractor's decision-making process is influenced by several factors depending on the added values to the contractor's company and its employees. Based on industry research findings, this section discusses such factors; both tangible and non-tangible, related to adopting the construction technology.

First, a significant purpose of contractors joining projects is **generating profit**. Accordingly, the capacity of construction technology in generating profit to the contractor affects its decision-making.

Second, the **size of the contractor** affects the investment decision in construction technology. The bigger the contractor is, the more projects executed and the higher the generated profit. Consequently, the higher the company's ability to sustain the construction technology investment costs and cushion the loss until technology starts to generate profit. Further, the bigger the contractor’s company is, the more likely the contractor is to invest in human capital to maintain longevity of the company’s know-how and safety edge in the market, even if such decisions do not generate near profits. It is crucial to note that the caliber and talent of contractor’s employees and their ability to learn and adapt to construction technology must be considered as part of the decision-making process.

Third, the **scale and nature of the project** plays a role in motivating the contractor to invest in construction technology. The riskier the project is, the more complex the project construction method statements are or the higher the contract price is; accordingly, the project size, the safer and more likely the contractor is to invest in construction technology since accidents could possibly be more frequent, fatal, and more expensive to remedy. Further, contractors may be more motivated to invest in construction technology for higher project scales than lower project scales as the impact of investment in construction technology does not significantly affect the profit generation from the higher project scales as it does to lower project scales.

Fourth, in the evolving construction industry nowadays, it has become more often that the **owners require the contractors** through the contracts to develop BIM for their projects. Such obligation is seen more likely in some governmental projects and projects that have investment structure from multilateral development banks. Accordingly, **the client type and required project criteria** play a role in the contractor’s decision to invest in construction technology.

Fifth and most humane of which, is the **moral obligation of the contractor towards their employees** in creating a healthy environment with lower fatigue levels and less human involvement to hazardous incidents. The improved on-site safety and relaxed working environment boost the confidence of workers in their employee and cause more undisturbed production cycles for the successful delivery of the project. In addition, this accounts to the corporate social responsibility in the form of corporate ethics in dealing with its employees.

Sixth, construction technology would have helped significantly in uninterrupting the construction production in times of the recent COVID-19 pandemic. Certain types of construction technology such as robotic fabrication, 3D printing and construction automation can continue working in times of epidemics, pandemics, hardship, natural disasters, and force majeure etc.… In general, the use of different types of construction technology might decrease the required optimum number of labor on-site and this would definitely improve dealing with **unforeseen events and catastrophes**.

Seventh, modern construction technology performs **alternative sustainable choices** to traditional construction practices and provide other benefits to the construction business over construction safety. Namely, BIM provides better design coordination between disciplines consequently saves any unneeded rework for better utilization for material, less waste and efficient profiteering from time and cost. VR training improves working skills for efficient labor involvement and reduced rework and provides sustainable alternative for eliminating commuting to training sessions; they can take place on-sites or wherever place requested by the contractor at whenever suitable time. Prefabricated and modular construction produce lower emissions than traditional construction controlled by the manufacturer in its factory and exhibit significant waste and energy reduction for reasons of mass production in prefabrication yards. Robotic fabrication, 3D printing and construction automation perform at highest precision standards, reduce human error, and can function with any sustainable form of material that might not be preferred by human labor. Finally, construction site IoT detect any leakage and control the environment in the most sustainable option as programmed for.

Finally, there are certain conditions that might oblige the contractor to adopt construction technology for the **successful delivery of the project**. Specific design criteria that need certain software for development, complex construction methods that cannot be done the traditional construction way, time restriction that need work performance at faster pace, time or quality standards that affect various progress factors, restricted site conditions that prevent on-site storage, harsh climate or under water environment, contract conditions and several other case by case factors can influence the contractor to adopt construction technology.

6.2 Contractor's Decision-Making Model

After several decision-making factors are discussed, a decision-making model is developed that bases the contractor's decision for adopting the construction technology on the concept of generating profit. The concept of this decision-making model is to compare the profit in case the construction technology is adopted to the profit without involving the construction technology.

To minimize the inputs to the model, the variables are not the factors themselves; profit, premium, etc.… rather are the differences (delta) between the factors before and after adopting the construction technology, such that; delta factor = new factor after construction technology – old factor before construction technology. Table 16 illustrates the mathematical symbols used in the model and their representation.

Table 16 List of mathematical symbols and their representation in the proposed decision-making model

Symbol	Representation
i	Construction technology type *i*
j	Accident type
N	Contract price
C	Contractor
I	Insurer
φ_{C}	Contractor's profit without using construction technology *i*
$\varphi_{i, C}$	Contractor's profit when using construction technology *i*
$\Delta\varphi_{i, C}$	Change in contractor's profit due to using construction technology $i = \varphi_{i, C} - \varphi_{C}$
$\Delta\varphi_{i, I}$	Change in insurer's profit due to using construction technology *i*
$\mu_{direct, i}$	Direct investment cost of construction technology *i*
$\Delta EV_{accidents, i}$	Change in expected value of accidents due to using construction technology *i*
υ_{i}	Cost savings due to using construction technology *i*
k	Premium without using construction technology *i*
k_i	Premium due to using construction technology *i*
p_j	Probability of accident j without using construction technology *i*
ARC_{j}	Average claim for accident j or Average for accident j remedial cost
$q_{C, j}$	Portion of ARC_{j} paid by contractor
$q_{I, j}$	Portion of ARC_{j} paid by insurer
S	Insurance policy deductibles
β_{max}	Insurance policy cap of liability = Insurance policy coverage limit
z_{i}	Percentage reduction in accidents due to using construction technology *i*
ε	Rate of insurance premium to contract price (per mil)

