Construction Accident Factors That Can Be Addressed During the Design Phase

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DECLARATION

I declare that the work contained in this thesis is my own original work, Sources where knowledge, concept or ideas were adopted from have been properly cited and referenced

ABSTRACT

The construction industry experiences accidents at alarmingly high rates, recording the highest fatality rate and the second-highest injury rate among all UK industries as of 2023. Substantial efforts have been directed towards reducing accidents and improving safety. A critical focus is the design phase of construction projects, which holds significant potential to reduce accidents in subsequent phases. This study aimed to identify factors leading to construction accidents that can be moderated during the design phase and the extent of designer influence over these causes. A quantitative survey and qualitative interviews were conducted with construction industry participants worldwide. A total of 298 participants from 46 countries responded to the survey, and six engaged in qualitative interviews. The findings identified five causal variables of accidents that designers can influence during the design phase: the permanent structure, temporary structure, building equipment, building materials, and site environment. However, Qualitative findings further reveal that designers do not exert equal influence over these areas. They have the strongest influence on the permanent structure and building materials, moderate influence on the temporary structure and site environment, and the least influence on building equipment. Content analysis revealed weaknesses in Construction Hazard Prevention through Design (CHPtD) methods and identified eleven challenges faced by designers. These include insufficient consideration of the project's full life cycle, limited involvement of other stakeholders in design decisions, and inadequate site experience and safety knowledge among designers -all of which hinder effective CHPtD implementation-. The findings underscore the critical role of designers in mitigating construction hazards and highlight the need for targeted interventions to enhance their impact on accident prevention. This study contributes to the field by identifying five key variables and illustrating the degree of influence designers have on each. These insights could improve training for designers on site-specific safety considerations and promote collaboration among stakeholders, making CHPtD more effective, ultimately reducing construction-related accidents and improving overall industry safety.

List OF ABBREVIATIONS

ACoP	Approved Code of Practice
AIChE	American Institute of Chemical Engineering (USA)
BIM	Building Information Modelling
CHPtD	Construction Hazard Prevention through Design
HVAC	Heat Ventilation and Air condition
COMAH	Control of Major Accidents hazards regulation 2015 (UK)
COMAH Site	Worksites fall within the COMAH regulation criteria
CCPS	Central for Chemical Process Safety (USA)
CDM	Construction (Design and Management) Regulations
EP	Emergency Plan
EVT	Event Tree Analysis
FMEA	Failure Mode and Effect analysis
FTA	Fall Tree Analysis
GIS	Geographical Information System is
HSE	Health and Safety Executive
HSL	Health and Safety Laboratory
HAZOP	Hazard and Operability study
ISD	Inherent Safety Design

ISD-H	Inherent Safety Design- Hazard
ISD-R	Inherent Safety Design-Risk
ISD-CO	Inherent Safety Design-Cost
LOPA	Layers Of Protection analysis
MOC	Management of Change
NEBOSH	National Examination board of Safety and Health (UK)
OSHA	Occupational Safety and Health administration
PHA	Process Hazard Analysis
P&ID	Piping and Instruments Diagram
PS	Process safety
PSM	Process safety management
SOP	Standard Operation Procedures
SME	Small and Medium enterprise
What-if	Type of process safety method

MEANINGS AND DEFINITIONS

This part is necessary to understand the meanings of the terminology in the current thesis, most of which are the same meanings or definitions used by the regulator or those common amongst field professionals.

Accident: unplanned undesired event that leads to injury or property damage.

Adverse event: an undesired event which occurs as a result of interaction between a person/s or thing and a hazard.

ACoP: Approved Code of Practice—a document issued by HSE (the regulator) to explain how to implement specific health and safety regulation.

BIM: Building Information Modelling—design software which is expected, in the near future, to be the main design and management software for building projects owing to its substantial advantages and potential

CHPtD: Construction Hazard Prevention through Design is a method aimed at eliminating construction hazards from the design stage of the project before any construction work begins.

CDM: Construction (Design and Management) Regulations are regulations issued by HSE for the construction industry, with which building projects in the UK should comply.

Designer: In the current study this term means a person who prepares or modifies a design in relation to structure, product, mechanical or electrical systems. This definition includes architects, engineers and any constructors carrying out design work.

GIS: The Geographical Information System is a business information system that helps to capture, analyse and present information on a map. The GIS utilises geography to aid us in making better decisions.

HSE: In this study HSE means Health and Safety Executive, the UK regulator authority in the field of health and safety. The HSE issues H&S regulation, standards and guidance.

Process safety: Process safety is a discipline framework dealing with the integrity of operations systems and processes that handle hazardous substances. Process safety deals with the events that have the potential to cause accidents during the lifecycle of the chemical manufacturing process.

Hazard: Anything that has the potential to cause harm.

Incident: An unplanned undesired event that leads, or could lead, to injury or property damage.

Near misses: An unplanned undesired event that did not lead to injury or property damage but might have done if the circumstances had been slightly different.

OSHA codes: These refer to the health and safety regulation in USA.

SOP: This means Standard Operation Procedures, equivalent to the method statement in the construction field. It can also be termed safety standard procedures.

Unsafe action: An act or neglect from a person/s that could lead to an accident.

Unsafe condition: Unsafe tools, equipment, machines, vehicles or work environments that could lead to an accident.

Five whys: This is a method of analysis, used mainly in accident investigation, designed to reveal immediate, underlying and root causes of the accidents.

Fishbone: A method of analysis, used mainly in accident investigations, where the analysis diagram resembles a fishbone to present accident causes.

Root cause analysis: A method of analysis used mainly in accident investigations and in process safety to reveal the root causes.

4P's: Used during risk assessment methods to consider People, Place, Plant and Procedures.

Immediate causes: The causes which directly lead to the accident which, the majority of the time, will be unsafe acts or unsafe conditions, or both.

Underlay causes: The causes that lead to the direct causes of the accident (underlying).

Root causes: The origin of the causes and the bottom cause which leads to the underlying and to the immediate causes of the accidents.

CHAPTER 1: Introduction

1.1 Background

Construction ranks among the most hazardous industries worldwide (Fang et al., 2015; Fang & Wu, 2013; Al-Humaidi & Tan, 2010; Ikpe et al., 2012; Wanberg et al., 2013), even in countries like the UK where comprehensive regulatory practices are established. Recent official accident data reveal that the UK construction industry recorded the highest fatality rate for the period spanning 2022–2023, accounting for over 33% of occupational deaths. It also ranks second for non-fatal injuries, with an annual average of 59,000 reported injuries (HSE statistics: 2019/2020 to 2021/2022). Several factors contribute to this high accident rate. Construction is a labour-intensive industry (Dainty et al., 2004) that relies on large equipment, vehicles (Gransberg et al., 2006), and extremely heavy materials (Alkhadim, 2018). Additionally, construction site layouts and activities change daily (Le, 2019), and pressures such as deadlines, budgets (Challal & Tkiouat, 2012), and adverse weather conditions are common (Senouce & Mubarak, 2014). These conditions expose construction teams to numerous hazards that can lead to accidents. Reducing these incidents requires all stakeholders to prioritise safety throughout each project phase.

Authorities, academics, industry bodies, and safety professionals have dedicated substantial efforts to reducing accidents in the construction sector, with particular focus on the design phase of projects. Decisions made early in a project's lifecycle can significantly impact later stages (Basbagill et al., 2013; Jack, 2009). Research over the past three decades indicates that between 42% and 51% of accidents could have been prevented if alternative decisions had been made during the design phase (Behm, 2005). Consequently, authorities in advanced countries such as the UK, the EU, Singapore, and Australia have introduced legal obligations for designers to consider safety during the design phase. To support this, designers are encouraged to adopt Construction Hazard Prevention through Design (CHPtD) or Design for Safety approaches, as exemplified in the UK's CDM 2015 regulations.

1.2 Justification of the research

In the construction industry, safety guidance, policies, and procedures are typically implemented during and after construction rather than in the design phase, with many countries not requiring designers to consider safety at this stage. Furthermore, it remains unclear which types of accident causes can be influenced during the design phase. Designers are often unaware of which accident causes could be addressed at this stage and the extent of their influence over these causes.

Recent studies in the field of CHPtD, including those by Cortes-Perez et al. (2020), Li et al. (2020), Yuan et al. (2019), and Rodrigues et al. (2018), have focused on utilising information technology (IT) to inform designers of potential building hazards and to suggest safer alternatives. Whilst integrating IT and Building Information Modelling (BIM) is a positive step, understanding which accident causes and associated hazards need consideration is crucial. This knowledge enables designers to focus their efforts on areas within their influence and avoid wasting time on causes beyond their control during the design phase.

Additionally, with both DfS and CHPtD widely recognised as frameworks for integrating safety into construction design phase to proactively prevent accidents, this research supports these frameworks by demonstrating that issues faced by designers are global, not limited to specific countries or regions. Moreover, the study illustrate how various countries has different legality toward DfS implementation, this research is expected to benefit academics and professionals by providing clear guidance on which types of accident causes should be prioritised during the design phase. Furthermore, the study seeks to enhance DfS & CHPtD training.

1.3 Aim and objectives

The aim of this research is to investigate construction accidents causes that has potential to be addressed during the design phase, while critically assessing the role and influence of designers in shaping safer construction outcomes.

The objectives of this thesis are as follows:

1. Undertake a literature review of relevant articles, legal requirements, and construction accident reports to reveal construction accidents' causes that can be influenced during the design phase.
2. Undertake a content analysis to determine the strengths and weaknesses of the current CHPtD methods.
3. Undertake semi-structured interviews and questionnaires with designers and building professionals to verify the accident causes that can be influenced during the design phase. And how far designers could influence each.

1.4 Scope of the research

The scope of this research is confined to health and safety issues in construction, specifically focusing on accident causes that can be influenced during the design phase. The study investigates the challenges faced by designers in this phase, without restricting its attention to a particular geographical area. Participants in the research come from 46 different countries, emphasising the global relevance of the challenges faced by construction designers in ensuring safety throughout the entirety of the construction project lifecycle. When exploring construction health and safety regulations, guidance, and standards, as well as process safety regulations, guidance, and standards have been reviewed. However, the thesis primarily relies on UK and USA regulations, considering them as leading benchmarks in the field of health and safety worldwide. Additionally, the thesis utilises UK occupational accident records to compare the construction industry with the record of other UK industries.

CHAPTER 2: Literature review

2.1 Construction accident causes

2.1.1 General accident causes

2.1.1.1 Accident definitions

Hollinagle (2016) defined an accident as a "short sudden and unexpected event or occurrence that results into unwanted and undesirable outcome", whilst the National Safety Council (2021) defined an accident as "An unexpected, unintended event that may cause harm to people, property, and the environment".

Additionally, US and UK regulators define accidents in a way similar to that employed by the aforementioned researchers. Indeed, the US regulator in the health and safety field, namely OSHA (2022), defined an accident as "An unplanned event or sequence of events that results in an injury, illness, damage to property, or other loss". Further, British regulator Health and Safety Executive (HSE, 2013) defined the term as "An unintended event that results in physical harm or damage to health". Based on these definitions, it can be said that an accident is an event which has the following characteristics: it is unwanted and undesired, it appears suddenly or unexpectedly, and the outcome of the accident is negative or harmful, be it injury, damage to property, or both.

2.1.1.2 Investigation into the techniques used to reveal the causes of accidents

Various accident investigation techniques exist internationally, each tailored to a specific type of accident, with the primary aim of revealing the causes behind the occurrence of accidents. During accident investigations, investigators conduct analyses to expose the immediate, underlying, and root causes. Despite the multitude of techniques available, two of the most common methods are the "five whys" and "fishbone" techniques. It is worth noting that certain process safety techniques also serve as accident investigation tools. These includes but not limited to Fault Tree Analysis, Root Cause Analysis, and Failure Mode and Effect Analysis and bow-tie.

2.1.1.2.1 Five Whys

According to Hugh and Ferret (2011), Leino and Helfenstein (2012), and Gangidi (2018), the five whys analysis is a technique used in accident investigations to reveal immediate, underlying, and root causes of accidents. It is a top-down diagram in which the investigators start from the accident event, asking ‘why’ it occurred. They identify causes—referred to as 'immediate causes’—of the accident based on gathered evidence. Subsequently, by asking ‘why’ again (the 2nd why layer), they uncover the reasons behind the existence of these ‘immediate causes’. This second layer of causes is termed ‘underlying causes’. Further ‘whys’ are then asked for each underlying cause, delving one layer further in depth. Generally, it takes more or less five 'whys' to reach the bottom causes, which are termed ‘root causes’. According to the HSE, in its guidance HSG-245 (2004), seven common root causes contribute to workplace accidents; these include lack of supervision, poor design, lack of competency, poor communications, poor controls, lack of cooperation, and poor implementation. It is worth mentioning that the answer to each 'why' during the implementation of this technique should be supported by evidence.

2.1.1.2.2 Fishbone

The fishbone diagram is a method of analysis which was primarily created as a problem-solving technique for the quality control field. The inventor, Ishikawa (1982), developed this analysis technique with the purpose of revealing the root causes that lead to a problem. The technique employs a diagram resembling a fishbone, where the fish head represents the problem (or the accident), and the fishbone signifies the causes leading to this problem. Generally, the fishbone analysis considers six factors: people, materials, machines, processes, measurement, and environment. These six factors form the main bones in the diagram, with the investigator categorising the causes under one of these factors. By the end of the analysis, the investigator has a diagram that demonstrates all the causes of the problem, categorised under the relevant factor.

Since its invention, the fishbone technique has spread widely across other fields and industries, including accident investigation. Each field or industry determines the factors used to create the main bones of the fish(see Figure 4). The Fishbone technique is also known by different names, such as the cause-and-effect diagram and the Ishikawa diagram.

Fishbone diagram

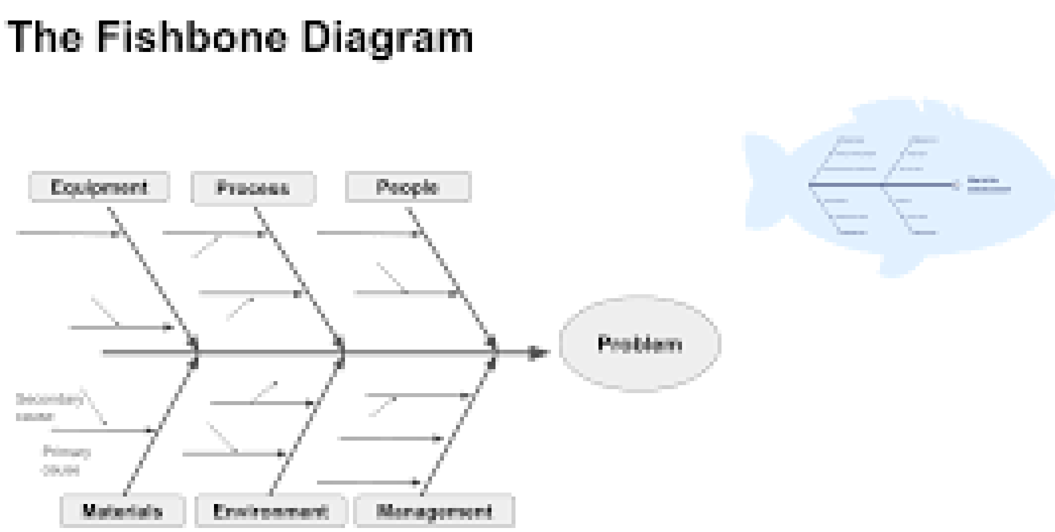


Figure 1 fishbone diagram

2.1.1.3 Types of accident causes

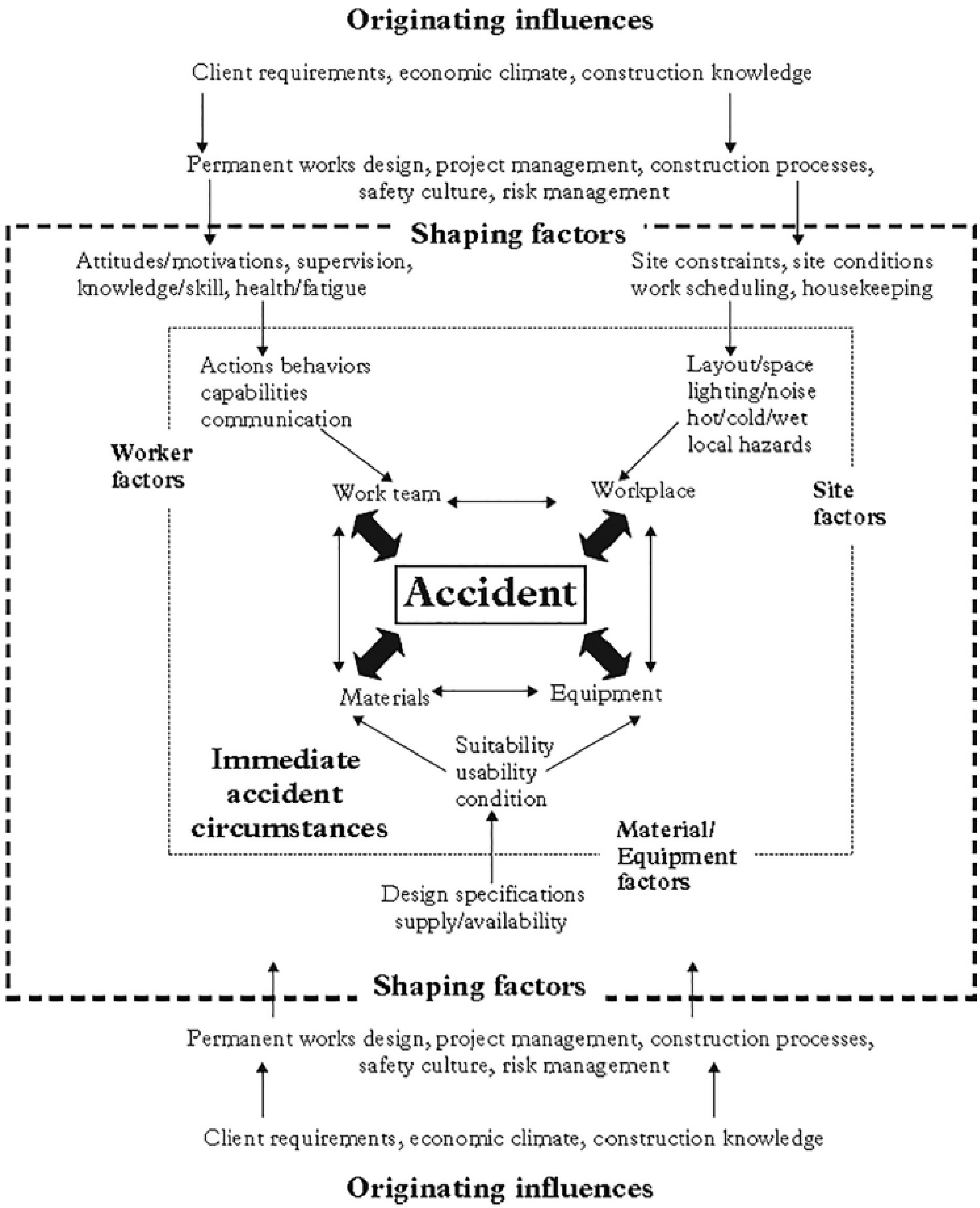
In the careful process of investigating accidents, it is evident that there are three main types of causes—namely immediate causes, underlying causes, and root causes—as outlined by the HSE (2004). Immediate causes, for example, include a range of factors that directly and immediately affect accidents. These factors can take different forms, such as actions or errors by staff, contractors, management, or visitors, or unsafe conditions such as faulty equipment, poor site layout, insufficient or wrong materials, or various combinations of these. Conversely, underlying causes are factors which are already in existence before accidents and create conditions for immediate causes to lead to accidents. These underlying causes might include systemic issues within organisations or deficiencies in safety procedures, which, whilst not directly causing accidents, significantly increase the chances of them occurring. Root causes, however, go even deeper into the chain of causation, representing the fundamental origin of the causes. For instance, a lack of comprehensive safety training at all levels within an organisation could lead to misinterpretations of safety guidelines and ultimately unsafe practices on-site. These root causes are the ultimate factors that give rise to underlying causes, which then lead to the immediate causes of accidents (Figure 3). According to the HSE (2004) more than 90% of accident root causes will come from one or more of the following seven root causes: Competency, Design, Co-operation, Supervision, Control, Communication and Risk assessment.

2.1.2 Accident causes in construction

Globally, the construction industry suffers from a high accident rate, even in well-regulated countries. For example, with regard to the UK—acknowledged as a global leader in health and safety, as validated by its statistical record—recent data sourced from the HSE underscores that its construction sector reported the highest fatality rate, constituting over 33% of occupational deaths during the period spanning 2022-2023. Additionally, the UK occupies the second position for non-fatal injuries, with an annual average of 59,000 reported injuries (HSE statistics: 2019/2020 and statistics: 2021/2022).

Safety concern within the construction field encompasses multifaceted and intricate conditions, characterised by diverse causal factors contributing to workplace accidents. A review of existing literature reveals the complexity of these causes. There exist comprehensive research studies in the field conducted to support the understanding of accidents and their causes. For instance, a study conducted by Hale et al. (2012) scrutinised 26 fatal construction accidents in the UK spanning from 2006 to 2008, revealing 61 underlying causes, including: busy phases, poor supervision, lack of availability of equipment, lack of competency, poor planning, hazardous materials, overload etc. Indeed, such causes demonstrate the difficulty around management of safety issues within the construction industry. Saraji et al. (2001) conducted a study that identified accident causes such as poor planning of construction work, safety plan, design of temporary structure, suitability of access and egress, lack of safety facilities, lack of safety components (such as guardrails, barriers and platform), and defective services (such as electricity) as causes of construction accidents on the site. Moreover, Hide et al. (2003) identified causes such as suitability of equipment, permanent building component work design, project management, suitability of building materials and site layout. Further, Manu et al. (2012) concluded that construction accident causes originate in the project's nature, design complexity and site restrictions (a full list of accident causes identified by these four studies can be found in Appendix 8). Similarly, researchers such as Behm (2005), Driscoll et al. (2008), Gambatese and Hinze (1999) and Gibb et al. (2001) have delved into construction accident causes, generating findings that converge on similar causes. Additionally, the UK regulator (HSE) conducted, in 2003, a comprehensive study in collaboration with the Loughborough and UMIST universities to systematically explore the influences, factors, and causes contributing to construction accidents. It took into consideration all causes identified by previous studies, and ended in the development of an explanation model (Figure 5) illustrating, in detail, influences that create factors which in return create accident causes. A closer review of this model reveals four key area, namely staff competency and behaviour; management, communications and stakeholders; space, work condition and environment; and design, equipment and material.

The following sections (2.1.2.1 to 2.1.2.4) will cover the four above-mentioned areas to explore causes of construction accidents within these domains, and indeed outside of such domains.



HSE, 2003, Causal factors in construction accidents, RR156, p.59

Figure 2 ConAc accident causations

2.1.2.1 Construction staff competency and behaviour

According to Wybo and Van Wassenhove (2016), a significant proportion of workplace accidents result from human error. Various studies on construction accidents corroborate this, with a lack of competency identified as a primary cause of human error (Chang, Chen, & Wu, 2012; Fang et al., 2018; Mazlan, Osman, & Saud, 2019). Furthermore, Feng et al. (2015) proved that there exists a positive correlation between competence and accident rates.

Dubis (1998) itemised the components that constitute competency, defining it as “the knowledge, skills, attitudes, and values that are necessary to successfully perform a particular activity or task”. In the safety field, the HSE expanded on Dubis's clarification, stating that competency involves “the combination of training, skills, experience, and knowledge that a person possesses and their ability to apply them to perform a task safely”. The HSE (2020) emphasised that a worker may perform a task effectively, but the crucial aspect is whether they do so safely to prevent accidents which could affect themselves and others on site. A lack of competency, defined by the HSE as “the ability to perform a task safely”, is a significant contributor to many on-site construction accidents.

To enhance competency amongst construction workers and managers, safety education should be integrated into the construction education syllabus (Wybo & Van Wassenhove, 2016). In both the USA and the UK, competency-based education (CBE) strategies, incorporating different education levels (basic, competent, advanced, and expert), aim to improve the safety competence of construction staff.

In addition to competency, Aguinis and Glavas (2013) stressed the importance of behaviour change programmes and how crucial they are for preventing accidents. Recognising the importance of not only possessing skills but also applying them consistently, the authors further explained that organisations must focus on fostering a positive safety culture. Embedding behavioural change initiatives in the workplace is essential when it comes to encouraging workers to adopt safe practices and adhere to safety protocols.

Moreover, improving safety culture is paramount, as highlighted by Guldenmund (2000), in preventing accidents. A positive safety culture creates an environment where safety is a shared value, influencing every aspect of work. Organisations should strive to instil a mindset that prioritises safety, encouraging employees to take responsibility for their actions and contribute to the collective effort in accident prevention. This cultural shift is integral to achieving sustained improvements in workplace safety.

2.1.2.2 Management, stakeholders and communication

Wing et al. (2019) identified eight management factors which affect safety performance in construction, namely roles and responsibilities; project management; learning; health and safety management and integration; the safety climate; site management; operative risk management; and staff management. Wing et al. stressed that the last three factors need to be present if the construction project wishes to achieve high safety performance. When looking closely at those three factors, it is clear that the person who manages safety, in most projects, is the supervisor or 'foreman'.

Moreover, according to various authors, site safety in construction is often delegated from upper-level management to supervisors, who are dealing with daily tasks on site (Hinze and Gordon, 1979; Mohamed, 2002; Swuste et al., 2012). In supporting the importance of the supervisor's role in safety, Lingard et al. (2012) found that supervisors have a greater impact on site safety compared to the top management.

However, many causes of accidents are related to management decisions upstream (Behm, 2005, p.1), where supervisors have little impact. For example, issues such as selecting subcontractors, budgets, procurement of materials, selection of machines or equipment, numbers and competencies of staff on site, and allocating roles and responsibilities etc. are normally decided by higher managers (project managers, site managers, engineers etc.) or by project owner(s). The aforementioned emphasises the importance of communication between all stakeholders in the project. Nevertheless, there exist numerous definitions of construction team communication. Tai et al. (2009) defined it as a process where project teams exchange information and interlink with each other to achieve project objectives. A project involves various teams which are interdependent from each other in completing the project, with a delay in one team potentially stopping other teams. Moreover, without effective communication, many conflicts, unnecessary costs, or time overruns will occur (Wu, 2017).

In relation to safety and accidents, communication is one of the key areas that should be managed effectively; indeed, CDM2015, and previously CDM2007, both recognised the importance of communication. Therefore, the HSE (the health and safety regulator in the UK) makes it mandatory to have good and effective communication between all project teams (all project stakeholders including the project owner) so as to exchange information and cooperate in matters related to health and safety issues.

This study intends to examine how CHPtD can benefit from good communication to eliminate and reduce hazards in the design phase, especially since there are many new and innovative communication technologies that can help to enhance and improve communication between project stakeholders, such as virtual reality, laser scanning, BIM, communication software, and applications.

2.1.2.3 Work condition and environment

The construction site presents some of the most difficult working conditions and is one of the most dangerous environments (Tunji-Olayeni, 2018), potentially leading to many safety issues and health problems. The aforementioned is due to the many challenges that come together to create such harsh working conditions, all of which are detailed below:

Workspace: many projects in big cities have limited available space, and so, in order to construct the building, the constructors need to bring in and move various vehicles and heavy plant, unload and store building materials, lift and position components, and process and handle building materials. Indeed, limited space makes all of these tasks difficult and raises the likelihood of accidents occurring.

Different levels: from deep underground to hundreds of metres above ground level, construction staff need to work at different levels that expose them to the risk of falls from height—one of the main causes of fatalities in the construction industry (Cooke et al., 2008).

Temporary services: poor connection of electricity/water needed during construction could lead to electric shocks and death (Floyd, 2008).

Welfare and hygiene: lack of or poor welfare facilities such as toilets, showers, eating and resting rooms etc. leads to discomfort, food poisoning and diseases related to poor hygiene (Health and Safety Commission, 1992).

Environment: varying temperatures, rain, dust, mud, poor lighting, high noise levels, aggressive wind and generator/vehicle fumes are common conditions on a construction site. These conditions could lead to frostbite, sunburn, slips and trips, asthma, falls, loss of hearing ability, falls from height, and breathing irritation accordingly (HSE, 2015).

Temporary structures: most construction projects use temporary structures such as scaffolding, supporting beams or sheets, ladders, hoists, elevators and temporary stairs, all of which can collapse for various reasons and lead to accidents on site (HSE, 2014).

2.1.2.4 Equipment, material, and design

Type and condition of equipment, material or design could lead to accidents in construction; below are details on why and how each could be a cause of an accident.

Equipment: construction machines, equipment and vehicles come in different shapes and sizes to help to process, install, move, lift or construct certain components of a building. Such equipment, machines or vehicles generate powerful mechanical force by using electricity or fuel. Staff working with them or near them are exposed to many types of hazards that could lead to death or severe injuries.

The HSE (2013) has detailed these types of mechanical hazards, which include crushing by heavy moving vehicles/machine parts, shearing from rotating parts, cutting from sharp parts, puncturing, frictions, electric shock…etc. Therefore, rigorous control and advance task planning are required.

Material: construction materials vary in size, shape and weight, each with its own chemical and physical properties. Normally, designers select the building material, but challenges arise over in which form (size, shape and weight) the selected material will be delivered to the site, as well as the processing of those materials, ensuring they are in the correct place on the building, and installing them. All of these activities in handling materials expose staff to many hazards that could lead to serious accidents. Lingard (2015) stated that designers focus on end product (she is referring to the building) and not on how the product is being built (she is referring to the handling of material and equipment to construct the building). Hughes and Ferrett (2012) detailed some examples of material hazards, such as chemical burns (from cement), musculoskeletal problems (from handling heavy materials), respiratory diseases (from silica dust, heavy metal dust and welding fumes), a fall from height, crushed by falling heavy objects (e.g. metal beams, glass), and dermatitis (from solvents, cement, glass wool). In addition, the risks from building materials extend beyond the construction phase; for example, some materials are difficult to extinguish in the event of a fire outbreak (e.g. from exterior cladding). The latent fire risk of such material will also be present throughout the occupation, maintenance and demolition phases, rather than just during the construction phase (Chen et al., 2019).

Design: the design of the building could also be hazardous to the constructor, maintenance and demolition teams, potentially exposing them to unnecessary risk. For example, glasses that cannot open from inside will force cleaners to hang for many hours at height, which could lead to fatal falls, as well as small narrow spaces for ventilation ducts, thus forcing installers and maintenance teams to adopt an awkward body position, which could lead to musculoskeletal injuries (Pertula et al., 2003).

2.1.3 Construction accidents and decisions during design phase

In relation to health and safety issues relevant to this study, first, a search was undertaken to identify issues that lead to accidents in construction. The second stage involved filtering the evidence to select only issues that designers can influence during the design phase.

There exist major studies which have focused on identifying accidents and their causes in the construction industry, with those causes having already been described in previous sections (2.1,2.1–2.1.2.4).

However, authors who support the CHPtD concept have proven their point regarding the importance of decisions during the design phase and have already undertaken research pertaining to previous accident causes which, in their view, could be influenced during the design phase. Below are listed some examples of those studies:

Gibb and Haslam (2004) investigated 100 accidents in the UK construction sector, concluding that 47% of those accidents could have been avoided or reduced by the designer's decisions. Further, Behm (2005) investigated 224 fatal accidents in the USA, finding that 42% could have been eliminated or reduced if designers considered safety during the design phase. Driscoll et al. (2008) subsequently studied 210 fatal accidents in Australia and found that 37% were definitely related to design issues and another 14% also had some connection with design. In addition, Hale et al. (2012) examined 26 cases of fatal construction accidents in the UK between 2006 and 2008 and identified 61 causes of accidents.

Further to this, the HSE (2003) investigated 100 accidents and determined their causes, influences and factors (illustrated in Section 2.1), subsequently proposing five questions to determine whether designers can influence these factors, as follows:

1. Is the health and safety issue related to equipment, machinery or plant?
2. Is the health and safety issue related to the site layout or space?
3. Is the health and safety issue related to the size, shape, weight, or properties of any building materials?
4. Is the health and safety issue related to temporary structures?

5. Is the health and safety issue related to permanent structures?

These questions give a hint as to what type of health and safety issues can be influenced during the design phase.

Analysis of these five questions, together with the review of accident causes detailed in Section 2.1, Appendix 9 and the review of construction (design and management) regulation 2015, reveals that designers may have the potential to impact unsafe conditions, but have no influence upon unsafe actions. This is also logic, because during the design phase no work is conducted on the site until the designs are completed, hence the unsafe behaviour(actions) exhibited by staff and management in the later phase, upon which the designer has no influence. Based on this logic, accident causes (in Appendix 9) have been filtered to distinguish between accident causes originating from unsafe acts (behaviour) and accident causes based on unsafe conditions. These unsafe conditions have also been categorised into five key areas (Table 1), namely Permanent structure, Temporary structure, building machines/equipment/vehicles, Building material and building site environment.

Table 1 accident causes that can be influenced during design phase

Source	Health and safety issues associated with construction accidents that can be influenced by designers	Category
1	Permanent work design	**Permanent structure**
3	Project features/project nature	
3	Design complexity	
3	Level of constructions	
4	Building design	
4	Ventilation, AC or heat design	
4	Available space for maintenance	
4	Car park and exterior space	
4	Landscape, paths and walk away layout and design	
1	Site layout and space	**Temporary structure**
1	Work environment—lighting on site	
2	Temporary structure	
2	Work platform and guardrail	

2	Site access and egress	
3	Site restriction	
4	Site welfare facilities	
1	Suitability of equipment	**Machines, equipment, vehicles or plant**
1	Usability of equipment	
2	Control of plant, equipment	
2	Working tools or instrument	
4	Vehicle or plant's positioning	
4	Selecting plant, vehicles, equipment and machines	
1	Suitability of material	**Building Material**
1	Usability of material	
4	Fire risk of interior and exterior material	
4	Prefabricated building material	

Sources in above table: **1:** Hide et al., 2003, **2:** Suraji et al., 2001, **3:** Manu et al., 2012, **4:** HSE, CDM2015

Note* for the full list of accident causes (whether or not related to design phase) identified by the above studies, see Appendix 9

The potential of designers to influence the above five key areas will be examined in this study by conducting quantitative and qualitative research.

2.1.4 Construction accident causes summary

This section reviews literature to explores accident definitions and illuminates the diverse types of accident causes, as well as techniques for investigating them. Subsequently, it narrows its focus to construction-related accident causes, such as causes related to: the competency of construction staff, management, stakeholders, and communication; design, material, and equipment; work conditions, and site environment. The chapter meticulously examines these causes to distinguish which has the potential to be influenced during the design phase, identifying five key areas: permanent structure, temporary structure, building material, equipment, and site environment. These crucial areas will undergo thorough examination in this thesis using a blend of quantitative and qualitative research methodologies.

2.2 Design for safety

2.2.1 Definitions of DfS and CHPtD in Construction

Design for Safety (DfS) and Construction Hazard Prevention through Design (CHPtD) are two frameworks developed to address safety risks proactively in construction, aiming to reduce the industry's historically high rates of accidents and fatalities. Both frameworks emphasise the importance of integrating safety considerations into the design phase of construction projects. According to the National Institute for Occupational Safety and Health (NIOSH, 2025) The U.S.-specific term Prevention through Design (PtD) is also used to describe similar practices, particularly within the National Institute for Occupational Safety and Health (NIOSH) initiatives (reference?).

DfS generally refers to the incorporation of safety measures during the initial stages of design to mitigate risks on-site. This approach has roots in several industrial sectors but has become increasingly significant in construction as designers are encouraged to embed safety principles to minimise physical hazards. In the UK, DfS principles are codified in the Construction (Design and Management) Regulations

(CDM) 2015, where the responsibility for anticipating and addressing risks in the design phase is explicitly mandated (HSE, 2023). According to Manu et al. (2022), DfS requires that designers prioritise hazard elimination in all stages, from the choice of materials to structural design, and anticipate future construction and maintenance hazards.

CHPtD, by contrast, is more commonly referenced in the U.S. construction context and involves a broader concept of hazard prevention that applies not only to designers but to a wider array of project stakeholders. CHPtD has been promoted by NIOSH under the PtD initiative, which focuses on eliminating hazards as early as possible in project planning. Although PtD is not legally enforced in the United States, it provides a framework for voluntary safety practices that aim to influence the broader culture of design safety. Umeokafor et al. (2023) note that DfS encourages collaboration between designers, contractors, and safety managers, establishing a shared responsibility for on-site safety and making hazard prevention an integrated part of the entire construction lifecycle.

The overlap between DfS and CHPtD is significant, with both frameworks focusing on hazard identification and proactive risk mitigation. In countries like Singapore and the UK, regulatory frameworks mandate designers to consider safety, aligning more closely with DfS principles. In contrast, the U.S. relies on industry driven PtD guidelines, meaning safety integration is encouraged rather than enforced, as highlighted by Manu et al. (2022). Both DfS and CHPtD will be reviewed in separate sections, as each concept is used individually in various studies, and certain details found in one may be absent in the other.

2.2.2 Introduction to Design for Safety (DfS)

Design for Safety (DfS) has been recognised under various terminologies across different regions, reflecting its widespread relevance. Commonly referred to as "Safety in Design" (SiD) or "Design for Occupational Safety and Health" (DfOSH), these frameworks share the common objective of prioritising workers' health and safety by designing out risks where possible. Research has consistently highlighted DfS's role in transforming construction safety culture, moving from reactive to preventive measures that place safety responsibilities on designers, rather than relegating these solely to contractors (Manuele, 2008; Che Ibrahim et al., 2022).The DfS framework has garnered international support, with many countries, particularly in Europe, mandating DfS practices through legislation. The UK's Construction (Design and Management) Regulations 2015 (CDM 2015) exemplify such regulatory advances, establishing a "duty of care" for designers to proactively address potential construction hazards (HSE, 2023). Other nations, including Singapore and Australia, have integrated DfS principles into occupational health and safety legislation, underscoring DfS as a means to improve safety performance and promote a safety-conscious design culture (Gibb et al., 2006; Manu et al., 2022)

2.2.3The Rationale for DfS

The justification for implementing DfS in construction is multifaceted. Studies by Behm (2005) and Schulte et al. (2008) suggest that up to 42% of construction fatalities could have been prevented had DfS measures been applied at the design stage. This statistic underscores the potential impact of DfS on saving lives and preventing injuries. By anticipating hazards in the design phase, designers can significantly reduce the need for safety interventions during construction, thus reducing the risk exposure of workers on-site. Moreover, DfS aligns with sustainable safety practices, promoting not only immediate risk reduction but also lifecycle safety improvements (Manu et al., 2024; Acheampong et al., 2024).

2.2.4 DfS Implementation in Construction

The integration of Design for Safety (DfS) practices varies significantly across different geographic, regulatory, and industry contexts. Analysing insights from recent literature reveals a range of perspectives on how DfS is perceived, implemented, and regulated in the construction sector. These perspectives underscore a growing recognition of DfS's value yet highlight inconsistencies in adoption and practice.

2.2.4.1 Implementation in Developed Regions

Authors such as Manu and Che Ibrahim (2022) highlight how developed countries with established regulatory frameworks, such as the United Kingdom and Australia, have integrated DfS effectively due to strong legislative support. In the UK, for instance, the Construction (Design and Management) Regulations 2015 (CDM 2015) mandate that designers prioritise safety in their projects, leading to systematic adoption of DfS (HSE, 2023). Similarly, Australian construction practices benefit from the Work Health and Safety Act, which requires safety considerations during the design phase, further fostering a culture where safety is embedded from project inception (Lingard et al., 2021).

Authors Acheampong et al. (2024) and Gibb et al. (2006) note that in these settings, DfS is not only a compliance requirement but is increasingly valued as a competitive advantage in the construction industry. Companies integrating DfS are often seen as proactive and forward-thinking, which enhances their reputation and attracts clients who prioritize worker welfare and regulatory compliance(Manu Ghana 2024). Studies of companies in these regions reveal that DfS adoption is driven by both regulatory pressure and organisational safety culture, resulting in standardised processes for risk assessment, hazard identification, and safety integration throughout the design phase (Che Ibrahim et al., 2020; Gibb et al., 2006)

2.2.4.2 Perspectives in Developing Regions

In contrast, developing countries face challenges that often hinder DfS implementation. Research by Manu and Acheampong (2024) on Ghana's construction sector illustrates how resource constraints, limited regulatory enforcement, and varying levels of safety awareness create significant barriers to DfS adoption. Ghanaian firms, according to Acheampong et al. (2024), frequently lack the financial resources and trained personnel necessary to incorporate DfS principles effectively, resulting in a predominantly reactive approach to safety that prioritizes hazard management during, rather than before, construction (Manu et.al., 2024)

Similarly, studies in Nigeria and Kuwait indicate that while awareness of DfS is increasing, the lack of mandatory regulations or government support limits widespread adoption. In Kuwait, Nasser et al. (2024) describe how DfS principles are viewed as desirable but optional, with only a few companies incorporating these practices due to limited incentives and an absence of clear enforcement guidelines. Nigerian research by Manu and Umeokafor (2023) shows that safety culture in the region is still developing, and DfS adoption remains limited to larger projects where international contractors impose safety standards (Umeokafor et al., 2023).

However, a distinct difference between academic perspectives on DfS and its application in professional practice emerges in the literature. Che Ibrahim and Manu (2022) discuss how academic frameworks for DfS are often thorough and theoretically sound but sometimes impractical or challenging for real-world implementation, particularly in developing regions where resource and knowledge constraints are pronounced. This discrepancy is partly attributed to a gap between academic research and practical application, where complex safety models developed in academia may be too resource-intensive or difficult to apply within budget-constrained construction firms (Che Ibrahim et al., 2022). Furthermore, there is evidence of a knowledge gap between academic understanding and practical application even within developed regions. Research from Palestine reveals that while Palestinian construction professionals are increasingly exposed to DfS through academic and international influences, challenges in translating this knowledge into practice persist due to limited industry-standard models and insufficient training programmes (Manu et al., 2020) . This insight highlights the need for practical, accessible DfS frameworks that bridge theoretical understanding and real-world application.

2.2.5 Gaps in DfS Knowledge and Practice

The reviewed literature highlights several gaps in both DfS research and its practical implementation, revealing areas where further exploration and adaptation are needed to fully integrate DfS across various construction environments. These gaps exist primarily in the realms of regulatory alignment, empirical data, industry training, and the adaptation of DfS practices for specific regional contexts.

2.2.5.1 Lack of Comprehensive Empirical Data

A significant gap in DfS research is the lack of extensive empirical studies that assess DfS effectiveness across a broad range of construction environments. Manu and Acheampong (2024) point out that while DfS studies from developed countries are well-documented, there is limited quantitative data from developing regions, where construction environments often differ significantly. This limitation creates an incomplete understanding of how DfS performs under varied socioeconomic and regulatory conditions (Acheampong et al., 2024). Additionally, without robust data on DfS's effectiveness across diverse project types, stakeholders may be less motivated to adopt these practices, as they lack evidence of DfS's cost-effectiveness and impact on safety outcomes in their specific contexts (Che Ibrahim and Belayutham, 2020)

2.2.5.2 Insufficient Regional Adaptations of DfS Frameworks

The predominance of DfS models based on Western regulatory systems, particularly in countries like the UK and Australia, has led to a gap in regionally adapted frameworks that suit the unique needs of developing countries. Research by Nasser et al. (2024) emphasizes the importance of tailoring DfS principles to align with the local regulatory, cultural, and economic conditions, especially in countries like Kuwait where Western safety models may be less effective. They suggest that a lack of regional adaptation restricts DfS applicability, as local firms may find Western models too costly or complex to implement effectively (Nasser et al., 2024).