$\Delta \varepsilon_i$	Percentage reduction in rate of insurance premium ε due to using construction technology *i*

6.2.1 Calculating the Contractor's Change in Profit Due to Adopting Construction Technology

The change in contractor's profit due to adopting construction technology type "*i*" (later referred to as construction technology *i*) is affected by the initial and on-going investment cost for adopting construction technology *i*, the change in expected value of accidents due to adopting construction technology *i*, the change in premium due to adopting construction technology *i* and any cost savings due to adopting construction technology *i*. Cost savings might takes place if implementing the construction technology *i* causes increase in labor productivity, improved material handling, fitter learning curve or reduction in material loss etc.… as the case may be. Equation 2 illustrates the calculation for the change in contractor's profit due to adopting construction technology *i*. The three expenditure factors reduce the change in profit and the savings improve the change in profit.

Change in contractor's profit due to using construction technology *i*	=	−	Direct investment cost of construction technology *i*	−	Change in expected value of accidents due to using construction technology *i*	–	Change in premium due to using construction technology *i*	+ Cost savings due to using construction technology *i*

Equation 2 Change in contractor's profit due to using construction technology i

$$\Delta \varphi_{i,C} = -\mu_{direct,i} - \Delta EV_{accidents,i} - \Delta k_i + \upsilon_i \quad (2)$$

The investment cost for adopting construction technology *i*, and the cost savings due to adopting construction technology *i* are calculated by the contractor based on the needs, the construction technology, project conditions and market prices. If the construction technology is an asset to the company, then only the portion allocated to the project is the input to Equation 2. This can be calculated as the weighted average of the project relative to all projects in the company according to the project costs.

The change in the expected value of accidents due to adopting construction technology *i* is based on the percentage reduction in accidents due to using construction technology *i* and the expected value of accidents without using the construction technology *i* which is the probability of accident j without using construction technology *i* multiplied by the average accident j remedial cost as shown in Equation 3. Yet the average accident j remedial cost is not borne by the contractor only, which is the purpose of the insurance, Equation 4. In case the accident remedial cost is less than the insurance policy's cap of liability, the contractor pays the deductibles only and the insurance company pays for the remaining of the accident remedial cost as shown in Equation 5 and Equation 6 respectively. If the accident remedial cost is greater than the insurance policy's cap of liability, the insurance company pays until the insurance policy's cap of liability while the contractor pays the deductibles in addition to any costs beyond the insurance policy's cap of liability as shown in Equation 8 and Equation 7 respectively. Hence, the change in the expected value of accidents due to adopting construction technology *i* for the contractor is calculated using Equation 9 where the average accident j remedial cost of Equation 3 is replaced by the contractor's portion of payment for accident j remedial cost.

Change in expected value of accidents due to using construction technology *i*	=	Percentage reduction in accidents due to using construction technology *i*	*	Total expected insurance claims

Equation 3 Change in expected value of accidents due to using construction technology i

$$\Delta\ \text{EV}_{\text{accidents,i}} = -\text{z}_{\text{i}} * \sum_{j=1}^{\text{j}} p_j\ ARC_j \quad (3)$$

Average claim/ remedial cost for accident j	=	Portion of claim/ remedial cost for accident j paid by contractor	+	Portion of claim/ remedial cost for accident j paid by insurer

Equation 4 Average claim for accident j

$$ARC_j = q_{C,j} + q_{I,j} \tag{4}$$

If $ARC_j \leq \beta_{max}$,

Equation 5 Portion of remedial cost for accident j paid by contractor if ARC ≤ β_{max}.

$$q_{C,j} = S \tag{5}$$

Equation 6 Portion of remedial cost for accident j paid by insurer if ARC ≤ β_{max}.

$$q_{I,j} = ARC_j - S \tag{6}$$

If $ARC_j > \beta_{max}$,

Equation 7 Portion of remedial cost for accident j paid by contractor if ARC > β_{max}.

$$q_{C,j} = S + (ARC_j - \beta_{max}) \tag{7}$$

Equation 8 Portion of remedial cost for accident j paid by insurer if ARC > β_{max}.

$$q_{I,j} = \beta_{max} - S \tag{8}$$

Hence;

Equation 9 Change in expected value of accidents due to using construction technology i for contractor.

$$\Delta \text{ EV}_{\text{accidents,i}} \; for \; C = -\text{z}_{\text{ i}} * \sum_{j=1}^{\text{j}} p_j \, q_{C,j} \tag{9}$$

The change in premium due to adopting construction technology *i* is based on the percentage reduction in the premium before adopting construction technology *i* and the premium before adopting construction technology *i*. Insurance companies often offer premiums in terms of a rate of the contract price. Accordingly, as shown in Equation 10, the change in premium due to adopting construction technology *i* is a function of the contract price, the premium rate, and the percentage reduction in the premium.