In Nigeria, Umeokafor and Manu (2023) similarly note that while international construction firms may adopt DfS as part of their global standards, local contractors face challenges in implementing these practices due to financial limitations and a lack of culturally relevant frameworks. This gap indicates the need for simplified, cost-effective DfS models that can be adapted for resource-limited environments (Umeokafor et al., 2023).

2.2.5.3 Deficiency in Industry-Specific Training Programmes

Another critical gap in DfS practice is the lack of specialised training programmes that equip designers with safety knowledge specific to construction. Manu and Che Ibrahim (2022) argue that traditional design education often excludes comprehensive safety training, resulting in a workforce that is inadequately prepared to implement DfS principles effectively. While universities and professional bodies have increasingly incorporated DfS into construction-related curricula, the coverage remains inconsistent, especially in developing countries where educational resources may be limited (Manu et al., 2020; Che Ibrahim et al., 2022).

The literature suggests that closing this gap requires coordinated efforts to develop accessible training programmes, ideally embedded in both academic and professional settings. Acheampong et al. (2024) highlight that such training programmes should be tailored to the skill levels and resources available within the local industry, providing a practical and cost-effective approach to DfS education in emerging markets (Manu, Acheampong and Umeokafor, 2024).

2.2.5.4Limited Studies on Lifecycle Integration

Despite the emphasis on safety during construction, the literature reveals a lack of studies on how DfS principles could be applied across the entire lifecycle of a project. Current frameworks often overlook post-construction phases, including maintenance and demolition, which are critical for comprehensive hazard prevention. Manu and Acheampong (2024) highlight that lifecycle safety, while acknowledged in theory, is rarely implemented in practice due to limited guidelines and industry standards that address these later stages comprehensively. This oversight results in gaps where potential hazards are not addressed beyond the construction phase, posing long-term safety risks to maintenance and demolition crews (Acheampong et al., 2024).

2.2.5.5 Underrepresentation of Critical Industry Sectors

Some studies indicate that DfS research and applications are predominantly focused on high-profile sectors like infrastructure and large commercial projects, often neglecting smaller, less-regulated sectors, such as residential construction. This gap is significant, as smaller projects frequently have fewer safety controls and are less likely to adopt advanced safety practices due to limited resources. The underrepresentation of these sectors in DfS research and practice perpetuates a safety gap, as smaller firms may lack the guidance and resources to adopt DfS effectively (Umeokafor et al., 2023).

2.2.6 Challenges and Barriers to DfS

2.2.6.1 Regulatory and Compliance Challenges

One of the most significant challenges to the widespread adoption of DfS is the disparity in regulatory requirements and compliance standards across regions. Manu and Acheampong (2024) highlight how DfS is more robustly implemented in countries with clear regulatory mandates, such as the Construction (Design and Management) Regulations 2015 (CDM 2015) in the UK. These regulations compel designers to account for safety during the design phase, supported by structured compliance frameworks. However, in regions without regulatory mandates, such as parts of Africa and the Middle East, DfS adoption remains inconsistent due to the absence of enforceable safety standards (Acheampong et al., 2024; Umeokafor et al., 2023; Nasser et al., 2024).

Umeokafor and Manu (2023) discuss how the lack of regulatory support in developing countries like Nigeria leads to a safety culture that is primarily reactive. In these environments, construction firms may only implement safety measures when required by project contracts, often with international clients. As a result, DfS remains underutilised, as local firms are not incentivised or required to incorporate preventive safety strategies into their designs (Umeokafor et al., 2023).

2.2.6.2 Financial Constraints

Financial limitations present another major barrier to DfS, particularly in resource-constrained settings. Studies from Ghana and Nigeria reveal that many firms view DfS as an additional cost rather than an investment, which discourages adoption among smaller companies with limited budgets (Acheampong et al., 2024; Umeokafor et al., 2023). This perception persists even in developed regions where

DfS is mandated, as implementing DfS often requires hiring safety consultants, conducting detailed risk assessments, and potentially redesigning elements to address identified hazards. Manu and Che Ibrahim (2022) note that while large firms are generally more capable of absorbing these costs, smaller enterprises in both developed and developing regions struggle to justify the upfront expenses associated with DfS. The lack of accessible financial incentives, such as tax breaks or grants, further exacerbates this issue, particularly in developing countries where construction budgets are already constrained (Che Ibrahim et al., 2022).

2.2.6.3 Cultural Resistance and Industry Attitudes

Cultural resistance and entrenched attitudes within the construction industry pose significant barriers to DfS adoption. Manu et al. (2020) and Acheampong et al. (2024) observe that in many developing regions, the construction industry often adheres to traditional practices where safety is viewed as a contractor responsibility rather than an aspect of design. This resistance is compounded by the perception that safety interventions are reactive measures best addressed on-site, rather than during the design phase (Acheampong et al., 2024).

In Nigeria, for example, Umeokafor and colleagues (2023) found that local firms were reluctant to implement DfS principles, viewing them as an imposition of foreign standards rather than an integral part of their operational practices. In such settings, DfS adoption is hindered not only by regulatory gaps but also by a mindset that prioritizes immediate cost savings and project timelines over long-term safety considerations (Umeokafor et al., 2023).

2.2.6.4 Lack of DfS Knowledge and Training

Insufficient DfS training among designers and project managers is a recurrent barrier highlighted in the literature. Manu and Che Ibrahim (2022) emphasize that construction professionals, especially in developing regions, often lack the technical expertise to identify and mitigate hazards during the design phase. Traditional design education typically does not incorporate DfS principles, leaving a knowledge gap among practicing designers who are unprepared to integrate safety proactively into their work (Che Ibrahim et al., 2022).

Acheampong et al. (2024) argue that without industry-specific training programmes, designers are less likely to adopt DfS principles effectively, as they may lack both awareness and practical skills. This training deficit is particularly problematic in regions without professional development programmes, where safety is often only briefly covered in broader construction curricula. Closing this gap would require comprehensive training initiatives aimed at both academic and professional levels (Acheampong et al., 2024)

2.2.6.5 Legal and Liability Concerns

Legal liability issues present another challenge to DfS implementation, particularly in countries where designers are cautious of assuming additional risks. In the United States, where DfS is often voluntary under the Prevention through Design (PtD) initiative, designers express concern that implementing safety interventions could expose them to liability if accidents occur during construction (Schulte et al., 2008). Manu and Acheampong (2024) further note that without clear legal protections, designers may avoid DfS to prevent any risk of legal repercussions. This concern is also relevant in developing countries where legal frameworks are underdeveloped, and designers lack protection if safety issues arise on-site due to design interventions (Acheampong et al., 2024).

2.2.6.Communication Gaps and Collaboration Challenges

The literature highlights the importance of collaboration between designers, contractors, and safety professionals for effective DfS implementation. However, communication gaps frequently arise, particularly on projects involving multiple subcontractors or international stakeholders. Manu and Che Ibrahim (2022) note that without structured communication channels, essential safety information may be overlooked or lost during project handovers, weakening the DfS process. This issue is exacerbated in complex projects where safety responsibilities are diffused across numerous stakeholders, making consistent DfS application challenging (Che Ibrahim et al., 2022)

2.2.7 Limitation and Criticisms of DfS application

While DfS is widely endorsed for its preventive safety potential, some authors argue that its practical application is limited, particularly in resource-constrained environments. Manu and Acheampong (2024) highlight that while DfS frameworks are effective in high-budget projects with regulatory backing, they may be challenging to implement in regions with limited safety infrastructure and financial resources. In developing countries, where construction practices are often informal and lack robust regulatory oversight, enforcing DfS is seen as an idealistic goal that may be out of reach for smaller firms (Acheampong et al., 2024).

Furthermore, Che Ibrahim and Belayutham (2022) suggest that DfS's effectiveness can vary depending on the project scale and complexity. Large infrastructure projects are more likely to benefit from DfS due to the availability of resources and formal project structures, but small-scale construction may find DfS an impractical addition due to its associated costs and procedural requirements (Che Ibrahim et al., 2022) These limitations highlight a criticism that DfS, while beneficial, may not be universally feasible without contextual adaptations and support mechanisms for smaller firms.

Another major critique is the perceived over-reliance on designers to manage construction safety. Critics argue that DfS places an excessive burden on designers, who may lack the on-site experience and detailed hazard knowledge that contractors and site supervisors possess. Umeokafor and Manu (2023) argue that while designers play a crucial role in hazard prevention, they are not always equipped to make practical safety decisions that align with on-the-ground construction realities. This disconnect can result in impractical safety recommendations that do not fully address risks or may complicate construction processes unnecessarily (Umeokafor et al., 2023).

A recurring criticism in the literature is the concern that DfS could stifle creativity and innovation in design. Some research discusses how safety-focused design constraints can limit designers' creative freedom, potentially leading to more conservative and less aesthetically ambitious projects Manu et al. (2020). The argument here is that by prioritizing safety to an extreme, DfS may inadvertently discourage design experimentation and the pursuit of unique architectural features that do not fit within traditional safety guidelines (Manu et al., 2020).

Moreover, Che Ibrahim et al. (2022) contend that designers may perceive DfS as a restrictive approach that forces them to make compromises on visual appeal or structural innovation to comply with safety standards. In cases where creativity is a primary client requirement, such as in commercial or public spaces, DfS might be seen as a limiting factor rather than an enhancement to project quality (Che Ibrahim et al., 2022)

Moreover, the legal implications of DfS have also raised concerns, particularly regarding liability. In many cases, DfS shifts safety responsibilities onto designers, potentially exposing them to legal repercussions if accidents occur due to their design choices. Manu and Acheampong (2024) discuss how this additional liability may deter designers from fully engaging in DfS, especially in regions without robust legal protections. In such cases, designers might avoid DfS practices to minimise exposure to litigation risks, ultimately undermining the objective of hazard prevention (Acheampong et al., 2024). In the U.S., where DfS is typically implemented on a voluntary basis, Schulte et al. (2008) found that many designers are hesitant to integrate DfS due to potential liability. The authors argue that the absence of legal protections and clear accountability frameworks makes designers wary of assuming responsibilities that traditionally fall within the contractor's purview (Schulte et al., 2008).

In addition, cost-effectiveness remains a critical point of contention, especially among smaller firms and contractors operating with limited budgets. Manu and Che Ibrahim (2022) note that the initial costs of implementing DfS, such as conducting risk assessments, hiring safety consultants, and adjusting designs, are often substantial.

For firms with narrow profit margins, the financial investment required for DfS may outweigh perceived benefits, particularly in environments where safety standards are not strictly enforced (Che Ibrahim et al., 2022). Acheampong et al. (2024) further suggest that DfS may be financially burdensome for projects in developing regions, where construction budgets are already stretched thin. The authors argue that without financial incentives or regulatory support, DfS may remain underutilised, as companies prioritise immediate project costs over long-term safety investments (Acheampong et al., 2024).

2.2.8 Recommendations for Improving DfS

Strengthening regulatory and policy support is a recurring recommendation across the literature, as it provides a foundation for consistent and enforceable DfS practices. Manu and Acheampong (2024) suggest that governments, especially in developing countries, should create mandatory DfS guidelines akin to the CDM 2015 regulations in the UK, which hold designers accountable for incorporating safety into their designs. This regulatory support not only sets clear expectations but also encourages a proactive approach to hazard prevention (Acheampong et al., 2024).

It has been recommended that offering financial incentives, such as tax breaks or subsidies, to offset the costs associated with DfS for small- and medium-sized enterprises (Umeokafor and Manu, 2023). These incentives could help alleviate financial burdens, making it more feasible for smaller firms to adopt DfS principles (Umeokafor et al., 2023). Additionally, scholars highlight the importance of legal protections to shield designers from excessive liability, as such safeguards would encourage them to engage more fully with DfS without fear of legal repercussions (Schulte et al., 2008).

The literature consistently emphasises the need for regionally adapted DfS frameworks that accommodate varying levels of economic and regulatory development. Nasser et al. (2024) recommends designing simplified, cost-effective DfS models that can be tailored to local contexts, particularly in countries like Kuwait and Nigeria, where construction practices and resources differ from Western models. Such adaptations could include reducing the complexity of DfS processes and offering step-by-step implementation guidelines, making DfS more accessible to smaller firms with limited resources (Nasser et al., 2024).

Manu and Acheampong (2024) argue that these localised DfS models should focus on high-impact, low-cost safety interventions that provide immediate benefits without imposing excessive financial or procedural demands. By focusing on practical, achievable safety measures, regionally adapted frameworks can support broader DfS adoption even in resource-constrained environments (Acheampong et al., 2024).

A recurring theme in the literature is the critical need for enhanced DfS education and training across academic and professional settings. Manu and Che Ibrahim (2022) advocate for integrating DfS principles into construction and design curricula, ensuring that future designers are equipped with the skills and knowledge needed to prioritize safety proactively. Educational institutions can play a pivotal role by embedding DfS modules into engineering and architecture programmes, bridging the gap between academic knowledge and industry practices (Che Ibrahim et al., 2022). Acheampong et al. (2024) further suggest the development of industry-specific training programmes that can be delivered through professional bodies, focusing on both DfS theory and its practical applications. Such programmes would cater to working professionals who may not have received formal DfS education during their academic training, thus raising the overall competency level within the industry. Collaborative training that includes designers, contractors, and safety managers could also promote a shared understanding of safety responsibilities, reinforcing a safety-first culture across project teams (Acheampong et al., 2024).

Further recommendation suggest that effective DfS implementation depends on robust collaboration between designers, contractors, and other construction stakeholders. Manu and Umeokafor (2023) emphasise the importance of establishing structured communication channels to facilitate regular exchanges of safety information throughout the project lifecycle. By embedding collaboration into the DfS framework, project teams can ensure that safety considerations are carried forward from design to construction (Umeokafor et al., 2023).

Moreover, Acheampong et al. (2024) propose developing a shared responsibility model for safety, where designers and contractors jointly identify, assess, and mitigate risks. This approach would enable both parties to leverage their expertise: designers provide the conceptual and technical aspects, while contractors contribute practical, site-based knowledge. Collaborative safety review meetings at project milestones are recommended as a way to address evolving safety risks dynamically and responsively (Acheampong et al., 2024).

The use of digital tools is a reoccurring recommendation, tools such as Building Information Modeling (BIM), Artificial Intelligence (AI), and Virtual Reality (VR), has been widely recommended for enhancing proactive safety planning within DfS frameworks. Manu and Che Ibrahim (2022) discuss how BIM can be used to create digital models that allow designers to simulate potential hazards and adjust designs before construction begins. This proactive approach not only improves risk identification but also enables designers to test alternative designs for safety compliance (Che Ibrahim et al., 2022).

Acheampong et al. (2024) also highlight the potential of AI and machine learning to analyse historical project data, predicting where hazards are likely to occur based on similar past projects. Such predictive tools could be invaluable for high-risk projects, as they allow for data-driven safety planning that addresses known risks specific to certain project types or conditions. Virtual Reality (VR) simulations are further recommended as an effective training tool, enabling workers to visualize potential hazards in a controlled environment before encountering them on-site (Acheampong et al., 2024).

2.2.9 Design for Safety Summary

This section review examines Design for Safety (DfS) as a proactive approach to embedding safety in the design phase of construction projects to mitigate hazards before they arise on-site. DfS required designers prioritise safety from the start, addressing risks through careful choices in materials, structural design, and maintenance planning, ultimately aiming to reduce construction-related accidents and fatalities. However, significant challenges hinder DfS adoption, particularly in developing regions, where limited regulatory support, inadequate resources, and insufficient industry-specific training prevent consistent implementation. Resource constraints in Ghana and regulatory gaps in Nigeria illustrate these difficulties, while further criticism highlights an over-reliance on designers who may lack practical site experience and the financial burden DfS places on smaller firms. Key gaps include a shortage of empirical data from diverse environments and the need for regionally adapted DfS practices suited to local economies and regulatory contexts. Recommended improvements include stronger regulatory frameworks, financial incentives for smaller firms, and the integration of DfS into educational curricula to build safety competence among future professionals. Additionally, adopting collaborative tools like Building Information Modelling (BIM) and Virtual Reality (VR) could support proactive hazard identification and a safety-first approach throughout all phases of construction projects.

2.3 Construction Hazard Prevention through Design (CHPtD): review of strengths, weaknesses and challenges

2.3.1 Meaning of Designers

According to the HSE (2015), the title of 'Designer' applies to any person who prepares or modifies a design in relation to structure, product, and mechanical or electric systems. This definition includes architects, engineers and any constructors involved with design work (this is the formal legal meaning of designer in the UK).

2.3.2 CHPtD meaning and its role in reducing accidents

CHPtD is a concept that requires designers to consider safety in the design phase of the construction process (Hardison & Hallowell, 2019). The CHPtD concept originated from the Prevention through Design (PtD) concept in the 1960s. PtD is defined as "designing out occupational hazards in equipment, structures, materials, and processes that affect workers". The use of PtD was encouraged in a wide range of industries, such as manufacturing, agriculture, oil and gas, mining, transportation, and even healthcare. CHPtD motivates designers and engineers to design out construction hazards through the lifecycle of the building, including construction, operation, maintenance, and the demolition phases (Hardison & Hallowell, 2019). CHPtD can influence the construction accident rate. Decisions made during the design phase can have a significant impact on workers' safety during all subsequent building phases, i.e. construction, occupation, maintenance, renovation, and/or demolition (Williams, 1998; Inze & Gambatese, 1996). It was reported that, amongst 100 accidents in the UK construction industry, 47% of them could have been impacted by designers (Gibb & Haslam, 2004). Additionally, it was deemed that 42% of 224 fatal accidents in the USA construction industry could have been avoided or reduced had designers considered safety during the design phase. Furthermore, Driscoll et al. (2008) studied 210 fatal accidents in Australia's construction industry and found that 37% were related to design issues and another 14% also had circumstances with some connections to design. It could thus be concluded that designers make a considerable contribution towards safety. Various H&S regulatory agencies in the UK, EU, Australia, and Singapore have implemented regulations which state that designers must consider safety during the design phase, with the UK example being the CDM2015 regulation (see Section 2.2.3).

2.3.3 Evaluating the strengths of current CHPtD

To measure the proposed methods of current CHPtD articles, a matrix representing the 16 strength points was created, presented in Table 8. Further analysis of the matrix led to the creation of four groups: 1- Design components (points 1, 2 and 9 in Table 8); the analysis found that 56.4% of existing CHPtD methods are missing this strength point. 2- Using advance technology/software to support CHPtD implementation (points 6 and 7), with the analysis revealing that 50% of CHPtD methods are missing this strength point; 3- Using safety principals to implement CHPtD (points 12, 13, 14, 15 and 16), with the analysis finding that 80% of existing CHPtD methods are missing this strength point. 4- Engage/consider other stakeholders' interests (3, 5, 8, 10 and 11), with the analysis revealing that 70.8% of CHPtD methods are missing this strength point.

Most reviewed articles (>93%) scored less than 8 out of 16 from the measuring points, whilst six articles scored 3-4, four articles scored 5-6, and two articles scored 7; only one article scored 11 (Table 8). In the coming section, CHPtD challenges will be highlighted..

2.3.1.Limitation and critics of CHPtD application.

Various criticism regarding CHPtD has been highlighted in literatures such as, that efficiency comes with potential costs, particularly for smaller firms. Implementing CHPtD requires dedicated resources, risk assessments, and training, which can increase project budgets and extend timelines. Fernández-Muñiz et al. (2014) argue that smaller firms may struggle to afford these upfront investments, particularly if local regulations do not mandate DfS and/or CHPtD practices. For these companies, the benefits of productivity gains might be outweighed by the added costs. In addition, designers reluctant to CHPtD compliance because it exposes companies to increased scrutiny and liability, particularly in markets like the U.S., where safety responsibility traditionally lies with contractors. By mandating safety during the design phase, CHPtD can inadvertently shift accountability from contractors to designers, creating legal risks. As noted by Saunders et al. (2016), some U.S.-based designers are hesitant to adopt CHPtD due to the potential for legal liabilities if accidents occur. Another counter argument to CHPtD implementation suggest that focusing on safety at the design stage may introduce complexities and may overlook on-site hazards that arise during the dynamic construction process. Hardison and Hallowell (2019) suggest that relying solely on CHPtD could reduce focus on necessary reactive safety measures that respond to real-time risks on-site. Additionally, some construction teams may resist safety-related design adjustments if these are perceived as impractical or excessive. Furthermore counter arguments raised by various authors criticise implementation of CHPtD principals without a structured model, they urge this is unrealistic and could lead to inconsistent or superficial safety measures. Some believe that the absence of detailed standards forces designers to rely on ad-hoc interpretations, resulting in variable and sometimes ineffective safety outcomes. Opponents propose that rather than imposing vague safety expectations on designers, a clear, standardized CHPtD model should be developed that includes specific guidelines for different project types and stages (Hardison & Hallowell, 2019; Fernández-Muñiz et al., 2014).

2.3.4 CHPtD current challenges

As mentioned above, the CHPtD concept heralds from a previous and well-known concept, namely Prevention through Design (PtD), which was used in 1950 in car manufacturing (Stewart, Heidel, & Quinn, 2009) during 'Process Safety'. CHPtD is a new concept in the construction industry, and many efforts by scientists, professionals and others have aimed to make it more effective. Numerous challenges and criticisms need to be addressed. This study conducted a ccritical review of CHPtD literature, revealing various challenges facing CHPtD implementation. Hardison and Hallowell (2019) carried out a comprehensive assessment of current CHPtD literature and concluded that the CHPtD concept has still not reached a mature level. Moreover, Toole and Gambatese (2008) highlighted another CHPtD challenge, namely poor communication between designers and field teams (constructor, maintenance and demolition teams). Good communication normally happens between construction teams, designers and clients during the construction phase, but not so much when it comes to safety issues, and not during the designing of the building. The communication between these two parties is more about the drawings and material specification to build the project; Moreover, Lingard and Holmes (2021) question the assumption that better communication between stakeholders automatically leads to improved safety outcomes. Their research highlights that, even when communication is effective, the financial constraints imposed by clients often take precedence over safety considerations. on top of that, the construction industry in various countries does not see safety as an issue to be discussed with the architects/designers, and rather an issue for the construction team only (Saunders et al., 2016). Furthermore, once the project is completed and requires maintenance after a few years, the maintenance team does not typically communicate with designers. On rare occasions when they do, it is usually to obtain drawings or specifications of the building. Regarding CHPtD, designers during the design phase often do not interact with the maintenance team or address their safety concerns. The same can be said for the demolition team. This gap of several years between designers' work and the activities of other stakeholders poses a communication challenge. Kim, Ryu, and Kim (2021) forwarded additional CHPtD challenges related to ‘data storing’ regarding design decisions and access of historical data from similar projects. The authors stated that many of the decisions taken regarding temporary structures, such as site layout, are taken manually and depend on the experience of the construction team; there is the need for electronic data banks for safer designs, construction hazards that can be prevented during the design phase, and alternative (safer) building components, mitigations and preventative measures which designers could embed in the design. Building such a data bank would help designers to select from ready design models, specifically of the temporary structure of the building. This data bank can aid and support designers with critical safety information and make such information available to relevant stakeholders during the lifecycle of the building. Another CHPtD challenge is ‘Lack of involvement’ of the site team (construction, maintenance, demolition) in design decisions. During the design phase, designers do not receive the input of the field team, with the main focus instead being to serve the desire of the client and occupier. As such, safety concerns of contractors (construction, maintenance or demolition teams) do not reach the designers (Fernández-Muñiz et al., 2014). Furthermore, one of the challenges faced in implementing CHPtD is the lack of site experience amongst designers. Research by Gambatese and Hinze (1999) highlighted that designers often lack firsthand construction experience, which leads to poor understanding of how designs are built (Lingard, McCabe, & Trethewy, 2015). This lack of awareness extends to site hazards, risks associated with building equipment, and hazards related to building materials, making it difficult for architects and designers to grasp the safety implications of their designs and to effectively implement the CHPtD concept.

Another challenge is the insufficient safety knowledge amongst designers—a problem that persists globally (NIOSH, 2010; Gambatese, 2019). Whilst safety education has improved through the inclusion of safety models in design curricula, specific training on implementing CHPtD during the design phase is still lacking. Consequently, designers struggle to consider all significant safety hazards throughout the building lifecycle and to devise design solutions accordingly.

Resistance to new technology presents another obstacle, with some stakeholders, including design and construction teams, hesitant to adopt emerging technologies such as BIM, VR, AR, and drones (HSE, 2018). This is not in the UK only; for instance, Umeokafor, Umar, and Evangelinos (2022) examined 30 years of safety issues in construction countries such as China, South Africa, Brazil and Malysia, noticing that construction lacked use of technology such as BIM tools. Despite their potential to facilitate communication and support safety information exchange between the office and the construction site, these technologies face resistance from traditionalists.

A notable criticism of existing CHPtD literature is the absence of a risk-based approach, as highlighted by Hardison and Hallowell (2019). Whilst risk assessment methods are commonly employed during construction, maintenance, and demolition phases, they are often overlooked during the design phase when implementing CHPtD. This oversight hinders the effectiveness of safety measures during the design process.

With regard to ‘Legal impact’, although implementing CHPtD is mandatory in advanced areas such as the UK, Australia and Singapore, in some other countries, such as the USA, the designers deliberately do not want to be involved in construction activities, i.e. selecting building methods, building equipment, and designing and selecting temporary structures, as this would make them liable should legal issues arise (Saunders et al., 2016). Moreover, many other countries in Africa, Asia, the Middle East and South America do not impose safety duties on designers during the design phase. Many designers in these countries view safety as a burden and prefer to not get involved with safety or site activity. To address the challenges mentioned above, there is a need for additional effort and research.

2.3.5 Designers’ challenges in implementing CHPtD

Regulation requires designers to implement CHPtD. However, designer safety competency is a key issue for successful implementation, and major work has been undertaken in the last 15 years by health and safety professionals, construction institutions, education organisations and regulators to develop theoretical and practical training for the improvement of construction staff competency—a process which continues today. The focus is on staff and management working on site (construction, maintenance or demolition phases), but the safety competency of designers who are involved in the design phase is not a well-developed paradigm (NIOSH, 2010; Gambatese, 2019); in most cases there is no clear training to ensure designers' competency. This can also be attributed to the fact that CHPtD is still not sufficiently developed and has not reached a mature state of knowledge (Hardison & Hallowell, 2019).

Consequently, designers do not have safety competency (Mill, 2010), and instead focus mostly on designing the building and not how the building will be built (Lingard, 2005); therefore, they also do not have construction experience (Gambatese & Hinze, 1999; Lingard, 2015; McCabe & Trethewy, 2015). Moreover, some legal systems contribute to designers' lack of construction experience, especially in the USA, where designers deliberately avoid engagement with construction methods or safety on site, because of concerns over legal liability (Saunders et al., 2016). Furthermore, insurance companies and the legal system in the USA hold constructors responsible for what happens on the site, whatever the design risk is (Hughes, 2006). In the USA court system, constructors are legally responsible for the construction 'means and methods', as is also adjudged in the insurance policy underwriting (Sounders et al., 2016). These designers' challenges are tabulated in Table 9 below, so that they can be used in the qualitative research interviews of this thesis.

Table 2 Designers' challenges

No	Designers' Challenges	Source
1	Poor communication	Toole and Gambatese (2008)
2	Storing of data	Ryu and Kim (2021)
3	Lack of involvement	Fernández-Muñiz et al. (2014)

4	Lack of site experience	Gambatese and Hinze (1999), Lingard (2015), McCabe and Trethewy (2015)
5	Lack of safety knowledge	Niosh (2010), Gambatse (2019)
6	Resistance of new technology	HSE (2018)
7	Lack of risk-based approach	Hardison and Hallowell (2019)
8	Legal impact	Saunders et al. (2016)

2.3.6 CHPtD summary

This section examines CHPtD, explaining its meanings and origins, and serving one of the thesis's objectives, i.e. to reveal the strengths, weaknesses, and challenges of CHPtD implementation. In this chapter, an evaluation of CHPtD's strengths and weaknesses has been conducted, emphasising designers' role in hazard elimination during the design phase and how this impacts worker safety across a building's lifecycle. Stress is also placed on the need for communication amongst designers and other construction stakeholders, as well as technology adoption, safety principles, and stakeholder engagement in design decisions. In addition, this chapter highlights designers' challenges during the design phase, which include poor communication, designers' lack of site experience, and poor safety knowledge.

2.3.7 Building Information Modelling (BIM)

In the previous section, details regarding the challenges associated with CHPtD were explained, weaknesses and barriers faced by designers were highlighted. In this section, emphasis will be placed on the details of technology, such as BIM, which can enhance, enable, and support designers in implementing CHPtD. BIM is recognised as a great tool that can be utilised to enhance safety in the construction industry (HSE, 2018).

2.3.7.1 BIM development

According to Autodesk (2020), BIM is the process of creating intelligent 3D models and enabling document management, coordination, and simulation throughout the entire lifecycle of a project.

The history of BIM began in the late 1950s, when the American defence contractor Itek Corporation invented a computer graphics system for engineering design. This system underwent multiple iterations and evolved into the Electronic Drafting Machine (EDM). By the mid-1960s, it had been commercialised and adopted by other companies (Weisberg, 2008). In the late 1970s, a group of MIT graduate programmers developed software for mechanical design and drafting known as BRAVO. Subsequently, AutoCAD was created and gained popularity amongst architects and designers. BIM entered the market in 2000 as a natural progression from AutoCAD (Autodesk, 2020). Since the software is continuously updated and new solutions are added regularly, it is challenging to mention every feature and describe every function of BIM. However, this section will highlight the significant features relevant to the current study.

2.3.7.2 BIM advantages

According to Demian and Walters (2014), Building Information Management (BIM) enhances information flow, promoting stakeholder integration and improving information exchange. Additionally, Abanda et al. (2017) appraised six different dimensions for BIM, creating a classification known as nD, which encompasses 6D and allows for the addition of various dimensions. In general, it is evident that BIM has the capacity to incorporate and utilise multiple dimensions.

Visualisation is one of the most important features of BIM. 2D drawings can often be unclear, but BIM provides visualisations in three dimensions that can be rotated for viewing from different angles. Furthermore, BIM can be integrated into laser scanning or drone imagery to swiftly and cost-effectively capture a 3D representation of the site (HSE, 2018). These visualisations play a crucial role in detecting clashes in building designs, understanding complex construction details, and testing processes in a safe environment. They also facilitate the engaging of site staff in discussions and the clarifying of tasks.

Training is another key application of BIM, especially when integrated into Virtual Reality and/or Augmented Reality. This integration creates a virtual scenario with precise dimensions and features of the construction site for training purposes. It allows construction staff to familiarise themselves with tasks, machinery, equipment, building materials, tools, and even traffic around the site, all represented in a dynamic 3D format (Akram et al., 2019).

Additionally, BIM serves as a versatile platform that can integrate into various applications and software, including real-time location data, GIS, project management, accounting software, and supplier management systems, etc. It can accommodate numerous plug-in applications, catering to different stakeholders’ interests in areas such as finance, procurement, supply chain, contract management, and task scheduling, with the expectation of further integrations in future iterations (Sacks, Girolami, & Brilakis, 2020).

Moreover, BIM offers a clash detection feature that allows designers to identify points where multiple structural features intersect, such as water pipes crossing electrical cables. Once highlighted by BIM, designers can devise solutions to prevent clashes (HSE, 2018).

The role of BIM in communication cannot be understated. It enhances communication amongst designers, engineers, managers, and on-site staff by offering 3D images of tasks, site conditions, risks, equipment specifications, and materials (HSE, 2018). Furthermore, the integration of BIM into GIS, laser scanning, or aerial drones enables real-time site monitoring, facilitating field-to-BIM communication (Sacks et al., 2020). BIM can also be accessed via mobile devices, tablets, or any internet-connected device to visualise and retrieve images or documents from BIM storage, enabling BIM-to-field communication. Field staff can contribute information, documents, images, or videos to BIM storage directly from their mobile or tablet whilst on site. These bidirectional communication methods improve project stakeholder collaboration and provide real-time information. Moreover, this section explores improvement tools such as BIM as a supportive technology to enhance CHPtD and DfS implementation.

2.3.7.3 BIM challenges

BIM encounters numerous challenges in its implementation within the construction industry. Eddie's (2013) study, which involved conducting an extensive online survey, notably highlighted a prevailing issue: a significant deficiency in BIM expertise amongst professionals in the construction sector. This conclusion, echoing a global sentiment, is substantiated by similar studies conducted in various parts of the world. For instance, research in China (Cao et al., 2013), Australia (Gue & London, 2010), and Singapore (Teo et al., 2016) all arrived at the same consensus.

Furthermore, Eddie's study brings to the forefront a concerning pattern: BIM finds its primary utility during the initial design phase of a project, with limited utilisation in subsequent stages. This disproportion raises questions regarding the full integration of BIM into the entire project lifecycle.

In addition to the expertise gap, another difficult challenge arises from the apprehension revealed by traditional construction entities. Specifically, this reluctance is most pronounced amongst medium and small contractors who are generally unfamiliar with BIM's intricacies. Their hesitancy to embrace this innovative technology stems from a lack of willingness to invest the necessary time and effort to become skilful in its utilisation.

2.3.7.4 Integrating Design for Safety (DfS) into Building Information Modelling (BIM)

Integrating Dfs in BIM is an emerging approach that enhances safety performance throughout the lifecycle of construction projects. The integration of DfS within BIM enables designers and project teams to proactively address safety hazards and risks during the design phase, well before construction begins. Through BIM, safety considerations can be visualised, simulated, and analysed in a virtual environment, allowing for more effective identification and mitigation of risks (Zhang et al., 2015). According to Hossain and Chua (2021), a key benefit of embedding DfS into BIM is its capacity to create a safety-informed model, where hazardous areas can be flagged, and preventive measures can be incorporated into the building process, reducing on-site incidents.

BIM facilitates clash detection and detailed spatial analysis, both essential for identifying potential safety risks, such as conflicts between structural elements and safety installations like fire exits, safety railings, or mechanical systems (Ganah and John, 2015). By modelling these safety-critical components in BIM, project teams can ensure that the final construction aligns with safety standards and regulatory compliance. Additionally, BIM's ability to model construction sequences enables the simulation of the build process, helping project teams foresee high-risk activities, plan safer work methods, and adjust the schedule to prioritise worker safety (Zhang et al., 2013). This foresight is particularly beneficial in high-risk environments such as high-rise buildings, where safety risks are compounded by complex logistics and dynamic workflows.

Moreover, parametric design tools in BIM allow for the integration of DfS principles by automatically adjusting design elements to maintain safety compliance. For instance, if a design parameter like a staircase or walkway is modified, the BIM system can ensure that the new design continues to meet safety regulations for dimensions, handrail placement, and emergency egress routes (Ganah and John, 2015). This dynamic capability reduces the likelihood of errors and omissions that could compromise safety during construction or throughout the building's lifecycle.

Additionally, BIM serves as a powerful tool for safety training and communication. Through the use of 3D models and immersive technologies, construction teams can visualise hazardous scenarios and practise safer construction methods within a controlled environment (Zhang et al., 2013). This enhances the effectiveness of safety briefings and fosters a stronger safety culture on construction sites. Furthermore, integrating DfS in BIM ensures continuous safety monitoring during the operation and maintenance phases of the building's lifecycle, as data related to safety systems—such as fire suppression, emergency exits, and structural integrity—can be stored and accessed within the BIM model (Hossain and Chua, 2021).

In conclusion, the integration of DfS into BIM enhances not only the design process but also the safety performance of construction projects by facilitating early hazard identification, improving safety compliance, and promoting a safer working environment through better planning and communication.

2.4 Regulations around the world regarding DfS

This section reviews regulations worldwide to explore how Design for Safety (DfS) is embedded across countries. Some mandate DfS, enforcing proactive safety integration during design with strict regulations and penalties, while others adopt voluntary guidelines that encourage, but do not require, DfS. In some regions, safety is primarily reactive, focused on site compliance over preventive design. Emerging awareness in certain areas lacks formal frameworks, relying on construction-phase practices. This diversity reflects varying regulatory priorities and commitment to preventive safety globally.

2.4.1 Singapore

Singapore is recognised as one of the most proactive countries in enforcing Design for Safety (DfS) in construction. The Design for Safety Regulations 2015, implemented by the Building and Construction Authority (BCA) in collaboration with the Ministry of Manpower (MOM), serve as a model framework for integrating safety considerations throughout construction projects. The legislation requires key project stakeholders—such as developers, Qualified Persons (QPs), contractors, and DfS professionals—to embed safety principles from the design phase through project completion. Inspired by the UK's Construction (Design and Management) Regulations (CDM), Singapore's approach incorporates mandatory risk assessments, safety meetings, and designated safety roles at each project phase, particularly for high-risk projects.

Singapore regulatory requirements

The DfS Regulations 2015 require all building projects of a certain scale to undergo structured safety assessments during the design and planning phases. Qualified Persons, who are typically architects and engineers registered with the BCA, are responsible for identifying potential hazards associated with the proposed design and mitigating these risks as part of their duty. For example, they must evaluate risks related to materials, structural features, and accessibility, ensuring that construction and maintenance activities can be carried out safely. Additionally, the regulations mandate DfS Review Meetings at critical stages, where QPs, contractors, and developers discuss safety measures, potential hazards, and mitigation strategies to ensure safety remains a priority across all phases of the project (BCA, 2015).

Practical Implementation and Impact

In practice, Singapore's DfS regulations have established a culture of collaborative safety planning in construction. Regular DfS Review Meetings facilitate communication between designers, contractors, and owners, allowing potential safety issues to be addressed before construction begins. Safety assessments focus on high-risk elements, such as excavation, working at heights, and handling heavy materials, which are common sources of accidents. The BCA's stringent enforcement and regular audits ensure compliance, with penalties for stakeholders who fail to meet safety obligations. Since the introduction of the DfS Regulations, Singapore has reported a decline in workplace injuries and fatalities, solidifying the country's position as a leader in construction safety in Asia (Chia, 2017; BCA, 2023).

Criticisms and Ongoing Challenges

Despite its effectiveness, Singapore's DfS approach faces several criticisms. Some industry professionals argue that the requirements add to project costs and timelines, as risk assessments and compliance checks require dedicated resources and time. Furthermore, smaller contractors and firms may struggle to comply fully due to resource limitations, despite the availability of BCA guidelines and training. Critics also note that the DfS framework places significant responsibility on QPs, potentially exposing them to liability in the event of an accident. Nonetheless, ongoing training programmes and regulatory support aim to address these challenges, reinforcing DfS as a foundational part of Singapore's construction industry (Ofori, 2020).

2.4.2 United Kingdom

The United Kingdom's Construction (Design and Management) Regulations 2015 (CDM 2015), enforced by the Health and Safety Executive (HSE), represent one of the most stringent frameworks for DfS globally. CDM 2015 assigns specific responsibilities to clients, principal designers, contractors, and workers to ensure safety considerations are embedded into every stage of a construction project. The regulations mandate that stakeholders eliminate foreseeable risks through proactive planning, making the UK a benchmark for integrating safety in construction design.

UK regulatory requirements

Under CDM 2015, all stakeholders, including clients, must ensure that sufficient time and resources are allocated to plan and manage safety from the outset. Principal designers are tasked with identifying and mitigating risks during the design phase, addressing potential hazards related to structure, accessibility, and maintenance. They must create a pre-construction information document, detailing identified risks and proposed safety measures for all involved parties. In addition, the CDM regulations require the appointment of a principal contractor who is responsible for implementing safety management on-site. The regulation emphasizes a "duty of care" for each party, making stakeholders accountable for both safety planning and execution (HSE, 2023).

Practical Implementation and Impact

The implementation of CDM 2015 has led to significant improvements in construction safety in the UK, with an emphasis on collaborative planning. Safety documents, such as the Construction Phase Plan and the Health and Safety File, facilitate transparent communication about risks and safety procedures across project phases. These requirements have contributed to a culture of accountability in the UK construction sector, as stakeholders work collectively to ensure compliance. Studies show that CDM 2015 has reduced fatal and non-fatal injuries on construction sites, demonstrating the effectiveness of DfS when backed by strong regulatory enforcement (Manu et al., 2022).

Criticisms and Ongoing Challenges

While CDM 2015 has been successful, it faces some criticism. For example, the extensive documentation and procedural requirements are sometimes seen as adding complexity and administrative burdens to projects, which can be challenging for smaller firms. Additionally, CDM places substantial responsibility on principal designers, potentially increasing their liability exposure in the event of an accident. Critics also argue that CDM 2015's compliance costs may deter firms from fully committing to DfS, particularly when budgets are constrained. To address these issues, HSE provides guidance and training, supporting stakeholders in meeting CDM obligations effectively (Saunders et al., 2016).

2.4.3 United States

In the United States, Design for Safety (DfS) principles are encouraged through the Occupational Safety and Health Administration (OSHA) and the Prevention through Design (PtD) initiative led by the National Institute for Occupational Safety and Health (NIOSH). However, unlike Singapore and the UK, the U.S. does not legally mandate DfS in construction, and OSHA's construction standards (29 CFR 1926) primarily place responsibility on contractors. PtD is voluntary, encouraging, but not enforcing, DfS principles across the industry.

USA Regulatory Requirements

OSHA's construction standards focus on site safety and place much of the accountability on contractors rather than designers. The PtD initiative, led by NIOSH, promotes DfS principles by encouraging designers and engineers to consider safety hazards in the design stage. NIOSH provides resources, training, and guidelines under PtD to support companies in adopting proactive safety measures, although adoption depends on individual company policies rather than regulatory mandates. PtD promotes the integration of safety practices across the design, construction, and maintenance stages, with an emphasis on eliminating hazards wherever possible (OSHA, 2023).

Practical Implementation and Impact

PtD is implemented as a best practice among larger companies and firms with strong safety cultures. For example, sectors such as heavy construction, manufacturing, and utilities have voluntarily integrated DfS into their design processes, benefiting from NIOSH's training and resources. However, without regulatory backing, PtD's impact remains limited. A survey of U.S. construction firms reveals that only a fraction fully adopt DfS practices, with many citing cost and liability concerns. In cases where PtD principles are adopted, firms report improved worker safety outcomes and lower incident rates (Schulte et al., 2008).

Criticisms and Ongoing Challenges

The voluntary nature of PtD is one of its main limitations, as it leads to inconsistent DfS application across projects. Critics argue that without mandatory regulations, DfS adoption will remain low, especially among smaller firms where resources are limited. Furthermore, U.S.-based designers express concerns over liability, as they could be held accountable for accidents linked to design choices even if safety protocols were followed. Industry stakeholders continue to debate whether DfS should be legally mandated to improve safety outcomes, as OSHA's current contractor-focused approach is seen as inadequate by some (Umeokafor et al., 2023).

2.4.4 European Union (EU)

The European Union implements DfS and/or CHPtD principles through directives that set safety standards across member states. The primary directives are the Framework Directive 89/391/EEC on occupational health and safety and the Temporary or Mobile Construction Sites Directive (92/57/EEC). These directives outline general safety responsibilities, mandating that all EU member countries implement national regulations that require designers to consider safety risks during the project's initial stages. The directives promote risk assessments and hazard prevention measures to protect construction workers by ensuring safe practices are embedded within design plans.

EU Regulatory Requirements

Under these directives, EU member states are required to develop their national laws that align with EU standards. Countries such as **France** and **Germany** have enacted laws that require designers to perform risk assessments and consider worker safety during the design and planning phases. For example, France's Labour Code emphasizes minimizing health risks, while Germany's Occupational Health and Safety Act requires safety planning throughout the lifecycle of a project. Both countries mandate comprehensive safety evaluations to mitigate risks during construction, maintenance, and demolition phases.