$$\text{Change in premium due to using construction technology } i = \text{Premium due to using construction technology } i - \text{Premium without using construction technology } i$$

$$\Delta \mathrm{k}_{\mathrm{i}} = \mathrm{k}_{\mathrm{i}} - \mathrm{k}$$

$$\text{Premium without using construction technology } i = \text{Contract price} * \text{Rate of insurance premium to contract price (per mil)}$$

$$k = N\,\varepsilon$$

$$\text{Premium due to using construction technology } i = \text{Contract price} * \text{Rate of insurance premium to contract price (per mil)} * \text{Percentage reduction in rate of insurance premium due to using construction technology } i$$

$$\mathrm{k}_{\mathrm{i}} = N\,\varepsilon\,(1 - \Delta\varepsilon_{\mathrm{i}})$$

Hence;

$$\Delta \mathrm{k}_{\mathrm{i}} = N\,\varepsilon\,(1 - \Delta\varepsilon_{\mathrm{i}}) - N\,\varepsilon$$

$$\Delta \mathrm{k}_{\mathrm{i}} = N\,\varepsilon\,(1 - \Delta\varepsilon_{\mathrm{i}} - 1)$$

Equation 10 Change in premium due to using construction technology i

$$\Delta \mathrm{k}_{\mathrm{i}} = N\,\varepsilon\,(-\Delta\varepsilon_{\mathrm{i}}) \qquad (10)$$

6.2.2 Contractor’s Decision Based on Change in Profit

After calculating the contractor’s change in profit due to adopting construction technology i, such value is compared to zero. In other terms, the profit after adopting the construction technology *i* is compared to the profit without involving the construction technology *i*. Accordingly, the contractor’s decision is to adopt the construction technology *i* if the change in profit due to adopting construction technology *i* is greater than 0 and vice versa as demonstrated in Equation 11 and Equation 12 respectively.

Equation 11 Contractor's decision to "go for" construction technology i based on profit.

$$\text{If} \quad \Delta\, \varphi_{i,C} \geq 0 \quad , \qquad \text{Go for construction technology } i \qquad (11)$$

Equation 12 Contractor's decision to "not go for" construction technology i based on profit.

$$\text{If} \quad \Delta\, \varphi_{i,C} < 0 \quad , \qquad \text{Do not go for construction technology } i \qquad (12)$$

6.3 Financial Impact on Insurers

Now being done with the contractor's decision of adopting the construction technology or not, the insurer is left to the fate of such decision. Accordingly, the model extends to calculate the change in insurer's profit in case the contractor's decision was to adopt the construction technology.

6.3.1 Calculating the Insurer's Change in Profit Due to The Contractor Adopting Construction Technology

The change in profit due to adopting construction technology *i* for insurers is a function of the change in premium due to adopting construction technology *i* and the change in the expected value of accidents due to adopting construction technology *i* as shown in Equation 13.

The change in premium due to adopting construction technology *i* is a common factor between the contractor and the insurer and is represented by Equation 10 as a function of the contract price, the premium rate, and the percentage reduction in the premium.

While the change in the expected value of accidents due to adopting construction technology *i* for the insurer is calculated using Equation 14 where the average accident j remedial cost of Equation 3 is replaced by the insurer's portion of payment for accident j remedial cost previously discussed under Equation 6 and Equation 8.

$$\begin{array}{c} \text{Change in insurer's profit} \\ \text{due to using construction} \\ \text{technology } i \end{array} = \begin{array}{c} \text{Change in premium due} \\ \text{to using construction} \\ \text{technology } i \end{array} - \begin{array}{c} \text{Change in expected value of} \\ \text{accidents due to using} \\ \text{construction technology } i \end{array}$$

Equation 13 Change in insurer's profit due to using construction technology i

$$\Delta\ \varphi_{\mathrm{i,I}} = \Delta\ \mathrm{k}_{\mathrm{i}} - \Delta\ \mathrm{EV}_{\mathrm{accidents,i}} \qquad (13)$$

Equation 14 Change in expected value of accidents due to using construction technology i for insurer.

$$\Delta\ \mathrm{EV}_{\mathrm{accidents,i}}\ for\ I = -\mathrm{z}_{\mathrm{i}} * \sum_{j=1}^{\mathrm{j}} p_j\ q_{I,j} \qquad (14)$$

It is crucial to note that insurance companies do not necessarily generate profit from every project and that the concept of insurance is based on the theory of large numbers (Bunni 2003). Accordingly, the more projects the insurance company insures, the more premiums (income) paid and the less the impact of risks (expenses) is to the income received.

As mentioned in interviews, insurance companies generate profit from the reinvestment of premiums and reinsuring the risks. That is, exactly as contractors sell the risk to insurance companies in return of insurance premium, insurance companies resell a portion of the risk to reinsurers in return of a portion of the insurance premium. This applies the concept of a shared pool of risks. Accordingly, insurers only get paid part of the premium based on the insurer's agreement with the reinsurer and whenever a risk occurs, insurers only pay an equivalent part of the portion of ARC_j paid by insurer ($q_{I,j}$).

More conclusive to mention is that as previously analyzed and concluded in the quantitative research, for all construction technology, the reduction in accidents in percentage is greater than the reduction of premium in percentage as shown in Figure 33. Having an in-sight on Equation 13 and Equation 14, the change in the expected value of accidents due to using construction technology *i* is always a negative number, hence, the change in insurer's profit due to using construction technology *i* is the change in premium due to using construction technology *i* which is a negative number plus the absolute value of the change in the expected value of accidents due to using construction technology *i*. Since the percentage reduction in accidents is greater than the percentage reduction of premium, often likely there would be a generation of profit possibility. Finally, a negative value for the change in premium does not necessarily mean a loss, it might simply mean a reduction in profit.