Practical Implementation and Impact

These regulations have contributed to a decrease in workplace incidents across Europe, though enforcement varies. The implementation and success of DfS practices depend heavily on national policies and local enforcement capabilities. Countries like France and Germany have established rigorous processes, while other EU nations have less stringent enforcement, leading to inconsistencies in DfS application. Despite these challenges, the EU's focus on proactive safety measures at the design stage has strengthened safety practices, especially in countries with robust regulatory frameworks and consistent enforcement (European Agency for Safety and Health at Work, 2023).

Criticisms and Challenges

One criticism of the EU's approach is the variation in how member states enforce these directives. Some countries implement strict DfS regulations, while others lack the resources to ensure full compliance, leading to a disparity in safety outcomes. The EU's broad directive-based approach has been effective overall, but the need for consistent enforcement across all member states remains an ongoing challenge (Saunders et al., 2016).

2.4.5 China

China's approach to construction safety combines central government policies and regional enforcement. The Work Safety Law and Construction Law require that designers address safety risks, though these guidelines are not as prescriptive as regulations like the UK's CDM. The Ministry of Housing and Urban-Rural Development (MOHURD) oversees safety guidelines and encourages DfS and/or CHPtD practices, especially in larger urban areas such as Beijing and Shanghai. However, DfS is not uniformly enforced nationwide, with stricter compliance observed in economically developed regions compared to rural areas.

China regulatory requirements

Chinese regulations require risk assessments, site safety measures, and the incorporation of safe construction methods. The Work Safety Law mandates general safety requirements, while the Construction Law emphasizes project accountability and safety management. These laws include penalties for non-compliance, particularly for companies operating in high-risk areas, and recent updates encourage designers to consider potential hazards. However, implementation is not yet standardized, and safety practices often vary based on regional resources and economic conditions (Zhang et al., 2015).

Practical Implementation and Impact

China's safety framework has led to improvements in construction safety in metropolitan areas, where regulatory enforcement is more accessible. Large-scale projects, especially those with government involvement, tend to adhere closely to DfS principles, incorporating safety features in the design phase to reduce on-site risks. The impact of these laws is evident in decreasing accident rates in urban regions, though rural construction sites continue to face higher risks due to limited regulatory oversight and fewer resources (Xue et al., 2021).

Criticisms and Challenges

China's DfS implementation faces criticisms related to inconsistent enforcement. Rural areas often lack the infrastructure and resources to fully enforce safety regulations, which creates disparities in safety standards across regions. Additionally, smaller firms may lack the financial capacity to implement comprehensive safety plans, leading to gaps in DfS compliance. The need for stronger central oversight and more accessible resources in rural regions remains a challenge in achieving uniform DfS application (Wang & Li, 2018).

2.4.6 Nigeria

Nigeria's construction safety standards are guided by various state and federal regulations, but a cohesive DfS framework is yet to be established. The Physical and Urban Planning Law in Lagos State is an example of localized regulation, requiring inspections and certifications to ensure structural integrity. At the national level, general safety practices are outlined under the Factories Act and various labor laws, yet DfS and/or CHPtD remain underdeveloped concepts, with safety often managed reactively rather than integrated into design.

Nigeria regulatory Requirements

In Lagos, the Physical and Urban Planning Law mandates stage inspections, issuing Certificates of Completion and Fitness for Habitation before buildings are approved for use. However, Nigeria's federal construction regulations generally focus on worker safety and workplace compliance, rather than preventive measures in design. This reactive approach to construction safety limits the role of DfS, as design professionals are not required to incorporate hazard prevention into their initial plans.

Practical Implementation and Impact

Nigeria's construction industry is gradually recognizing the need for proactive safety planning, though DfS practices are limited to high-profile projects or companies with strong international influence. In recent years, there has been an increase in safety training programmes targeting construction professionals to improve awareness of DfS principles. However, the lack of regulatory mandates for DfS has hindered widespread adoption, resulting in high accident rates and a heavy reliance on reactive safety measures.

Criticisms and Challenges

Nigeria faces challenges in implementing DfS, largely due to limited regulatory support and enforcement infrastructure. Safety training is improving, but critics argue that without legislative backing, DfS adoption will remain inconsistent. Smaller firms and contractors also struggle to allocate resources for proactive safety measures, making it difficult to shift from reactive to preventive safety practices. Calls for updated policies and federal mandates continue to grow among industry professionals and safety advocates (Abubakar et al., 2021).

2.4.7 Saudi Arabia

Saudi Arabia is undergoing significant transformations in its construction sector, especially as large-scale projects like NEOM and Vision 2030 initiatives push for modernization. The Ministry of Municipal and Rural Affairs (MOMRA) and the Saudi Building Code (SBC) set safety standards for construction, but these codes focus primarily on structural integrity and on-site safety compliance. Although DfS is not explicitly mandated, there is an emerging trend towards incorporating preventive safety measures in large projects due to international influence.

Saudi regulatory Requirements

The Saudi Building Code, enforced by MOMRA, emphasizes compliance with safety standards and structural regulations, particularly for high-rise developments and critical infrastructure. The SBC requires risk assessments and regular safety audits on construction sites, but preventive safety practices in the design phase remain largely optional. However, major projects under Vision 2030 increasingly incorporate DfS principles to align with global safety expectations, promoting safer design practices as a best practice rather than a regulatory mandate.

Practical Implementation and Impact

In high-profile developments such as NEOM, Saudi Arabia’s construction industry has started integrating DfS principles more actively. International firms involved in these projects bring DfS expertise, leading to improved safety standards and the use of advanced technologies like Building Information Modeling (BIM) to simulate and mitigate risks during design. While the full impact of DfS integration is still developing, these high-visibility projects have the potential to shift Saudi Arabia's safety culture and encourage broader adoption of proactive safety practices.

Criticisms and Challenges

Saudi Arabia's DfS adoption faces challenges, particularly due to its current regulatory focus on compliance rather than prevention. Smaller contractors may lack the resources and awareness to incorporate DfS voluntarily. Critics argue that Saudi Arabia would benefit from explicit DfS regulations within the SBC to ensure consistent application. However, the trend toward proactive safety in major projects offers a promising shift towards DfS adoption as the industry continues to modernize (Al-Humaidi et al., 2021).

2.4.8 Australia

Australia enforces DfS principles primarily through the Model Work Health and Safety (WHS) Act and Safety in Design (SiD) guidelines, administered by Safe Work Australia. These regulations mandate that designers, architects, and engineers integrate safety considerations during the design phase, focusing on eliminating hazards before they become a risk in the construction and operational stages. Australia's SiD principles have set a high standard in the Asia-Pacific region, making proactive design a legal responsibility for stakeholders across the construction lifecycle.

Australia regulatory Requirements

The WHS Act requires designers to eliminate or minimize safety risks during the design phase. Under this legislation, designers must conduct comprehensive risk assessments that address potential hazards related to construction, maintenance, and eventual demolition. Designers must consult with engineers, contractors, and end-users to ensure that all foreseeable risks are addressed. Each state and territory enforces the WHS Act independently, but Safe Work Australia provides national guidance to standardize DfS practices, reinforcing the legal obligation to prioritize safety from project inception (Safe Work Australia, 2011).

Practical Implementation and Impact

In practice, SiD has led to better collaboration across the design and construction sectors. For example, construction teams often work with designers to review safety documentation and address high-risk elements like scaffolding, crane operation, and electrical installations early in the project. Australia’s approach to DfS has resulted in a noticeable reduction in workplace accidents, especially on complex projects that involve high-risk construction techniques. Companies that comply with SiD guidelines report fewer on-site incidents and improved worker satisfaction, benefiting from both safety and productivity gains (Lingard et al., 2021).

Criticisms and Challenges

Despite its success, Australia’s DfS framework faces challenges, particularly around enforcement. Since each state has jurisdiction over WHS, enforcement consistency varies. Smaller companies may struggle with the cost and expertise required to implement SiD, which can act as a deterrent to compliance. Some industry professionals argue that the procedural requirements add complexity to projects, making it difficult for small and medium-sized enterprises to meet SiD obligations without government support (Hardison & Hallowell, 2019).

2.4.9 Egypt

Egypt’s construction safety practices are governed by general occupational safety laws, with minimal focus on DfS principles. Safety in construction is mainly managed by the Building Code of Egypt, which mandates site safety but does not require designers to proactively address hazards during the planning stages. As a result, Egypt’s approach to construction safety emphasizes reactive measures, relying on compliance with basic site safety protocols rather than integrating preventive strategies into design.

Egypt regulatory Requirements

The Building Code of Egypt requires construction firms to adhere to safety practices that ensure worker protection on-site, including the provision of personal protective equipment (PPE) and safety training. However, the code lacks specific mandates for designers to conduct risk assessments or implement hazard mitigation strategies during the design phase. Construction companies are responsible for maintaining safe work environments, but the absence of a DfS framework limits the scope of safety efforts to site management rather than preventive design (ResearchGate, 2024).

Practical Implementation and Impact

In practice, Egypt's construction industry relies heavily on safety management practices enforced by contractors and site supervisors. The focus is on compliance during construction rather than hazard identification at the design stage, which often results in reactive safety measures rather than proactive prevention. High-risk projects occasionally adopt international DfS standards if foreign stakeholders are involved, but this is not widespread. Consequently, Egypt's construction industry has higher incident rates, with safety management heavily reliant on individual site managers.

Criticisms and Challenges

Critics argue that Egypt's reliance on site-level compliance limits the potential of DfS to enhance safety outcomes. Without regulatory backing, designers are not encouraged to incorporate safety features early in the project, leading to higher on-site risks. Advocates for construction safety reform have called for regulatory updates that include DfS principles, as this would improve hazard management and reduce the frequency of accidents in Egypt's rapidly expanding construction sector (El-Sayegh et al., 2020).

2.4.10 India

In India, construction safety is regulated by the Building and Other Construction Workers Act (1996) and the National Building Code. These regulations are designed to ensure site safety and worker welfare, but they do not mandate DfS practices in the design phase. Most safety regulations emphasize the responsibilities of contractors and site managers, focusing on worker protection during construction rather than preventive design strategies that mitigate risks before construction begins.

India regulatory Requirements

The Building and Other Construction Workers Act requires contractors to ensure safe working conditions, provide adequate welfare facilities, and conduct safety training for workers. However, the act does not assign responsibility to designers for hazard identification and mitigation in the planning phase. Similarly, the National Building Code sets guidelines for structural safety, fire protection, and accessibility but does not require designers to proactively address potential construction hazards. Consequently, DfS practices remain largely voluntary in India, often implemented only in high-profile or internationally funded projects (Sundaram, 2021).

Practical Implementation and Impact

In practice, India’s construction industry generally implements reactive safety measures, with safety management carried out by contractors and supervisors. Larger projects, particularly those funded by foreign investments, may incorporate DfS principles to meet international safety standards, but smaller projects tend to rely on basic compliance measures due to resource constraints. Although construction safety awareness is increasing in India, the absence of a mandated DfS framework limits the adoption of preventive safety practices in the design phase.

Criticisms and Challenges

The lack of mandatory DfS regulations in India has led to higher accident rates and persistent safety challenges. Critics argue that regulatory reforms are needed to incorporate DfS principles, as these would promote proactive safety planning and potentially reduce the industry's accident rates. Advocates also call for improved training and awareness programmes to help designers and contractors understand the importance of integrating safety within the design stage (Basu & Jha, 2019).

2.4.11 Indonesia

Indonesia's construction safety regulations are managed by the Ministry of Manpower and Transmigration through Occupational Safety and Health (OSH) laws. These laws require risk assessments, safety training, and compliance with safety standards on construction sites, but they do not include specific mandates for DfS during the design phase. Instead, Indonesia's approach focuses on site-level safety management, with limited regulatory emphasis on preventive design measures that address hazards before construction begins.

Indonesia regulatory Requirements

The OSH laws in Indonesia mandate safety protocols for workers on-site, including PPE, emergency response procedures, and regular safety inspections. However, these laws do not assign responsibility to designers for considering construction hazards during the design process. Instead, the regulations focus on ensuring contractors and site managers adhere to safety protocols during construction. This results in a reactive approach to safety, where risk management is primarily the responsibility of those managing the site rather than the designers who plan the project.

Practical Implementation and Impact

In Indonesia, larger companies and high-profile projects are more likely to adopt DfS principles, often influenced by international stakeholders. However, for most construction projects, safety management remains limited to site compliance, and DfS practices are not widely implemented. The result is a safety framework that lacks proactive design measures, relying heavily on contractors’ ability to manage risks on-site. While Indonesia has seen improvements in construction safety in urban areas, rural projects often have higher incident rates due to inconsistent enforcement and limited resources (CORE, 2017).

Criticisms and Challenges

Critics argue that Indonesia’s reliance on reactive safety measures limits the potential for DfS to improve safety outcomes. Without regulatory requirements for designers to address hazards, construction projects continue to face preventable safety risks. Industry professionals advocate for regulatory updates to include DfS principles, which would shift the focus from reactive safety management to proactive hazard prevention at the design stage. Additionally, smaller contractors often lack the resources and training to implement effective site safety practices, further complicating efforts to improve construction safety in Indonesia (Ismail et al., 2019).

2.4.12 United Arab Emirates (UAE)

In the UAE, construction safety standards are regulated primarily by local emirate laws, with Dubai Municipality and the Abu Dhabi Occupational Safety and Health Center (OSHAD) setting guidelines for the most populous emirates. Although there is no comprehensive nationwide DfS mandate, the Dubai Code of Construction Safety Practice and OSHAD-SF in Abu Dhabi provide frameworks for ensuring safety on construction sites. These guidelines are heavily influenced by international standards and emphasize the importance of safety compliance but do not legally require safety integration at the design stage.

UAE regulatory Requirements

The Dubai Code of Construction Safety Practice mandates that all contractors and site managers adhere to safety protocols, particularly on high-risk projects. Requirements include detailed risk assessments, safety training, and the provision of PPE. However, while there is encouragement to adopt DfS principles, these are generally implemented only on high-profile or government-related projects. Abu

Dhabi's OSHAD-SF mandates similar requirements, focusing on comprehensive site inspections, emergency planning, and occupational health management to enhance worker safety, although DfS is not explicitly enforced.

Practical Implementation and Impact

High-profile developments in the UAE, such as skyscrapers and large-scale infrastructure projects, often adopt DfS principles voluntarily, especially when international stakeholders are involved. This has led to an improvement in safety practices on large-scale projects, as many follow global safety standards that incorporate preventive design practices. While the absence of a legal mandate for DfS limits the framework's impact on smaller projects, safety standards in Dubai and Abu Dhabi have helped reduce on-site incidents, particularly in urban areas.

Criticisms and Challenges

One of the main challenges for DfS adoption in the UAE is the reliance on voluntary compliance rather than enforceable regulations. Smaller contractors often lack the resources to implement preventive safety measures, relying instead on reactive site management. Critics argue that the UAE would benefit from a nationwide DfS mandate to ensure consistent safety practices across all projects, not just high-profile ones. The push for DfS has been growing, especially with increased global scrutiny and an emphasis on safety in the wake of rapid infrastructure growth (Al-Bahar & Crandall, 2019).

2.4.13 Kenya

Kenya's construction safety is governed by the Occupational Safety and Health Act (OSHA) 2007, administered by the Directorate of Occupational Safety and Health Services (DOSHS) under the Ministry of Labour. While Kenya's OSHA covers general workplace safety, it lacks specific provisions for DfS or preventive safety measures during the design phase. The safety management approach is primarily reactive, focusing on on-site safety practices rather than embedding hazard prevention in the design.

Kenya Regulatory Requirements

Kenya's OSHA mandates that employers provide safe working environments, conduct risk assessments, and offer adequate PPE. DOSHS enforces regular site inspections, with significant penalties for non-compliance, especially in Nairobi and other urban centers where construction activity is highest. However, the regulations fall short in addressing hazards proactively at the design stage, leaving much of the responsibility to contractors and site supervisors once construction begins.

Practical Implementation and Impact

Kenya has seen improvements in on-site safety standards, particularly for large projects in Nairobi, as DOSHS enforces compliance through regular inspections. In high-profile developments funded by international investors, DfS principles are sometimes adopted voluntarily, aligning with global best practices. However, without a formal DfS mandate, smaller projects often operate with minimal safety oversight, relying primarily on reactive safety measures, which has led to a high rate of accidents in the industry.

Criticisms and Challenges

Critics argue that Kenya's focus on reactive safety management is insufficient for the growing construction industry. The high accident rates on smaller projects indicate a need for proactive safety planning through a structured DfS framework. Advocates call for regulatory reforms to incorporate DfS principles within Kenya's OSHA, which would help establish a more consistent approach to safety and reduce preventable accidents (Maina & Wachira, 2018).

2.4.14 Brazil

In Brazil, construction safety standards are governed by the Ministry of Labour and Employment under NR 18 – Conditions and Environment of Work in the Construction Industry. NR 18 mandates safety compliance on construction sites, including the use of PPE, safety training, and detailed risk assessments. However, it lacks a clear mandate for DfS, focusing instead on reactive safety measures during construction rather than preventive planning in design.

Brazil regulatory Requirements

NR 18 outlines responsibilities for contractors and site managers to ensure worker safety through regular inspections and adherence to prescribed safety standards. It requires that employers conduct risk assessments, provide PPE, and implement on-site safety protocols. While safety compliance is enforced with heavy penalties, NR 18 does not assign responsibilities to designers, meaning that DfS remains underutilized in the Brazilian construction industry.

Practical Implementation and Impact

Larger firms, especially those involved in international or government-funded projects, occasionally incorporate DfS principles voluntarily, often influenced by international partners. However, for most projects, safety management is limited to site-level compliance, and proactive safety measures at the design stage are rarely considered. Despite the strict enforcement of NR 18, accident rates remain relatively high, highlighting the limitations of a reactive safety approach.

Criticisms and Challenges

Critics of Brazil's safety framework argue that the reliance on NR 18 limits the scope of safety practices, as preventive design measures are not mandated. There is a growing push for the Ministry of Labour to update regulations to include DfS, which would encourage hazard prevention earlier in the construction process and potentially lower accident rates. Until then, DfS practices will likely remain optional, adopted only in high-profile projects where international safety standards are in play (Cavalcanti et al., 2017).

2.4.15 Russia

Russia's construction safety standards are outlined by the Federal Service for Environmental, Technological, and Nuclear Supervision (Rostekhnadzor), which enforces workplace safety laws across various industries, including construction. Russia's safety regulations emphasize structural safety and compliance with construction standards but do not explicitly require DfS. Safety management in Russia focuses on site compliance and structural integrity rather than preventive measures within the design phase.

Russia regulatory Requirements

Russian construction laws require contractors to ensure safe working conditions on-site and mandate compliance with technical standards for structural stability, fire safety, and equipment use. Rostekhnadzor enforces site safety through regular inspections, especially in high-density urban areas like Moscow and Saint Petersburg. However, regulations do not assign specific safety responsibilities to designers, limiting the integration of DfS principles.

Practical Implementation and Impact

In practice, Russian construction projects prioritize structural and site safety compliance rather than proactive design measures. High-profile infrastructure projects, particularly those associated with international firms, may incorporate DfS on a voluntary basis. However, for most domestic projects, safety is managed reactively, addressing hazards only once construction begins. This has led to inconsistent safety outcomes, with higher accident rates reported on projects that lack robust safety planning.

Criticisms and Challenges

Critics argue that Russia's construction safety framework is outdated, as it focuses heavily on compliance without encouraging preventive safety design. The lack of regulatory support for DfS limits its application, contributing to preventable accidents in the construction industry. Industry experts advocate for updating Russia's safety laws to include DfS principles, which would align Russia's safety practices with global standards and improve overall worker safety (Perevedentsev & Volkova, 2020).

summary of DfS and/or CHPtD Adoption and Regulatory Mandates by Country

The adoption of Design for Safety (DfS) and Construction Hazard Prevention through Design (CHPtD) varies widely across countries, from those with strict mandates requiring designers to integrate safety during the design phase to those with limited or reactive safety protocols. The following summary categorizes each country based on their stance toward DfS, the presence or absence of a formal regulatory framework, and whether DfS responsibilities are mandatory for designers.

2.4.16 Summary countries' regulations positions from DfS

Singapore, UK and Australia have formalised DfS, making it a legal responsibility for designers. In Singapore and the UK, enforcement is particularly strong, with penalties for non-compliance, while Australia's implementation varies across regions.

While countries such as China, Japan, EU and USA recommend or encourage DfS principles but lack a binding mandate for designers to integrate safety into design. The U.S., for example, relies on voluntary compliance, which limits widespread DfS adoption, while EU countries vary in their enforcement depending on national legislation.

Furthermore, countries such as Russia, Brazil, Kenya and UAE focus on site compliance, lacking formal DfS regulations that assign preventive responsibilities to designers. Safety management tends to be reactive, addressing hazards only after construction begins.

Finally, countries such as Egypt, India, Indonesia, Nigeria have minimal DfS awareness and site-focused safety

This study will primarily utilise UK regulations and statistics, as the UK is regarded as a benchmark in safety field. This status is attributed to its mandatory implementation of Design for Safety (DfS), its exceptionally low injury rate, and its active promotion of Building Information Modelling (BIM) to improve safety in construction projects. In addition the UK transparency and accuracy of the fatality and injury statistics .

2.5 Literature review conclusion

This literature review examines Design for Safety (DfS) and Construction Hazard Prevention through Design (CHPtD), two terms used interchangeably in the literature to describe the same proactive approach of embedding safety considerations in the design phase of construction projects to mitigate hazards before they arise on-site. While some literature uses one term over the other, this study reviews both to identify comprehensive gaps, challenges, and recommendations for improvement. Both DfS and CHPtD share the objective of shifting construction safety practices from reactive to preventive measures, empowering designers to address safety concerns early in the project lifecycle. Common gaps identified in the literature include limited empirical data from diverse environments, insufficient region-specific adaptations to suit local regulatory and economic contexts, and a lack of comprehensive safety education in design curricula, especially in developing regions. Challenges also include an over-reliance on designers who may lack practical site experience, compounded by a lack of structured collaboration across project stakeholders in some cases, as well as financial constraints, particularly for smaller firms, which hinder widespread adoption.

Recommendations to enhance DfS and CHPtD adoption focus on strengthening regulatory frameworks to provide clear, enforceable safety standards and offering financial incentives to ease the adoption burden on smaller firms. Embedding safety-focused education in design and engineering curricula is suggested to build future competency in safety-conscious design. Additionally, region-specific adaptations of DfS and CHPtD practices are advised to align these approaches with local economic and regulatory conditions. The integration of digital tools such as Building Information Modelling (BIM) and Virtual Reality (VR) is recommended to support proactive hazard identification and to foster collaboration across project teams. Collaborative training programmes involving designers and contractors can further promote a shared understanding of safety responsibilities, reinforcing a safety-first culture across all phases of construction projects.

A review of DfS regulations across 15 countries reveals varying approaches to safety mandates. Countries such as the United Kingdom, Singapore, and Australia make DfS mandatory, incorporating safety obligations for designers within their regulatory frameworks. In the next level, countries like the United States, the European Union (varied by member state), Japan, and China encourage DfS through voluntary frameworks or strong recommendations, lacking full regulatory enforcement. Another group, including the UAE, Kenya, Brazil, and Russia, shows limited regulation, focusing more on-site compliance and reactive safety measures. Finally, emerging markets such as Egypt, India, Nigeria, and Indonesia demonstrate minimal awareness or formal frameworks for DfS, with safety practices largely restricted to site-based, reactive compliance.

The literature review has analysed the causes of construction accidents and identified five key categories that can potentially be addressed during the design phase: permanent structure, temporary structure, building materials, equipment, and site environment. To further understand these areas, this study will employ quantitative and qualitative methods to examine these accident causes, aiming to provide designers with critical insights into which accident causes could be impacted during the design phase

CHAPTER 3: Methodology

3.0 Introduction

A mix of research methods was employed, closely aligning with the "Research Onion" framework designed by Saunders et al. (2009). Within this chapter, an examination of research approaches unfolds, encompassing different philosophies, methods, approaches, strategic considerations, and the thoughtful rationale behind the chosen mix of methods.

Furthermore, this chapter will provide the theoretical basis for research design whilst also explaining the quantitative and qualitative aspects of the research. This encompasses an exploration of the details of research design, a thoughtful approach to sample selection, an application of data collection methods, and a rigorous analysis of data that encompasses both quantitative and qualitative elements which have been considered for this project.

3.1 Philosophy of knowledge

This section provides an outline of the philosophical ideas of knowledge considered by the study. The reasoning behind the configuration of the exploration has been widely audited in the literature (Bryman, 2004; Creswell, 2003). The section explains the concepts of ontology, epistemology, and axiology.

3.1.1 Ontology

The concept of ontology in research makes it possible to discover the fundamental categories of existence and the nature of reality concerning research queries. It involves scrutinising assumptions regarding reality, identifying the entities or elements under study, and realising their interconnections (Maali & Jaara, 2014). This examination of existence and the manner in which things exist plays an essential role in shaping research questions and defining the extent of investigations (Rousel, 2009), Further, Rousell (2009) stated that ontology is influenced by researchers' perspectives on the world's nature and what is considered fact.

3.1.2 Epistemology

Epistemology explores the processes through which researchers acquire knowledge (Grosslight et al., 1991). This branch of philosophy rigorously examines not only the acquisition of knowledge, but also the dimensions involved in its development, validation, and the fundamental beliefs that motivate and support it, as articulated by Buehl and Alexander (2005). Researchers follow a process in acquiring knowledge. Further, they establish the knowledge's relevance and validity through a multifaceted approach that encompasses the sourcing of information, meticulous organisation, and utilisation of various methodologies, as outlined by Dana and Dumez (2015). These methodologies include a spectrum of complexities, encompassing processes such as conceptual formation and reasoning (Campbell, 2018). In this study, epistemology philosophy is important because it assures the process, the reasoning and validation of how research has been conducted to obtain knowledge regarding designers' influence on project safety in the best possible way.

3.1.3 Axiology

Axiology, a branch within philosophy, focuses on values and their impact on studies (Brown, 2004). Axiology aids in understanding diverse research methodologies and shapes the knowledge acquired through them. Serving as a guiding framework, it assists researchers in defining objectives and rationales in their studies (Shim et al., 2020). Ultimately, it clarifies the influence of values on the subjects of study and the consequent discoveries. It extends beyond scientific research, influencing the ethical standards guiding research practices. Axiology is essential in this study, as the information generation impacts the safety of all teams working on the building project throughout its lifecycle (Creswell, 2016).

3.2 Research framework

The methodology of this study will be explained based on Saunders' (2009) framework, known as the 'Research Onion' concept. This framework demonstrates the components and phases of the research methodology and has been utilised in the current study. It is worth noting that the 'peeling onion' is a well-known concept in accident investigation, which is part of this study. The HSE (2005) states that the accident investigation process is similar to peeling an onion to reveal layers of causes, including immediate, underlying, and root causes. Saunders' (2009) model comprises six layers, starting with the philosophical stance as the first layer, followed by approaches, research strategy, research methodology, time horizon, and research techniques (Figure 8).

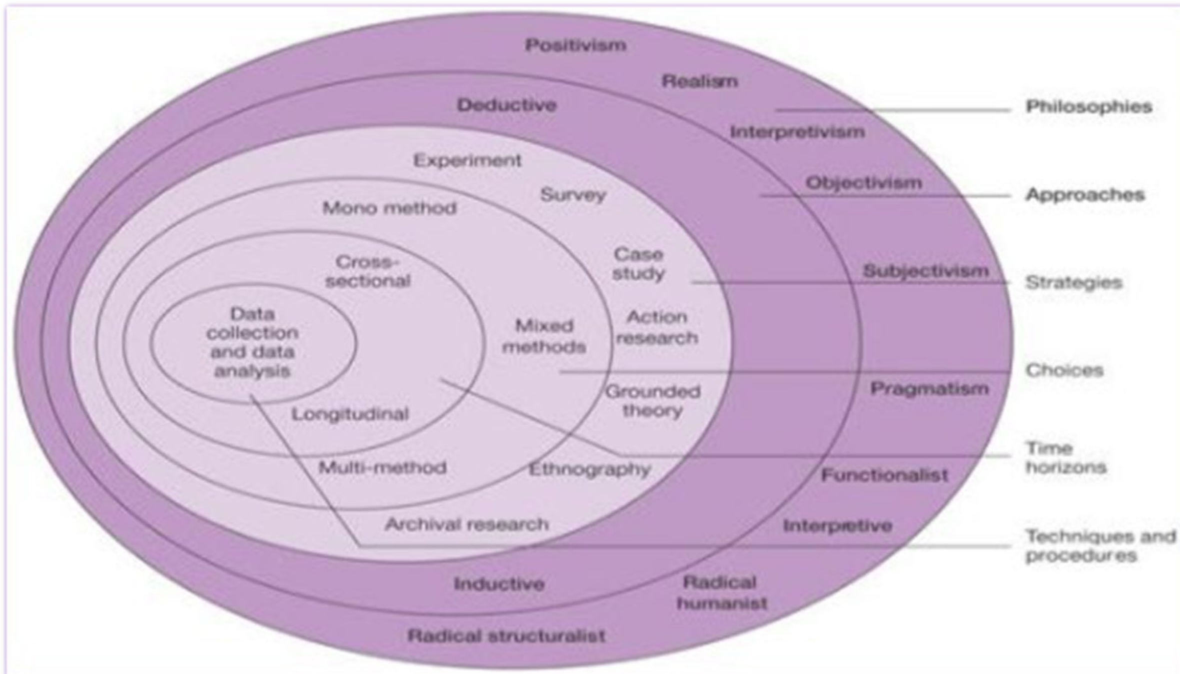


Figure 3 Saunders et al.'s (2009) Research Onion

3.3 Research philosophy

3.3.1 Positivism

Positivism, as a research paradigm, utilises scientific methods and observable data to obtain knowledge. It asserts that genuine understanding is derived from empirically-measurable phenomena, whilst the positivism philosophy also advocates for systematic observation, testing, and experimentation to uncover truths about the world (Rahaman et al., 2022). Positivism holds that there is only one reality which can be tested objectively. Positivism fits into laboratory experiments, and the natural science field, such as chemistry, physics, mathematics and the like. This study utilises both qualitative and quantitative data, such as accident statistics and survey data, and qualitative data, such as the views of professionals regarding safety variables that can be influenced by designers (interviews). The positivism paradigm can serve the quantitative data but cannot serve the qualitative data which are part of this study.

3.3.2 Interpretivism

The interpretivism paradigm acknowledges the subjective nature of reality (Guba & Lincoln, 1994). It theorises that truth is not universal but shaped by individual perceptions, cultural contexts, and social interactions (Denzin & Lincoln, 2011). Interpretivists favour qualitative research methods, such as interviews and observations, to explore diverse meanings which individuals attach to their experiences (Denzin & Lincoln, 2011). Considering the nature of this study, which comprises both quantitative and qualitative data, the pure interpretivism paradigm will not be suitable.

3.3.3 Realism

The realism philosophy emphasises the existence of an external reality independent of individual perceptions or emotions. Realism stresses the objective existence of reality and the possibility of understanding it through empirical means (Morton & Smith 1982). Realism and positivism differ in their perspectives on reality and the pursuit of knowledge. Realism acknowledges an objective reality but allows for the influence of subjective interpretations and experiences, recognising the role of individual perspectives in shaping our understanding of the world (Sankey, 2016). This study uses the mixed methods approach to collect and analyse data objectively (questionnaire) and subjectively (interviews). Realism, as a philosophy has the potential to fit this study, since it allows interpretation of interview data next to numerical data obtained from questionnaires. However, based on the above, realism is essentially objective in nature. Finding a philosophical stance which views objective and subjective at an equal level will be favourable for this study.

3.3.4 Pragmatism

Pragmatism is a goal-driven philosophical paradigm (Richwine et al., 2022) which values practical utility over fixed correctness and emphasises the effective resolution of everyday challenges; it focuses on achieving results or solutions to the studied problem. Pragmatism encourages adaptable thinking and practical problem-solving (James, 1907). Within research, particularly in mixed methods work, pragmatism advocates for a multipurpose approach, utilising various methodologies or a blend of them to achieve research goals (Ghiara, 2019). Professionals often prefer the pragmatism paradigm, as it aligns with their need to address real-life issues. For instance, in educational research, pragmatism might involve combining quantitative surveys with qualitative interviews to understand both statistical trends and individual experiences in learning environments (Shaw et al., 2017). In healthcare, it might involve integrating clinical trials into patient interviews to offer a more holistic understanding of treatment efficacy and patient perspectives (Shaw et al., 2017). This approach acknowledges that each method offers unique insights, contributing to a more comprehensive understanding (Biddle & Schafft, 2014). Whilst critics raise concerns about this approach possibly not paying enough attention to important philosophical ideas that go deeper on truthfulness, pragmatism's strength lies in its adaptability and flexibility, allowing for the integration of diverse methodologies to enrich analysis and problem-solving capacities (Godwin et al., 2003). This study is set in the safety field context, and so naturally seeks to solve safety issues that cause fatalities and injuries amongst staff. Therefore, a goal-driven philosophy such as pragmatism is suitable for this study, whilst, additionally, the mixed methods approach which is used here is a favourite choice amongst pragmatism authors.

3.4 Research approaches

3.4.1 Deductive

The deductive approach starts with a theory explained in past research, then moves on to the development of hypotheses, based on that theory, followed by the gathering and examination of facts to test those hypotheses (Shar et al., 2022). The deductive approach typically employs numerical data and statistical analysis. This approach fits the quantitative research undertaken in this study, although it does not fit quantitative research.

3.4.2 Inductive approach

Inductive research, commonly utilised in social sciences and anthropology, focuses on identifying repeated patterns through the examination of qualitative data (Lewis, 2015). This approach begins by precisely scrutinising data to distinguish recurrent patterns, progressing steadily from specific observations to broader concepts (Wuetherick, 2010). The qualitative methods employed with the inductive approach, such as narratives, interviews, or observations, align seamlessly with these fields, enabling a deeper understanding of complex human behaviours and cultural contexts (Hsieh & Shannon, 2005). As this study adopts the mixed methods strategy, the inductive approach will not fit the quantitative part.

3.4.3 Adaptive approach

The adaptive approach in research represents a flexible methodological stance that integrates elements from both deductive and inductive methods (Bryman, 2006). This adaptive stance allows researchers to adjust their hypotheses and research methods based on emerging data, promoting an iterative research process (Clark & Ivankova, 2016). Unlike unbending methodologies, the adaptive approach acknowledges the evolving nature of research and encourages responsiveness to new insights and changing circumstances (Caldas, 2003). This approach is notably prevalent in mixed methods research, where it seamlessly combines qualitative and quantitative methodologies (Gray & Oprescu, 2016). By embracing this adaptability, researchers can employ diverse techniques, such as surveys, interviews, experiments, or observations, to comprehensively address research questions (Bryman, 2006). The adaptive nature of this approach fosters a holistic understanding of complex phenomena by leveraging the strengths of different methods, allowing for a more detailed exploration (Lewis, 2015). Amongst the strengths of the adaptive approach is its ability to bridge diverse research methods and accommodate varying research contexts (Thurber et al., 2020). For instance, in a study investigating the effectiveness of an educational programme, researchers might initially use quantitative methods to gather numerical data on student performance. As the study progresses, qualitative methods such as interviews or focus groups could be incorporated to understand the subjective experiences and perceptions of the participants, offering a comprehensive view (Gray & Oprescu, 2016). This is an appropriate approach for the current study, as it serves the quantitative and qualitative parts.

3.5 Research strategy

3.5.1 Experimental

The experimental research strategy is broadly recognised for establishing cause-and-effect connections between variables and is extensively applied across multiple fields, especially in medicine and the natural sciences, relying heavily on quantitative methods for data analysis (Anderson-Cook, 2005). In medicine, particularly within clinical trials, experimental research is instrumental when it comes to assessing the effectiveness and safety of new treatments or medications before they fall into widespread use (Goozen et al., 2007). For instance, pharmaceutical companies conduct randomized controlled trials (RCTs) to rigorously evaluate the impact and viability of new drugs in treating specific medical conditions (Goozen et al., 2007). Within the natural sciences, experimental strategies are essential when it comes to understanding phenomena in areas such as physics, biology, and chemistry (Hyman, 2005). Controlled experiments are frequently employed to study the effects of varying environmental conditions on plant growth or to investigate chemical reactions under specific contexts (Tijhuis et al., 2019). One of the main advantages of the experimental strategy is its ability to yield reliable and replicable results, consequently contributing significantly in the advancement of knowledge and informing evidence-based practices in these fields (Worrall et al., 2018). The experimental strategy, when combined with quantitative methods, allows researchers to discover causal relationships, leading to informed conclusions and influencing progress in diverse scientific disciplines (Douglas et al., 2004). Since the current study does not conduct experiments, this strategy will not be considered.

3.5.2 Survey

According to Frey (1994), the research survey strategy plays a fundamental role in social sciences, market research, and various academic domains, employing diverse formats including questionnaires, interviews, or polls. These surveys, executed via various mediums encompassing online platforms, phone calls, or in-person interactions, provide flexibility in exploring an extensive range of subjects, spanning opinions, preferences, and demographics. They facilitate multifaceted investigations in various fields (Bonevski et al., 2014).

Park et al. (2020) stated that, within research philosophy, surveys are commonly linked with positivism, with the aim being to acquire objective and quantifiable data. Their structured design, geared towards precision in measurements and statistical analysis, aligns with quantitative data collection methods. However, surveys extend beyond positivist paradigms. They find relevance within interpretivist approaches, particularly employing open-ended questions in interviews or qualitative surveys (Kwan, 2002). Surveys function as a means to explore subjective experiences and individual perceptions, aligning more with qualitative research methods.

Further, Avotra et al. (2021) explained that surveys act as a vital connection between qualitative and quantitative methodologies, making them a significant component of mixed methods research. Their incorporation of both closed-ended and open-ended questions enables a comprehensive approach to data collection, thus facilitating the critique of findings and a deeper understanding of research inquiries.

Despite the challenges inherent in surveys’ design and administration, they continue as a valuable tool for articulating insights from diverse populations (Sajak et al., 2020). Their adaptability and scalability, enabling the gathering of extensive data, establish surveys as an integral element when it comes to assessing trends, behaviours, and attitudes across varied populations and disciplines. This adaptability accommodates multiple research paradigms and methodologies (Sajak et al., 2020). The survey strategy is suitable for this mixed method study as it makes the connection between quantitative research and qualitative research, thus helping to build up and accumulate results from both quantitative and qualitative research.

3.5.3 Case study

The case study research strategy is widely utilised, particularly in qualitative studies, where it primarily follows an inductive approach. It involves an in-depth examination of particular case within its all context and circumstance in field , seeking to derive theories and understanding from the specific case itself rather than starting with rigid hypotheses, as stated by Johnson and Stake (1996). This strategy provides a holistic view, capturing the relationship between factors influencing the subject and uncovering hidden patterns not evident in broader research designs (Pell et al., 2011). Whilst mainly inductive, case studies might integrate deductive reasoning, using existing theories to guide the research framework or validate emerging concepts (Prince & Felder, 2006). However, Creswell et al. (2007) articulated challenges in generalising findings to broader populations or contexts due to the focus on specific case/s, and raised concerns about potential subjectivity and researcher bias in interpreting qualitative data. Nonetheless, the case study research strategy remains a powerful tool in qualitative research, offering a detailed exploration and understanding of specific phenomena (Hietajärvi et al., 2017). Case study is not a suitable strategy for this study, as it requires a specific case/s with certain participants who are involved in that case, which is not available to the current work.

3.6 Methodological choice

3.6.1 Quantitative research

Creswell et al. (2006) highlighted that the quantitative methodology is rooted in the positivist philosophy; its connection with the positivist philosophy emphasises its commitment to objective inquiry, seeking to understand the world through empirical observation and measurable evidence; it emphasises the collection and analysis of numerical data to discover relationships, patterns, and or trends within research inquiries. It aligns with the positivist paradigm by advocating for an objective and systematic investigation of the world, aiming to uncover universal laws and regularities (Creswell & Creswell, 2017). The quantitative approach is the favoured methodology in scientific domains such as physics, chemistry and biology, where precise measurements and statistical analysis play essential roles. The quantitative strategy often utilises deductive research approaches, beginning with a formulated hypothesis and proceeding to collect data to either confirm or refute it. It also employs research strategies such as controlled experiments, surveys, or structured observations, focusing on gathering measurable, numerical data. Further, the quantitative methodology uses techniques such as statistical analysis to interpret data, correlating variables to uncover causal relationships (Bryman, 2017). However, Morgan (2014) criticised the quantitative methodology for oversimplifying complex phenomena and overlooking contextual or individual experiences. Morgen (2014) argued that this method may struggle to capture the depth and richness of human behaviour or societal intricacies. Nonetheless, the quantitative methodology remains influential, particularly in scientific research. It permits rigorous testing of hypotheses, providing a structured framework to objectively measure phenomena, thus facilitating predictions and generalisations. By adhering to rigorous standards of data collection, analysis, and interpretation, the quantitative methodology contributes to the accumulation of empirical evidence and the advancement of scientific knowledge across various disciplines (Teddlie & Tashakkori, 2011).

3.6.2 Qualitative research

Denzin and Lincoln (2018) explained that qualitative research, as a research methodology, centres on interpreting human behaviour, experiences, and social phenomena through non-numerical data. It emphasises a thorough exploration of meanings, perceptions, and context, often employing methods such as interviews, observations, and analysis of texts or artifacts (Creswell & Poth, 2016). This methodology finds its philosophical roots in interpretivism, declaring that reality is subjective and shaped by individuals' perceptions rather than existing independently (Crotty, 1998). Further, aligned with the interpretivist philosophy, qualitative research strategies prioritise capturing the depth of human experiences, seeking to uncover underlying meanings and social constructs (Merriam, 2009). Researchers using qualitative methodologies often adopt various strategies to gather data, such as ethnography, grounded theory, interview or case studies (Creswell & Creswell, 2017). This fosters an in-depth understanding of social contexts and subjective interpretations, offering a holistic view (Merriam, 2009). However, qualitative research faces criticism for its subjective nature, lack of generalisability, and potential for researcher bias (Creswell & Poth, 2016). Yet, given its significance in understanding the intricate and multifaceted aspects of human behaviour, it remains essential, particularly within fields such as anthropology, sociology, psychology, and education (Denzin et al., 2017). this will be used in the study, to capture the view of six interviewees regarding accident causes during the design phase and the influence that designer have on these causes.

3.6.3 Mixed methods research

Mixed methods research, recognised for its incorporation of qualitative and quantitative methodologies within a single study, has found widespread adoption across numerous academic disciplines such as education, sociology, health sciences, psychology, programme evaluation, policy analysis, market research, business analytics, and healthcare delivery (Johnson & Onwuegbuzie, 2004; Tashakkori & Teddlie, 2010; Plano Clark & Creswell, 2007). Originating in the latter part of the 20th century, and gaining formal recognition in the early 21st century, this adaptive methodology has earned appreciation due to its demonstrated effectiveness in addressing multifaceted research questions (Johnson, Onwuegbuzie, & Turner, 2007). Notably, researchers utilising the mixed methods approach often embark on quantitative investigations, preceding them with qualitative inquiries, thereby allowing a sequential exploration that supplements numerical findings with deeper contextual insights (Creswell & Plano Clark, 2018; Creswell & Creswell, 2017). Alternatively, they may start with a qualitative investigation to gain an understanding and then test it with numerical statistics from the quantitative study. Indeed, some researchers use both methods in parallel.