6.4 The Cost Effectiveness of the Construction Technology

Since the change in premium due to adopting construction technology *i* is a common factor between the contractor and the insurer and is represented by Equation 10 as a function of the contract price, the premium rate, and the percentage reduction in the premium; Equation 2 and Equation 13 were added (or change in premium due to adopting construction technology *i* is equated between Equation 2 and Equation 13) to see the overall change in profit for both the insurer and the contractor together in any project adopting construction technology i in Equation 17.

Using Equation 2:

Equation 15 Change in premium due to using construction technology i

$$\Delta \mathrm{k}_{\mathrm{i}} = -\Delta \varphi_{\mathrm{i,C}} - \mu_{\mathrm{direct,i}} - \Delta \mathrm{EV}_{\mathrm{accidents,i}}\ for\ C + \upsilon_{\mathrm{i}} \tag{15}$$

Using Equation 13:

Equation 16 Change in premium due to using construction technology i

$$\Delta \mathrm{k}_{\mathrm{i}} = \Delta \varphi_{\mathrm{i,I}} + \Delta \mathrm{EV}_{\mathrm{accidents,i}}\ for\ I \tag{16}$$

Equating Equation 15 and Equation 16:

$$\Delta \varphi_{\mathrm{i,I}} + \Delta \mathrm{EV}_{\mathrm{accidents,i}}\ for\ I = -\Delta \varphi_{\mathrm{i,C}} - \mu_{\mathrm{direct,i}} - \Delta \mathrm{EV}_{\mathrm{accidents,i}}\ for\ C + \upsilon_{\mathrm{i}}$$

$$\Delta \varphi_{\mathrm{i,I}} + \Delta \varphi_{\mathrm{i,C}} = -\mu_{\mathrm{direct,i}} - \Delta \mathrm{EV}_{\mathrm{accidents,i}}\ for\ C + \upsilon_{\mathrm{i}} - \Delta \mathrm{EV}_{\mathrm{accidents,i}}\ for\ I$$

Equation 17 Change in profit due to using construction technology i

$$\Delta \varphi_{\mathrm{i}} = -\mu_{\mathrm{direct,i}} - \Delta \mathrm{EV}_{\mathrm{accidents,i}} + \upsilon_{\mathrm{i}} \tag{17}$$

The overall change in profit due to adopting construction technology *i* for the project entities assuming the project risks; insurer and contractor, is a function of the investment cost for adopting construction technology *i*, the change in expected value of accidents due to adopting construction technology *i*, and any cost savings due to adopting construction technology *i*. The contractor is responsible for the investment cost for adopting construction technology *i* and makes the benefit from the cost savings due to adopting construction technology *i* if any. While for the change in expected value of accidents due to adopting construction technology *i*, it is shared between both entities according to their contract (insurance policy) based on the deductibles and the insurer's cap of liability. The overall change in profit due to adopting construction technology *i* is inversely linear to the change in expected value of accidents due to adopting construction technology *i*. In all means, the change in expected value of accidents is a quantification for risk that possibly translates into profit for both parties if no accidents happen in the project. Finally, the insurer will only loose the mild change in premium for a significant decrease in the risk of paying for the accidents/ claims, while the contractor has its change in profit negatively affected by the investment cost of construction technology *i* in return of the change in premium, the savings from the construction technology *i* and the significant reduction in the risk of accidents and filing and paying for claims.

6.5 Case Study

6.5.1 Project Description

A 60-story high-rise project in the MENA region with a footprint area of 6500 m^2 and a height of 315 m is under construction by on one of the leading contractors in the MENA region. The contract is awarded for a contract price of $695,746,600 and a project duration of 4 years, while the estimated project cost is $665,246,950. The contractor does not implement any of the construction technology discussed in this research, except for minimal non-proficient use of 3D BIM. Table 17 shows the provided project data that will be used as input to the model.

Table 17 Case-study project details

Project Data	
Contract price (N)	$695,746,600
Expected project Cost (V)	$665,246,950
Expected profit (φ_C)	$30,499,650

When introduced to the construction technology, the contractor expects an investment cost of $196,704 for VR safety training for all full-time employees and daily based workers on-site for this project based on a service providing company's previous proposal. No study has been done for any expected cost savings due to providing the VR safety training for workers and employees and no savings are expected due to the VR safety training. Table 18 shows the provided construction technology data that will be used as input to the model.

Table 18 Case-study VR Safety training details

Construction Technology Data–- VR Safety Training	
Direct cost of Construction Technology *i* ($\mu_{direct, i}$)	$196,704
Cost savings due to using Construction Technology *i* (υ_i)	$0.00

According to the contractor's in-house recorded history of claims, the contractor majorly previously claimed for the accidents mentioned in Table 19. The contractor also provides the reason for each accident as elaborated in Table 19. The contractor mentions that there are no severe weather conditions or critical project surroundings that are to cause any additional risks. The contractor believes that any insurance claims to be reported for this project are highly expected to be due to the accidents previously recorded in the contractor's database and that such accidents are expected to account for the vast majority of claims with all other accidents with almost negligible probabilities of occurrence.