This strategic blending of approaches is favoured by pragmatist and realistic researchers, facilitating a comprehensive understanding that capitalises on the strengths of diverse methodologies and epistemological stances (Greene et al., 1989; Morse, 2003). Furthermore, the integration of qualitative and quantitative data serves to enhance the credibility and validation of research outcomes. This merging fosters a triangulation of data, supporting the overall robustness and trustworthiness of findings by verifying and validating results from different methodological vantage points (Teddlie & Tashakkori, 2011; Creswell, 2014; Bryman, 2016). Such methodological flexibility, marked by its ability to combine various research paradigms and techniques, remains in a constant state of evolution. Its evolution contributes significantly to enriching our understanding not only across a diverse spectrum of academic disciplines, but also within practical and applied research domains.

3.6.4 Justification for the selection of the mixed methods approach

An integral aspect of this study involves uncovering accident causes that might be influenced during the design phase. However, the scarcity of literature that precisely identifies these causes poses a significant challenge. Solely relying on quantitative research would limit the depth of understanding (Morgan, 2014) regarding these causes and the extent to which designers can impact them during the design phase. Conversely, relying solely on qualitative research would hinder the study's ability to generalise findings, particularly when dealing with a small sample, and might also introduce bias into the study (Creswell & Poth, 2016). To overcome these limitations and harness the strengths of both approaches, this study will utilise a mixed methods methodology.

The current study adopts a sequential mixed research method. It commences with a quantitative study to establish a broad and comprehensive perspective amongst professionals. Subsequently, the qualitative study digs deeper, capturing professionals' perceptions regarding these accident causes and understanding the barriers preventing designers from considering safety during the design phase. The study separately collects and analyses both qualitative and quantitative data. Although the results of the quantitative study were known before initiating the qualitative phase, these findings aid in refining and tailoring interview questions, focusing the qualitative study on relevant issues. Moreover, employing a mixed methods approach, as highlighted by Ostlund et al. (2011), enables the researcher to interrelate and/or compare findings from individual methods, validating and enhancing quantitative results with qualitative data for a more comprehensive understanding of the research problem. Additionally, it provides credibility to the study results (Bryman, 2014; Creswell, 2016).

3.6.5 Research time horizon

Time horizon in research is about how long a study lasts, from collecting information to analysing it. This aspect determines the size and depth of the study, depending on its objectives and the subject being explored (Creswell, 2014). There are three main types of time horizon: the first focuses on a single point in time, whilst the second observes changes over a long period, and the third looks into historical information (Johnson & Christensen, 2017; Bryman, 2016). For instance, when examining climate change, a short-term view might focus on temperature changes over a single year, representing a cross-sectional study, providing a snapshot of that specific moment. Conversely, a longitudinal study on the same subject could track temperature variations and weather patterns over several decades, offering insights into long-term trends. Additionally, a retrospective study concerning climate change might investigate historical climate data from past centuries, providing a historical perspective on climate patterns. The selection of a suitable time horizon, aligning with research goals, is essential, as it impacts what the study reveals and how it is structured (Wilson & Abram, 2010)). In this work, the cross-sectional time horizon will be used as a result of time and budget limitations.

3.7 Quantitative study

3.7.1 Questionnaire's survey design

An online questionnaire was chosen to collect quantitative data, due to its ease of use, cost-effectiveness, and the advantage of finding participants worldwide (Johnson & Christensen, 2017). Meanwhile, Creswell (2014) underscored the crucial role of the research questionnaire design within the broader research methodology, emphasising its significance in efficiently collecting valuable data. According to Johnson and Christensen (2017), the process begins with defining research goals and integrating the questionnaire into the research framework. A well-organised questionnaire requires careful sequencing, grouping of related topics, and a logical flow to effectively engage respondents (Wilson, 2010). Ultimately, a well-crafted questionnaire, as emphasised by Bryman (2016), serves as a vital research tool within the broader methodology, facilitating data collection.

The questionnaire in this study functions as a data collection tool designed to be respondent-friendly, encouraging participants to complete it and maximise response rates. The questionnaire aimed to measure the professional views of design, construction, maintenance and demolition teams on possible causes of accidents, which can be influenced during the design phase, encompassing permanent structures (Variable 1), temporary structures (Variable 2), construction vehicles and equipment (Variable 3), construction materials (Variable 4), and site environment (Variable 5). To achieve this, four hypotheses have been formulated, and the empirical data collected through the questionnaire will be used to test these hypotheses:

1- Professionals working in the construction industry agree that designers can influence the five identified variables during the design phase.

2- There is no correlation between professional views regarding the temporary structure and site environment domains, even though both are temporary in nature and occur during the construction phase only.

3- There is no difference in views amongst professionals working in narrow site spaces and those working in wide site spaces regarding the temporary structure.

4- There is no difference in the views of professionals working on projects inside the city and those working outside the city regarding site environment conditions.

This study utilises the JISC online survey. The questionnaire has been divided into three parts. The first part aims to assess the eligibility of participants based on inclusion and exclusion criteria. Additionally, this section requires participants to specify the type of project they have experience in and the country where they gained this experience. The second part consists of five pages, with each page containing five questions to measure one of the aforementioned domains (variables). This part employs a five-point Likert scale, providing participants with five options to choose from: strongly disagree, disagree, undecided, agree and strongly agree. The final part of the questionnaire provides participants with the possibility to add comments, advice, opinions, or any information they think would be relevant; Appendix 7 provides the questionnaire survey.

3.7.2 Inclusion and exclusion criteria

Exclusion criteria, in research are specific conditions or characteristics used to disqualify certain individuals, groups, or items from participating in a study. These criteria are established to ensure that the sample is as homogenous as necessary to address the research question effectively, to reduce potential biases, and to increase the validity and reliability of results. Exclusion criteria are typically defined alongside inclusion criteria, which outline the characteristics necessary for participation. Excluding participants who do not meet the study’s criteria helps ensure that findings are specific and relevant to the population the study intends to represent (Hulley et al., 2019). Without these criteria, studies could yield unreliable results due to variations that are unrelated to the main variables being investigated. However, setting exclusion criteria requires careful consideration, as overly restrictive criteria could lead to a sample that is not representative of the wider population, potentially limiting the generalisability of findings. Based on this principal, this study request participants to be adults aged 18 and above, employed within the construction sector with a minimum of three years' experience, and have been involved in building projects valued at no less than £20 million. These criteria ensure that participants have attained a level of professional expertise conducive to providing valuable insights into the subject matter.

Conversely, participants were excluded if they have been engaged in small building projects valued below £20 million. This is to prevent the inclusion of participants who only have experience with small construction projects, such as two dwellings, as these types of projects do not provide sufficient information regarding the design phase. Such projects also do not involve the use of heavy equipment, e.g. cranes, bulldozers, cement mixer trucks, etc., which is the focus of certain survey questions.

3.7.3 Questionnaire’s ethical consideration

Ethical approval has been granted by Manchester Metropolitan University Faculty of Health and Education (Ethos ID 23905) (Appendix 1). Participants are provided with an information sheet (Appendix 3) and consent form (Appendix 4).

Ensuring participant anonymity stands as a cornerstone in fostering trust and reinforcing security within the research process (Creswell, 2009; Farell, 2011). The participant information sheet and consent form ensure voluntary participation, assuring confidentiality and data security solely for research purposes. Participants are asked to sign the consent form before accessing the survey, which is displayed on the first page along with links to the study protocol and participant information sheet (Appendix 4). No personal information, such as names or phone numbers, is requested; each participant is assigned an automatic ID number to ensure anonymity. This approach guarantees voluntary participation whilst protecting privacy. Additionally, details of the researcher, study supervisor, and department director are provided in the participant information sheet for further contact. The university's data protection officer's address and email are provided for any concerns, and the contact details of the university's head of ethics are also included for potential complaints.

3.7.4 Quantitative sampling and selection

Sampling is a valuable method used by researchers to gather insights into a population by studying a subgroup rather than every individual (Acharya et al., 2013). Jawale (2012) emphasised that reducing the number of participants in a study can cut costs, time and workload, potentially improving the quality of collected information. However, maintaining a balance is crucial in ensuring that there is a sufficient sample size capable of identifying genuine connections. In this study, the approach adopted was probability sampling (random sampling). Random sampling is a research technique used to select a representative subset of individuals or items from a larger population, ensuring each member has an equal chance of being chosen (Etikan & Bala, 2017). This approach minimises selection bias, enabling researchers to produce findings that are more likely to reflect the wider population accurately. Various forms of random sampling, such as stratified and systematic sampling, help refine this approach further to suit specific research needs, especially when certain population characteristics require representation. As this study measures the view of construction professionals, the participants should be from the construction industry. This study has posted the survey link repeatedly in a professional construction LinkedIn group, each individual of these groups has equal chance to participate, once he qualified the exclusion criteria.

In Other hand, determine sample size was challenging as stated by Lewis and Hosien (2006) the construction working population size is unknown, due to there being no records in some countries, formal and informal workers, and a large number of temporary workers as well as a huge variety of contractors. To overcome the unknown number of the construction population, the Cochran (1977) formula is selected because it is suitable for unknown and infinite populations. The equation is as follows:

$$n = \frac{Z^2 * P * (1 - p)}{E^2}$$

where n is sample size, Z is z score (here a confidence interval value of 1.96 is used), P is population proportion (assumed to be 50% variability) and E is margin of error, which is selected in this study to be 0.05. The formula gives a sample size of 384.16, and therefore 385 participants were sought out to take part in the study.

Smith (2015) highlighted the function of inclusion and exclusion criteria in the realm of research, stating that they serve as guidelines determining who qualifies to participate in a study. Inclusion criteria specify necessary attributes such as specific experience levels or particular trade skills essential for study inclusion (Johnson, 2018). Conversely, exclusion criteria aim to eliminate factors such as previous injuries or specific certifications that might influence the study's outcomes (Adams et al., 2019). Striking a careful balance in applying these criteria is essential to ensure the selection of appropriate and representative participants (Brown, 2020).

3.7.5 Questionnaire data collection

The designed questionnaire was internet-based, whilst a link to the survey was distributed to construction, H&S groups and LinkedIn. Construction professionals were targeted, such as architects, construction H&S professionals, quantity surveyors, site managers, construction engineers, civil engineers and construction contractors. Table 18 illustrates the top 20 groups used, and a full list of groups with full names and logos is attached in Appendix 11. Some of these groups are locals (UK) and others are internationals; all groups used English as their main communication language.

Table 3 LinkedIn targeted groups

No	Group's Name	No	Group's Name
1	Construction Consultant	11	Sensible Health and Safety
2	Major Projects UK	12	Safety Professional Connect
3	Construction & Infrastructure Group UK	13	IOSH Construction Group
4	Construction People Middle East	14	The Project Manager Network
5	HVAC Design Engineers	15	Building Information Modeling
6	HSE Knowledge Sharing	16	Building Design Construction
7	Highway and Bridge Construction Engineers	17	Construction & Project Managers
8	American Society of safety Professionals (ASSP)	18	Consultant Network
9	Safety Professional Connect	19	India Construction Who's Who
10	Commercial Construction Professionals	20	Construction Environmental Health and Safety

3.7.6 Quantitative data analysis

Quantitative research analysis involves the systematic collection and interpretation of numerical data to understand phenomena, patterns, or relationships within a specific field of study (Phakiti, 2015). During the analysis stage of quantitative research, statistical and mathematical tools are employed to measure, quantify, and analyse data, aiming to uncover neutral and empirical insights.

Central to quantitative analysis is the formulation of research hypotheses or questions, followed by the collection of structured data through methods including surveys, experiments, or observations. These data, often in the form of numerical values, undergo rigorous analysis using statistical techniques such as descriptive statistics and inferential statistics (Sorensen., 2009).

Descriptive statistics entail organising and summarising data to identify key characteristics such as mean, median, mode, standard deviation, and range (Miller, 2012). The five variables, which included permanent structure, temporary structure, building material, building equipment and building environment, were analysed using descriptive statistics, with the result presented as means and standard deviation. Graphics such as bar charts were used for visualisation and comparison; the descriptive statistical analysis provided a clear snapshot of the dataset's central tendencies and distribution, aiding researchers in understanding the data's distribution and patterns. It offers a concise and comprehensible summary, facilitating easier interpretation and communication of findings (Creswell, 2016).

In contrast, inferential statistics are utilised to determine relationships amongst variables, establishing connections and dependencies between different aspects of the data (Phakiti, 2015). Additionally, inferential statistics are used to draw conclusions or make predictions regarding a larger population based on sample data (Garcia et al., 2020). Inferential statistical methods utilise regression analysis, correlation, and hypothesis testing, allowing researchers to generalise findings from the sample to the broader population. According to Garcia et al. (2020), inferential statistics play a pivotal role in extending research findings beyond the sample to make broader predictions or conclusions. Similarly, Miller (2012) emphasised the significance of descriptive statistics in providing a clear summary of data characteristics for easier interpretation. Sorensen (2009) further asserted that both descriptive and inferential statistics are fundamental components in the analytical toolkit of quantitative research, each offering distinct benefits when it comes to comprehending data. In this thesis the questionnaire survey Likert scale was turned into a numeric value, thus making it more suitable for quantitative analysis. SPSS software 27 was used to obtain descriptive and inferential analysis, whilst the reliability of the data was measured by Cronbach’s alpha descriptive statistics; the relative importance index was utilised to find the importance of each item in each variable, Inferential statistical analysis was employed to test three hypotheses. An independent t-test was used to identify any significant differences amongst groups’ views in the same variable, and the Pearson correlation test was utilised to explore any relations between any of the five variables. These analyses and tests will be explained below.

3.7.6.1 Data cleaning

Aguinis, Gottfredson, and Joo (2013) explained that cleaning data before analysis is crucial for reliable results. This process involves identifying and rectifying errors, inconsistencies, and missing information in datasets. One key aspect is detecting outliers—data points significantly different from others. Outliers can distort analysis, and so methods such as box plots, z-scores, or visual inspections help identify them. By addressing outliers, duplicates, or inaccuracies, data integrity improves, thus enhancing the accuracy of analysis (Dasu & Johnson, 2003). Cleaning ensures uniformity in formats, standardises variables, and eliminates irrelevant information, refining the dataset for analysis. Properly cleaned data reduces bias and errors (Pleiss et al., 2020), enabling more precise understandings and robust conclusions. It streamlines the analysis process, fostering trust in research outcomes and facilitating accurate interpretations for informed decision-making (Aguinis, Gottfredson, & Joo 2013). In this study, the Excel function was used to detect any outliers in the dataset; visual inspection was caried out to identify missing data in participants' responses, and only clean data were proceeded to the next step.

3.7.6.2 Data reliability

Streiner (2003) stressed the importance of ensuring data reliability, which is crucial in research to establish the consistency and accuracy of measurements. Data that are reliable provide a foundation for trustworthy analysis and valid conclusions. Cronbach's alpha, a statistical measure, assesses the internal consistency of a scale or set of variables in a questionnaire or survey. The alpha coefficient, ranging from 0 to 1, with higher values indicating stronger reliability, evaluates how well items (question) within a scale (survey) correlate with each other. Generally, a Cronbach's alpha of 0.70 or higher is considered acceptable, signifying satisfactory internal consistency for research purposes. However, striving for higher alpha values, ideally above 0.80, enhances the reliability and robustness of the data's measurement of the underlying construct (Tavako & Dennick, 2011). Data reliability in this study was measured via Cronbach's alpha test, in advance of any analysis, so as to determine if the data obtained were suitable for the research purposes. The consistency was tested by Cronbach's alpha using the below formula:

$$\alpha = \frac{k * \bar{c}}{\bar{v} + (k-1)\bar{c}}$$

where K refers to the number of scale items, $\bar{c}$ is the average of all covariances between items, and $\bar{v}$ is the average variance of each item.

Whilst validity is designed to test whether the score of the data is valid and measures what it intends to measure, SPSS software is used to determine duplications and unusual cases.

3.7.6.3 Descriptive statistics

Descriptive statistics are essential in research data analysis, and highlight dataset characteristics. These statistical measures, such as the mean and standard deviation, simplify complex data, aiding comprehension and exploration (Liu, Parelius, & Singh, 1999). They serve as data snapshots, revealing patterns and variances crucial for further investigation (Kaur, Stoltzfus, & Yellapu, 2018). As an initial step in research analysis, descriptive statistics provide an overview before the use of more sophisticated techniques. They are crucial tools allowing researchers to understand data nuances effectively (Marshall & Jonker, 2010). In this study, descriptive statistics constituted the first analysis conducted to find the means and standard deviation of each of the five variables (Permanent structure, Temporary structure, Building equipment/vehicles, Building material and Building environment). Analysis was conducted using SPSS (v27, Chicago, Illinois) and Microsoft Excel tools. Descriptive analysis provides a snapshot of each variable's percentage of respondence to each choice of the Likert scale, and through utilisation of standard deviations it illustrates the range amongst participants' respondence.

3.7.6.4 Relatively important index (RRI)

Mahmood and Shahzad (2020) explained the purpose of the relative importance index (RII), stating that the RII functions as a statistical method widely used to evaluate the significance of distinct elements within datasets. It serves to determine the relative contributions of individual factors to a particular outcome or phenomenon under investigation. Typically employed in decision-making procedures and survey analyses, the RII involves assigning scores or weights to different factors based on respondents' perceptions or judgments. Practically, computing RII involves participants ranking factors according to perceived importance using a Likert-type scale. Subsequently, these rankings are translated into scores, typically between 0 and 1, with 1 representing the highest importance. The RII formula encompasses averaging the scores per factor and dividing this by the maximum achievable score, resulting in a relative importance value for each factor (Firouzian & Esmaeili, 2021). The RII aids in pinpointing the most influential factors within datasets, guiding decision-making or prioritisation processes. For instance, in marketing (Mahmood & Shahzad, 2020), the RII might assess customer preferences regarding product features, whilst in urban planning, it could evaluate various aspects affecting residents' quality of life. Its versatility lies in providing a structured method to quantify and prioritise elements based on stakeholders' opinions or perceptions, facilitating effective strategies or interventions (Yousaf et al., 2019). This study used the RRI to measure the importance of each item (questions) in each variable. The purpose was to prioritise the importance of items within each domain (each domain presents one variable of the five variables of this study); the RII is calculated by using the below formula:

$$\text{RRI} = \frac{\sum w}{A*N} = \frac{5n5+4n4+3n3+2n2+1n1}{5*290}$$

where w is the weighting given to each factor by the respondent, ranging from 1 to 5, (n1 = number of respondents for weight 1, n2 = number of respondents for weight 2, n3 = number of respondents for weight 3, n4 = number of respondents for weight 4, n5 = number of respondents for weight 5. A is the highest weight (i.e. 5 in the study) and N is the total number of samples. The RII ranges from 0 to 1.

Akadiri's (2011) RRI scale was used, where High ($0.8 \le RI \le 1$), High-medium ($0.6 \le RI \le 0.8$), Medium ($0.4 \le RI \le 0.6$), Medium-low ($0.2 \le RI \le 0.4$), Low ($0 \le RI \le 0.2$).

This study comprises five variables, each containing five items (questions). The use of the RII test helps to measure the significance of each item within its domain (variable), also aiding in capturing the importance of each question and ranking them according to the result of the RII test. This test does not directly serve objective 3, although it gives more credibility to the survey.

3.7.6.5 Independent T-test

Myors et al. (2010) stated that the t-test is an essential tool in inferential statistics, facilitating the comparison of mean values between two groups to determine whether observed differences stem from true variations or random chance. The t-test serves as a critical method in hypothesis testing. Widely used across disciplines such as psychology, medicine, and business, this test manifests in two different forms: one for comparing independent group means and another for related data within a single group, i.e. test changes before and after in the same group (Lakens, 2017). The t-test provides two significant measures: the t-value and the p-value. Within statistical analysis, a t-value below 2 is often considered indicative of weak or minor differences, suggesting that observed variations are relatively modest compared to the essential variability within the groups (Bühlmann, & Van De Geer, 2011). Meanwhile, the p-value estimates the probability of these differences occurring purely by random chance. Smaller p-values (typically $p < 0.05$) indicate a reduced likelihood of chance, implying probable substantive differences between the scrutinised groups or conditions in the study. The t-test equation used for two independent groups is as follows:

$$t = \frac{M_{\dot{A}} - M_B}{\sqrt{\frac{\dot{s}^2}{n_A} + \frac{s^2}{n_B}}}$$

where mA and mB represent the mean value of groups A and B, respectively.
nA and nB represent the sizes of groups A and B, respectively.
S2 is an estimator of the pooled variance of the two groups.
The study used SPSS 27 software to conduct a two-tailed independent t-test so as to measure whether there was a significant difference between two independent groups: A- A group working on a narrow construction site, and B- A group working on a wide construction site. The t-test was also used to measure any significant differences amongst: A- A group working on an urban area's construction project, and B- A group working in a rural area. this test was conducted to explore whether these changes in site condition could lead to differences in the participants' views. The independent t-test was conducted to measure the average mean between these groups in the five variables (permanent structure, temporary structure, building vehicle and equipment, building material and building environment). The independent t-test provided results for hypotheses 3 and 4 of this study. These tests will serve objective 3 of this thesis (see Section 1.4).

3.7.6.6 Pearson correlation

The correlation test, attributed to Sir Francis Galton's late 19th-century contributions, emerged within academic realms during that era, when Galton's pioneering work introduced the correlation concept, aiming to quantify and comprehend associations amongst different variables (Stanton, 2001). This innovative approach laid the foundation for statistical methods to assess connections between continuous variables, offering a means to measure the strength and direction of relationships within datasets. A correlation nearing +1 denotes a robust positive relationship, whilst an approximation close to -1 signifies a strong negative association; values approaching 0 indicate weaker or negligible relationships between variables. These analyses aid in elucidating how alterations in one variable align with changes in another (Koo & Li, 2016). This, in turn, helps researchers to understand how variables are related in different fields, such as psychology, sociology, economics, and various areas of science. In relation to this study, the Pearson correlation test was conducted to measure the relation amongst temporary structure and building environment variables, which serves hypothesis 2 of this study (see Section 3.7.1). this test was conducted to explore whether there is any relation or influence between these two variables and whether a cause and impact relation could be established.

3.8 Qualitative study

3.8.1 Interview design

The interview, conducted subsequent to the completion and analysis of the quantitative study, provided the researcher with a clearer understanding of five variables that designers can influence during the design phase. Moreover, the questionnaire yielded suggestions, feedback, and additional information provided by the 298 participants (questionnaire participants), highlighting challenges preventing designers from considering safety. Based on these findings, a set of 12 interview questions were formulated (see Appendix 8), with focus being to more deeply investigate these challenges, elaborate on the aforementioned variables, and identify additional key areas for designer influence during the design phase.

The interview questionnaire was structured into three parts. The initial segment comprised five general questions intended to reveal the interviewee's years of construction experience, current and past positions held, types of construction phases involved in, and the scale and nature of projects the interviewee had experienced.

The subsequent part encompassed queries focused on the five variables, as follows: Question 6 asked participants about the potential of permanent structures causing accidents, seeking examples and whether designers had influence in determining their components. Question 7 probed into temporary structures, who selects them, the temporary structure's contribution to accidents, and the designer's role in their selection during the design phase. Question 8 explored the impact of building plants and equipment on accidents, discussing selection processes and the potential influence of designers in their choice during the design phase. Question 9 inquired about building materials, their accident potential, selection procedures, and the phase at which they are chosen, as well as the role of the designer in selecting them. Question 10 addressed building site environmental conditions such as mud, wind, light, noise, and temperature, investigating their potential to cause accidents and whether designers, during the design phase, could influence mitigating these conditions.

The final segment, part 3, comprised two questions inviting participants to contribute additional factors leading to construction accidents and whether designers had the capacity to alter these factors. The ultimate question sought the participants’ advice on how designers could enhance the safety of teams engaged in construction projects. The interview questions have been added to Appendix 8.

The interviews were conducted through the Zoom application, and each interview lasted between 30 minutes and 2 hours, depending on the participant’s responses and the flow of the discussion.

3.8.2 Interview ethical consideration

Ethical research interviews prioritise ethical principles whilst seeking valuable information (Roulston & Choi, 2018). Therefore, ethical approval was granted by Manchester Metropolitan University Faculty of Health and Education (Ethos ID 23905) (Appendix 1). Participants were provided with the project protocol (Appendix 2), an information sheet (Appendix 5), and a consent form (Appendix 6).

During the conducting of the research interviews, upholding ethical standards is paramount. Respect for participants’ privacy, autonomy, and dignity remains essential (Giordano et al., 2007). Securing informed consent and providing comprehensive information about the study's objectives are fundamental aspects. Maintaining transparency and honesty throughout the process fosters trust and credibility, whilst ensuring participants' comfort and emotional well-being reflects a conscientious approach. Acknowledging and embracing diversity and cultural variations are essential for inclusivity and unbiased representation (Roulston & Choi, 2018). Safeguarding confidentiality through stringent data protection measures upholds participants' trust, whilst adhering to professional conduct and steering clear of personal biases or conflicts preserve the integrity of the research. At the start of each interview, participants were assured of their complete freedom to answer or decline any question. Participation was voluntary, and strict anonymity was guaranteed, with no personal details sought.

3.8.3 Interview participant selection

Selecting the right participants for research interviews is essential in gaining meaningful perspectives. Rowley (2012) stated that a participant's suitability is based on their direct involvement, expertise, or experience relevant to the research topic. Aligning their knowledge with the study's objectives ensures the insights shared are both valuable and relevant. Majid et al. (2017) added that diversity amongst participants enriches the data, offering multifaceted viewpoints that contribute to a comprehensive understanding of the subject.

Furthermore, participants should exhibit willingness and openness to candidly share their perspectives (McDaniel et al., 1994). Their engagement and ability to articulate thoughts and experiences significantly impact the depth and quality of the information gathered (Rowley, 2012). Striking a balance between diversity and relevance in participant selection optimises the richness and validity of research findings (Farooq et al., 2017).

3.8.4 Inclusion and exclusion criteria

In qualitative research, which aims to explore, in depth, the accident causes, it is imperative to carefully select participants who possess the requisite knowledge and experience to contribute profoundly to the study. Thus, robust inclusion criteria were employed to ensure the selection of individuals who could provide profound and comprehensive perspectives on the subject matter. A minimum of seven years of experience in the construction sector ensures that participants possess a depth of practical knowledge and expertise in the field, enhancing the credibility and richness of the data collected. Moreover, mandating that participants must have completed at least three building projects serves to further refine the selection process, prioritising individuals who have a demonstrated track record of involvement in various construction activities, thus potentially offering diverse and multifaceted understandings of accident causation.

Conversely, the formulation of exclusion criteria was equally crucial in maintaining the integrity and relevance of the research outcomes. By excluding individuals who do not work in the construction sector, the study ensures that participants have direct experience and familiarity with the unique challenges and dynamics of the industry, thereby minimising the risk of obtaining irrelevant or uninformed perspectives. Similarly, excluding individuals with less than seven years of experience in the construction field safeguards against the inclusion of relatively inexperienced participants whose insights may lack depth or sophistication. Thus, through the careful application of both inclusion and exclusion criteria, the research assembled a cohort of participants who are not only well-equipped to contribute profoundly to the study, but also representative of the diverse perspectives and experiences inherent in the construction industry.

3.8.5 Interview data collection

Interviews took place outside working hours to accommodate participants' preferences. Face-to-face interviews were not convenient, as participants were not in the same country. Therefore, online interviews were utilised using Zoom meetings. At the beginning of each interview, the researcher thoroughly explained the research's aims, emphasising the valuable contribution participants provide in addressing crucial issues.

For convenience and accuracy, the researcher asked participants to record the meeting and, as explained in the information sheet, it was deleted as soon as it had been transcribed, so as to maintain confidentiality in the transcript. Each transcript contained the full conversation, with any personal details or names of specific projects carefully removed. The Zoom application provides a 45-minute session, which was sufficient for a full interview with four participants. However, two participants preferred longer conversations, requiring two sessions to complete the interview.

Upon the conclusion of each interview, the researcher expressed gratitude to the participant for their invaluable contribution and time. Within one week of each interview, the researcher fully transcribed the interview and assigned each participant a code (e.g. PS1 = participant one, PS2 = participant two, and so on). After completing all six transcripts, a second review was conducted to ensure they included all the data the participants provided. Thereafter, each transcript was uploaded to NVIVO 12 software to begin the analysis.

3.8.6 Interview data analysis

3.8.6.1 Transcription process

To streamline analysis and optimise NVivo software usage, every interview was transcribed into a written format. This process occurred within a Word document, standardising the layout with 'Heading 1' for each question, a 12-point font size, and double spacing to maintain consistency across all transcripts. This deliberate formatting, incorporating expanded spacing and a larger font size, significantly expedited and simplified the data coding process within NVivo. In line with Azevedo et al.'s (2017) recommendations, the author transcribed each interview, fostering a more intimate engagement with the data. Anonymity was preserved by assigning participant numbers. Subsequently, Creswell's (2009) thematic approach was employed for data analysis.

3.8.6.2 Thematic analysis

Thematic analysis represents a robust method for interpreting qualitative data. It involves sifting through data sourced from interviews, surveys, or observations to identify recurring patterns or themes. Researchers immerse themselves in the information, spotting common concepts or ideas, before categorising and interpreting these themes (Creswell, 2019). This method allows for flexibility, enabling both data-driven and theory-driven approaches. Thematic analysis is a valuable tool for distilling complex information; Braun et al. (2019) stated that thematic analysis is one of the most popular methods within qualitative research, aiding in providing a deeper understanding of various perspectives or phenomena. Its application proves beneficial for academic research and practical real-world implementations.

Moreover, thematic analysis is a method used to recognise study patterns and group data into themes. In the last four decades, thematic analysis has proven its suitability for a wide range of research philosophies and is used in various fields, from physiology and marketing to social sciences and others. It involves logical steps, starting with familiarisation with the data and ending up with themes. Given all of the aforementioned advantages, thematic analysis was employed in the current study.

3.8.6.3 Familiarity with the data

Developing familiarity with the data in thematic analysis involves thorough engagement and understanding of the qualitative information. This immersion enables the identification of recurring ideas and patterns within the dataset (Creswell, 2019). The profound familiarity aids in establishing a coding framework that represents the data complexity. By deeply comprehending the content, researchers generate codes that encapsulate core concepts. This preparatory phase ensures accurate and relevant codes for subsequent analysis, fostering interpretation whilst avoiding direct replication in later stages of thematic analysis (Rowley, 2012).

The transcripts of all six interviews were uploaded individually to the NVivo software. A list of each word and its frequencies was reviewed, and a pictorial display of the so-called 'word cloud' was used (Figure 14). Reading the transcripts repeatedly helped the author to reveal more ideas and generate more codes.

3.8.6.4 Data coding

The hyper-code approach, combining deductive and inductive methods, began with an initial deductive phase. In this phase, a predetermined list of codes was devised from insights gathered during prior literature reviews and quantitative studies conducted earlier in this thesis. These established codes provided a framework for the initial categorisation of data within the transcripts. Subsequently, the process moved into a more detailed coding phase. The data within the transcripts were systematically aligned with the pre-existing codes, using an inductive line-by-line approach to uncover new and emerging codes that captured aspects not covered by the initial coding framework.

During the second phase of coding, the emphasis was on refining and validating the codes. This involved cross-referencing the data with the existing codes to ensure accurate representation. Consequently, certain codes were merged to encapsulate overarching themes, whilst others underwent label modifications for improved alignment with the underlying data. Furthermore, some codes were subdivided to accommodate the multifaceted nature of the information, enhancing the precision and depth of analysis.

3.8.6.5 Theme identification

In qualitative analysis, theme identification stands as an essential phase. Braun and Clark (2006) shed light on distinguishing between codes and themes. Codes represent succinct expressions capturing the essence of the data, whilst themes interpret coding outcomes. The process of spotting themes within codes involves researchers grouping similar codes, linking diverse strands of information into broader categories to encapsulate multiple ideas under singular labels. This systematic approach aims to recognise larger patterns within the data.

The pursuit of themes within codes prompts a thorough categorisation process. Researchers strive to combine varied strands of information under singular labels, fostering a comprehensive grasp of the data. Braun et al. (2016) underscored that this thorough process surpasses mere description; it mandates a detailed explanation of the data's significance, connections, and implications within the research narrative. This comprehensive process plays an essential role in theme identification within qualitative analysis.

3.8.6.6 Theme purifying

The themes identified in the previous phase underwent a two-layer review—codes and data—to cross-check whether the themes reflected the meaning of the codes within them. Additionally, a more in-depth check ensured that each code accurately represented the intended meaning of the data. This process facilitated the refinement of the themes. Throughout this refining process, some data remained uncoded, whilst other parts were reassigned to different codes or moved to alternative themes that better represented their intended meaning.

3.7 Content analysis

In addition to the interviews described in the previous section, this research employed a content analysis. a customised evaluation framework is specifically designed to analyse critique papers on CHPtD. of the goal was to identify advantages and disadvantages of various models or frameworks within the CHPtD field. Unlike traditional content analysis, which often focuses on frequency or thematic patterns, this method centres on identifying functional strengths and weaknesses as discussed by experts. By initially reviewing key critique papers, researcher extract specific evaluation points—such as use of risk assessment, use of safety principals, use BIM and VR, and relevance—that form a checklist or scoring scale for evaluating subsequent works. This structured approach enables comparison of models based on functional effectiveness rather than academic rigour, making it particularly valuable in applied fields where practical impact is essential (Vaismoradi et al., 2020). Once these criteria are established, researchers apply the scale across a body of literature, scoring each model or framework based on its inclusion of advantageous features and its avoidance of common drawbacks, as identified in critiques.

While effective, this method has received criticism for its reliance on subjective interpretation; extracting nuanced criteria from critique papers can lead to biases, particularly if the evaluator's opinions influence the coding process (Kiger & Varpio, 2020). Additionally, the method may struggle with replicability, as variations in criteria interpretation may arise between different evaluators, the last critics regarding interpretation is a critic to almost all types of qualitative analysis not just content analysis. despite these limitations, the approach remains a robust tool for comparing models or frameworks across studies. Overall, qualitative content analysis with a customised evaluation framework allows researchers to construct a practical scale for evaluating models' strengths and weaknesses, making it a useful method in fields requiring comparative functional assessment. This method is well-suited to the study's objective two, which identifying the strengths and weaknesses of current CHPtD proposed models.

3.7.1 CHPtD Literature search

To find relevant literature on CHPtD, a search was conducted using key words such as 'Construction Hazard Prevention through Design' OR 'CHPtD'. The search yielded tens of thousands of articles across various data sources, including Science Direct, Google Scholar, and others. However, the search engines of these sources brought up results containing one or more of the searched words, rendering the outcome less useful. Subsequently, a review of academic literature on CHPtD was undertaken using Web of Science, revealing 61 articles that made reference to CHPtD. Additionally, four regulatory documents (regulations, guidance, or reports) relevant to CHPtD, originating from the UK, USA, Singapore, and Australia, were considered in this study.

Amongst the CHPtD-related articles published, 17 appeared in scientific/professional journals, and six were presented at conferences. Notably, 10 articles were found in safety science journals, eight in journals of construction engineering and management, four in Automation in Construction, and three in journals of safety research, with the remaining articles spread across various other journals, each featuring one or two articles. Considering the topics of each of these 65 articles, they could be categorised into five groups, illustrated in Table 6 below.

Table 4 Categories of CHPtD literature

1	Use of software or IT (such as BIM, ARM and VR) to implement some part of CHPtD, i.e. recognising hazards, better visualising of site activities, detecting clashes between components, training of workers, facilitating communications etc.
2	Analyses of the attitudes, perspectives, and perceptions of some project stakeholders, i.e. owners, designers, workers etc., towards using CHPtD.
3	Implementation of the CHPtD concept in certain construction activities.
4	Describing, explaining, reviewing and critiquing articles about CHPtD implementation, studies, past and future of CHPtD, potentials, weaknesses etc.
5	Accident causes and how CHPtD can eliminate or mitigate those causes.

Subsequently, the ‘Prisma’ flow-chart (Figure 6) outlined by Moher (2009) was employed to further filter the 65 articles. In total, 17 articles were excluded as they were not related to the construction design phase, whilst an additional five articles were excluded due to the lack of free access. All in all, 30 articles were identified as relevant to critics, reviews, accidents, or competency, and these were used to establish measuring points (Table 7) for the remaining articles. Consequently, based on the above criteria, 13 articles were selected for assessment.

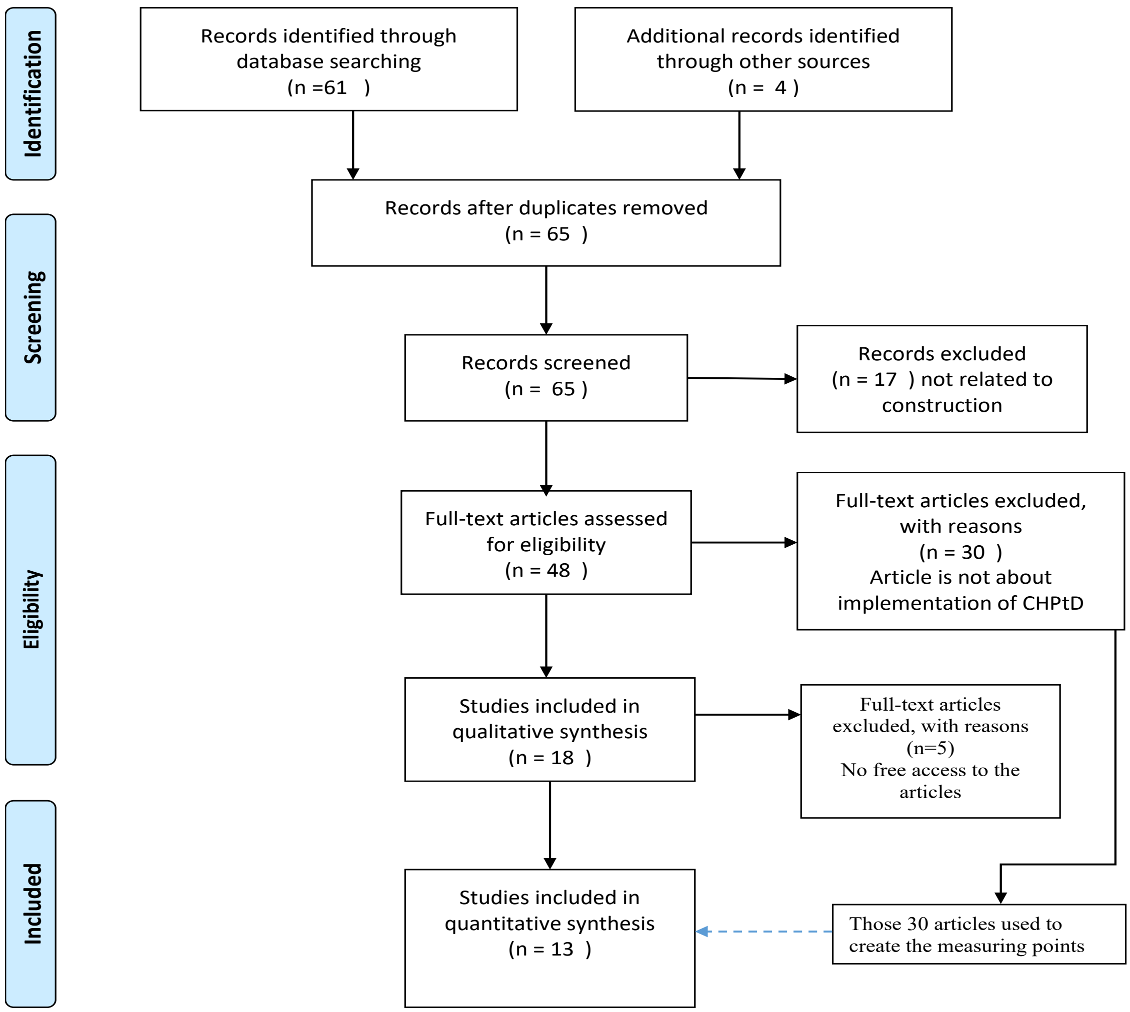


Figure 4 Prisma analysis to select CHPtD literature

3.7.2 CHPtD strengths and weaknesses

Based on the search conducted above, 30 critical articles on CHPtD were utilised to identify the strengths and weaknesses of CHPtD. A review of these articles yielded 12 strengths points, as illustrated in Table 7 below, along with their respective sources.

Additionally, four points were added to assess whether current CHPtD literature has benefitted from process safety techniques. These four points include: 1) breaking down the project into parts to assess the risk of each part (these strengths are used in Process Hazard Analysis and FMEA techniques, for instance), 2) considering the full building lifecycle (which is used in HAZOP techniques, for instance), 3) employing a hierarchy of control measures (used in risk assessment principles and Layer of Protection Analysis techniques, for instance), and 4) utilising process safety tools (tools used in process safety techniques). These process safety techniques will be explained in detail in the Process Safety section of this thesis (see Section 2.4).

Table 5 CHPtD strength measuring points

Strength creteria to measure existing literatures		
No	**Strength CHPtD point**	**Source**
1	Encourage prefabricated construction materials	Toole and Gambatese 2008
2	Selecting inheretent safer materials	Toole and Gambatese 2008
3	Involve in construction method and techniques	Toole and Gambatese 2008
4	Consider mechanical forces, dynamic motions, electricity and stresses	Toole and Gambatese 2008
5	Improve schedule and decrease cost	Toole and Gambatese 2008
6	Using BIM	HSE 2018
7	Using VR, AR, laser scan or GIS	HSE2018
8	integration with other key area sustainability, quality management..etc	Mill 2010
9	Design temporarily structure and site layout	safe work Australia
10	Actively communicate with other stakeholders	safe work Australia, CDM15
11	engage of stakeholders in design decisions	Safer work Australia, Guide Singapore, HSE 2018
12	Using hazard design risk assessment	Safer work Australia, Guide Singapore, Hardison and
13	using process safety	
14	breakdown the project into parts to assess its risk	
15	Consider the full building lifecycle	
16	Using hierarchy of control measures	

*VR = virtual reality, AG = Augmented reality, GIS = Geographic information system

3.8 Study validation

Quantitative validation relies heavily on statistical rigor to ensure the accuracy, objectivity, and generalisability of findings. This method uses statistical measures, such as p-values for significance testing and Cronbach's alpha for reliability, to verify that data accurately represent objective reality. Validity in quantitative research is further broken down into internal, external, and construct validity, with reliability as an additional key measure. To achieve reliable and consistent outcomes, quantitative studies focus on replicability, aiming to produce the same results under similar conditions. The researcher's role is minimised to maintain objectivity, thereby avoiding any influence over outcomes. This approach ensures that findings can be generalised across larger populations with a high degree of confidence. In this study the Cronbach alpha and p-value will be used to insure validity of the quantitatea part of the study

In contrast, qualitative validation emphasises credibility and trustworthiness, focusing on whether findings truly reflect the perspectives of participants and the context being studied. This approach utilises techniques such as member checking, triangulation, peer debriefing, and prolonged engagement with participants to establish credibility and confirm interpretations. Reflexivity, where researchers critically examine their own influence on the study, is also integral to qualitative validation. Rather than aiming for replicability, qualitative research seeks transferability by providing detailed descriptions of the context, enabling readers to assess the applicability of findings to other situations. Thus, qualitative validation prioritises depth, context, and an authentic representation of complex social phenomena over statistical generalisability. In this study member check and triangulation with secondary data (literature review) will be used to insure validity of qualitative part of this study

In summary, quantitative validation prioritises statistical measures and replicability to achieve generalisability and objectivity, whereas qualitative validation focuses on establishing credibility, contextual relevance, and a genuine understanding of participant perspectives. Each approach applies a unique set of validation techniques suited to the nature of the data and the research aims.

CHAPTER 4: Results and findings

4.0 Overview

The results section of this thesis presents a comprehensive analysis derived from a mixed methods research approach, combining qualitative and quantitative methodologies. It aimed to address the objective of finding construction accident causes that can be influenced by designers during the design phase, which was outlined in the earlier chapters (objective 1 see Section 1.4).

Quantitative findings are presented through statistical analyses, offering numerical insights into the patterns, trends, and relationships within the dataset. This includes descriptive statistics, inferential statistics, and graphical representations, providing a quantitative foundation for the subsequent qualitative exploration. This part serves objective 3 (see Section 1.4).

Subsequently, qualitative findings delve into these accident causes, offering a deeper understanding of the causes and challenges faced by designers. Through thematic analysis and coding techniques, themes and patterns emerge, capturing the rich context and perspectives of the participants. Direct quotations from interviews and literatures are included to enhance the credibility and authenticity of the qualitative findings. This part serves objectives 1 and 3 (see Section 1.4).

The integration of both quantitative and qualitative results forms a comprehensive narrative, allowing for a robust interpretation of the research outcomes. Triangulation of findings occurs, where the strengths of one method compensate for the limitations of the other, contributing to a more holistic understanding of the research topic, thus enriching the depth and breadth of the study's findings. The results section unfolds as a cohesive synthesis of numerical data and qualitative insights, fostering a comprehensive summary of the research's outcomes.

4.1 Quantitative analysis results

4.1.1 Participants

Participants have gained professional experience in 46 different countries, with a notable percentage having worked on projects in the UK. Table 19 illustrates the distribution of participants based on the countries and the continent where they gained their experience. Notably, 18 participants possess experience in more than one country, as detailed in the accompanying table. This mix of different experiences makes the study's findings more global and helps gain insights into the accident causes. Having participants from around the world shows how their combined experiences cover a lot of ground within the construction industry. It is worth noting that participants' country of experience is not part of the statistical analysis in this study but is provided here for additional information.

Table 6 *P*articipant distribution by country

Continent	Project location	Participants number
Europe	United Kingdom	79
	Irland	6
	Germany	4
	Netherlands	3
	Sweden	2
	Serbia	1
	Croatia	1
	Denmark	1
	Total European paricipants	**97**
Asia	United Arab Emirates	21
	India	19
	Saudi Arabia	9
	Qatar	7
	Pakistan	5
	Indonesia	5
	Kuwait	4
	Maldives	4
	Russia	3
	Bahrain	3
	Iraq	3
	Oman	2
	Iran	2
	Malaysia	2
	Jordan	2
	Kazakhstan	1
	Bangladesh	1
	Afghanistan	1
	Vietnam	1
	Total Asian participants	**95**
Africa	Nigeria	14
	South Africa	10
	Egypt	2
	Morrocco	1
	Liberia	1
	Namibia	1
	Senegal	1
	Ethiopia	1
	Algeria	1
	Zimbabwe	1
	African participant	**33**
N. America	United States	25
	Canada	16
	Total N.American participants	**41**
Australia	Australia	7
	New Zealand	5
	Total Australian participants	**10**
S.Americal	Panamá	1
	Trinidad	1
	Nicaragua	1
	Colombia	1
	Total S.American participants	**4**
Multi	**Experience in multi countries**	**18**

In relation to project type, participants have acquired experience across various types of construction projects, with 59% having expertise in two or more project categories. These encompass diverse projects such as airports, oil and gas, hospitals, industrial ventures, roadwork, office blocks, towers, shopping centres, stadiums, leisure buildings, power plants, residential blocks, and logistic facilities. Table 20 below presents the participants' distribution across each construction type, acknowledging that many individuals possess experience in multiple categories. Furthermore, all participants are affiliated with professional construction groups on LinkedIn, indicating a high level of education and experience in the field.

Table 7 types of building projects

Participants' project experience	Number of participants
Hospitals	62
Roadwork	86
Airport	63
Office blocks	116
Residential blocks	145
Retail	74
Sport and leisure	55
More than on category	170

Figure 9 shows how many participants have single project type experience (41.4%) and how many participants have multi project type experience (58.6%).

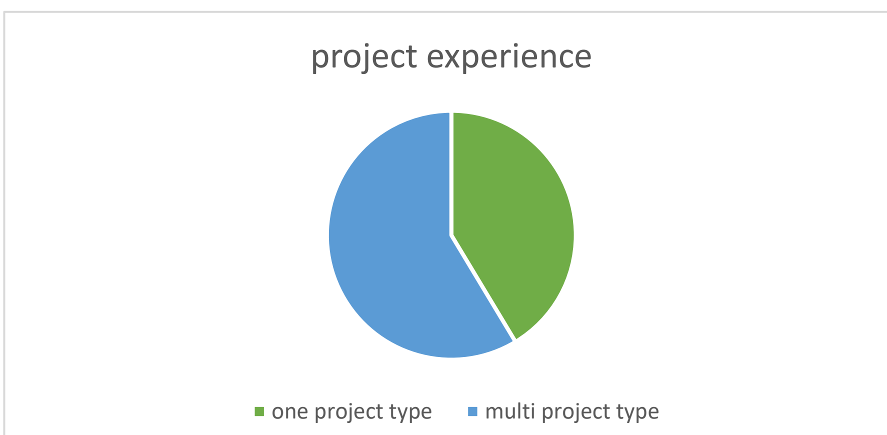


Figure 5 Experience in multi or single projects

4.1.2 Data collection result

Out of the initial pool of 1,087 candidates, a total of 298 participants from 46 diverse countries completed the survey, with a notable 27.5% coming from the UK. The participant selection process prioritised adherence to inclusion criteria rather than geographical origin.

4.1.3 Reliability tests

Data reliability was assessed for each item in the questionnaire, comprising 25 items spread across five sections, using the Cronbach's alpha test (SPSS v.27, Chicago, Illinois). The scores, documented in Appendix 10, ranged from 0.638 to 0.848, depending on the specific item removed. Additionally, an overall Cronbach's alpha was calculated for the entire set of items, yielding a score of 0.849. As per Nunnally and Bernstein (1994), a score exceeding 0.600 was considered reliable. This comprehensive reliability testing ensured the consistency and robustness of the data, supporting the credibility of the findings and conclusions drawn from the survey.

4.1.4 Result of the five variables

4.1.4.1 Permanent structure variable

Analysis showed that 92% of participants agree that building design, type, shape, or size can influence safety during construction. Additionally, 97% agree that "Some features/components of the building are riskier to build". As for participants' views on the influence of changing permanent structures during the design phase, the results showed that 89% of participants agree or strongly agree with the statement that "Designing fixed points on the structure could help to install, maintain, and clean HVAC safely". Furthermore, 96% agree that "Designing safe access to external higher parts of the building will prevent fall accidents (e.g. fixed guardrails, safety lanyard attaching points, scaffold attaching points)", and 92% agree that "Wider space to install, maintain, test, and clean electric and/or plumbing systems will help reduce accidents". The total mean of the permanent structure variable (five items) is

4.49, with a standard deviation of 0.70, and the average total agreement in this variable is 93%.

Table 8 Responses to permanent structure items affecting safety

NO	Permeant structure items	Strongly agree	Agree	Undecided	disagree	Strongly Disagree
Q5.1	Building design, type, shape or size influence safety during the construction	165	103	9	14	1
Q5.2	Some features/components of the building are riskier to build	137	123	5	5	0
Q5.3	Designing fixed points on structure could help to install, maintain and clean HVAC safely	134	125	27	6	1
Q5.4	Designing safe access to external higher parts of the building will prevent fall accidents (fix guardrail, safety lanyard attaching points, scaffold attaching points…etc.)	204	75	7	7	0
Q5.5	Wider space to install, maintain, test and clean electric and/or plumbing system will help to reduce accidents	148	119	17	8	1

4.1.4.2 Temporary structure variable

This variable consists of five items (Q6.1 to Q6.5) to measure participants' views regarding the importance of temporary structures in increasing safety on site and their views regarding whether the advance design of such structures during the design phase will help to make work safer in the field. The number of responses to each item is illustrated in Table 22. It was found that 96% of all participants agree with the statement "Designing site layout to make room for storage, road for vehicles, pedestrian path, space for welfare facility, will make the site safer". Additionally, 97% of participants agree or strongly agree with Q6.2, "Designing excavation, scaffold, guardrail, barriers, fences… etc., increases the safety of construction workers". Furthermore, 97% of participants agree or strongly agree with Q6.3, "Designing site access and egress, traffic manoeuvre areas, unload and lifting zone will increase site safety”, whilst 98% of participants agree or strongly agree with Q6.4, "Designing temporary barriers, closing openings, and protection for open edges will prevent fall accidents”. The final item in this variable scores 99% agree or strongly agree with Q6.5, “Poor design of scaffold can lead to an accident”. The total average agreement for this variable (the five items) is 94.4%, with a domain total mean of 4.76 and a standard deviation of 0.50.

Table 9 Responses of temporary structure items

No	Temporary Structure items	Strongly agree	Agree	Undecided	disagree	Strongly Disagree
Q6.1	Designing site layout to make room for storage , road for vehicles, pedestrian path, space for welfare facility, will make the site safer	200	84	6	5	0
Q6.2	Designing excavation, scaffold, guard rail, barriers, fences….etc increase safety of construction workers	208	77	2	6	0
Q6.3	Design site access and egress, traffic manoeuvre areas, unload and lifting zone will increase site safety	213	74	4	3	1
Q6.4	Design temporary barriers, close opening and protection for open edges will prevent fall accidents	205	81	2	6	0
Q6.5	Building designer can help with the select of best available equipment and vehicles types to support the construction of buildings	244	48	1	1	0

4.1.4.3 Building equipment/vehicles variable

This variable consists of five items crafted to measure participants’ views on how designers can be involved in selecting building equipment/plants or vehicles. It was found that 61% of participants agree with Q7.1, “Building designers can help with the selection of the best available equipment and vehicle types to support the construction of buildings”. Additionally, 55% of participants agree with Q7.2, “Designers can determine the best position on site to locate cranes, lifts, hoists, silos… etc.”, whilst 34% of participants agree with Q7.3, “Building designers can determine the best handheld power tools to use in construction”. Moreover, 56% of participants agree with Q7.4, “Building designers can suggest the best position/location on site for generators, fuel tanks, and temporary electric panels and switches”. The last item in this variable sees 97% of participants agreeing with Q7.5, “Unsuitable location of the crane can lead to an accident”. In summary, the participants’ average agreement with this variable is 59.4%. The variable's average total mean is 3.72, with a standard deviation of 1.09 (Table 23).

Table 10 Responses form Building Equipment items

No	Building Equipment/vehicles	Strongly agree	Agree	Undecided	disagree	Strongly Disagree
Q7.1	Building designer can help with the select of best available equipment and vehicles types to support the construction of buildings	87	95	53	54	7
Q7.2	Designer can determine the best position on site to locate cranes, lifts, hoists, silos…etc	69	95	38	81	12
Q7.3	Building designer can determine the best handheld power tools to use in construction	40	58	51	106	40
Q7.4	Building designer can suggest the best position/location on site for generators, fuel tanks and temporary electric panels and switches	66	100	33	72	24
Q7.5	Unsuitable location of the crane can lead to accident	215	74	3	4	1

4.1.4.4 Building material variable

This variable comprises five items (Q8.1 to Q8.5) designed to measure participants' views on whether building materials could be a cause of accidents on site and to what extent designers can be involved in selecting building materials during the design phase. The Study found that 83% of the participants agree with Q8.1, “Building material's property, size, and shape can be a cause of an accident on a construction site”. Moreover, 71% of participants agree or strongly agree with Q8.2, “Prefabricated building components are easier and safer”. Additionally, 85% of participants agree with Q8.3, “Building designers play a major role in selecting building materials”. A significant 97% of participants agree with Q8.4, “Designers during the design phase should consider the fireproof level of the building material (cladding, insulations, ceiling, paints)”. Furthermore, 89% of participants agree with Q8.5, “Building material manufacturers should fit lifting holes/points on building materials to make lifting operations on site safer (beams, walls, frame…etc)”. The average agreement level for this variable is 83.3%. The total mean of all five items is 4.28, with a standard deviation of 0.80. Table 24 below demonstrates the number of responses to each item.

Table 11 Number of responses to building material items

No	**Building Material**	Strongly agree	Agree	Undecided	disagree	Strongly Disagree
Q8.1	Building material's property, size, shape can be a cause of accident on construction site	93	148	24	24	4
Q8.2	Prefabricated building components are easier and safer to handle, install, maintain and dismantle	73	136	54	30	1
Q8.3	Building designer play major role in selecting building material	127	124	25	19	0
Q8.4	Designer should consider fireproof level of the building material (cladding, insulations, ceiling, paints)	198	89	8	1	0
Q8.5	Building material manufacturer should fit lifting holes/points on building materials to make lifting operation on site safer	155	110	20	10	2

4.1.4.5 Building environment variable

This variable comprises five items (Q9.1 to Q9.5), crafted to measure participants’ views on whether the building site environment could be a cause of accidents. Indeed, 97% of participants agree with Q9.1, “Wet weather (especially heavy rain) makes the construction site riskier”. Additionally, 100% of participants agree with Q9.2, “Wind can affect crane safety during operation”. Moreover, 96% of participants agree with Q9.3, “Freezing weather makes it difficult to work on a construction site”. Furthermore, 91% of participants agree or strongly agree with Q9.4, “Extreme heat (+30°C) makes it difficult to work on a construction site”. Lastly, 88% of participants agree with Q9.5, “Darkness and short days during the winter season make work conditions difficult on a construction site”. The total average agreement in this variable scores 91%, and the average mean is 4.60, with a standard deviation of 0.60. Table 25 below demonstrates the number of responses to each item.

Table 12 Number of responses to fifth variable

No	**Building Environment**	Strongly agree	Agree	Undecided	disagree	Strongly Disagree
Q9.1	Wet weather (especially heavy rain) makes construction site riskier	187	100	4	5	1
Q9.2	Wind can affect crane safety during operation	251	43	0	1	0
Q9.3	Freezing weather make it difficult to work on construction site	191	96	7	4	0
Q9.4	Extreme heat (+30c) makes it difficult to work on construct site	159	110	13	13	0
Q9.5	Darkness and short-day during winter season make work condition difficult on construction site	133	125	20	16	0

Moreover, Figure 10 below illustrates the total average means and standard deviation for each variable.

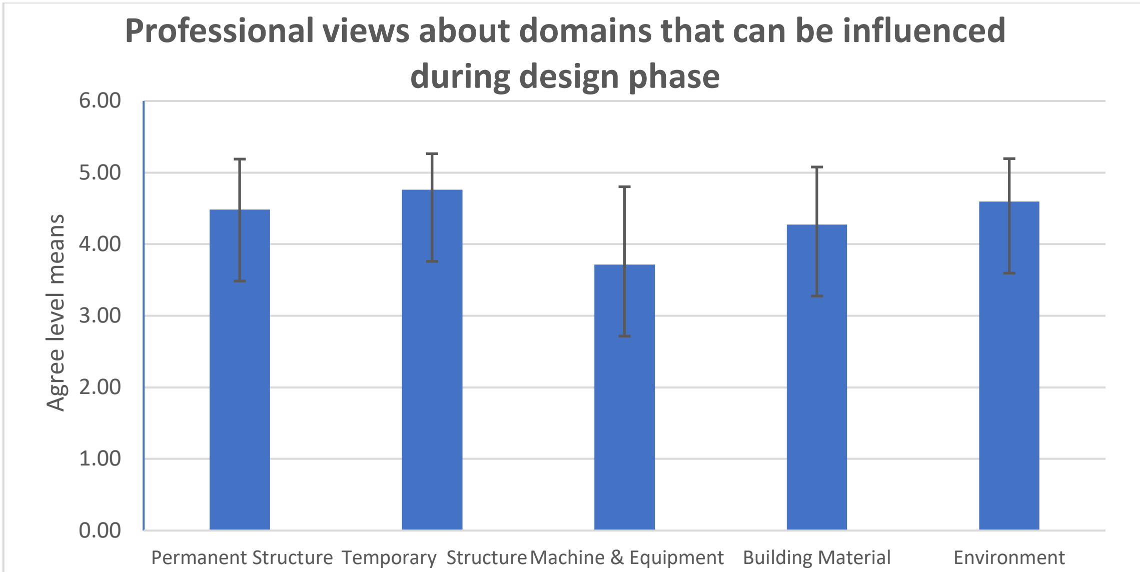


Figure 6 Result of professionals' agreement level (Means, SD)

4.1.5 Relatively important index (RII)

The RII is a valuable tool in this survey as it helps distinguish the relative importance of each item, guiding a more rigorous interpretation of participant responses. The survey items (questions) were organised according to their importance (Table 26) below, where no. 1 is the item (question) that scores the highest within its domain, and no. 5 is the lowest score. The items range between 0.98 and 0.60, indicating that items fall within a high to medium-high level of importance.

Table 13 Relatively important index of questionnaire items

Relatively important index for items within each domain										
piority rank	**Permenant Domain 1**		**Temporary Domain 2**		**Equipment Domain 3**		**Material Domain 4**		**site Environment Domain 5**	
	question	**RRI score**	**question**	**RRI score**	**question**	**RRI score**	**question**	**RRI score**	**question**	**RRI score**
1	5.4. Design safe access to external higher-parts of the building will prevent fall accidents (fix guard rail, safety lanyard attaching	0.94	6.5. Poor design of scaffold can lead to accident	0.98	7.5. Unsuitable location of the crane can lead to accident	0.96	8.4. Designer during the design phase should consider fireproof level of the building material (cladding, insulations,	0.94	9.2. Wind can affect crane safety during operation	0.98
2	5.2. Some features/component of the building is more risky to build	0.92	6.3. Design site access and egress, traffic manoeuvre areas, unload and lifting zone will increase site safety	0.96	7.1. Building designer can help with the select of best available equipment and vehicles types to support the construction of buildings	0.74	8.5. Building material manufacturer shuould fit lifting holes/points on building materials to make lifting operation on site safer	0.90	9.1. Wet weather (especially heavy rain) make construction site more risky	0.93
3	5.5. More wider space to install, maintain , test and clean electric and/or plumbing system will help to reduce accidents	0.89	6.2. Designing excavation, scaffold, guard rail, barriers, fences….etc increase safety of construction workers	0.95	7.4. Building designer can suggest the best position/location on site for generators, fuel tanks and temporary electric panels	0.72	8.3. Building designer play major role in selecting building material	0.86	9.3. Freezing weather make it difficult to work on construction site	0.92
4	5.1. Building design, type, shape or size influence safety during the construction	0.88	6.1. Designing site layout to make room for storage , road for vehicles, pedestrian path, space for welfare facility, will make the site	0.94	7.2. Designer can determine the best position on site to locate cranes, lifts, hoists, silos…etc	0.71	8.1. Building material's property, size, shape can be a cause of accident on construction site	0.80	9.4. Extreme heat (+30c) make it difficult to work on construct site	0.90
5	5.3. Designing fixed points on structure could help to install, maintain and clean HVAC safely	0.86	6.4. Design temporary barriers, close opening and protection for open edges will prevent fall accidents	0.93	7.3. Building designer can determine the best handheld power tools to use for use in constructing building	0.60	8.2. Prefabricated building components are easier and safer to handle, install, maintain and dismantle	0.78	9.5. Darkness and short day during winter season make work condition difficult on construction site	0.86

4.1.6 Result of professionals' views regarding designers' influence on the five variables

(Hypothesis 1: Construction professionals agree that designers can influence the five domains identified in the literature)

Cronbach's alpha test demonstrates the acceptance level of consistency of the items within each domain, as shown in Table 27 below.

Table 14 Five variables' Cronbach's a

Domains	Means	Standard Deviation	Cronbach's α
Domain 1: Permanent structure	21.85	3.46	0.64
Domain 2: Temporary structure	23.19	3.09	0.79
Domain 3: Building equipment	18.00	4.40	0.83
Domain 4: Building material	20.92	2.93	0.65
Domain 5: Building site environment	22.59	2.61	0.75

Based on the results obtained from the data analysis, it is evident that construction professionals hold a strong consensus regarding the influence of designers on accident causes related to "Building permanent structure" during the design phase. A substantial 97.6% of participants agree with this assertion. The domain mean is 21.85, with a standard deviation of 3.46, thus providing a measure of the overall agreement within this variable.

Similarly, the analysis of items focusing on "Building temporary structure" reveals that 97.9% of participants express a positive view. The domain total mean of 23.19, along with a standard deviation of 3.09, underscores the importance participants place on emphasising how designers can play a vital role regarding temporary structures on construction sites.

Furthermore, the positive perception of the role of designers regarding “Building equipment/plants, and the role designers could play in determining the location of construction vehicles and equipment on site” is notable, with 74.8% expressing agreement. The domain mean is 18, with a standard deviation of 4.40.

Regarding accident causes related to “Building material”, participants show a strong consensus, with 97.6% agreeing that designers have great influence in this domain during the design phase; the variable mean is 20.92, with a standard deviation of 2.93.

Finally, 87.8% of the professionals agree that “Designers during design phase can consider building environment”; the domain mean score is 22.59, with a standard deviation of 2.61 (Table 30).

Based on the results above, professionals largely agree that the identified domains need to have more attention during the design phase. This result confirms hypothesis 1.

4.1.7 Pearson correlation: temporary structure and site environment domains

(Hypothesis 2: There is no correlation between professionals’ views regarding temporary structure and site environment domains, although both are temporary in nature and occur during the construction phase only)

Pearson correlation revealed that there is a significant positive weak association between temporary structure and site environment ((r(290) = .312, p<.001). Figure 11 below shows

the significant (p<.001) positive (+) moderate correlation (correlation coefficient .312).

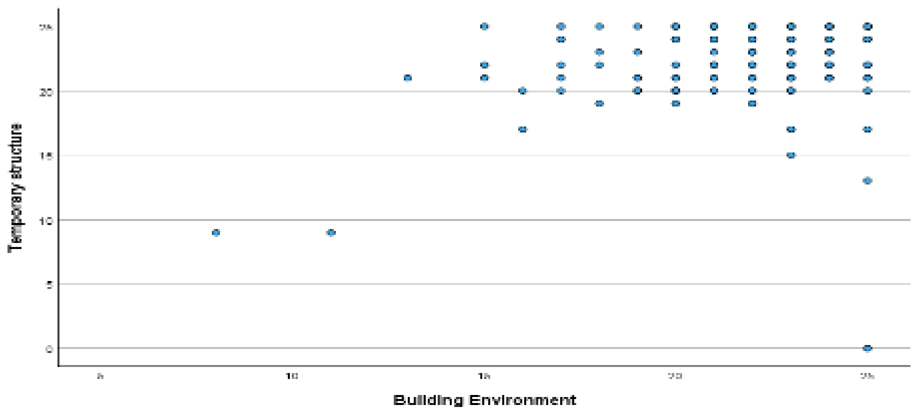


Figure 7: Correlation between temporary structure and site environment domains

Based on this weak correlation (0.31) amongst these two variables, it can be concluded that hypothesis 2 is, to a certain degree, confirmed.

4.1.8 Views of group work on narrow site and group work on wide site

(Hypothesis 3: There is no difference in the views of professionals working in a narrow site space or professionals working in a wide site space regarding temporary structure)

The t-test was utilised to test this hypothesis. Based on participants' views regarding temporary structure on site, there is found no significant difference between participants working in narrow site spaces, group 1 (n = 182, m = 23.30, SD = 2.66) and participants working in wide site spaces, group 2 (n = 97, m = 23.15, SD = 3.09). The outcome is t(277) = .417, p = 0.677).

In addition, the t-test was conducted for each of the five variables. From the result obtained it is clear that there is no significant difference between the group working in narrow site spaces and the group working in wide site spaces for any of the five variables (Table 29).

Table 15 T-test result for narrow & wide sites

Domains	T-test result .	P-value
Domain 1: Permanent structure	t(277) = -.324	p = 0.75
Domain 2: Temporary structure	t(277) = .417	p = 0.68
Domain 3: Building equipment	t(277) = -1.57	p = 0.12
Domain 4: Building material	t(277) = 1.087	p = 0.28
Domain 5: Building site environment	t(277) = .409	p = 0.68

Result is not significant because p-value is greater than 0.05

4.1.9 Views of group work on urban and group work on rural sites

(Hypothesis 4: There is no difference between the views of professionals working on projects inside the city and professionals working outside the city regarding site environment condition)

~~Participants (n = 90) were classified into three groups: group 1 (less environmental exposure n = 31), group 2 (more environmental exposure n = 36), and group 3 (experienced both types of exposure). Only groups 1 and 2 were used for the t-test here. For group 1 (M = 23.23, SD = 2.05) and group 2 (M = 22.92, SD = 2.36), the independent t-test results are t(65) = 0.57, p = .57 ns, and there is no difference between the means of groups 1 and 2.~~

Participants (n = 291) were classified into three groups: group 1 (less environmental exposure n = 98), group 2 (more environmental exposure n = 179), and group 3 (experienced both types of exposure n=15). Only groups 1 and 2 were used for the t-test here. For group 1 (M = 22.53, SD = 2.20) and group 2 (M = 22.62, SD = 2.61), the independent t-test results are t(276) = 0.262, p = 0.79 ns, and there is no difference between the means of groups 1 and 2.

Regarding participants' assessment of safety around projects located on urban and those on rural sites, no significant different is found as regards harsh environmental conditions experienced, t(276) = .262, p = 0.794 between groups (Table 2). Based on this result, hypothesis 4 is confirmed.

In addition, the t-test was conducted for all five variables between urban and rural groups (Table 29). No significant difference is found, and thus both groups have similar views regarding the five variables.

Table 16 T-test result for urban and rural projects

Domains	T test result .	P-value
Domain 1: Permanent structure	t(276) = -1.44	p = 0.35
Domain 2: Temporary structure	t(276) = -1.77	p = 0.78
Domain 3: Building equipment	t(276) = -1.94,	p = 0.53
Domain 4: Building material	t(276) = 0.249,	p = 0.80
Domain 5: Building site environment	t(276) = 0.262,	p = 0.79

Result is non-significant because p > 0.05

4.1.10 T-test result of the highest and lowest variables' scores

A further t-test was conducted by utilising SPSS27 between the highest score variable (Temporary structure–domain 2) and the lowest score domain (Construction equipment–domain 3), to compare:

1-Domain 2 (Temporary structure), groups that have narrow site space (group 1) and groups that have wide site space (group 2); the result is not significant, $t(276) = -1.77$, $p = 0.78$

2-Domain 3 (Building equipment), same groups above; again, the result is not significant, $t(276) = -1.94$, $p = 0.53$

4.1.11 Quantitative search summary

Based on the views of the 298 participants in this quantitative study, the results confirm that professionals in the field mostly agree that the five variables—permanent structure, temporary structure, building material, building equipment and building environment—are causes of accidents that can be influenced during the design phase (objectives 1 and 3 of this thesis, see Section 1.4).

4.2 Qualitative analysis result

This study incorporates a qualitative research phase following the quantitative research to validate the quantitative results, gain a deeper understanding of accident causes which have the potential to be influenced by designers, and explore challenges and barriers hindering the integration of safety considerations during the design phase, particularly in implementing the CHPtD concept.

4.2.0 Participants

Six participants were identified with professional experience spanning from 7 to 35 years. Their project involvement encompasses financial values ranging from £20 million to £12 billion. In terms of educational attainment, 83% hold university degrees in engineering, with three participants being qualified architects, one specialising in construction electromechanical drawings, one specialising in civil engineering design, and one functioning as a project manager after 14 years of experience as an architect.

Regarding construction phases, two participants were engaged in the design phase, three in the construction phase, and one participant operates in both phases. The participants' work extends across countries, including Saudi Arabia, Nigeria, Egypt, and the United Arab Emirates. Their project portfolios encompass diverse domains such as villa compounds, high-rise buildings, hospitals, airports, stadiums, recreation parks, and manufacturing facilities. Moreover, some participants have contributed to infrastructure projects involving tunnels, roads, highways, power plants, and national grid towers. These six participants are highly qualified and have extensive hands-on experience.

4.2.1 Preliminary data analysis

Commencing the analysis by identifying words' occurrences in the transcripts and their frequencies, throughout the interviews, over 1,000 different words were identified. Table 30 illustrates the frequencies of the top 20 words, organised in descending order. The most frequently mentioned word is 'construction', appearing 115 times, followed by 'safety', mentioned 111 times, and subsequently the word 'building', mentioned 85 times, amongst others. The query presents each word in the transcript with its corresponding weighted percentage, providing a comprehensive insight into the recurring themes and emphases within the interview data.

Table 17 Frequency of words in transcripts

Word	Length	Count	Weighted Percentage (%)
Construction	12	115	2.91
Safety	6	111	2.80
Building	8	85	2.15
Project	7	66	1.67
Yes	3	63	1.59
Work	4	52	1.31
Site	4	41	1.04

Designers	9	40	1.01
Design	6	37	0.93
Type	4	37	0.93
Affect	6	35	0.88
structure	9	35	0.88
give	4	33	0.83
temporary	9	33	0.83
architect	9	32	0.81
equipment	9	32	0.81
material	8	30	0.76
size	4	30	0.76
shape	5	29	0.73

Another tool for visualising word frequencies is the ‘word cloud’. Words that appear more frequently are displayed in a larger font and positioned closer to the centre of the cloud. Figure 12 depicts the result of running a word cloud analysis on all transcripts, offering a visual representation of the prominence of certain terms in the dataset.

Figure 8 Word cloud of all files

4.2.2 Initial coding

This qualitative study followed the quantitative study, resulting in the identification of five variables that designers can influence during the design phase: permanent structure, temporary structure, building equipment/plants/machines, building material, and building environment. Initial codes were created using these five variables as code labels. Text in the transcripts related to these codes was identified and assigned accordingly. Table 31 provides a summary of how many texts (referred to as references in the NVivo software) have been coded under each of these five codes. The term ‘files’ in the table represents the transcripts of interviews, with one file for each participant, indicating how often these codes appear in the transcripts.

Table 18 Initial codes

Name
Permanent structure
Temporary structure

Vehicles, machines and equipment
Building materials
Site environment

4.2.3 Second phase of coding

Line-by-line reading resulted in the addition of more references to the previous five codes, incorporating sentences or paragraphs with meanings fitting each respective code. Furthermore, this meticulous reading process led to the creation of an additional 16 codes, bringing the total to 21 codes that encompass 95% of all words and sentences in the transcripts. Table 32 below provides a detailed list of these 21 codes along with the total number of references and the number of transcripts (uploaded as files, one file per participant) from which each code originated. In addition, the distributions of codes and references amongst participants are shown below in Table 33. Moreover, the links between participants and the codes are shown in Figure 13.

Table 19 List of all codes

Name
Building materials
Disagree with building material
Disagree with permanent structure
Disagree with designer responsibility
Client’s negative influence
Lack of designer safety competency

Burden of cost
Other challenges
Time limit
Permanent structure
Site environment
Advance planning
Client’s positive influence
Design and build under one contractor
Good communication and engagement
Prefabrication of building components
Standards and regulation
Using BIM
Temporary structure
Vehicles, machines and equipment

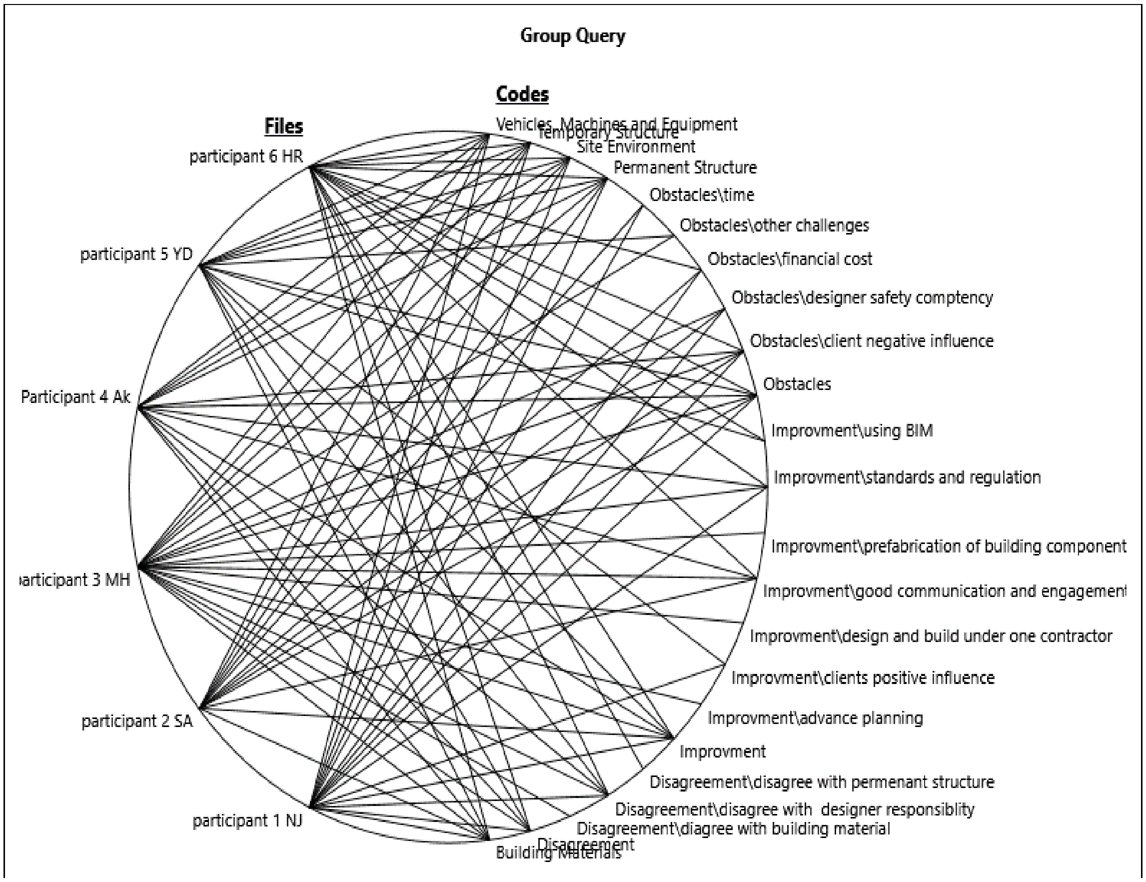


Figure 9 Links between participants and codes

4.2.4 Finding themes

The five variables, previously identified in quantitative research and confirmed by this qualitative study, are defined as five themes, each variable being a theme in its own right. Subsequently, the remaining 16 codes were reviewed to distinguish the meaning of each and how they could be combined or aggregated under one parent code; the parent code label should encompass the higher meaning of all codes within. This process resulted in the creation of three parent codes (Table 34). The parent code ‘Disagree’ contains three child codes with a total of 16 references, whilst the parent code ‘Difficulties Faced by Designers’ contains five child codes with a total of 29 references, and the parent code ‘Proposal for Improvements’ contains seven codes with a total of 28 references.

Table 20 Parent and child codes

Type of code	Codes
Parent	**Disagreement**
Child	Disagree with building material
Child	Disagree with permanent structure
Child	Disagree with designer responsibility
Parent	**Difficulties faced by designers**
Child	Client’s negative influence
Child	Lack of designer safety competency
Child	Burden of cost
Child	Other challenges
Child	Time limit
Parent	**Proposal for improvement**
Child	Advance planning
Child	Client’s positive influence
Child	Design and build under one contractor
Child	Good communication and engagement
Child	Prefabrication of building components
Child	Standards and regulation
Child	Using BIM

4.2.4.1 The disagreement themes

In the search for a harmonised label for codes reflecting participants’ disagreement towards the five variables or relating to designer responsibility, the common characteristic amongst these codes is disagreement. Therefore, these codes were aggregated under the ‘Disagreement’ theme, consisting of three child codes: disagreement with designers’ responsibility, disagreement with building material, and disagreement with permanent structure. The ‘Disagreement’ theme contains 16 references from five participants. The distribution of these child codes within the ‘Disagreement’ theme is illustrated in Figure 14 below.

Figure 10 Distribution of child codes within disagreement parent code

4.2.4.2 ‘Difficulties faced by designers’ theme

Many participants have mentioned barriers and issues that prevent them from considering safety during the design phase. These issues were coded with suitable labels reflecting their meanings, resulting in the creation of five codes, including time pressure, burden of cost, negative influence of the client, safety competency of the designer, and others. The total number of references in this theme is 29, coming from all six participants. The distribution of these five codes within the theme is illustrated in Figure 15.

Figure 11 Distribution of child codes within 'difficulties faced by designers' theme

4.2.4.3 Proposal for improvement theme

At the end of each interview, the participant was asked to provide suggestions to encourage designers to consider safety during the design phase. These suggestions have been coded into seven different categories, including regulation and standard, positive client influence, using Building Information Modelling (BIM), using prefabricated building components, promoting good communication and engagement, adopting design and build under one contractor, and emphasising advance planning. This theme contains 28 references coming from all six participants. Figure 16 below illustrates the volume and distribution of these seven codes within this theme.

Figure 12 Distribution of child codes within 'proposal for improvement' theme

4.2.4.4 'Permanent structure' theme

This theme emerged from the literature review, confirmed by quantitative research conducted in advance in this study, and supported by evidence from the current qualitative research. All six participants provided examples of how the type, shape, and geometry of the permanent structure could cause accidents. In total, there are 21 references coming from six files (participants) in this theme. Using NVivo enabled the researcher to measure the percentage of data related to this theme in each participant's transcript (Figure 17 below).

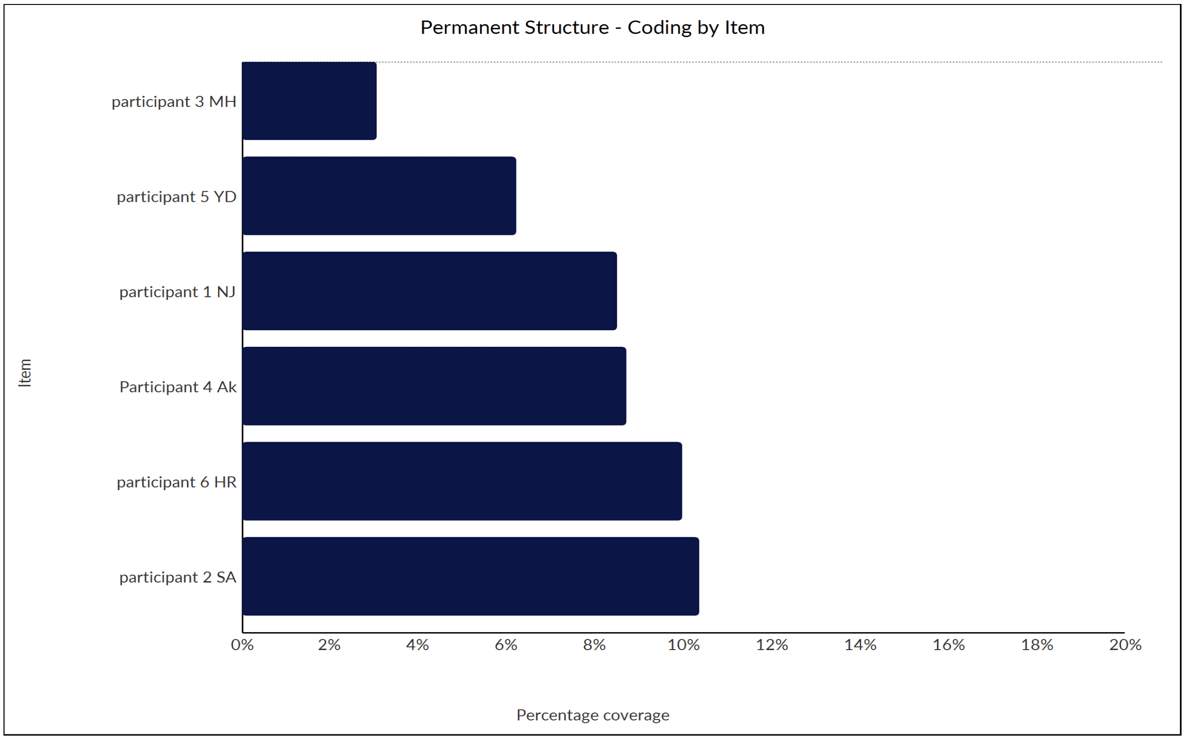


Figure 13 Percentage of data in transcripts related to 'permeant structure' theme

4.2.4.5 'Temporary structure' theme

This theme emerged from the literature review, was confirmed by the quantitative research, and is supported by evidence from the current qualitative research. All six participants provided examples of temporary structures that could lead to accidents. In total, this theme comprises 20 references from the six participants. The use of NVivo enabled the researcher to measure the percentage of data related to this theme in each participant's transcript (refer to Figure 18).

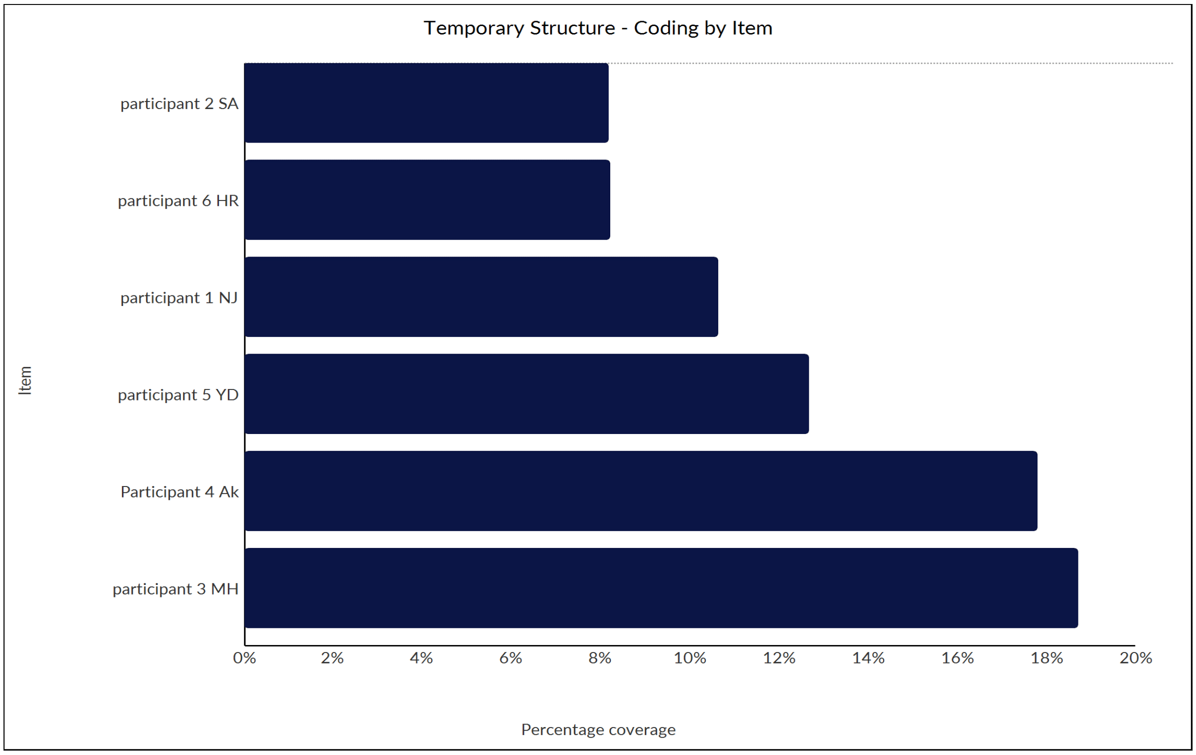


Figure 14 Data percentage in the transcripts related to 'temporary structure' theme

4.2.4.6 'Building vehicles, machine and equipment' theme

This theme surfaced during the literature review, solidified by the previously-conducted quantitative research and fortified by evidence from this qualitative investigation. Each of the six participants contributed examples of how building vehicles, machinery, and equipment could cause accidents. In its entirety, this theme encompasses 12 references from the six participants. The utilisation of NVivo empowered the researcher to gauge the proportion of data pertinent to this theme in each participant's transcript (figure 19).