Table 19 Case-study contractor's previous accidents and cause for each accident

Accident	Cause of Accident
Loss of equipment/ machinery	Overloading a crane causing its collapse and complete replacement
Fire	Worker's negligence
Soil caving in on excavated areas with underground works	Design error in the retaining structure caused complete loss of the equipment and machinery in the collapsed zone
Collapse of part of a structure	Early overloading the structure before gaining its desired strength

The procured wrap-up insurance policy for that project has an insurance premium rate of 4‰ (0.4%) of the contract price as shown in Table 20. The wrap-up insurance policy provides several coverages such as Construction Equipment Insurance, Third Party Insurance, Automobile Liability Insurance, Worker's Compensation, Employer Liability Insurance, Marine Cargo Insurance and Construction and Erection All Risks Insurance for the construction and commissioning phases. Each of the coverages has its own limitation of liability, exclusions, and deductibles.

Accordingly, for the accidents expected by the contractor for this project, each accident is categorized by the contractor under its relevant policy and the related limitation of liability and deductibles are presented in Table 20.

Table 20 Case-study project insurance criteria

Insurance Policy			
Rate of insurance premium to contract price (per mil) ε = 4‰ = 0.40% = 0.004			
j	**Accident j Type**	**Policy Coverage Limit (β_{max})**	**Deductibles (each and every occurrence) (S)**
1	Loss of equipment/ machinery	$50,000	$0
2	Fire	unlimited	$100,000
3	Soil caving in on excavated areas with underground works	unlimited	$100,000
4	Collapse of part of the structure	unlimited	$100,000

The contractor is then asked to provide the probability of occurrence and average claim value for each of the expected accidents. The contractor provides such data as presented in Table 21 based on the risk assessment and evaluation for the project criteria, the contractor's history of recurrence for the recorded accidents relative to all the company's projects, in-house expertise, and the cost evaluation for the project BOQ items.

Table 21 Case-study probability of accidents and expected average impact.

j	Accident j Type	Probability of accident j without using construction technology *i* (p_j)	Expected average claim for accident j (ARC_j)
1	Loss of equipment/ machinery	15%	$55,000
2	Fire	30%	$5,000,000
3	Soil caving in on excavated areas with underground works	5%	$30,000,000
4	Collapse of part of the structure	0.10%	$100,000,000

6.5.2 Applying the Empirical Profit Prediction Decision-Making Model

All input data required for implementing the model is provided by the contractor except for the expected reduction in accidents and expected reduction in premium that are provided by the quantitative research results. Such data is presented in Table 22 based on Figure 33 and for the expected reduction in premium, it is based on the premium reduction calculated from the accident reduction using Equation 1 previously discussed in Chapter 3.

Table 22 Case-study input from the research findings (See Chapter 5)

Expected reduction in accidents	28%
Expected reduction in premium **(Calculated from Equation 1 based on accident reduction:** $\Delta\,\varepsilon = -1.406\,z^3 + 1.4322\,z^2 - 0.0582\,z + 0.0501$; **Condition:** $0.05 \leq z \leq 0.65$**)**	11%

Table 23 Case-study calculation for expected average accident remedial cost

	Contractor Input				**Solution**			
#	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
j	p_j **(%)**	ARC_j **($)**	β_{max} **($)**	**S ($)**	$q_{C,j}$ **($)**	$p_j * q_{C,j}$ **($)**	$q_{I,j}$ **($)**	$p_j * q_{I,j}$ **($)**
1	15	55,000	50,000	0	5,000	750	50,000	7,500
2	30	5,000,000	∞	100,000	100,000	30,000	4,900,000	1,470,000
3	5	30,000,000	∞	100,000	100,000	5,000	29,900,000	1,495,000
4	0.10	100,000,000	∞	100,000	100,000	100	99,900,000	99,900
Sum						35,850		3,072,400

Solution steps for calculating the contractor's change in profit due to adopting construction technology and building up contractor's decision.

Step 1: Calculate the change in expected value of accidents due to using construction technology *i*

a) Calculate the portion of accident j remedial cost paid by contractor using Equation 5 and Equation 7. Results presented in Column 5 of Table 23: For j=1, the ARC_j is greater than β_{max} so any value beyond the β_{max} will be paid by the contractor; Equation 7 applies. For j=2, 3 and 4, Equation 5 applies.

b) Calculate the change in expected value of accidents due to using construction technology *i* for contractor using Equation 9 as presented in Column 6 of Table 23: Δ EV $_{\text{accidents},i}\,for\,C = -28\%$ * \$35,850 = −\$9,893.

Step 2: Calculate the change in premium due to using construction technology *i* using Equation 10: Δ k = \$695,746,600 * 4‰ * −11% = −\$316,047

Step 3: Calculate the change in contractor's profit due to using construction technology *i* using Equation 2:

$\Delta \varphi_{i,C}$ = −\$196,704 − (−\$9,893) − (−\$316,047) + 0.00 = \$129,236

Contractor is likely generating more profit in this case (as the change in profit is positive) so no need to complete the next step. It is just done for the sake of having a complete solution manual.

Step 4: Compare the contractor's change in profit due to using construction technology *i* to the profit without using construction technology using Equation 11 and Equation 12:

$$\Delta\varphi_{i,\,C} \geq 0$$

$$\$129{,}236 \geq 0$$

Therefore; Go for VR Safety Training

Solution steps for calculating the insurer's change in profit due to the contractor adopting construction technology.

Step 1: Calculate the change in expected value of accidents due to using construction technology *i*

a) Calculate the portion of accident j remedial cost paid by insurer using Equation 6 and Equation 8. Results presented in Column 7 of Table 23: For j=1, the ARC_j is greater than β_{max} so any value beyond the β_{max} will be paid by the contractor; Equation 8 applies. For j=2, 3 and 4, Equation 6 applies.
b) Calculate the change in expected value of accidents due to using construction technology *i* for insurer using Equation 14 as presented in Column 8 of Table 23: Δ EV $_{accidents,i}$ $for\ I$ $= -$28% * \$3,072,400 = −\$847,897.

Step 2: Calculate the change in insurer's profit due to using construction technology *i* using Equation 13:

$\Delta \varphi_{i,I}$ = −\$316,047 – (−\$847,897) = \$531,849

Insurer is likely to generate more profit in this case as the change in profit is positive.

Solution steps for calculating the overall change in profit.

The overall change in profit for the contractor and insurer can be calculated using either:

1- The summation of the change in profit for the contractor and the change in profit for the insurer

$\Delta\ \varphi_{\ i} = \Delta\ \varphi_{\ i,C} + \Delta\ \varphi_{\ i,I} = \$129{,}236 + \$531{,}849 = \$661{,}086$

2- Using Equation 17 that includes the direct investment cost of construction technology *i*, the change in expected value of accidents due to using construction technology *i* for both the contractor and insurer and the cost savings due to using construction technology *i*.

$\Delta\ \varphi_{\ i} = -\$196{,}704\ - [(-\$9{,}893) + (-\$847{,}897)] + 0 = \$661{,}086$

In this case, both the contractor and insurer are generating profit so the net change in profit is positive. This indicates that adopting VR safety training is likely to generate profit to both; the contractor and the insurer, since the cost for the expected reduction in accidents decreases accounting to savings for both; the contractor and the insurer. Hence, adopting VR safety training for this project proves itself in terms of cost efficiency of the construction technology.

6.5.3 Empirical Profit Prediction Model Verification Using the Case Study

The concept of verifying the empirical profit prediction model used below is based on calculating the project revenues, the project costs and profit before and after implementing the VR safety training then comparing the difference of such values before and after to the results from the model. Accordingly, the premium and the expected value of accidents before implementing the VR safety training are considered part of the project cost provided by the contractor. Hence, the project cost without such two items is the base project cost that will be added to the new expected reduced premium and the new expected value of accidents to calculate the new project profit for the contractor.

Table 24 shows the values of the factors before and after adopting virtual reality safety training. The difference between such values is then placed next to the model values. As seen in Table 24, the output from the model for each factor is exactly equal to the difference between the corresponding factories before and after adopting VR safety training. In this case the contractor is generating profit because the investment cost of VR safety training is covered by the reduction in premium more than it is by the expected value of accidents. Accordingly, the reduction in premium could be the number one cause for the contractor generating profit from adopting the VR safety training.

Table 24 Case-study contractor's factors before and after adopting construction technology compared to model results.

Contractor				
Factor	**After adopting VR safety training**	**Before adopting VR safety training**	**Difference due to adopting VR safety training**	**Model values (As calculated above)**
Investment cost of VR safety training	$196,704	$0	$196,704	$196,704
Premium	$2,466,939	$2,782,986	($316,047)	($316,047)
Project cost without premium and expected value of accidents	$662,428,113	$662,428,113	$0	-
Expected value of accidents	$25,956	$35,850	($9,893)	($9,893)
Total cost	$665,117,713	$665,246,950	($129,236)	-
Savings due to VR safety training	$0	$0	$0	$0
Total profit	$30,628,886	$30,499,650	$129,236	$129,236
	Model values are equal to the difference due to adopting technology values. Accordingly, the model is mathematically verified.			

Same concept is applied for the insurer where is the premium and the expected value of accidents that resemble the project risks are calculated before and after implementing the virtual reality safety training. Based on such concept, the profit before and after implementing the virtual reality safety training is calculated. Finally, the difference between the premium, the expected value of accidents and the insurer's profit before and after are compared to the values from the model. Table 25 shows that the model values are exactly equal to the difference of corresponding factors before and after adopting VR safety training.

Table 25 shows that the insurer has a greater possibility of having a loss from the project if VR safety training is not applied. Due to the contractor adopting VR safety training, this construction technology causes significant reduction in accidents that significantly decreases the expected value of accidents followed by lower reduction in premium. Such significant decrease in the project risks accompanied by a reduction in premium shifts the insurer from the probability of having a loss to a probability of generating a profit. In this case study, VR safety training acts for the benefit of both the contractor and the insurer.

Table 25 Case-study insurer's factors before and after adopting construction technology compared to model results.

Insurer				
Factor	**After adopting VR safety training**	**Before adopting VR safety training**	**Difference due to adopting VR safety training**	**Model values (As calculated above)**
Premium	$2,466,939	$2,782,986	($316,047)	($316,047)
EV	$2,224,502	$3,072,400	($847,897)	($847,897)
Profit	$242,436	($289,413)	$531,849	$531,849
	Model values are equal to the difference due to adopting technology values. Accordingly, the model is mathematically verified.			

6.5.4 Empirical Profit Prediction Model Validation Using Project Expert's Perception Regarding the Case Study

To validate the proposed empirical decision-making profit prediction model, the project manager, the construction manager, and the safety officer for the project are contacted and informed about the previous findings.