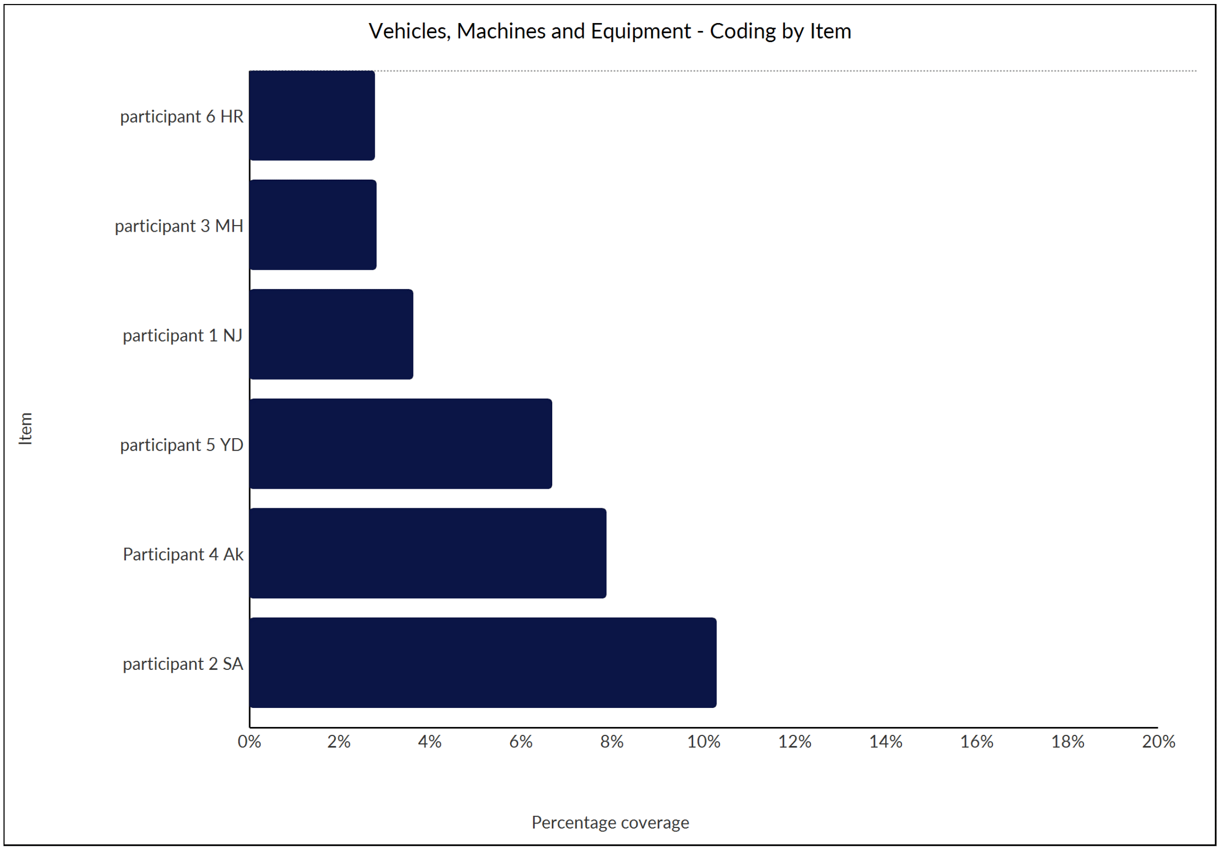


Figure 15 Data percentage of 'building equipment' theme

4.2.4.7 'Building material' theme

This theme emerged from the literature review, further validated by the quantitative research and substantiated by evidence in this qualitative research. All six participants provided examples illustrating how building materials could lead to accidents. In total, this theme comprises 18 references from the six participants. The use of NVivo enabled the researcher to assess the percentage of data related to this theme in each participant's transcript (see Figures 20).

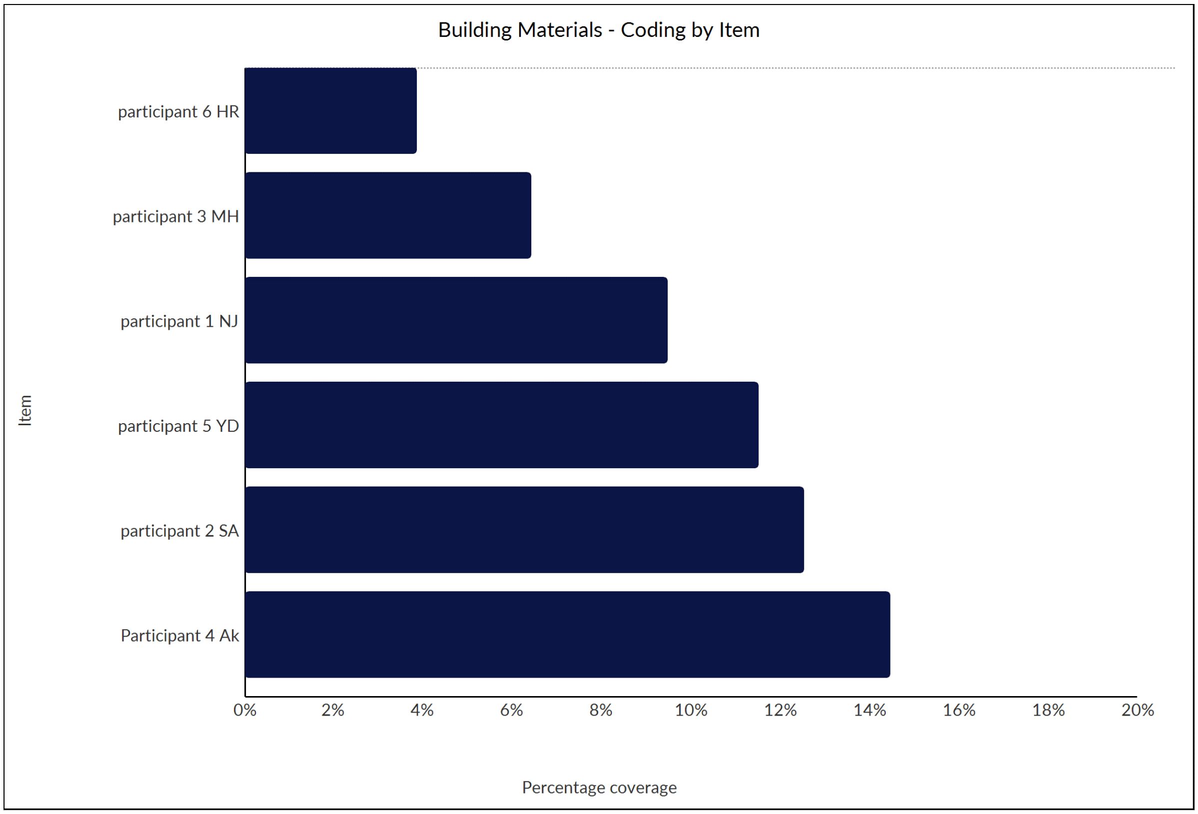


Figure 16 Data percentage in the transcripts related to the 'building material' theme

4.2.4.8 'Site environment' theme

This theme surfaced during an extensive literature review, fortified by quantitative research and substantiated through evidence from this qualitative research. The six participants provided examples of the building site environment that could lead to accidents. This theme encapsulates 18 references from the participants, with NVivo facilitating the measurement of data percentages pertinent to this theme in each participant's transcript (refer to Figure 21 below).

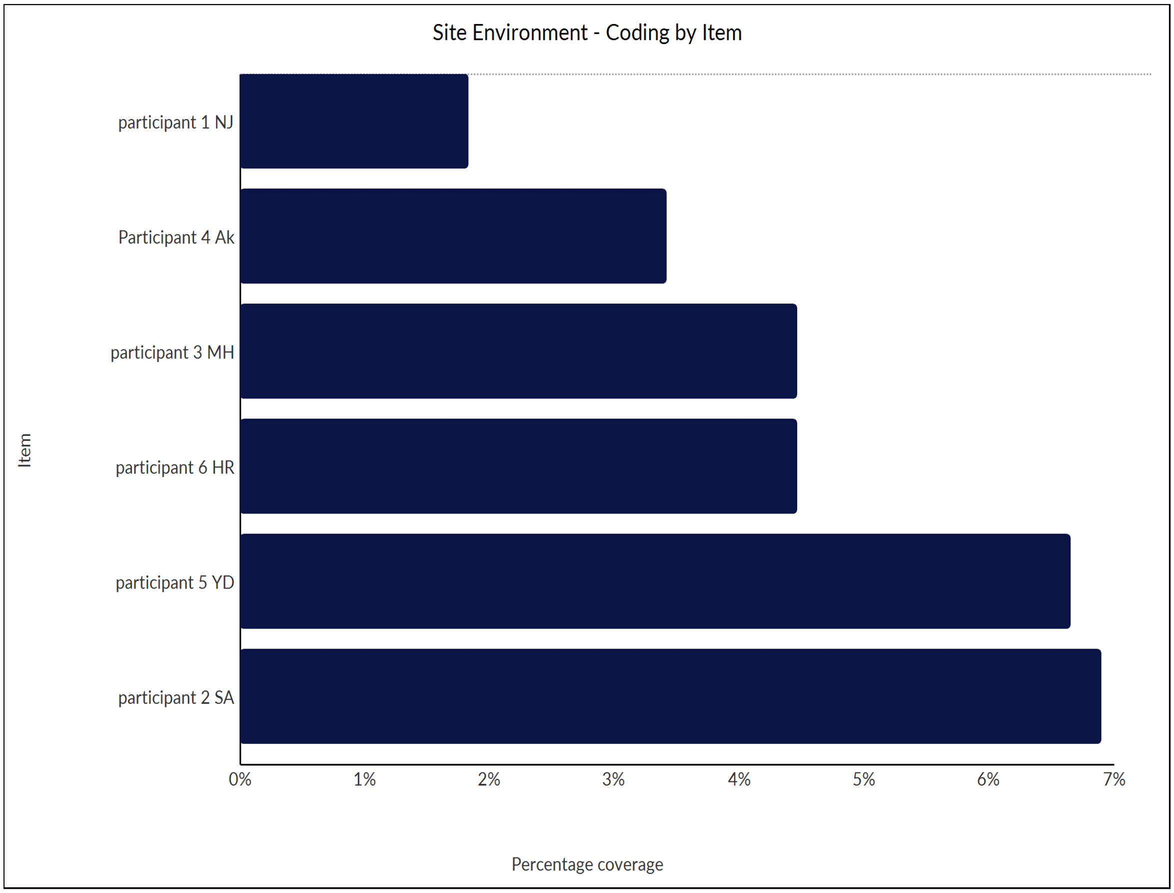


Figure 17 Data percentage in transcripts related to the 'site environment' theme

4.2.5 Final themes

In this phase, the author refined, adjusted, generalised, and shortened the theme names, which led to changes in some theme labels. Table 35 below demonstrates the initial and final names of each theme. In this stage, each theme was highlighted, supported by participants' quotations, and a summary was provided regarding points of agreement, disagreement, or doubt.

Table 21 Final theme names

No	Initial name	Final name
1	Permanent Structure	Permanent Structure
2	Temporary Structure	Temporary Structure
3	Building vehicles, machine and equipment	Building Equipment
4	Building material	Building material
5	Site Environment	Site Environment
6	Difficulties facing designers	Obstacles
7	Proposal for improvements	Improvement
8	Disagreement	Disagreement

4.2.5.1 Participants' view on 'permanent structure' theme

In the interview, questions were asked regarding building permanent structures to measure the level of agreement with the statement that the shape, size, and weight of such structures can lead to accidents. All participants come from a construction background and understand that permanent structure refers to any part of the building that remains throughout its lifecycle, such as walls, columns, floors, roofs, glass, doors, cladding, etc. All participants unanimously agree that permanent structures could cause accidents and provide examples of such structures.

For instance, PS1 stated:

"I can give you an example of a permanent structure that is more dangerous than others; for instance, a steel structure is much more dangerous than concrete". – (PS1)

Moreover, PS3 viewed building elevation as a risk factor, disclosing that:

"Yes, sure, high-rise buildings, in general, are much riskier than horizontal buildings". – (PS3)

PS5 confirmed and justified this by saying:

“Many things in high-rise buildings are taken into consideration where it is not considered in small buildings. For example, wind load, earthquake impacts. Surely, size and shape have a great influence on the safety of the project”. – (PS5)

According to PS2, building geometry could be a risky factor:

“Safety is very important, and some geometric shapes are more dangerous than others. I give an example in Riyadh; the HQ of the police is a building that looks like the opposite pyramid. It is an eye-catching iconic building but was a great challenge to build, extremely dangerous for the construction team, and later will be a great challenge for the demolishing team as well.” – (PS2)

The participants confirmed that building permanent structures can lead to accidents, and they emphasised that designers during the design phase are the ones who determine it. PS2 stated:

“The architect is the one who starts the creative process that ends up as a building. The safety of all teams involved in the building project, including the occupier, depends on the building's permanent structure. The most dangerous phases are the construction and demolishing phases”. – (PS2)

PS6, who is an architect with 35 years of experience, confirmed that designers are the ones who determine the permanent structure. He raised objections against certain types of buildings by saying:

“Here in the Middle East, there is architectural criminality happening, by building a full glass building. This type of glass box is not fit for the hot area, too much cost for cooling”. – (PS6)

The direct and indirect statements of the participants confirm that designers are the ones who determine the permanent components of the building and have a significant influence on the building's permanent structure during the design phase.

4.2.5.2 Participants' views on 'temporary structure' theme

The participants were asked whether building temporary structures can lead to accidents in construction. The concept of temporary structures, including components used temporarily to construct the building, such as, but not limited to, scaffolding, storage, site layout, barriers, fences, temporary site roads, excavations, supports, etc., was explained to the participants. This question was asked to measure the agreement level of the participants. In addition, the participants were asked to provide examples, from their experience, of such temporary structures that could lead to accidents.

PS4 agreed that temporary structures could cause accidents and provided an example:

"Yes, it does. For instance, one of the causes of accidents here in Nigeria is removing the scaffold parts (dismantling the scaffold). If the parts are not tied well or not installed well, it could lead to the collapse of the scaffold during dismantling. Also, before erecting scaffold, you have to test the material and the components of the scaffold and make sure it is to the accepted standard". – (PS4)

PS2, who is an architect and project manager, gave a comprehensive answer on this topic as he had worked in both the design and construction phases:

"Temporary structure has a major contribution to safety during the construction phase. For example, scaffold; it is by itself a project that has expert designers and professional erectors. Designers, civil engineers, and project managers contribute towards the specification and the function of the scaffold that serves the manoeuvre and material handling and staff access to higher floors. Designers also develop the site layout that contains places for storage, roads for plants and vehicles movements, residence and accommodations for staff, offices. The site layout is part of the design document". – (PS2)

PS3 also perceived the same meaning and stated:

"Look, anything not planned in advance will create problems. We cannot get rid of temporary structures; it is a very essential component that helps to build the project.

To minimise hazard created because of temporary structure, it needs to be well planned in advance. You need to have examples from previous projects which will assess the suitability of the temporary structures. For example, site layout, normally we do M numbers of layouts because in each stage the site layout will change depending on the timeline of the project during the execution phase". – (PS3)

In relation to how much control designers have over temporary structures, all participants agreed that designers can contribute. However, the main figure who decides on the temporary structure is the project manager during the construction phase. PS5 explained that:

"The project managers with the construction team decide on the mobilisation and site layout plans. During the executions (construction phase), locations and types of temporary structures will be determined". – (PS5)

According to PS2 and PS3, designers make some contributions to temporary structures. However, some participants did not accept that designers can contribute to the safety of temporary structures. For instance, PS1 disclosed that:

"In general, we as designers do not design the temporary structure or interfere with that. Because: One, it is extra time and cost, which the client is not willing to pay for, and two, it is the main contractor's job, and we don't have a legal obligation to do that". – (PS1)

From the participants' answers, it is clear that temporary structures could cause accidents during the construction phase. However, the designer's influence on temporary structures is much less compared to that on permanent structures; this will be further discussed (in the discussion chapter).

4.2.5.3 Participants' views on 'building equipment' theme

This theme describes the participants' views on whether building equipment could cause accidents and whether designers have any influence on building equipment during the design phase. The meaning of equipment in this theme has been explained to the participants, including vehicles, machines, heavy plants, and electrical and mechanical tools.

All participants agreed that building equipment could be a source of accidents on a construction site. PS1 disclosed that:

"Yes, it is affecting the safety. The bigger the equipment or plant, the more dangerous it is. But we, as designers, do not get involved in selecting this plant or equipment. Normally, contractors are responsible for it. The designers do not interfere with the building equipment at all". – (PS1)

PS3 supported this view, stating that:

"Yes, building vehicles and equipment affect the safety. Always in the technical proposal, the construction company should provide (to the owner and his consultants) the type, the age, the specification of each piece of equipment that will be used during the construction phase". – (PS3)

Regarding whether designers have influence on building equipment during the design phase, most participants objected to that idea and saw building equipment as something to be concerned with during the construction phase and not earlier (design phase). The quotations of PS1 and PS3 demonstrate this, and are supported by PS2, who disclosed that:

"Unfortunately, the architect and designers do not involve in selecting plant and construction vehicles or equipment unless the architect is the project manager as well". – (PS2)

PS4 had the same view, stating that:

"Interviewers: who determine the type of equipment and its locations on-site Interviewees: the project managers, not the designers. The project managers take advice from mechanical and civil engineers before deciding on the equipment". – (PS4)

The same answer was also given by PS5. However, PS6 agreed that designers can contribute to the safety of handling building equipment. He disclosed that:

“Normally, the contractors who determine that. The designers can be engaged in determining their locations, but the full mobilisation plan is done by contractor engineers and it must be approved by the site manager”. – (PS6)

As clearly shown above, participants agree that building equipment is dangerous and could cause accidents but doubt and disagree when it comes to the designer’s ability to influence the selecting of equipment or its location during the design phase (this will be examined further in the discussion chapter).

4.2.5.4 Participants’ views on ‘building material’ theme

In this theme the participants were asked whether building material could cause accidents and whether designers during the design phase can influence building material. The meaning of building material has been explained to the participants, which includes any material that is part of the building, such as glass, steel, cement, timber, PVC, etc., or any materials used to attach parts, such as silicon, foam, glue, wires, etc.

Five participants agreed that building material could lead to accidents, and some building materials are more dangerous than others. PS2 disclosed that:

“Certainly, materials affect the safety of the construction staff, even in decoration. For example, if a worker has to install a 150kg decoration cladding stone to an upper level, it is much more dangerous than using paint to decorate the building”. – (PS2)

This view was supported by PS1, PS3, PS4, and PS5, as they accepted that building material could cause accidents and provided many examples. For instance, PS6 stated:

“Precast and post-tension slabs are much more dangerous. The cables could snap and lead to fatal accidents, and it happens during the construction phase many times”. – (PS6)

To a high degree, participants agreed that designers, during the design phase, select the building material and write its specification, thus having great influence on building material.

PS1 stated that:

"Yes, it is affecting the safety, and the designers generally determine its specification. The designers determine the vendor list, and the consultant supervises and checks that the main contractor uses exactly the building material which is specified in the vendor list". – (PS1)

This view was supported by all participants. However, some participants, such as PS3, found that the material itself and its specification are not safety issues. According to PS3, handling the material is what causes accidents. PS3 disclosed that:

"Yes, it is. Normally, building material shape and size are standard. The safety hazard really here is the handling of the building material". – (PS3)

Based on most interviewees' responses, building material can cause accidents on construction sites, and the designers are the main stockholders who decide the specification of the building material, thus meaning that designers have great influence on the 'building material' theme.

4.2.5.5 Participants' view on the 'site environment' theme

Participants were asked in this theme whether the site environment could lead to accidents and if designers have any influence that could help to reduce accidents emerging from the site environment. It was explained to participants that site environment here means weather conditions such as rain, wind, temperature, and also light level, mud and slippery ground, dust, and noise.

All participants agreed that the site environment could lead to accidents and provided various examples. PS1 disclosed that:

"Yes, wind and very high temperature in summer cause many accidents in airport projects". – (PS1)

Another example was provided by PS2:

"Yes, and it's an essential factor in high-rise buildings. Wind load is a main factor to consider, especially the horizontal load. In upper floors, the wind speed is very high. When architects take the decision to build the tower from a light metal structure (the most common structure amongst high-rise buildings), it is very sensitive to wind load". – (PS2)

Moreover, PS4 found rain to be a particular issue that hinders safety, disclosing that:

"It does. The only weather condition that affects the construction project in Nigeria is rain. We are blessed here in Nigeria with good weather; only rain could be an issue during the construction". – (PS4)

In answering the question regarding whether designers have influence on the site environment, all participants agreed that part of the designer's job is to consider environmental conditions in the building. For instance, PS3 declared that:

"Sure, it affects. The heat in this country stops us from work, and even we cannot precast the concrete. The cold weather in Europe, rain and snow, make extra load on the roof. The building in front of the sea with high humidity destroys the façade of the buildings and corrodes the steels of the building. Yes, surely, it's affecting, and especially in the long term. Designers should take that into consideration during the design phase". – (PS3)

In this theme, participants totally agreed that the site environment could lead to accidents, and they also agreed that the designer considers it during the design phase, hinting at influence that could contribute to making building projects safer from the site environment.

4.2.5.6 Participants' view on obstacles

During the interviews, the participants revealed the difficulties faced by designers that prevent them from considering safety and hinder the full exercise of their influence on the above themes. The first obstacle in this theme is client negative influence. PS4's statement highlights this difficulty in his contribution. He disclosed that:

"Where you see building collapse or road collapse, that is because of the influence of the client who goes against the professional advice regarding the best material to use. But when the client insists on using the wrong material, that is where the problem starts and it could lead to the collapse of the building". – (PS4)

Along the same lines, PS1 mentioned client negative influence as an obstacle and added two more obstacles: time and cost. PS1 disclosed that:

"Safety is the last thing we care about during design; this is because many clients' main goal is the cost or quality of the building's material, not the safety of construction workers during the project". – (PS1)

Another added obstacle is the lack of designer safety competency, with PS3 stating that:

"Designers and architects should practice engineering; they should spend some time during their career on-site as building and construction engineers. This will give them great experience regarding the challenges faced by construction teams". – (PS3)

Based on the interviewees' views, the common obstacles include client negative influence, time, cost, and designers' lack of safety competency.

4.2.5.7 Participants' suggested improvements

This theme emerged from the last question put to the participants, where they were asked if they could provide any suggestions to help designers consider safety during the design phase. For instance, PS1 mentioned that enforcement by authorities and clients could push designers to consider safety during the design phase. PS1 disclosed:

“I guess enforcement from clients and authorities helps to engage them to consider safety issues.” – (PS1)

Meanwhile, PS2 suggested good communication and using BIM. He stated that:

“Collaboration with the construction team, the architect should be part of the team and use an integrated process that has been facilitated by BIM software, which helps all designers and constructors to exchange information and have good communications amongst them”. – (PS2)

Another smart suggestion was contributed by PS3, who proposed using the design and build approach under one company, as this will enforce designers to consider the safety and constructability of the building. PS3 disclosed that:

“If you want a safe design, it is good to use the ‘design & build’ approach because the designer and the builders both are in the same firm under one director. The director will enforce the designer team to come up with a safe, constructable, and easy-to-build design. To summarise it, the project delivery method has a great impact on safety. That's why major companies such as Ar---- and Ad---- use the EPC approach, Engineer, Procure and Construct all in one contract”. – (PS3)

The interviewees suggested, for improvement, the following: enforcement from client and/or authority, collaboration with construction project teams, using BIM and using one company that does design and build in one contract.

4.2.5.8 Disagreements raised by participants

This theme emerged as participants rejected certain variables as causes of accidents or rejected the notion that designers can contribute to making one of the main themes safer.

PS6 contributed the most to this theme, viewing safety as an issue for the construction phase and having nothing to do with the design phase. He stated that:

“The designer has no guilt in safety accidents during the construction phase. Normally, the project managers, construction engineers, site supervisors, and the

workers are the ones to blame for safety accidents during the construction phase". – (PS6)

Moreover, PS1 described the reality from his experience, asserting that designers make no contribution to the selecting of safer equipment. PS1 stated that:

"As designers, we do not get involved in selecting this plant or equipment. Normally, contractors are responsible for that. The designers do not interfere with the building equipment at all". – (PS1)

Another disagreement was raised by PS3 regarding building material. He stated that:

"In my opinion, no. What can make a difference is it on-site or off-site, the more it is prefabricated modular, the easier and safer to handle. But the type of building material itself does not make a difference in my opinion". – (PS3)

The disagreements raised by the participants include viewing safety during the construction phase as irrelevant to designers, as well as considering equipment safety and the safety of building materials as non-relevant to designers. These peculiar disagreements were voiced by a minority of interviewees, with none of them being mentioned by more than one participant. To provide clarity on the codes that were agreed upon and disagreed upon, the NVivo diagram option was utilised to compare the transcript with the most disagreements (PS6) and that with the most agreements (PS2), as depicted in Figure 22 below. It illustrates that there are four to six different codes, whilst both agree on 11 codes. This result indicates that the main five themes are agreed upon by all participants, with variations in improvement and obstacle codes.

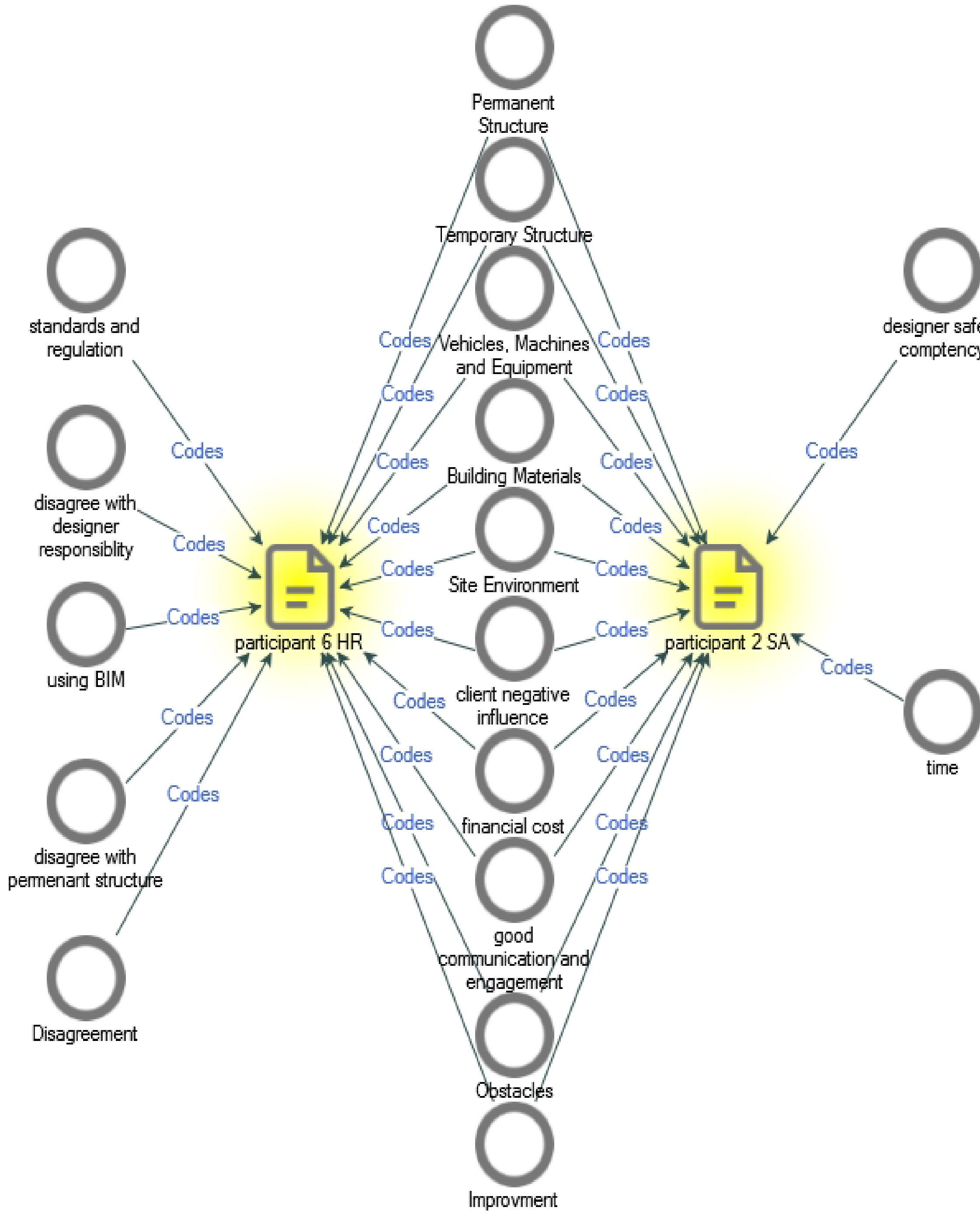


Figure 18 similar codes and different codes amongst PS2 and PS6

4.2.5.9 Level of designers' influence on the five variables' themes

Based on this research, the causes of accidents that could be influenced by designers during the design phase are identified as five themes: permanent structure, temporary structure, building equipment, building material, and building environment. However, participant responses suggest that designers have varying levels of influence on each of these themes during the design phase. The analysis reveals that designers have significant influence over permanent structure and building material, as confirmed by all six participants. They exert a moderate influence on the building environment; participants acknowledge that designers consider environmental conditions affecting the building but overlook their impact on construction teams and equipment (e.g. wind's effect on crane stability). Conversely, designers have a weak influence on temporary structure and building equipment, with 33% of participants disagreeing on their ability to influence these variables. Table 36 below summarises the levels of influence. This qualitative study offers an understanding of numerous factors that can either hinder or facilitate designers' consideration of safety during the design phase, potentially leading to a more comprehensive safety approach in design.

Table 22 Designers' potential influence on themes

Theme	Causing accident	Ranking designer's influence
Permanent Structure	Yes	1
Building Material	Yes	2
Building Environment	Yes	3
Temporary Structure	Yes	4
Building Equipment	Yes	5

4.2.6 CHPtD strength and weaknesses

Based on content analysis (explained in 3.8.6), The 16 strength point of CHPtD (Section 3.8.6.1) were used to evaluate the current 13 CHPtD methods, which were selected through the Prisma analysis (Section 3.8.6.1). The resulting evaluation is presented in Table 8 below, showing how many strength points each method possesses and the number of weaknesses identified. The total score can be found in the last column.

Table 23 CHPtD strength and weaknesses

Strengths and weaknesses of current CHPtD

"CHPtD Matrix""

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
No	**Author/s**	**Measuring strength points**																**Total strength points**
		Encourage prefabricated construction materials	Selecting inherent safer materials	Involve in construction method and techniques	Consider mechanical forces, dynamic motions, electricity and	Improve schedule and decrease cost	Using BIM	Using VR, AR, laser scan or GIS	integration with sustainability, quality management, Etc	Design temporarily structure and site layout	Actively communicate with other stakeholders	engage of stakeholders in design decisions	Using hazard design risk assessment	using process safety	breakdown the project into parts to assess its risk	Consider the full building lifecycle	Using hierarchy of control measures	
1	Ho, C; Lee, HW; Gambatese, JA, 2020	X	Ü	ü	ü	Ü	X	X	X	X	ü	ü	ü	X	X	X	X	**7**
2	Cortes-Perez, JP; Cortes-Perez, A; Prieto-Muriel, P, 2020	X	X	X	X	X	ü	X	X	X	X	X	ü	X	ü	X	X	**3**

3	Li, SM; Yuan, LW; Yang, H; An, HM; Wang, GJ. 2020	X	X	ü	ü	X	X	ü	X	X	X	X	ü	X	X	x	x	**4**
4	Jin, ZY; Gambatese, J; Liu, D; Dharmapalan, V 2019	ü	Ü	ü	x	Ü	ü	ü	x	x	ü	ü	ü	X	ü	x	ü	**11**
5	Yuan, JF; Li, XW; Xiahou, XE; Tymvios, N; Zhou, ZP; Li, QM 2019	ü	Ü	x	x	X	ü	x	x	ü	x	x	ü	x	ü	x	x	**6**
6	Din, ZU; Gibson, GE, 2019	x	X	ü	ü	X	x	ü	x	ü	x	x	x	x	x	x	x	**4**
7	Han, WJ; White, E; Mollenhauer, M; Roofigari-Esfahan, N, 2019	x	X	x	ü	x	x	ü	x	ü	x	x	x	x	x	x	x	**3**
8	Tixier, AJP; Hallowell, MR; Rajagopalan, B; Bowman, D, 2017	x	X	ü	ü	Ü	ü	ü	x	x	x	x	x	x	x	x	x	**5**
9	Ruikar, D, 2016	x	Ü	ü	x	X	ü	ü	x	x	ü	x	ü	x	ü	x	x	**7**
10	Zhang, SJ; Sulankivi, K; Kiviniemi, M; Romo, I; Eastman, CM; Teizer, J 2015	ü	X	ü	x	Ü	ü	ü	x	ü	x	x	x	x	x	x	x	**6**
11	Behm, M, 2012	x	Ü	ü	x	X	x	x	x	ü	x	x	ü	x	x	ü	x	**5**
12	Gangolells, M; Casals, M; Forcada, N; Roca, X; Fuertes, A, 2010	ü	Ü	ü	ü	X	X	X	X	X	X	X	X	X	X	X	X	**3**
13	Floyd, HL; Liggett, DP, 2008	X	X	ü	ü	X	X	X	X	ü	X	X	X	X	X	X	X	**3**

CHAPTER 5: Discussion

5.0 Overview of discussion chapter

This study's primary objective is to formulate a working model by employing process safety to improve CHPtD implementation. The discussion chapter is structured into five segments. The first part discuss accident causes that are susceptible to influence during the design phase, all of which emerged from the literature review and quantitative and qualitative results. The second part discusses CHPtD challenges faced by designers, grounded in the literature and qualitative findings. The third part discusses process safety techniques and their applicability to the construction design phase, derived from content analysis. The fourth part demonstrates how process safety could improve CHPtD implementation, whilst the fifth part demonstrates solutions based on process safety to overcome designers' challenges. These five components will contribute to the development of a detailed work model, which will be explained in the next chapter (Chapter 6) of this thesis.

5.1 Part 1: accident causes that could be influenced during the design phase

The current section addresses the first and third objectives of this thesis, so as to identify construction accident causes that can be influenced during the design phase. Throughout this study, accident causes have been categorised into four key areas: staff competency and behaviour; management, communications, and stakeholders; design, equipment, and materials; and space working conditions, and environment. These causes of construction accidents are supported by Hide et al. (2003), Manu et al. (2012) and Suraji et al. (2001). However, the aforementioned authors did not specify in which construction phase these causes can be influenced, and by whom; it should be noted that, during the design phase, it may not be possible for staff behaviour and management to be influenced (Farooq & Moda, 2022). Nevertheless, the other categories related to unsafe conditions have the potential to be influenced by designers. Moreover, scientific evidence suggests that decisions made during the design phase significantly contribute to the occurrence of accidents in subsequent construction phases.

A critical review of literature on construction accident causes has further split these three categories into five variables, including permanent structure, building equipment, building material, and building environment. This thesis assumes that these five variables are the accident causes that could be influenced during the design phase. The following discussion will explore the results of the literature review, along with the quantitative and qualitative research methods conducted to validate these variables as factors that can cause accidents and can be influenced during the design phase.

5.1.1 Permanent structure

The permanent structure is the outcome of designers' drawings, including the building's type, shape, size, and height, along with its components. During building projects, the designer is responsible for determining all specifications related to permanent structures, forming the basis for the construction team throughout the building process (Hammad et al., 1997).

Quantitative data from the research in this thesis reveal that 97.6% of participants agree regarding the influence of building design—encompassing shape, type, size, and permanent components—on safety during construction, maintenance, or demolition phases. This finding aligns with previous studies (Beham, 2005; Heinz & Gambatese, 1996; Lingard et al., 2015; Driscoll, 2008; Gibb & Haslam, 2004; Toole, 2005). However, Gambatese et al. (2013) and Lingard et al. (2015) pointed out that current practices of designers and architects tend to prioritise the safety of end-users (occupiers) whilst neglecting the safety of workers during construction and other phases. Both studies affirm that designers can indeed influence safety during subsequent construction phases.

Consistent with the literature, the quantitative findings affirm that designers can exert influence over permanent structures during the design phase. Designers have the authority to select permanent components, shape, type, and size of the building, and in many projects they determine the exact specifications of these permanent structures (Einan, Shahda, & Adil, 2019). Consequently, permanent structures and their components fall directly under the influence of designers during the design phase.

Similarly, qualitative research in this thesis suggests that permanent structures can contribute to accidents, which aligned with the statements of the six interviewees. They acknowledge that designers, during the design phase, determine the building geometry, type, and specifications of permanent structures. To mitigate risks, adherence to standard shapes/sizes of the building, as recommended by PS3, is advisable. PS3 highlighted potential hazards when dealing with non-standard shapes or sizes, expressing: *"The safety hazard really here is the handling of the building parts"*. This participant emphasised the challenges arising when architects design something unique, posing difficulties for the construction team in handling it safely. This challenge extends to maintenance during the occupancy phase and demolition. (Examiner 1 , point 16)

Whilst the link between the designer's decisions during the design phase and accidents is well-established, the percentage of accidents that could be prevented by considering safety during design varies. According to Gibb and Haslam (2004), this figure is 47%, whilst Beham (2005) saw it as 42%, and Driscoll et al. (2008) as 37%. Unfortunately, designers in various countries often do not view safety as their responsibility. According to PS6, it is the construction team's job: *"Whatever geometry shape designed by architects, the construction engineer will find a safe way to build it"*. Some participants suggested that regulations and intervention from authorities could compel clients and designers to consider safety. PS6 expressed the following: *"Here, if the government is not enforcing safety regulations, the client, architect, and construction team will not care"*.

In summary, both the quantitative and qualitative research results suggest that designers have significant influence on this variable/theme. Various changes during the design phase could enhance the safety of building design, and considering the safety of permanent structures could prevent a significant number of accidents in the later phases of the project lifecycle.

5.1.2 Temporary structure

Temporary structure refers to any structure built temporarily during the construction, maintenance, or demolition phases; it helps support or provide access to certain parts of the building. Generally, as the name suggests, the temporary structure is removed after the on-site work completes (Mosly & Arabia, 2015). Based on the quantitative study of this thesis, the data suggest an agreement of 97.9% (either strongly agree or agree), whilst the domain total mean is 23.19, with a standard deviation of 3.09. The survey respondents affirm that consideration of the design of the site layout, scaffolding, barriers, material storage, excavation, space for welfare facilities, fences, and closing openings can increase safety and reduce accidents during construction work. However, in practice, such consideration is often left to the main contractors, becoming a secondary issue that can lead to accidents due to poor location or missing temporary structures. Therefore, an opportunity exists where the architect, together with the main contractor, could design these components to help reduce the number of hazards during the construction, maintenance, and demolition phases. NIOSH (2013) recognised that designers have the potential to influence the temporary structure during the design phase; the results of the quantitative study demonstrate that site space, whether narrow or wide, does not make any difference, as the professionals who worked in a narrow site space provided the same level of agreement as the group who worked in a wider site space. Additionally, the result suggests no difference in agreement amongst professionals working on urban or rural projects regarding this variable. From these results, it can be concluded that planning and designing temporary structures during the design phase, in cooperation with the construction team, will reduce the hazards of construction workers on site. Nonetheless, it is worth mentioning that, in some countries, designers avoid becoming involved in construction site activities and the layout, including designing temporary structures, to avoid legal responsibility (Saunders et al., 2016).

In parallel, qualitative research suggests that temporary structures can influence safety on site; PS3 disclosed that: *"We cannot get rid of temporary structures; they are a very essential component that helps to build the project"*. Meanwhile, the temporary structure is one of the main causes of construction accidents; according to Luo et al. (2022), various records exist on the collapse of temporary structures causing damage and injury. The author explained that this happens because not enough attention is paid to safety; here, the authors spoke about the construction phase and the construction team. If we look back at the design phase, it is even more challenging. Designers do not become involved in temporary structures and are reluctant to do so for various reasons. PS1 revealed some of the reasons when he disclosed: *“we, as designers, do not design the temporary structure or interfere with that. Because: One, it is extra time and cost, which the client is not willing to pay for; two, it is the contractor's job, and we don’t have a legal obligation to do that”*. Along the same lines, PS4, PS5, and PS6 also agreed with this statement. Additionally, in countries such as the USA, the architects deliberately do not want to be involved in any construction activities or construction methods, as this could lead to legal liability (Saunders et al., 2016). Moreover, designers’ poor experience and knowledge of how their designs are constructed (Gambatese, Behm, & Rajendran, 2008; Mill, 2010) constitute challenges that still exist today.

Conversely, there are many enablers that could help designers play a role in the safety of temporary structures. An example here is using BIM; this exceptional tool can record and save data regarding the specification of temporary structures, whilst it also facilitates the exchange of information amongst designers and constructors. The 3D tool of BIM makes it easy to visualise each component of the temporary structure; PS6 agreed with and supported the use of BIM, stating that: *“Here in Saudi, we need regulatory enforcement. I hope they enforce using BIM during all phases, the same as the UAE, to enhance cooperation and to improve safety”*. Another example that can assist is AR (augmented reality), which helps workers, when scanning the QR code of a building component, to visualise on their mobile phone the drawings and the specification of certain items (e.g. electrical network, plumbing, water pipes, etc.). At the same time, this tool could be used to demonstrate, to designers, how certain items could be constructed. Increasingly innovative software programmes and applications are coming to the market, such as cameras, drones, construction management systems etc. All of these help construction management teams obtain real data from the field and visualise the work (Vincke et al., 2019); these tools, which record the construction stages, could be employed to help designers understand how building components are built in the field.

In this variable/theme, it is clear that the designers have less influence because of the challenges mentioned above (time, cost, client influence, experience, and regulation). However, there is great potential for designers to be able to contribute positively to the safety of temporary structures with the help of enablers: BIM, construction management system, AR, and other applications. It is worth mentioning that the qualitative research results explain, in detail, the challenges that prevent designers from becoming involved in temporary structures in comparison to quantitative research.

5.1.3 Building equipment

Accident causes related to 'Building vehicles and equipment' that can be influenced during the design phase were tested in the quantitative study of this thesis. Five questions were asked to confirm the extent to which professionals agree with the literature. The level of participant agreement was 74.8%. Considering the level of acceptance amongst the participants that designers can play a role in selecting plants/equipment and their locations on site, with advanced technology such as BIM and VR (virtual reality), the designers have the ability to visualise the movements of plants and equipment on the virtual simulation space during the design phase; indeed, this will help determine location and vehicle/plant specifications that fit the job, thus potentially reducing many unnecessary hazards during the construction phase.

According to Jung et al. (2022), building equipment is one of the leading causes of fatal accidents on construction sites. Notably, a study by Hide et al. 2003 also concluded that equipment could be a cause of accidents on construction sites. In the current study (qualitative part), many participants gave the tower crane as an example of a vehicle that could affect safety on construction sites, with PS2 declaring: *“Yes selecting the right type of plant is very important, for example, there are about 20 different types of cranes and selecting the right one for the function is essential for the safety of the lifting operation”*. The same was disclosed by PS5: *“Yes, especially the tower crane, its design, location and its heights; the correct specification of the crane is very important, need to use the correct type and size”*. The participant also stressed how important it is to manage building equipment on site, and that it is vitally important that site managers are strict with contractors regarding the equipment used on construction sites. PS3 disclosed: *"Yes, building vehicles and equipment affecting safety. Always in the technical proposal the contractor company should provide (to the owner and his consultants) the type, the age, the specification of each piece of equipment that will be used during the construction phase"*. The belief of the interviewees that construction equipment could lead to accidents is consistent with researchers' conclusions, with authors such as Qi et al. (2023), Wang et al. (2022), Fang and Teizer (2014) and Hide et al. (2003) confirming the significance of construction equipment.

The other question which this study explores pertains to whether the professionals in the field agree that the designers, during the design phase, can play a role in making building equipment safer. Most participants' first answer was 'No', and they consider this variable to be non-relevant to the designer's job; equipment, in their first view, is something which contractors select and manage on site after obtaining approval from the site manager. When PS4 was asked who decides which equipment should be used, he stated: *"Interviewees: the project managers not the designers, the project managers take advice from mechanical and civil engineers before deciding on the equipment"*, whilst PS1 demonstrated his objection to involving designers when it comes to building equipment: *"the bigger the equipment or plant the more dangerous it is, but we, as designers do not get involved in selecting these plants or equipment; normally contractors are responsible for that"*. When the author explained to the participants how new technology, such as simulation, 3D animation, VR and AR can help visualise how equipment works on site and how BIM can be coupled with a database of equipment specifications, they agreed that designers can play a role in selecting equipment and its location on construction sites. PS5 disclosed: *"Interviewers: exactly with this new technology, the designer can test many various equipment and plant movement to select the best one and can also determine the best location for erecting the tower crane. Interviewees: surely if the architect and designers do that, it will make the execution phase very easy and will eliminate many problems and safety issues"*.

It is worth mentioning that there are not many studies concerning how designers, during the design phase, can contribute to the selection of equipment, as the current norm in the industry is that equipment is something for the construction team, during the construction phase. This variable/theme discussion holds that building equipment is a potential cause of accidents on construction sites. Indeed, academics and professionals agree with this statement. However, designers, during the design phase, do not become involved in selecting the equipment. Meanwhile, new technology provides great potential to designers to play a positive role in reducing accidents associated with the use of building equipment (Huang et al., 2018).

5.1.4 Building material

Building material accident causes related to 'Building material' that can be influenced during the design phase have been examined in the quantitative study of this thesis. Five questions were set to confirm the extent to which professionals agree with previous studies. The level of participant agreement was 97.6%. Each building material has its own properties, which may be hazardous; indeed, cement, glue, metal dust, silica, and wooden dust are examples of building material that could lead to health problems (HSE, 2015). In addition to this, processing material, lifting it to the required position, and installing it are all hazardous activities that could lead to accidents on site (Haslam et al., 2005). Moreover, the size, weight, and shape of the used building material can cause serious accidents on site (Galeoto et al., 2017). In addition, the qualitative study confirms the same; the participants of the interviews agreed with this, with PS4, for example, stating that *"Yes it does, the heavy material is riskier"*. Moreover, PS5 added that the working method associated with handling material should also be a concern; he disclosed that: *"each material and working method has its specific risk, working, for example, with precast and prefabricated material will need to use cranes and riggers"*. The responses of PS1 and PS6 were in the same direction. Moreover, PS3 found that building material itself is not a safety issue; handling and processing building material are hazardous activities and how more building parts fabricated in the factory (prefabricated) it reduces time on-site and makes it easy to handle; it will, in return, reduce the probability of accidents.

He stated: *"in my opinion no. What can make a difference is it on-site or off-site, the more it is prefabricated modeller the easier and safer to handle, but the type of building material itself does not make a difference in my opinion. Off-site is building in the factory and it can be controlled with much better safety measures than the construction site"*.

In answering whether designers can influence material selection, PS1 stated: "*the designers generally determine its specification. The designers determine the vendor list and the consultant supervises and checks that the main contractor uses exactly the building material which is specified in the vendor list"*. PS6, PS5, and PS2 put forth similar responses. Moreover, PS4 stated that building material is decided by various professionals; he disclosed that: *"the architect, structure engineer, project managers determine the type of material and the safety officer also input on this decision"*. When looking to improve this theme, prefabricated building material presents as one of the most suitable options to reduce time and work activities on construction sites; Hardison and Hollywell (2019) predicted that prefabrication will improve CHPtD in the future. PS3 supported that by disclosing: *"the more it is prefabricated modeller the easier and safer to handle"*.

In this variable/theme, it is clearly demonstrated that building material could be a cause of safety accidents. According to academia and professionals, the designer is one of the essential stakeholders who determine its selection (Giribini et al., 2019; Behuinova et al., 2021). Based on this study, the building material theme is the second theme after the permanent structure that designers have great influence on during the design phase.

5.1.5 Building environment

In terms of building environment regarding accident causes related to 'Building site environment' that can be influenced during the design phase, five questions were asked to confirm the extent to which professionals agree with the academics. The level of participant agreement was 98.3% (either strongly agree or agree). Weather condition is one of the key issues which designers should consider for the stability of the building itself; at the same time, weather condition can affect the stability of construction sites, as heavy rain, mud, and strong wind lead to many accidents. Various cranes have collapsed as a result of the wind (Klinger, 2014). Hot weather, specifically heat waves, has been proven to affect workers' health and well-being (Rameezdeen & Elmualim, 2017); when PS1 was asked if the site environment could lead to accidents, he stated: *"Yes, wind and very high temperature in summer cause many accidents in airport projects"*; PS6 and PS3 both talked about heat and wind as challenges that face workers during the construction phase. PS6 also revealed that designers should consider corroded weather (near to the sea), and select building material that has high resilience against corrosion.

When participants were asked whether designers can contribute to the safety of construction projects, most interviewees referred to the calculation of the wind load during the design phase and the selection of building material, whilst they also referred to authority regulations that prohibit work during heat hours (from 11:00 until 15:00 in summer time). It became clear, in this theme, that all participants agree that the site environment is an issue that could lead to accidents; meanwhile, they also agreed that designers, during the design phase, can contribute to reducing construction accidents which emerge from the environmental condition.

5.1.6 Summary of part 1

Based on the discussion above, the five variables/themes are causes of accidents that can be influenced during the design phase. Meanwhile, designers have a significant influence on two variables/themes, namely permanent structure and building material, although a lack of knowledge on construction activities and construction methods means that designers cannot fully know how to select safer permanent structures or safer material. It would be beneficial for designers to join on-site meetings, and it would help to let young designers work for a couple of weeks on site to attend critical construction activities; this is to appreciate and understand the impact of the design on construction teams' lives. Moreover, the new technology which exists nowadays helps and opens new doors for designers to interfere in selecting building equipment and temporary structures; it would be helpful if designers participated in specialist contract meetings to understand the impact, limitations, and challenges realised of these two variables. Moreover, the study illustrates that designers are knowledgeable and aware of the building site's environmental impact on safety, and they cautiously consider the effect of wind directions and loads on the building itself. This hints that they consider the occupier phase; however, not much consideration is given, during the design phase, regarding the building's environmental impacts on the safety of staff on site (construction, maintenance, and demolition teams). This part of the discussion achieved objectives 1 and 3 of this study (see Section 1.4).

5.2 Part 2: CHPtD evaluation and designers' challenges

This section addresses the second objective of the thesis, which is to evaluate the strengths and weaknesses of CHPtD literature. The analysis involved identifying the strengths (n = 16) present in CHPtD literature and then assessing each piece of selected CHPtD literature based on these identified strengths. The strengths were categorised into four groups (5.2.1 - 5.2.4) to facilitate a comprehensive examination. Simultaneously, the current section aims to uncover the challenges and difficulties encountered by designers during the implementation of CHPtD. The literature review uncovered eight primary challenges, and three new additional challenges emerged during the qualitative research. These difficulties will be thoroughly discussed in Section 5.2.5.

5.2.1 Design's components

Under this domain, there were four identified strength points: encouraging prefabricated construction materials, selecting inherently safer materials, designing temporary structures, and site layout. The data suggest that 56% of the selected CHPtD methods lack one or more of these four points. The importance of these points aligns with studies by Jin et al. (2019) and Boadu et al. (2020). It is concerning that over half of the CHPtD methods are missing vital strengths, thus contradicting the basic concept of CHPtD, which aims to eliminate hazards through design changes. The absence of crucial points, such as 'selecting inherently safer material', indicates a serious weakness in these CHPtD methods. Using methods with such significant weaknesses will not support designers in implementing CHPtD effectively or complying with CDM2015 regulations.

5.2.2 Using advanced technology/software

This group comprises two strength points: Using Virtual Reality, Augmented Reality, laser scan or GIS, and Using Building Information Modelling (BIM). The data indicate that 50% of CHPtD methods lack these strength points. Additionally, three interview participants (PS3, PS5, and PS6) admitted that such technology is rarely used, especially in many Middle Eastern countries, where it is limited to well-funded mega projects. Despite the importance stressed in various pieces of literature (Cortés-Pérez et al., 2020; Zhang et al., 2015), particularly the promotion of BIM by regulatory bodies (HSE, 2018), limited adoption poses challenges. Case studies by the HSE (2018) highlight the potential of BIM features, enabling designers to engage in key areas previously not accessible. Resistance and incompetence in using such technology impair effective communication and the storing of safe design data for future projects, thus representing a weakness that hinders CHPtD implementation.

5.2.3 Using safety principles to implement CHPtD

In this domain, there are five strength points related to basic safety principles, including using risk assessment, breaking the design into manageable parts, using safety hierarchy of control measures, considering the full lifecycle phases, and using process safety techniques. The data indicate that 80% of current CHPtD methods lack two or more of these strength points. Many authors creating these methods lack a safety background, resulting in missing essential safety principles. This weakness makes CHPtD methods ineffective, as designers lacking safety experience may struggle to eliminate design hazards. NIOSH (2010) and Gambatese (2019) highlighted designers' lack of safety knowledge, emphasising the importance of incorporating basic safety principles into CHPtD methods.

5.2.4 Engage/consider other stakeholders

In this domain, the five strength points include involving the construction team with experience in construction methods and techniques, project managers with experience in project schedules, individuals considering quality and sustainability, actively communicating with other stakeholders, and involving stakeholders in design decisions. The data suggest that 70% of current CHPtD methods lack one or more of these strength points. Isolation from other stakeholders hinders the identification of all design hazards. Toole and Gambatese (2008) and Li, Greenwood, and Kassem (2019) similarly pointed out poor communication as a weakness amongst construction stakeholders. Most interviewees admitted to communicating with clients and some construction teams only (PS1, PS3, PS4, PS5, and PS6). There is a need for multidisciplinary teams, including construction safety, project management, procurement, site experience, and specialist contractors, to make design decisions together with designers. This collaborative approach will consider many angles affecting safety issues. Moreover, considering hazards throughout the lifecycle of the building project also requires the engaging of maintenance and demolition teams.

5.2.5 Designers' challenges during CHPtD implementation

Kim, Ryu, and Kim (2021) asserted that there is no data bank which stores safety design decisions, following which they suggested that having one would facilitate the creation of a real-time database for future projects, offering solutions and alternatives. The data indicate that all interviewees acknowledge the absence of a safe design data bank. Recent literature attempts to address this challenge, as seen in the works of Jin et al. (2019) and Lu et al. (2021).

The data likewise indicate that some designers lack site experience and safety knowledge. Several designers do not consider these aspects as essential in the design phase, as stated by PS3 and PS6. They perceive their role as designers without the need to be involved in site activities, relegating safety responsibilities to the construction team. Similarly, this challenge is identified by Manu et al. (2020) and Acheampong et al. (2024). The lack of safety knowledge and site experience hampers designers in effectively eliminating hazards through design, hindering the implementation of the CHPtD concept. This perception highlights that CHPtD is an unfamiliar concept amongst designers in certain countries. In **triangulation** with literature review Similar weaknesses were identified by Gambatese and Hinze (1999) and Lingard, McCabe, and Trethewy (2015). Additionally, Sanders et al. (2016) emphasised that the legal system in some countries, such as the USA, discourages designers from becoming involved in site decisions due to potential legal liability. Consequently, designers in these countries deliberately avoid site involvement or engagement in safety issues.

The data support the observation that designers face challenges in communication, as noted by PS, PS3, PS4, PS5, and PS6. This finding aligns with the conclusions of Toole and Gambatese (2008), and this finding also **triangulate** with DfS literature, a poor communication highlighted by Manu and Che Ibrahim (2022) and (Che Ibrahim et al., 2022), One possible reason for this is that many stakeholders are not yet identified, including the maintenance team. Some stakeholders, such as the demolition team, may join the project years after the design phase. Furthermore, not engaging with other stakeholders prevents designers from being aware of hazards that could be eliminated through design decisions or alternative designs that could enhance the safety of the maintenance or demolition teams.

Moreover, the qualitative findings of this thesis bring to light three additional challenges, with a notable focus on time and cost—two critical concerns for designers. PS2, PS3, PS5, and PS6 collectively emphasised that giving due consideration to safety necessitates a more substantial investment of time and an increased frequency of meetings. These aspects contribute to additional costs, thus posing a dilemma, as clients and investors are often reluctant to bear such financial burdens. Additionally, PS1, PS4, and PS5 voiced complaints regarding the adverse influence of clients. They highlighted instances where clients advocate for expediting the design process, often at the expense of thorough safety considerations for subsequent project phases. This pressure to meet tight deadlines and cost constraints introduces a challenge for designers, as it may compromise the meticulous integration of safety measures into the design. These three challenges found in the qualitative study **triangulate** with DfS literature as its similarly identified by Acheampong et al., (2024) and Umeokafor et al., (2023).

5.2.6 Links between accident causes and gaps in DFS/CHPtD

As highlighted in sections 2.2.5.1 and 2.2.5.4, there is a significant gap in empirical research measuring the effectiveness of Design for Safety (DfS) within construction projects. Specifically, there is limited research addressing the full lifecycle of construction projects. Bridging these gaps presents considerable challenges, as it necessitates the identification of an existing and widely recognised DfS work model as a subject of study. Furthermore, it requires the identification of multiple projects implementing this model to facilitate comparisons with other construction projects that do not adopt DfS principles throughout their lifecycle. The comparative analysis would examine safety outcomes, particularly the incidence of accidents, across these two groups. Notably, the lifecycle of a construction project—from design to demolition—can span decades, further complicating longitudinal studies.

Nevertheless, understanding the causes of accidents attributable to designers' influence could aid in developing a robust DfS work model. This model should emphasise five key domains of accident causes under the influence of designers: permanent structures, temporary structures, building materials, construction equipment, and the building environment.

Moreover, there is an identified gap in the regional adoption of DfS practices (section 2.2.5.2). The findings of this study, which categorise five types of accident causes that can be mitigated during the design phase, offer a guide to safety regulators globally. These findings can inform the development of regulations that provide explicit guidance to designers, encompassing all five domains rather than focusing solely on permanent structures and building materials. Such regulations could detail safety considerations for each domain, thereby encouraging more comprehensive integration of safety issues into the design phase.

The gap in industrial training (section 2.2.5.3) could also be addressed through the development of detailed work models based on these five domains of accident causes. These models, covering the entire lifecycle of construction projects, should embed risk assessments and safety principles—features often absent in existing Construction Hazard Prevention through Design (CHPtD) models (e.g., Table 8 in section 4.2.3). Incorporating these elements into training programmes would enhance designers' understanding of safety in building equipment and temporary structures—areas where their expertise is often very limited. Additionally, training should address accident causes associated with permanent structures, building materials, and the construction environment.

Finally, addressing the underrepresentation of critical industry sectors (section 2.2.5.5) will require a long-term approach. Historically, safety models are first implemented in large-scale or public projects before cascading to medium-sized and small projects. Over time, as these models are practised, the cost of implementation decreases, their efficacy is demonstrated, and regulatory frameworks mandate their adoption, they become standard practice. The identification of the five key accident causes in this study provides a foundation for developing practical work models that clarify how designers can influence safety during the design phase. Such clarity will be crucial in promoting DfS across projects of varying scales.

In summary, addressing these gaps—empirical evaluation, lifecycle integration, regional adoption, industrial training, and sectoral representation—requires the development of comprehensive, lifecycle-inclusive DfS models. These models should align with identified accident causes, incorporate training elements, and guide regulatory development to achieve widespread and effective implementation of DfS in the construction industry

5.2.7 Summary of part 2

The evaluation of CHPtD literature identified weaknesses, with a majority of methods lacking crucial components, such as challenges in technology adoption, safety knowledge and stakeholder involvement. Considerations during implementation were evident. Additionally, designers faced hurdles related to a lack of safety data banks, insufficient site experience, lack of safety knowledge, and communication issues. Clients' influence and time pressures emerged as critical challenges. In conclusion, addressing these deficiencies is vital for enhancing the effectiveness of CHPtD implementation, ensuring comprehensive safety integration in construction design, and fostering a collaborative approach amongst stakeholders to overcome the identified challenges. This part of the discussion achieved objective 2 of the current study (see Section 1.4).

5.3 Conclusion of discussion chapter

In conclusion, there has been presented a comprehensive overview of the challenges and solutions surrounding construction safety, with a particular focus on the role of designers in mitigating project safety risks during the design phase.

Designers have significant influence over variables such as permanent structure and building materials, yet face hurdles stemming from a lack of construction knowledge and inadequate consideration of environmental impacts on site safety. Recommendations to address these challenges include active participation in on-site meetings, leveraging new technologies, and providing opportunities for young designers to gain practical experience. In addition, designer has less influence on temporary structure and building equipment, however new technology enable designer to have an impact on these two variables. Evaluation of CHPtD literature reveals deficiencies in current methods such as technology adoption, risk-based approach and stakeholder involvement. Overcoming these shortcomings is vital for enhancing safety integration and fostering collaboration amongst stakeholders throughout the project lifecycle. Leveraging advanced technology and engaging all construction stakeholders promote holistic safety considerations, aligning with regulatory standards and reducing accident causes. Meanwhile, scrutiny of challenges faced by designers underscores the importance of addressing issues such as deficient communication and reluctance towards technology adoption.

CHAPTER 6: Conclusions & Recommendations

6.1 Conclusion overview

This chapter provides a summary of key findings in relation to the aim and objectives, as well as its contribution and value to the knowledge. It also discusses the limitations and proposes suggestions for future studies. Recommendations for the designer's society and policymakers are included.

6.2 Achievements of aim and objectives

One of the objectives of this thesis is to identify construction causes that can be influenced during the design phase (objective 1, see Section 1.4). The literature review and quantitative and qualitative research indicate five variables: permanent structure, temporary structure, building material, building equipment, and building environment. The study reveals that designers have varying levels of influence on these variables, with significant influence on permanent structure and building material, moderate influence on building environment, and weaker influence on temporary structure and building equipment.

Moreover, objective 2 about assessing the strengths and weaknesses of current CHPtD methods. The results show that none of the selected CHPtD methods exhibit all 16 strength points. Weaknesses include not incorporating safe design or safe building components, lacking supportive IT solutions (e.g. BIM, simulations, AR or VR), not utilising safety techniques and principles to identify and eliminate construction project hazards, and failing to engage all stakeholders during design decisions. Additionally, no CHPtD method clearly considers the entire lifecycle of the building project.

The third objective involves evaluating professionals' views regarding the five variables of construction accident causes that can be influenced during the design phase. The mixed methods research confirms a high percentage of agreements regarding these five variables.

The aim of this study has been achieved by revealing the five variables of accident causes and ranking the influence of designer regarding these variables In conclusion, the study has significantly achieved its aim and its three objectives.

6.3 Contribution to theoretical knowledge

The research presented in this thesis makes a contribution to H&S in the construction field, particularly in the design phase. The work conducted here demonstrates which accident causes can be influenced by designers, focusing on the following five variables: permanent structure, temporary structure, building material, building equipment, and building environment. Additionally, it highlights aspects that cannot be influenced, such as the unsafe behaviour of workers and management. These findings have been published in the 2022 conference of the Association of Researchers in Construction Management. Moreover, it show the level of influence designers has regarding these five variables, the highest impact designer can impact on permanent structure and building materials, and less on Building environment and weak influence on Temporary structure and building equipment. Finally, the study illustrates that the challenges in construction design phase is common around the world and not just in particular country

Moreover, Section 5.2.6 highlights the critical link and benefits of understanding these five variables in addressing some of the persistent gaps in the field. This includes the recommendation for future studies to develop a comprehensive DfS work model that effectively incorporates these five variables, ensuring their relevance and applicability in real-world scenarios. Furthermore, these variables can be integrated into designers' training programmes to enhance their knowledge and awareness, fostering a proactive approach to safety considerations during the design phase.

6.4 Contribution to practical field

The study aids designers in the design phase, focusing on the five variables and avoiding unnecessary time and effort spent on safety issues beyond their influence.. Additionally, the thesis clarifies designers' ambiguity regarding compliance with CDM2015 regulations and provides regulatory authorities with a clear understanding of what designers can impact during the design phase and what lies beyond their capabilities.

6.5 Study limitation and strengths

6.5.1 Study limitations

Certain process safety techniques have been excluded from this study because they evaluate software failures, particularly automated software controlling manufacturing operations. This omission arises from the absence of such automated systems in the construction field.

Regarding the quantitative research of this study, it is important to note that quantitative results alone may not be suitable for generalisation to the whole construction population, since the sample size (n = 298) falls below the minimum required sample size required to have a powered study (n = 385).

In addition, the qualitative research of this study has limitations. Although the participants were highly-experienced professionals, only six interviews were conducted, due to difficulties in finding willing and suitable participants.

6.5.2 Study strengths

The research centres on H&S in the construction sector, with a specific focus on the design phase of construction projects. Whilst the study has broadened its references to encompass H&S regulations, policies, and standards from various countries, the primary focus remains on UK and USA regulations. The research incorporates diverse sources beyond academic papers, including Approved Codes of Practice, materials from training courses (e.g. Nebosh, Iosh, & CIEH), professional magazines such as Iosh-magazine and the British Safety Council, professional conference papers, and publications from regulatory bodies such as HSE, OSHA, and WorkSafe-Australia reports. Utilising a mixed methods study offers a robust approach by combining qualitative and quantitative methods to provide a deeper understanding of accident causes that could be influenced during the design phase. Each of these methods overcomes the weaknesses of the other and strengthens the results' credibility.

6.6 Recommendations and implication

6.6.1 Recommendations for the construction designer's community

The designer's community should:

1. Acquire a comprehensive understanding of the building lifecycle journey, gaining experience in various construction activities and existing demolition methods.
2. As demonstrated in the study, the five variables can be influenced during the design phase. Therefore, engaging with site professionals and learning about diverse construction methods, building machines, equipment, and heavy plants will help the designer community consider safety issues arising from these activities
3. Establish an open-access data bank for the safety of common and building components, documenting alternatives and solutions over time to enhance construction safety.
4. Building a DFS work-model that take in consideration the full project lifecyle and embed through its risk assessment the five type of accident causes that could be influenced during the design phase.
5. Utilise new technologies such as VR, AR, BIM and simulations for improved communication, visualisation, and information storage, beneficial even after decades (demolition phase).
6. Enhance ethical conduct guidance for designers to prioritise stakeholder safety in each construction phase, emphasising the potential consequences of design decisions, and embed the five variables of accident causes demonstrated in this study into the guidance.

6.6.2 Recommendations for regulators and policymakers

Regulators and policymakers should:

1. Establish a record-keeping system (data-bank) for decisions made during the design phase, accessible to relevant stakeholders and controlled by authorities.
2. Create an updated approved code of practice that illustrates the five variables' designers can influence, with practical examples for each.
3. Encourage collaboration amongst stakeholders and a sense of safety responsibility amongst designers.
4. Create updated regulations prohibiting the approval of building designs that do not consider the safety of all stakeholders throughout the building's lifecycle.
5. Embed the proposed work model within the guidance of CDM2015, providing case studies to showcase its implementation.

6.6.3 Recommendations for designers' educational institutes

Educational institutes for designers should:

1. Enhance educational frameworks to support compliance with CDM2015 regulations and broaden perspectives on design implications for safety.
2. Include practical models illustrating construction site issues, various construction methods, and case studies demonstrating how design decisions impact safety in later project phases.
3. Include model in designer courses, explaining construction methods, construction equipment and site activities in each phase of the building lifecycle.
4. Include a compulsory module in designer courses addressing construction safety, specifically focusing on how the design phase can influence all subsequent phases and how to address accident causes within the designers' scope of influence (the five accident causes variables).

6.7 Suggestions for future study

Potential areas for future research include:

1. Investigating the influence of clients on designers and the impact of such influence on safety considerations.
2. Exploring techniques from other fields that could enhance safety in construction design.
3. Developing a construction design data bank accessible to the designer community.
4. Identifying the most hazardous construction designs and suggesting safer alternatives.
5. Enhancing the current designer's educational syllabus to promote safety considerations during the design phase.

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Appendixes

Appendix 1 Ethical approval letter

11/09/2020
Project Title: Work model to improve CHPtD

EthOS Reference Number: 23905

Ethical Opinion

Dear Abdul Rahman Farooq,

The above application was reviewed by the Health, Psychology and Social Care Research Ethics and Governance Committee and, on the 11/09/2020, was given a favourable ethical opinion. The approval is in place until 22/10/2022 .

Conditions of favourable ethical opinion

Application Documents

Document Type	File Name	Date	Version
Consent Form	3Consent for interview	14/08/2020	4.0
Consent Form	3Consent for online survey	14/08/2020	4.0
Information Sheet	3PIS4.0 interview	14/08/2020	4.0
Information Sheet	3PIS4.0 online survey)	14/08/2020	4.0
Additional Documentation	Gatekeeper letter2	14/08/2020	4.0
Project Protocol	protocol4.0v	14/08/2020	4.0

The Health, Psychology and Social Care Research Ethics and Governance Committee favourable ethical opinion is granted with the following conditions

Adherence to Manchester Metropolitan University's Policies and procedures

This ethical approval is conditional on adherence to Manchester Metropolitan University's Policies, Procedures, guidance and Standard Operating procedures. These can be found on the Manchester Metropolitan University Research Ethics and Governance webpages.

Amendments

If you wish to make a change to this approved application, you will be required to submit an amendment. Please visit the Manchester Metropolitan University Research Ethics and Governance webpages or contact your Faculty research officer for advice around how to do this.

We wish you every success with your project.

HPSC Research Ethics and Governance Committee

HPSC Research Ethics and Governance Committee

For help with this application, please first contact your Faculty Research Officer. Their details can be found here

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Appendix 2 contents of study ethical protocol 4 V0

Contents

Appendix 3 online survey participant information sheet 3PIS4 online

Manchester Metropolitan University

Participant Information Sheet for online survey

Developing work model based on process safety to improve Construction Hazard Prevention through Design (CHPtD)

1. Invitation to research

I would like to invite you to take part in research study of the above title, my name is Abdul Farooq and I am undertaking PhD study in the area of safety management in the construction industry. My research project is about developing model to help improve safety through better building design. The study aims to create a work model that can be used to identify hazards in building: design, materials, equipment or methods and provide knowledge on ways to eliminate these hazards before the construction of the building starts. I hope you can participate to help us achieve this goal. The researcher is conducting this study as part of his PhD degree.

2. Why have I been invited?

The survey aim to 500 construction professionals, as a person with experience of working in the construction industry, you will have seen a lot on site, as person with knowledge around day to day happenings on major construction sites, you are in a position to respond to the survey questions and help answer the overall research question.

3. Do I have to take part?

Participation is voluntary; it is up to you to decide. We will describe the study and go through the information sheet, which we will give to you. We will then ask you to sign a consent form to show you agreed to take part. You are free to withdraw at any time, without giving a reason.

4. What will I be asked to do?

A link to the survey will be sent to you that will take you to the consent form, where you can access the information sheet, to read it carefully, once you are happy to proceed you will be required to provide your consent by ticking the boxes on the consent form and press submit.

Thereafter the questionnaire will appear, with 30 question asking your view using Likert scale of 1-5, where 1=totally disagree 5= strongly agree. All questions relates to health and safety issues that designer can improve during design phase, before construction begin.

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Version:4.0 Date: 14-08-2020
Ethical approval number (EthOS): 23005

Manchester Metropolitan University

Once you complete answer all questions you can click in Submit, then a thank you message will appear to show the researcher gratitude for you that you have participate in the survey.

5. Are there any risks if I participate?

You will not be exposed to any risk in taking part in the study. Link to the survey can be accessed using computer or mobile device linked to the internet.

6. Are there any advantages if I participate?

We cannot promise the study will help you directly, but the information we get from the study will help to increase the understanding of the health and safety issues that can be influenced by designers, which, in return, can help to address those issues and reduce the chance of accidents to everyone involved in the construction industry.

7. What will happen to the samples that I give?

No Samples collected in this study, it is not applicable

8. What will happen with the data I provide?

When you agree to participate in this research, we will collect from you personally identifiable information.

The Manchester Metropolitan University ('the University') is the Data Controller in respect of this research and any personal data that you provide as a research participant.

The University is registered with the Information Commissioner's Office (ICO), and manages personal data in accordance with the General Data Protection Regulation (GDPR) and the University's Data Protection Policy.

We collect personal data as part of this research (such as name, telephone numbers or age). As a public authority acting in the public interest we rely upon the 'public task' lawful basis. When we collect special category data (such as medical information or ethnicity) we rely upon the research and archiving purposes in the public interest lawful basis.

Your rights to access, change or move your information are limited, as we need to manage your information in specific ways in order for the research to be reliable and accurate. If you withdraw from the study, we will keep the information about you that we have already obtained.

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Ethical approval number (EthOS): 23005

Manchester Metropolitan University

We will not share your personal data collected in this form with any third parties.

If your data is shared this will be under the terms of a Research Collaboration Agreement which defines use, and agrees confidentiality and information security provisions. It is the University's policy to only publish anonymised data unless you have given your explicit written consent to be identified in the research. The University never sells personal data to third parties.

We will only retain your personal data for as long as is necessary to achieve the research purpose. All documents, reports or publications of this study will have only clean data (without any personal data that could lead to identifying any participant). Any audio-recorded data will be deleted immediately after transcription, clean data (without any personal details) will be kept securely for five years on the MMU H-drive, considered highly secured and guarded by the university IT department.

For further information about use of your personal data and your data protection rights please see the University's Data Protection Pages (https://www2.mmu.ac.uk/data-protection/)

What will happen to the results of the research study?

Data from the study will be published in conference proceeding, in seminar and as journal article while the work in its entirety will be developed into a thesis that will lead to the award of PhD.

Who has reviewed this research project?

This research has been reviewed by the study director, Dr Haruna Moda, and Ethic committee of MMU University

Who do I contact if I have concerns about this study or I wish to complain?

If you have a concern about any aspect of this study, you should ask to speak to the researcher who will do his best to answer your questions. You can contact Abdul Farooq by email: [illegible]@stu.mmu.ac.uk

If you wish to report an incident or make a complaint, you can do so by contacting your preferred contacts below:

Principal Investigator: Abdul R Farooq
Manchester Metropolitan University
Faculty of Health, Psychology and Social Care
Cavendish Building

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Version:4.0 Date: [illegible]
Ethical approval number (EthOS): 23005

Manchester Metropolitan University

Cavendish Street
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Head of Ethics: Dr Juliet Goldbart
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Director of Study: Dr Haruna Moda
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Faculty of Health, Psychology and Social Care
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If you have any concerns regarding the personal data collected from you, our Data Protection Officer can be contacted using the legal@mmu.ac.uk e-mail address, by calling 0161 247 3331 or in writing to: Data Protection Officer, Legal Services, All Saints Building, Manchester Metropolitan University, Manchester, M15 6BH. You also have a right to lodge a complaint in respect of the processing of your personal data with the Information Commissioner's Office as the supervisory authority. Please see: https://ico.org.uk/global/contact-us/

THANK YOU FOR CONSIDERING PARTICIPATING IN THIS PROJECT

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Version:4.0 Date: [illegible]
Ethical approval number (EthOS): 23005

Appendix 4 Online ethical consent form

Manchester Metropolitan University

CONSENT FORM FOR Online survey

Developing work-model based on process safety to improve Construction Hazard Prevention through Design (CHPtD)

Participant Identification Number:

	Please tick your chosen answer	YES	NO
1.	I confirm that I have read the participant information sheet, version 4.0, date.14-08-2020. for the above study.	☐	☐
2	I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐	☐
3	I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected.	☐	☐
4	I agree to participate in the project to the extent of the activities described to me in the above participant information sheet.	☐	☐
OPTIONAL			
5	I agree to my participation being audio recorded for analysis. No audio clips will be published without my express consent (additional media release form).	☐	☐
6	I understand and agree that my words may be quoted anonymously in research outputs.	☐	☐
7	I wish to be informed of the outcomes of this research. I can be contacted at: ______________________	☐	☐
8	I give permission for the researchers named in the participant information sheet to contact me in the future about this research or other research opportunities.	☐	☐
9	I give permission for a fully anonymised version of the data I provide to be deposited in an Open Access repository so that it can be used for future research and learning.	☐	☐

______________________	______________________	______________________
Name of participant	Date	Signature

______________________	______________________	______________________
Name of person taking consent	Date	Signature

EthOS ID: 23905 version 4.0 14-08-2020

Appendix 5 Participant information sheet for interview survey

Manchester Metropolitan University

Participant Information Sheet for interview

Developing work-model based on process safety to improve Construction Hazard Prevention through Design (CHPtD)

1. Invitation to research

I would like to invite you to take part in research study of the above title, my name is Abdul Farooq and I am undertaking PhD study in the area of safety management in the construction industry. My research project is about developing model to help improve safety through better building design. The study aims to create a work model that can be used to identify hazards in building design, materials, equipment or methods and provide knowledge on ways to eliminate these hazards before the construction of the building starts. I hope you can participate to help us achieve this goal. The researcher is conducting this study as part of his PhD degree.

2. Why have I been invited?

The study aim to interview 10 construction professionals, as a person with experience of working in the construction industry, you have seen a lot on site, as a professional with informed knowledge around day to day happenings on major construction sites you will be in a position to respond to the interview questions and help answer the overall research question.

3. Do I have to take part?

Participation is voluntary, and it is up to you to decide. We will describe the study and go through the information sheet, which we will give to you. We will then ask you to sign a consent form to show you agreed to take part. You are free to withdraw at any time, without giving a reason.

4. What will I be asked to do?

The researcher will provide you with the relevant information sheet and a link to visual meeting, in pre-agreed time and date, you will login to the visual meeting, the researcher will read the consent form and respond to any question you have to ensure you agree to all points to be considered during the interview process.

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Manchester Metropolitan University

The overall process will [illegible] building design and safety considerations, where the researcher will focus on gaining your professional view around issues that designer can improve to make the building construction safer. It is hoped the meeting will last around 30 minutes and at the end of the process the researcher will allow you time to seek further clarification on the subject where need be.

Please note: the researcher cannot remember everything you said, therefore, with your permission, the researcher will audio-record your response and later transcribe it. Once this is done, audio will only be stored for the duration of data analysis to all for quick reference to any missed point thereafter the recorded interview will be deleted.

5. Are there any risks if I participate?

You will not be exposed to any risk in taking part in this study. You will be in the comfort of your work environment while the entire process will be conducted via the internet using either computer or mobile device to login to the virtual meeting.

6. Are there any advantages if I participate?

We cannot promise the study will help you directly, however the information generated from the process will help to increase the understanding of the health and safety issues that can be influenced by designers, which, in turn help to address such issues and reduce the chance of accidents to everyone involved in the construction industry.

7. What will happen to the samples that I give?

No biological samples will be collected in this study.

8. What will happen with the data I provide?

When you agree to participate in this research, we will collect from you personally identifiable information.

The Manchester Metropolitan University ('the University') is the data controller in respect of this research and any personal data that you provide as a research participant.

The University is registered with the Information Commissioner's Office (ICO), and manages personal data in accordance with the General Data Protection Regulation (GDPR) and the University's Data Protection Policy.

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Manchester Metropolitan University

We collect personal data as part of this research (such as name, telephone numbers or age). As a public authority acting in the public interest we rely upon the 'public task' lawful basis. When we collect special category data (such as medical information or ethnicity) we rely upon the research and archiving purposes in the public interest lawful basis.

Your rights to access, change or move your information are limited, as we need to manage your information in specific ways in order for the research to be reliable and accurate. If you withdraw from the study, we will keep the information about you that we have already obtained.

We will not share your personal data collected in this form with any third parties.

If your data is shared this will be under the terms of a Research Collaboration Agreement which defines use, and agrees confidentiality and information security provisions. It is the University's policy to only publish anonymised data unless you have given your explicit written consent to be identified in the research. **The University never sells personal data to third parties.**

We will only retain your personal data for as long as is necessary to achieve the research purpose. All documents, reports or publications of this study will have only clean data (without any personal data that could lead to identifying any participant). Any audio-recorded data will be deleted immediately after transcription, clean data (without any personal details) will be kept securely for five years on the MMU H drive, which considered highly secured and guarded by the university IT department.

For further information about use of your personal data and your data protection rights please see the University's Data Protection Pages (https://www2.mmu.ac.uk/data-protection/).

What will happen to the results of the research study?

Data from the study will be published in conference proceeding, in seminar and as journal article while the work in its entirety will be developed into a thesis that will lead to the award of PhD.

Who has reviewed this research project?

This research has been reviewed by the study director, Dr Haruna Moda, and Ethic committee of MMU University

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Manchester Metropolitan University

Who do I contact if I have concerns about this study or I wish to complain?

If you have concern about any aspect of this study, you should ask to speak to the researcher who will do his best to answer your questions. You can contact Abdul Farooq by email. [illegible]

If you wish to report an incident or make a complaint, you can do so by contacting your preferred contacts below:

Principal Investigator: Abdul R Farooq
Manchester Metropolitan University
Faculty of Health, Psychology and Social Care
Cavendish Building, Cavendish Street
Manchester
M15 6BG
Email: [illegible]

Head of Ethics: Dr Juliet Goldbart
Department of Psychology
Faculty of Health, Psychology and Social Care
Manchester Metropolitan University
Brooks Building, Birley Fields Campus, 53 Bonsall Street
Manchester M15 6GX, United Kingdom
Phone: 161 247 2778
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Director of Study: Dr Haruna Moda
Manchester Metropolitan University
Faculty of Health, Psychology and Social Care
Department of Health Professions
Cavendish Building, Cavendish Street
Manchester
M15 6BG
Phone: 01612472781
Email: H.Moda@mmu.ac.uk

If you have any concerns regarding the personal data collected from you, our Data Protection Officer can be contacted using the legal@mmu.ac.uk e-mail address, by calling 0161 247 3331 or in writing to: Data Protection Officer, Legal Services, All Saints Building, Manchester Metropolitan University, Manchester, M15 6BH. You also have a right to lodge a complaint in respect of the processing of your personal data with the Information Commissioner's Office as the supervisory authority. Please see: https://ico.org.uk/global/contact-us/

THANK YOU FOR CONSIDERING PARTICIPATING IN THIS PROJECT

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Ethical approval number (EthOS): 23905

Appendix 6 Consent form for interview

Manchester Metropolitan University

CONSENT FORM FOR THE INTERVIEW

Developing work-model based on process safety to improve Construction Hazard Prevention through Design (CHPtD)

Participant Identification Number:

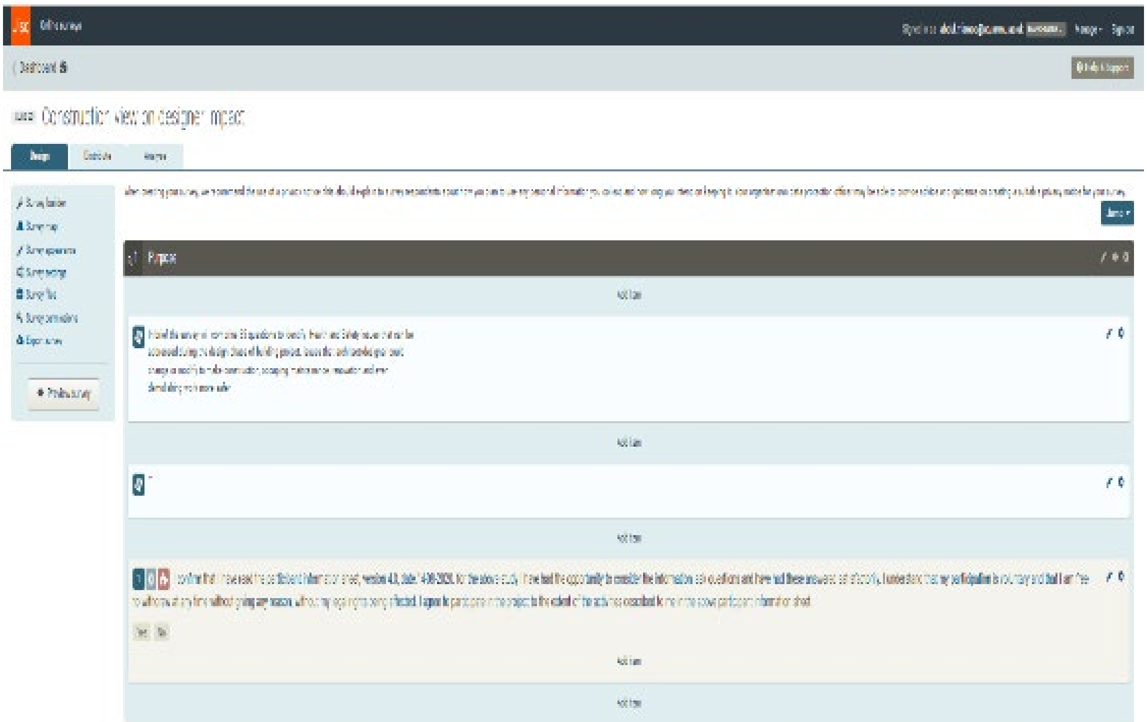
	Please tick your chosen answer	YES	NO
1.	I confirm that I have read the participant information sheet, version 4.0, date.14-08-2020. for the above study.	☐	☐
2	I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐	☐
3	I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected.	☐	☐
4	I agree to participate in the project to the extent of the activities described to me in the above participant information sheet.	☐	☐
OPTIONAL			
5	I agree to my participation being audio recorded for analysis. No audio clips will be published without my express consent (additional media release form).	☐	☐
6	I understand and agree that my words may be quoted anonymously in research outputs.	☐	☐
7	I wish to be informed of the outcomes of this research. I can be contacted at: ______________________________	☐	☐
8	I give permission for the researchers named in the participant information sheet to contact me in the future about this research or other research opportunities.	☐	☐
9	I give permission for a fully anonymised version of the data I provide to be deposited in an Open Access repository so that it can be used for future research and learning.	☐	☐

____________________	____________________	____________________
Name of participant	Date	Signature

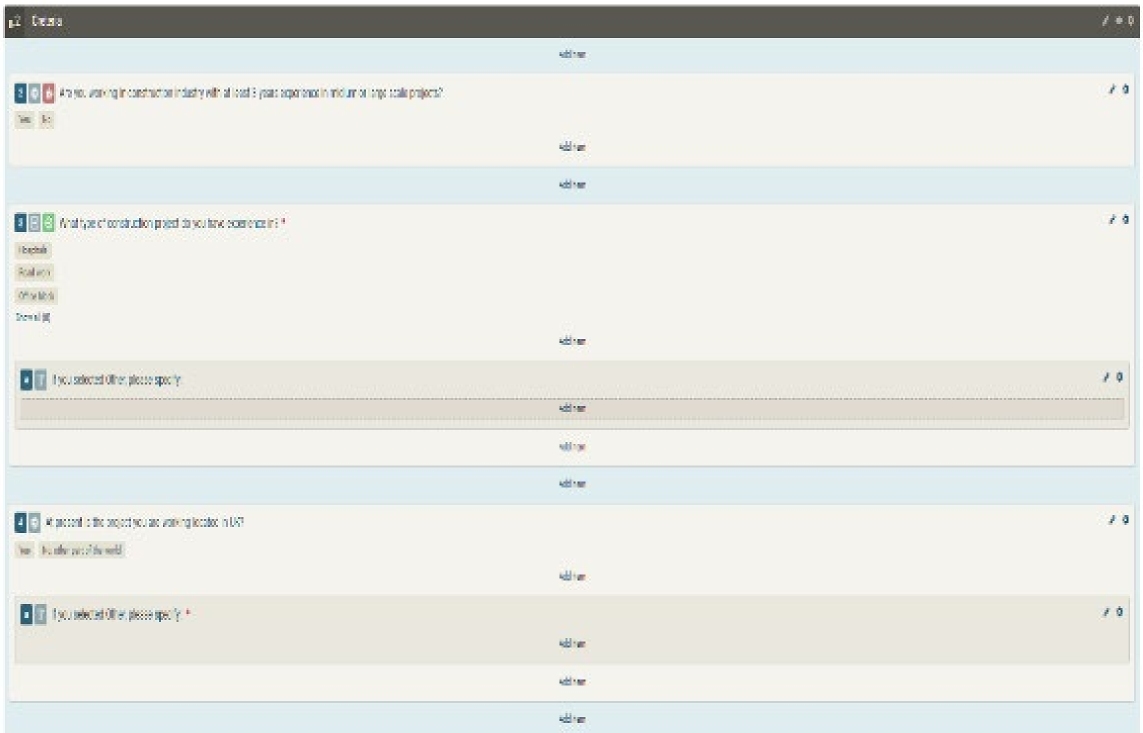
____________________	____________________	____________________
Name of person taking consent	Date	Signature