The experts are asked to rate the model on a scale of 1 to 5 (5 being most effective) for its:

- ease of application
- confidence, adequacy, and reliability of results
- possible adoption for the project
- possible adoption within the company's decision-making process for upcoming projects

Table 26 presents the number of experts choosing each scaled rating for the factors tested during validating the model. Depending on the experts' response and a following discussion:

- Experts highly believe that the model input variables are basic measures already available within the construction company or at most not expensive to attain.
- All three experts reflect that the empirical profit prediction for decision-making model will provide valid results and is reliable a tool for deciding whether or not to apply the construction technology in a profitable manner.
- Experts do not recommend the model application to the case-studied project as the insurance policies already exist. However, experts confirmed that such model could have been a game-changer if it existed prior to procuring the insurance policy given that there is a guarantee for a consequent premium reduction due to VR safety training. Especially that, the company's safety personnel are concerned about the technology and receiving proposals for VR safety training from service providers.
- All three experts recommend implementing the empirical decision-making profit prediction model for upcoming projects to decide on adopting construction technology for its various benefits with precise quantification for the expected profit.
- Experts are concerned that insurance companies will not reduce premiums except until the technology is widely consumed, and historical records start to reflect on the statistical models for premium pricing. Until then, the term "Change in premium due to using construction technology i (Δk_i)" needs to be deleted from the empirical profit prediction for decision-making model.

Table 26 Number of experts rating the factors tested during model validation

Factor/ Rate	1	2	3	4	5
Ease of application	-	-	-	1	2
Reliability of results	-	-	-	-	3
Possible adoption for the project	3	-	-	-	-
Possible adoption for future projects	-	-	-	1	2

Given the above expert validation, the model is claimed to be a valid, efficient, and applicable decision-making tool for contractors to adopt construction technology or not for a specific project based on the expected project profit.

6.5.5 Case Study Conclusion and Recommendation

The contractor is more likely generating more profit since its change in profit is $129,236. The investment cost of VR safety training is fully covered by the reduction in premium not by the reduction in expected value of accidents. The reduction in the expected value of accidents is minimal for the contractor with respect to the insurer since the insurer pays for the vast portion of the claims. Accordingly, the reduction in premium is the main factor for the contractor to generate profit from adopting the VR safety training.

The insurer has a greater possibility of having a loss from the project if VR safety training is not applied. Set aside resorting to the theory of large numbers and the reinvestment of premiums, since the insurer pays for the vast portion of the claims, the fact that the ratio of the probability of accidents reduction on-site to premium reduction is drastically high made the insurer more likely to generate profit than loss for a change in profit of $531,849. Such ratio exists in business from the contractor adopting the VR safety training.

Given the above, VR safety training acts for the benefit of both the contractor and the insurer. For this case study, the contractor is highly recommended to invest in the VR safety training for the benefit of the company and the by-product benefit of the insurer. VR safety training generates more profit from the project since the reduction in accidents and the reduction in premium way exceed the cost of applying the technology. It is a win-win-win situation; a win for the contractor, a win for the insurer and a win for the project effective and sustainable expenditure.

Chapter 7. Conclusion

7.1 Summary and Conclusion

The construction sector is among the most dangerous industries and is under continuous R&D searching for technological solutions for on-site safety enhancement that function since the design phase and throughout the construction phase of the project. Such construction technology discussed in literature and considered in this research are:

1. Building Information Modeling (BIM)
2. Virtual Reality (VR) safety training
3. Prefabricated and Modular Construction
4. Robotic Fabrication, 3D Printing and Construction Automation
5. Construction Site IoT (Internet of Things)

The level of advancement and utilization for each construction technology varies but sooner or later, construction technology will function in full capacity.

While insurance is the trade of business risks for a premium, and that insurance plays a significant role for contractors' risk coverage, the insurance industry is not modernized enough to service provide the evolution in the construction technology in terms of premium evaluation and policies adjustment.

Regarding the premium evaluation, literature widely discusses factors of influence on the premium, yet no quantification for the contribution of each to the premium evaluation due to the confidentiality of actuarial models utilized by the insurance companies and based on historical business records. While for the policies adjustment, minimal research exists to fully cover such topic.

This research is conducted in two phases; an industry research to understand the interaction between insurance and construction industries, the governing factors that affect insurance premiums, insurance industry responsiveness to construction technology and to prepare for the second research phase which is a quantitative survey conducted by 57 CC and IB experts to classify the insurance premium indicators according to their significance in insurance premium estimation and quantify the impact of construction technology on accident reduction and premium reduction.

While there are different factors affecting insurance premium, they are classified into project risk factors, project parties' risk factors, and insurer risk factors. Almost all factors have moderate to high impact on insurance premiums, such being reinforced by industry research claiming that neither a piece of information does not influence the insurance premium estimation. Among the factors of a high impact on insurance premiums are the project criteria, nature and complexities, safety and hazard management policies, safety technology used on-site, and any factor directly related to site conditions. Other factors of moderate impact are more concerned by the contractual obligation between parties. All the safety practices from any party and the historical record of claims are those that account for the higher contribution to premium estimation over the other factors related to contractors' size or experience or other factors of similar nature. Insurance market competition is of recognizable impact on the insurance premium.

Regarding the different construction project types, the size of insurance claims and the frequency of filing insurance claims simultaneously decrease from tunneling construction to high-rise construction to road and bridge construction and least for residential & commercial buildings construction. Accordingly, it is advised to adopt construction technology in the same above order of project types.

The general concept is that the safer the project is, the less expected claims and value for such claims are, thus the lower the premiums will be. The premium depends on the distribution of risk within the project and the other project, parties' and insurance market factors previously discussed, and often ranges between 0.3‰ (0.03%) to 1.5‰ (0.15%), however exceptionally it might reach up to 5‰ (0.5%) for severely critical projects. The risk increases by the end of the project, yet the premium rate is a fixed rate throughout the project duration. Whenever the risk in a project gets higher, the premium increases and the insurer profit margin for that project also increases. Needless to mention that negotiation is an effective tool for tuning the premium, with its range of estimating the risks and market factors, for both party's satisfaction. An insurance broker could be of help in supporting the contractor's procurement for an insurance policy for an attractive deal for the premium rate, policy coverages and exclusions, limitation of liability, and deductibles from several insurance companies.

The percentage reduction in premium is provided in three measures; calculated from accident reduction for each construction technology, expected premium reduction by IB for each construction technology, and deserved premium reduction as estimated by CC. Having the first as the least value and the most reliable since each party CC and IB made its professional evaluation and judgment regarding its field of expertise; CC for the evaluation of the impact of construction technology on accident reduction and IB for the evaluation of the impact of accident reduction on insurance premiums. Based on gathered data, an equation was derived to describe the relationship between the percentage reduction in accidents and the percentage reduction in insurance premium. In addition, Kendal's tau b test was applied where it indicated a strong relationship between the reduction in accidents and the reduction in insurance premium.

Conclusively, the percentage accident reduction and respective premium reduction for each construction technology are presented in Table 27. It is concluded that the reduction in accidents and premium decrease in the order of construction technology presented in Table 27.

Table 27 Concluded percentage reduction and premium reduction for each construction technology

Technology	Accident Reduction	Premium Reduction Calculated from the Derived Accident Reduction Empirical Equation
Robotic Fabrication, 3D Printing and Automated Construction	44%	18%
Construction Site IoT	42%	17%
Prefabricated and Modular Construction	31%	13%
Virtual Reality Safety Training	28%	11%
Building Information Modelling (BIM)	15%	7%

The industry research concluded that if the construction technology is a new prototype, the insurance premium will be very high at first until history builds up for the construction technology that helps for statistical evaluation for the premium and the drawback of construction technology appear. Except when the construction technology is related to the supervision of work, such as construction site IoT, there will be instantaneous significant reduction in premiums since the hazard is predictable and controllable at an early stage. Undoubtedly if the construction technology improves the on-site safety, premiums will decrease, however another benefit for the contractor might be a reduction in the deductibles. Briefly, construction technology will reduce project risks and accordingly insurance premiums, it is just a matter of time.

Regarding the insurance policies adjustment, new policies emerge to support the risks from the adoption of construction technology. Namely, for BIM, policies need to cover for the virtual models' developed level of detail, authorized users to viewing, editing, deleting, executing, and operating the models, in addition to the accounting for errors that develop in the model; similar to professional indemnity insurance but for 3D, 4D, 5D, 6D, 7D and 8D models to account for both design and software errors. While for robotic fabrication, 3D printing and automated construction, the electronic equipment policy shall be adapted to cover for such equipment tailored to the equipment needs. In parallel, older policies such as coverage of the loss of paper are outdated. Finally, cyber liability insurance policy is needed to cover against cybersecurity breaches.

Other risks and limitations reaped from the use of construction technology include cyber security breaches, technological unemployment, safety prospects of labor working next to automated equipment, need for highly experienced safety officers, need for labor with specialized training and expertise to supervise and control the construction technology, untrained workmanship dealing with construction technology, mass training for workers, resistance to change by aged labor, IT storage capacity, technological management for the construction technology, the resistance to change by aged labor and sometimes the higher managerial level for the contractor, need for higher capacity cranes, need to resort to subcontractor service providers to safely manage the construction technology on-site, adaptation for the safety management plans, risk transfer to transportation and/or manufacturing facilities, creating suitable storage environment for minimal quality deterioration of prefabricated elements or modules, high initial investment costs for robotics or 3D printers, and confidence of users of IoT that their personal privacy is not invaded.

Finally, several factors influencing the contractor's decision in adopting construction technology are presented; such as profit, the size of the contractor, the scale, nature and complexity of projects, contractual obligation for using construction technology reinforced by owner requirement, moral obligation of the contractor towards its employees, support in cases of force majeure, and sustainability of construction technology. Further, a decision-making model is proposed to guide contractors in the worth of investment in the construction technology based on the expected change in profit from the change in premium due to using construction technology, direct investment cost of construction technology, change in expected value of accidents due to using construction technology and cost savings due to using construction technology. The model also calculates the financial impact on the insurers provided that they insure projects adopting construction technology and the overall cost efficiency from adopting construction technology within the project. An illustrative case study from an actual construction project is implemented for the developed decision-making model for verification and validation.

7.2 Limitations and Recommendations for Future Research

The limitations of the study and respective proposed recommendations for future research are:

1. In depth study for the terms and conditions of the new insurance policies required to cover for the additional risks of construction technology is suggested for future research.
2. In depth study for the terms and conditions of the construction contracts for the benefits and risks in relation to construction technology adoption is suggested for future research. In case of BIM, AIA and ICE contracts insurance clauses are already developed for reference.
3. The empirical profit prediction decision making model does not consider the contribution of reinsurers; the portion of premium taken by the reinsurers and the portion of claimed costs paid by reinsurers and is recommended for study by future research to represent the actual financial impact on insurers from the adoption of construction technology.
4. This research classified project types according to the size and frequency of insurance claims. It is recommended for future research to identify which technology suits each project type.
5. Identifying the minimum extent of adopting construction technology that still provides significant reduction in accidents and insurance premiums.
6. Identifying the effect on accident reduction and premium reduction if construction technologies are adopted simultaneously.

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