Appendix 7 The online questionnaires

Page one



Page two



Page three and four

p.3 Building Permanent Structure

Add item

5 Tell us how far you agree with the following

	strongly agree	agree	undecided	disagree	strongly disagree
Building design, type, shape or size influence safety during the construction	☐	☐	☐	☐	☐
Some features/component of the building is more risky to build	☐	☐	☐	☐	☐
Designing fixed points on structure could help to install, maintain and clean HVAC safely	☐	☐	☐	☐	☐
Design safe access to external higher-parts of the building will prevent fall accidents (fix guard rail, safety lanyard attaching points, scaffold attaching points...etc)	☐	☐	☐	☐	☐
More wider space to install, maintain , test and clean electric and/or plumbing system will help to reduce accidents	☐	☐	☐	☐	☐

Add item

Add item

p.4 Temporary Structure

Add item

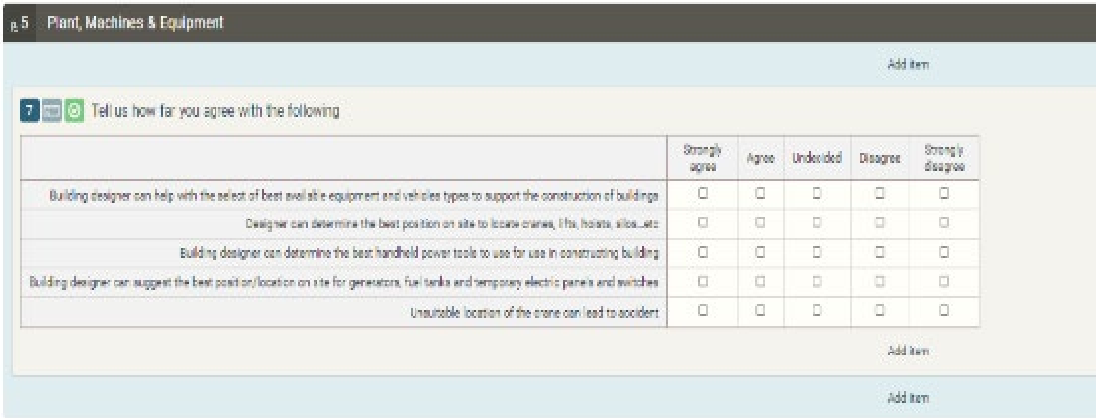
6 Tell us how far you agree with the following

	Strongly Agree	Agree	Undecided	Disagree	Strongly disagree
Designing site layout to make room for storage , road for vehicles, pedestrian path, space for welfare facility, will make the site safer	☐	☐	☐	☐	☐
Designing excavation, scaffold, guard rail, barriers, fences...etc increase safety of construction workers	☐	☐	☐	☐	☐
Design site access and egress, traffic manoeuvre areas, unload and lifting zone will increase site safety	☐	☐	☐	☐	☐
Design temporary barriers, close opening and protection for open edges will prevent fall accidents	☐	☐	☐	☐	☐
Poor design of scaffold can lead to accident	☐	☐	☐	☐	☐

Add item

Add item

Page five and six



p.5 Plant, Machines & Equipment

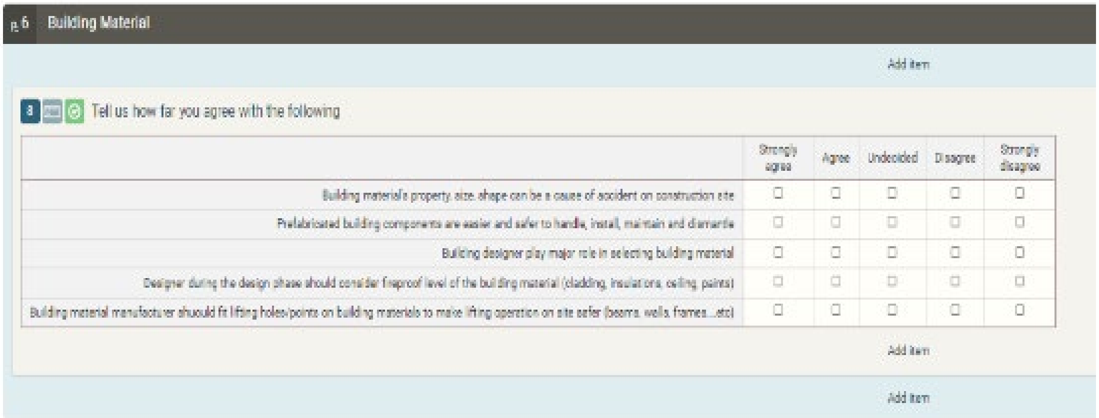
Add item

7 Tell us how far you agree with the following

	Strongly agree	Agree	Undecided	Disagree	Strongly disagree
Building designer can help with the select of best available equipment and vehicles types to support the construction of buildings	☐	☐	☐	☐	☐
Designer can determine the best position on site to locate cranes, lifts, hoists, silos...etc	☐	☐	☐	☐	☐
Building designer can determine the best handheld power tools to use for use in constructing building	☐	☐	☐	☐	☐
Building designer can suggest the best position/location on site for generators, fuel tanks and temporary electric panels and switches	☐	☐	☐	☐	☐
Unsuitable location of the crane can lead to accident	☐	☐	☐	☐	☐

Add item

Add item



p.6 Building Material

Add item

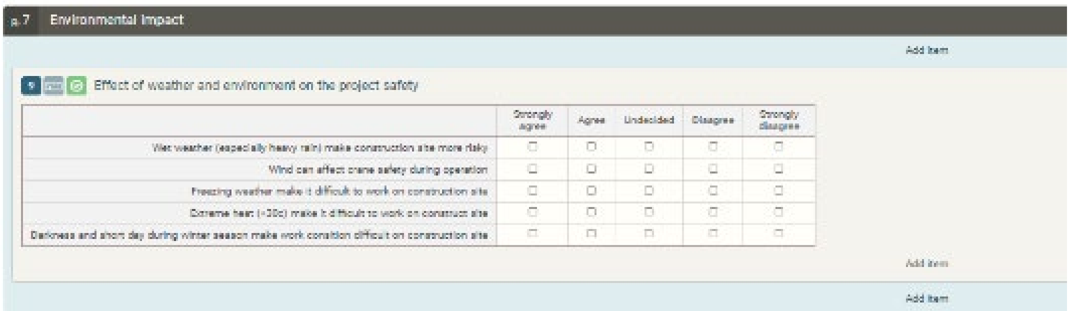
8 Tell us how far you agree with the following

	Strongly agree	Agree	Undecided	Disagree	Strongly disagree
Building materials property, size, shape can be a cause of accident on construction site	☐	☐	☐	☐	☐
Prefabricated building components are easier and safer to handle, install, maintain and dismantle	☐	☐	☐	☐	☐
Building designer play major role in selecting building material	☐	☐	☐	☐	☐
Designer during the design phase should consider fireproof level of the building material (cladding, insulations, ceiling, paints)	☐	☐	☐	☐	☐
Building material manufacturer shuould fit lifting holes/points on building materials to make lifting operation on site safer (beams, walls, frames...etc)	☐	☐	☐	☐	☐

Add item

Add item

Page Seven, Eight and nine



p.7 Environmental Impact

Add item

9 Effect of weather and environment on the project safety

	Strongly agree	Agree	Undecided	Disagree	Strongly disagree
Wet weather (especially heavy rain) make construction site more risky	☐	☐	☐	☐	☐
Wind can affect crane safety during operation	☐	☐	☐	☐	☐
Freezing weather make it difficult to work on construction site	☐	☐	☐	☐	☐
Extreme heat (+30c) make it difficult to work on construct site	☐	☐	☐	☐	☐
Darkness and short day during winter season make work condition difficult on construction site	☐	☐	☐	☐	☐

Add item

Add item

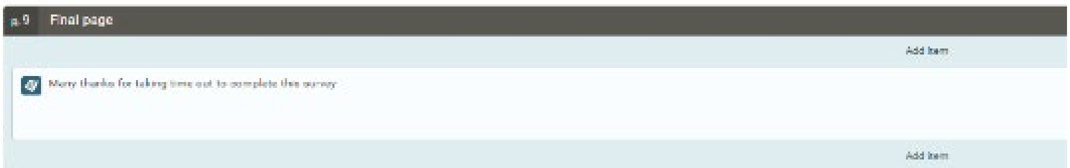
p.8 Comments

Add item

10 Please add any additional comment you may have that can help designer to make consturction project much safer

Add item

Add item



p.9 Final page

Add item

Many thanks for taking time out to complete this survey

Add item

Appendix 8 Interview questions

Interview questions

General information

1	How long have you worked in construction industry
2	positions you for fill during your carear
3	Which construction phases have you worked in
4	In which country have you worked
5	Type of projects

Construction safety

	Key area
6	Permenant Structure
7	Temporary Structure
8	Vehicles , plant , Machines, tools and equipment
9	Building Material
10	Environmantal condition
11	Additions
12	Improvement

Appendix 9 Construction accident causes and impact during design phase

Source	Health and Safety Issue lead to accident	potential impact during design phas
Hide et al., 2003	worker cabapilties and competency	×
Hide et al., 2003	communication	×
Hide et al., 2003	immediate supervision	×
Hide et al., 2003	worker health	×
Hide et al., 2003	site conditions(exclude equipment, materials, weather)	×
Hide et al., 2003	site layout/space	✓
Hide et al., 2003	working environment (light, noise,hot,cold, wet)	×
Hide et al., 2003	work schedurling	✓
Hide et al., 2003	housekeeping	×
Hide et al., 2003	suitability of materials	✓
Hide et al., 2003	usability of materials	✓
Hide et al., 2003	condition of materials	×
Hide et al., 2003	suitability of equipment	✓
Hide et al., 2003	usability of equipment	✓
Hide et al., 2003	condition of equipment	×
Hide et al., 2003	permanenet work design	✓
Hide et al., 2003	project management	✓
Hide et al., 2003	construction processes	×
Hide et al., 2003	safety culture	×
Hide et al., 2003	riskmanagment	×
Suraji et al., 2001	consttuction planning - method statement	×
Suraji et al., 2001	consttuction planning - preparatory training	×
Suraji et al., 2001	consttuction planning - indintification and assessment of risk	×
Suraji et al., 2001	consttuction planning - planning construction work	✓
Suraji et al., 2001	consttuction planning - safety plan	✓
Suraji et al., 2001	consttuction planning - temperary stracture design	✓
Suraji et al., 2001	consttuction control - supervision of oprative work	×
Suraji et al., 2001	consttuction control - control system of work	×
Suraji et al., 2001	consttuction control - control of temperary structure stability	×
Suraji et al., 2001	consttuction control - control of plant, equipment operation	×
Suraji et al., 2001	site condition - weather or climate conditiion	×
Suraji et al., 2001	consttuction operation - breach of regulations	×
Suraji et al., 2001	consttuction operation - access and egress suitability	✓
Suraji et al., 2001	consttuction operation - safety facilities	✓
Suraji et al., 2001	consttuction operation - construction procedures	×
Suraji et al., 2001	consttuction operation - condition of equipment, vehicle	×
Suraji et al., 2001	consttuction operation - safety site precaustions	✓
Suraji et al., 2001	consttuction operation - working platform and guardrails	✓
Suraji et al., 2001	consttuction operation - uncompetent workforce	×
Suraji et al., 2001	consttuction operation - operation of plant or equipment	×
Suraji et al., 2001	consttuction operation - instructions to operatives	×
Suraji et al., 2001	consttuction operation - working tools or instrument	×
Suraji et al., 2001	consttuction operation - temperary structure	✓
Suraji et al., 2001	consttuction operation - Defective services	✓
Suraji et al., 2001	consttuction operation - communications and coordination	×
Suraji et al., 2001	Operative action - PPE	×
Suraji et al., 2001	Operative action - not follow instruction	×
Suraji et al., 2001	Operative action- not follow safety procedures	×
Suraji et al., 2001	Operative action- careless	×
Suraji et al., 2001	Operative action- working postion	×
Suraji et al., 2001	Operative action -judgment, error, overconfidence, underestimat	×
Suraji et al., 2001	Operative action - Others	×
Manu et al.,2012	project features- project nature	✓
Manu et al.,2012	project Features - method of construction	×
Manu et al.,2012	project Features - site restriction	✓
Manu et al.,2012	project Features - project duration	×
Manu et al.,2012	project Features - procurement system	×
Manu et al.,2012	project Features - Design compexity	✓
Manu et al.,2012	project Features - level of construction	×
Manu et al.,2012	project Features - subcontracting	×
HSE, CDM 2015	Site trafic design	✓
HSE, CDM 2015	space available for maintenance	✓
HSE, CDM 2015	construction task time availability	×
HSE, CDM 2015	Vehicls positioning	✓
HSE, CDM 2015	Avilability of welfare facility	✓
HSE, CDM 2015	building desing and its impact on Evacution speed	✓
HSE, CDM 2015	selction of equipments, plant and vehicles	✓
HSE, CDM 2015	type of ventialtion, AC and heating system	✓
HSE, CDM 2015	fire risk of interiors and exteriors of the building	✓
HSE, CDM 2015	Car park design and space	✓
HSE, CDM 2015	landscape, pathes and walk away layout and design	✓
HSE, CDM 2015	prefebrikate construction material	✓
HSE, CDM 2015	coolaportaion between designers and construction team	✓
HSE, CDM 2015	coolapration between principal contractors, and contractors	×
HSE, CDM 2015	coolapration between contractors	×

Appendix 10 scale items mean, squared correlation and Alpha

Item-Total Statistics

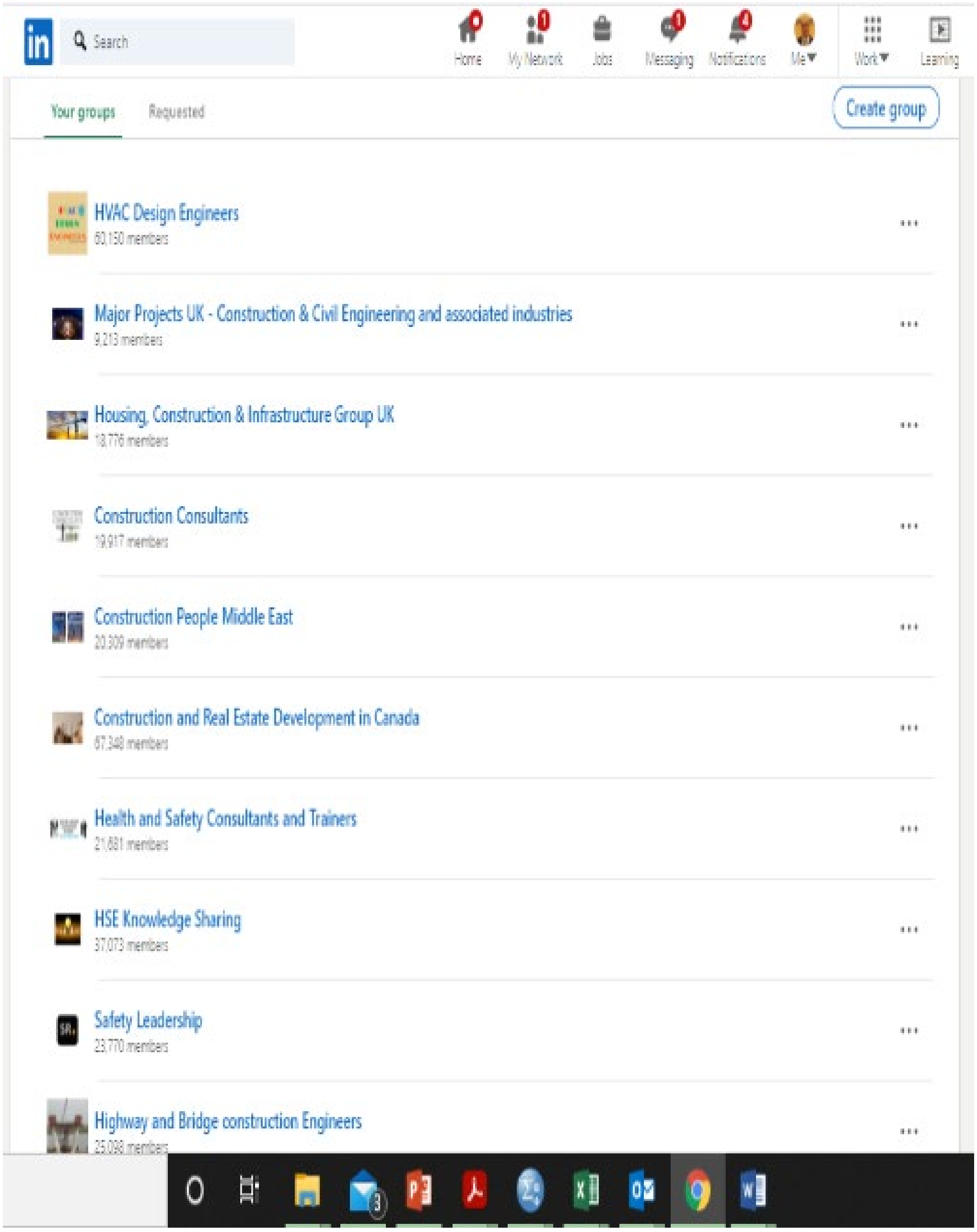
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
5.1. Building design, type, shape or size influence safety during the construction	103.10	80.993	.417	.326	.843
5.2. Some features/component of the building is more risky to build	103.03	84.311	.262	.304	.848
5.3. Designing fixed points on structure could help to install, maintain and clean HVAC safely	103.20	82.979	.308	.273	.847
5.4. Design safe access to external higher-parts of the building will prevent fall accidents (fix guard rail, safety lanyard attaching points, scaffold attaching points…etc)	102.90	81.971	.443	.407	.843
5.5. Wider space to install, maintain, test and clean electric and/or plumbing system will help to reduce accidents	103.14	80.578	.486	.404	.841

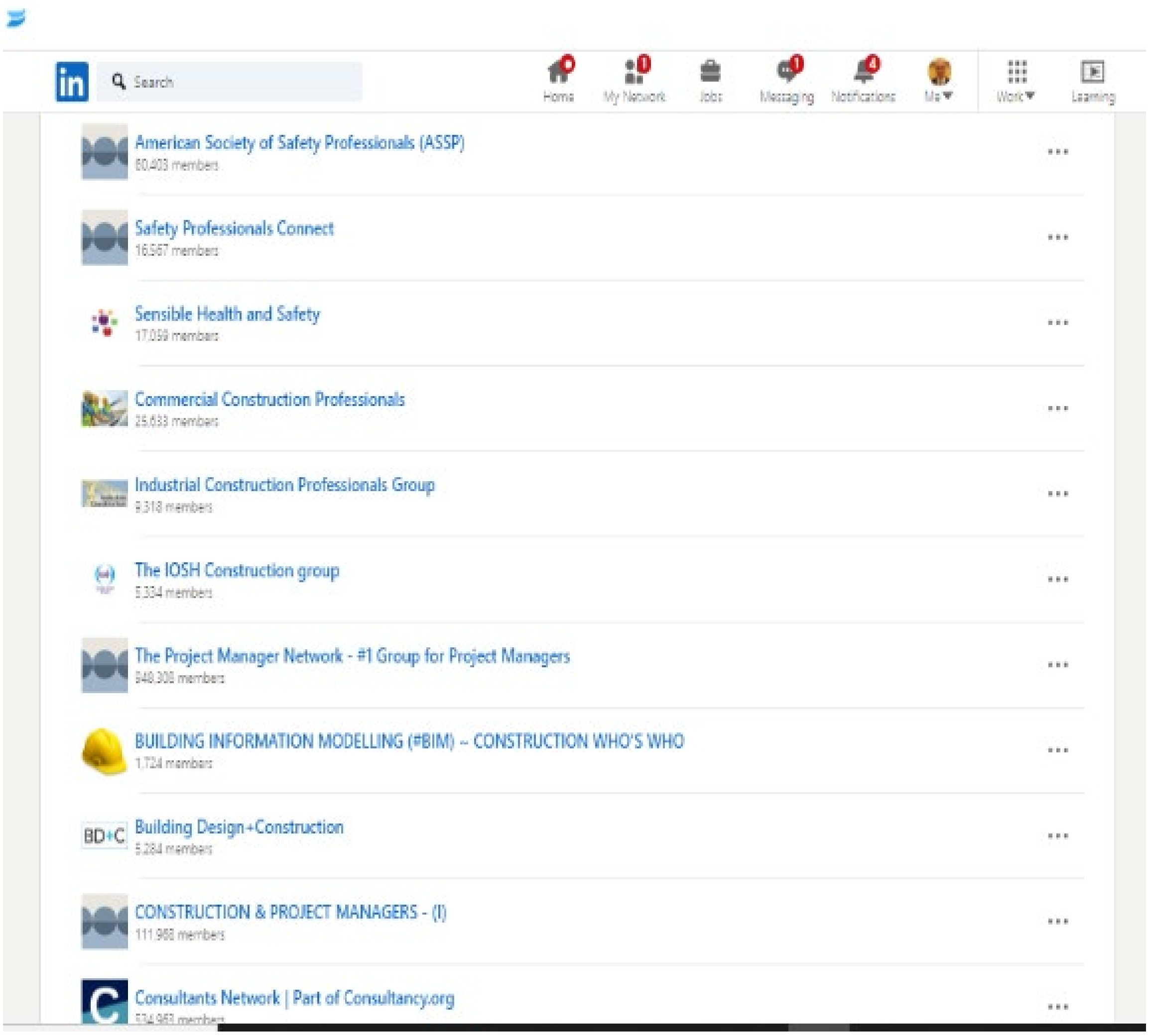
6.1. Designing site layout to make room for storage , road for vehicles, pedestrian path, space for welfare facility, will make the site safer	102.88	82.878	.395	.426	.844
6.2. Designing excavation, scaffold, guard rail, barriers, fences….etc increase safety of construction workers	102.85	81.825	.511	.592	.841
6.3. Design site access and egress, traffic manoeuvre areas, unload and lifting zone will increase site safety	102.84	82.011	.495	.654	.842
6.4. Design temporary barriers, close opening and protection for open edges will prevent fall accidents	102.85	82.250	.480	.601	.842
6.5. Poor design of scaffold can lead to accident	102.69	85.170	.309	.267	.847
7.1. Building designer can help with the select of best available equipment and vehicles types to support the construction of buildings	103.84	76.537	.497	.483	.840
7.2. Designer can determine the best position on site to locate cranes, lifts, hoists, silos…etc	104.07	74.763	.543	.648	.838

7.3. Building designer can determine the best handheld power tools to use for use in constructing building	104.69	74.758	.520	.674	.840
7.4. Building designer can suggest the best position/location on site for generators, fuel tanks and temporary electric panels and switches	104.11	75.114	.493	.581	.841
7.5. Unsuitable location of the crane can lead to accident	102.82	83.851	.338	.295	.846
8.1. Building material's property, size, shape can be a cause of accident on construction site	103.49	80.845	.367	.281	.845
8.2. Prefabricated building components are easier and safer to handle, install, maintain and dismantle	103.64	81.332	.335	.178	.846
8.3. Building designer play major role in selecting building material	103.31	81.786	.337	.256	.846
8.4. Designer during the design phase should consider fireproof level of the building material (cladding, insulations, ceiling, paints)	102.88	84.016	.331	.358	.846

8.5. Building material manufacturer should fit lifting holes/points on building materials to make lifting operation on site safer (beams, walls, frames….etc)	103.14	81.508	.381	.301	.844
9.1. Wet weather (especially heavy rain) make construction site more risky	102.94	82.526	.403	.395	.844
9.2. Wind can affect crane safety during operation	102.67	85.012	.358	.383	.846
9.3. Freezing weather make it difficult to work on construction site	102.92	83.262	.381	.499	.845
9.4. Extreme heat (+30c) make it difficult to work on construct site	103.11	83.027	.294	.390	.847
9.5. Darkness and short day during winter season make construction work difficult on site	103.25	80.666	.425	.391	.843

Appendix 11 Targeted LinkedIn groups for online survey




Search
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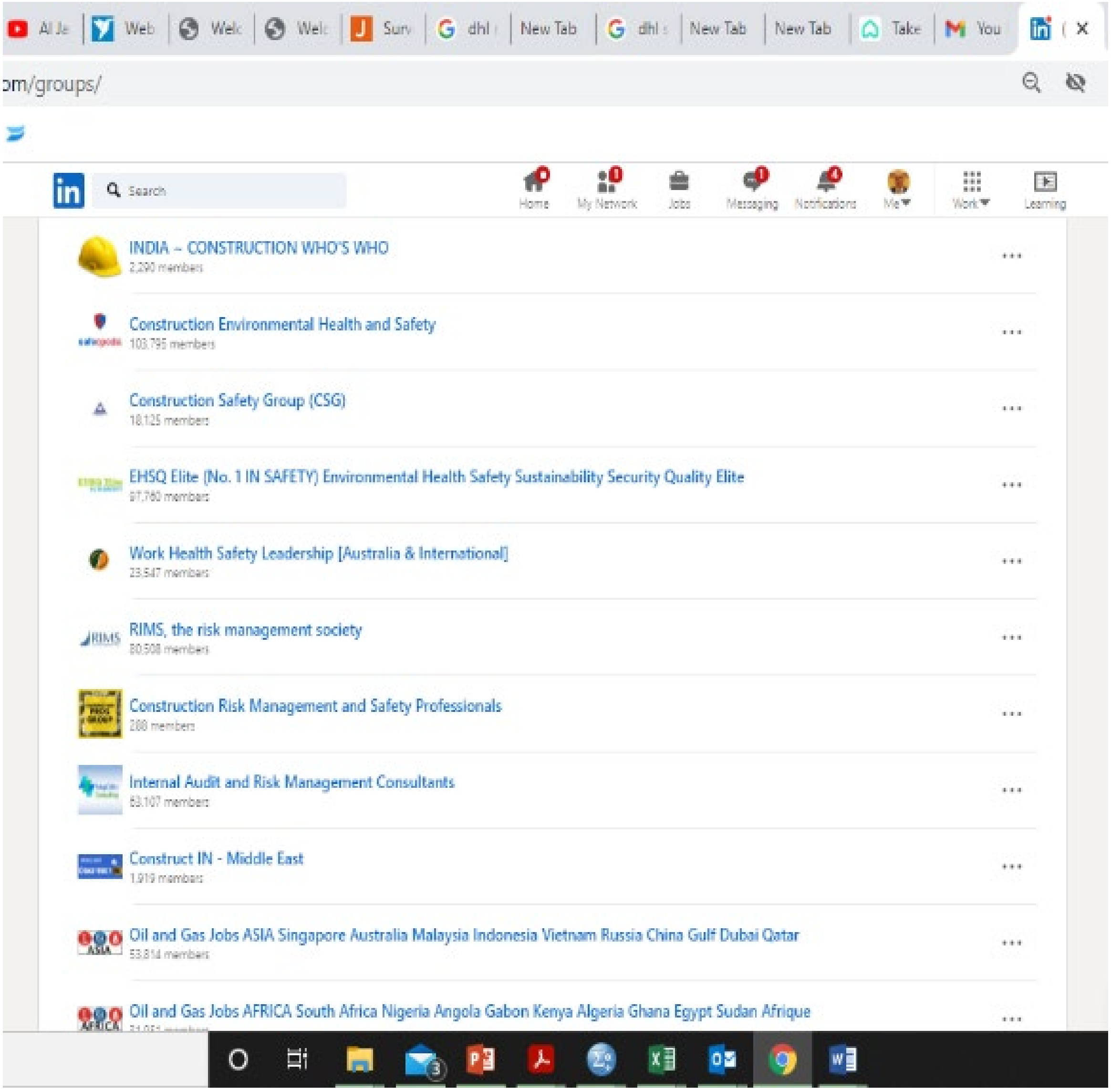
American Society of Safety Professionals (ASSP)
Safety Professionals Connect
Sensible Health and Safety
Commercial Construction Professionals
Industrial Construction Professionals Group
The IOSH Construction group
The Project Manager Network - #1 Group for Project Managers
BUILDING INFORMATION MODELLING (#BIM) ~ CONSTRUCTION WHO'S WHO
BD+C
Building Design+Construction
CONSTRUCTION & PROJECT MANAGERS - (I)
Consultants Network | Part of Consultancy.org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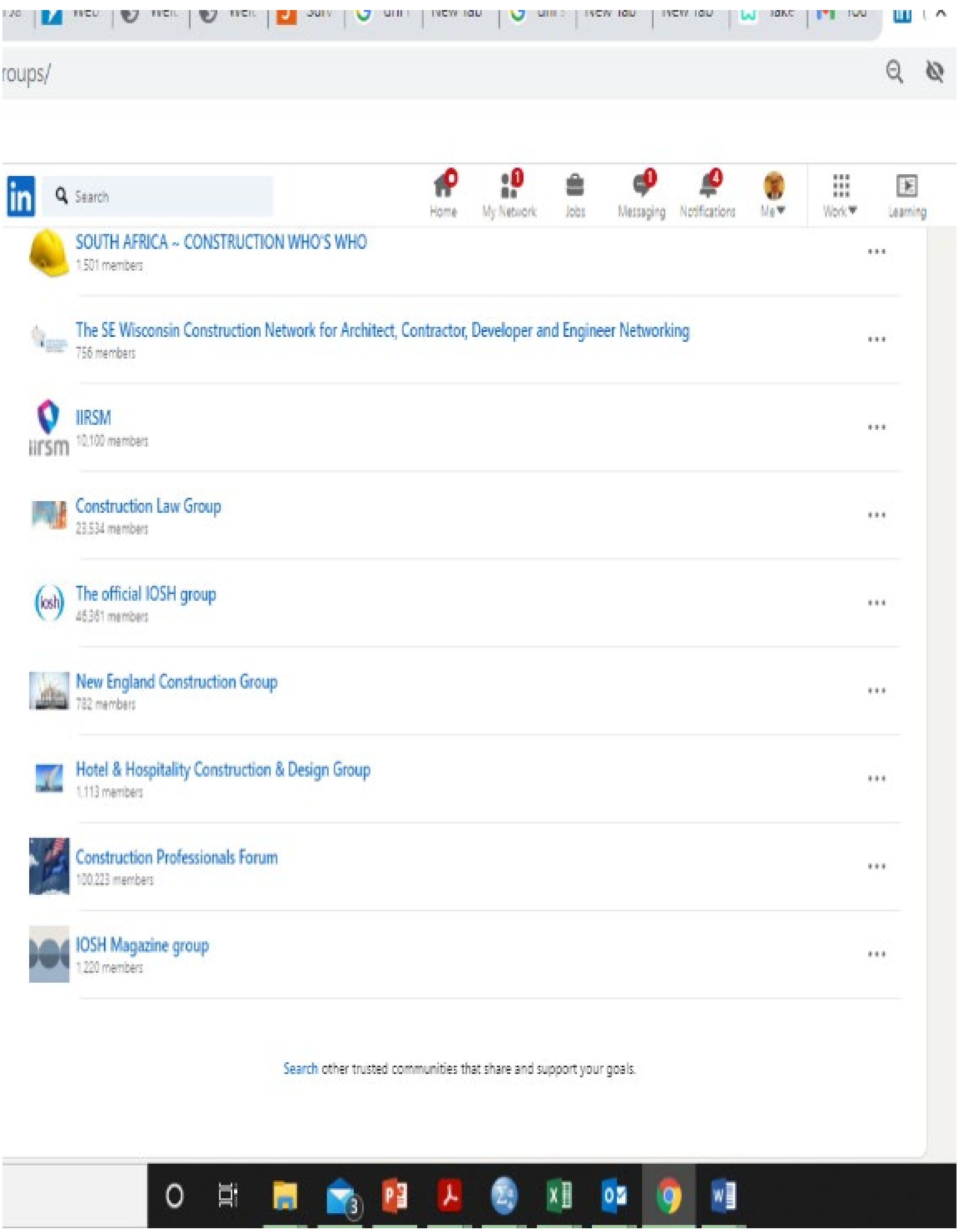
INDIA – CONSTRUCTION WHO'S WHO
2,290 members
Construction Environmental Health and Safety
103,795 members
Construction Safety Group (CSG)
18,125 members
EHSQ Elite (No. 1 IN SAFETY) Environmental Health Safety Sustainability Security Quality Elite
97,760 members
Work Health Safety Leadership [Australia & International]
23,547 members
RIMS, the risk management society
80,508 members
Construction Risk Management and Safety Professionals
288 members
Internal Audit and Risk Management Consultants
63,107 members
Construct IN - Middle East
1,919 members
Oil and Gas Jobs ASIA Singapore Australia Malaysia Indonesia Vietnam Russia China Gulf Dubai Qatar
53,814 members
Oil and Gas Jobs AFRICA South Africa Nigeria Angola Gabon Kenya Algeria Ghana Egypt Sudan Afrique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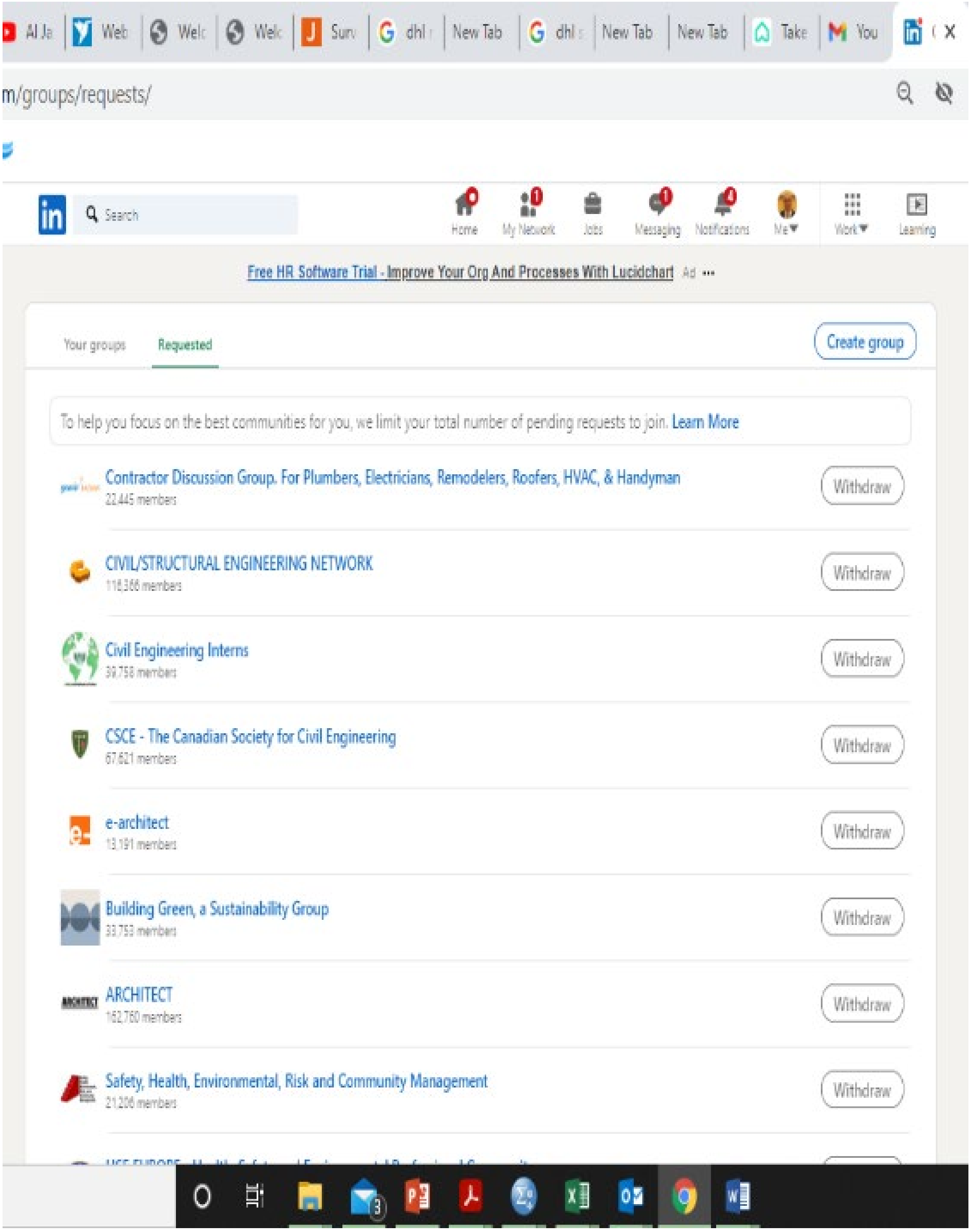
SOUTH AFRICA ~ CONSTRUCTION WHO'S WHO
1,501 members
The SE Wisconsin Construction Network for Architect, Contractor, Developer and Engineer Networking
756 members
IIRSM
10,100 members
Construction Law Group
23,534 members
The official IOSH group
46,361 members
New England Construction Group
782 members
Hotel & Hospitality Construction & Design Group
1,113 members
Construction Professionals Forum
100,223 members
IOSH Magazine group
1,220 members
Search other trusted communities that share and support your goals.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Free HR Software Trial - Improve Your Org And Processes With Lucidchart
Your groups
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Create group
To help you focus on the best communities for you, we limit your total number of pending requests to join. Learn More
Contractor Discussion Group. For Plumbers, Electricians, Remodelers, Roofers, HVAC, & Handyman
Withdraw
CIVIL/STRUCTURAL ENGINEERING NETWORK
Withdraw
Civil Engineering Interns
Withdraw
CSCE - The Canadian Society for Civil Engineering
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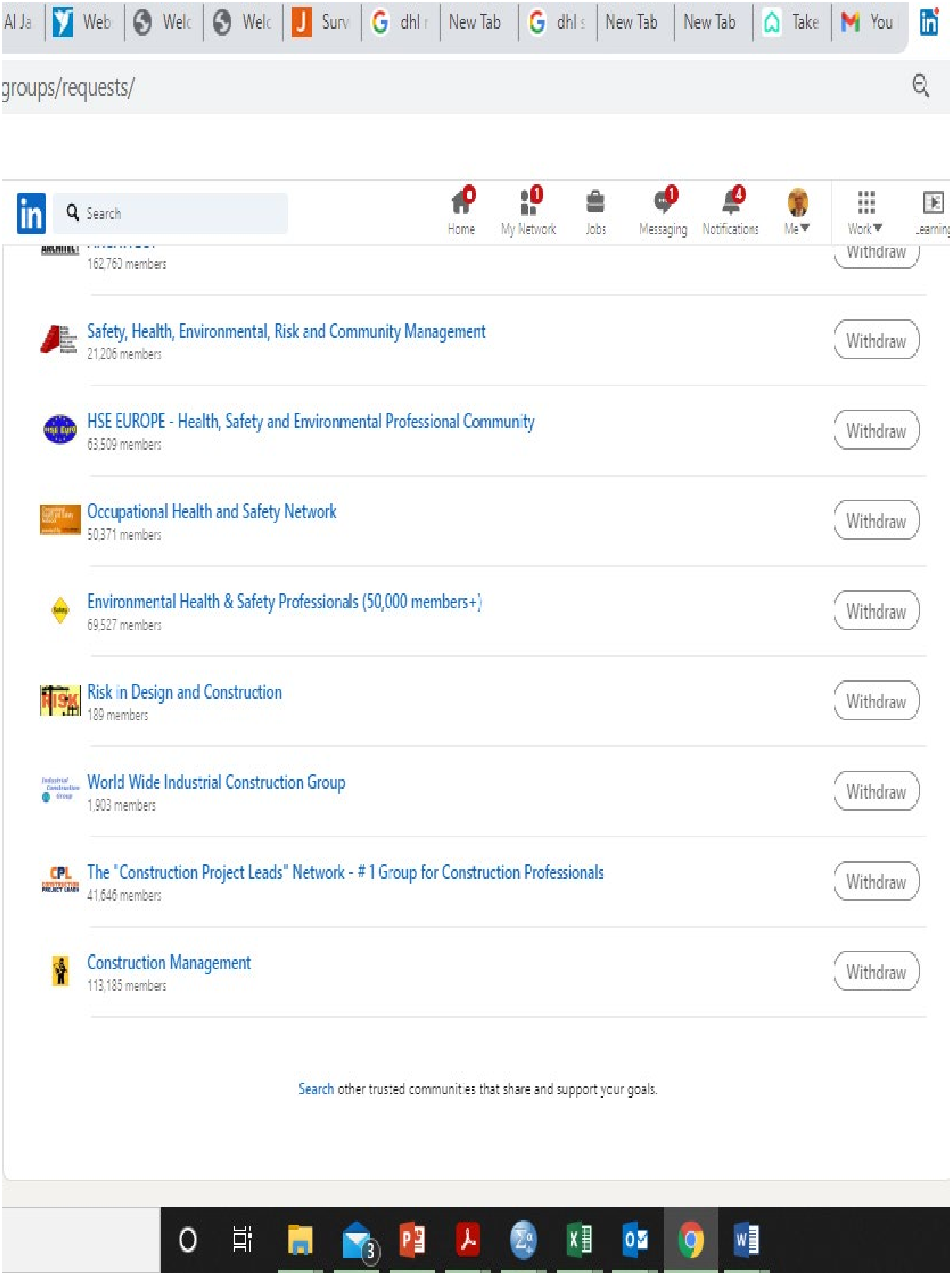
e-architect
Withdraw
Building Green, a Sustainability Group
Withdraw
ARCHITECT
Withdraw
Safety, Health, Environmental, Risk and Community Management
Withdraw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162,760 members
Withdraw
Safety, Health, Environmental, Risk and Community Management
21,206 members
Withdraw
HSE EUROPE - Health, Safety and Environmental Professional Community
63,509 members
Withdraw
Occupational Health and Safety Network
50,371 members
Withdraw
Environmental Health & Safety Professionals (50,000 members+)
69,527 members
Withdraw
Risk in Design and Construction
189 members
Withdraw
World Wide Industrial Construction Group
1,903 members
Withdraw
The "Construction Project Leads" Network - # 1 Group for Construction Professionals
41,646 members
Withdraw
Construction Management
113,186 members
Withdraw
Search other trusted communities that share and support your goals.

Appendix 12 Expert response regarding the five variables

Hello Abdul,

Thank you for sharing the paper. I am glad to hear of research related to CHPtD. The five design domains which designers should focus on look right to me. I believe those domains are impactful to safety hazards on construction sites and domains in which design professionals can make changes to improve design.

Best of luck with your research on the topic.

Sincerely,

John Gambatese

John Gambatese, PhD, PE(CA) | 541-737-8913 | john.gambatese@oregonstate.edu

From: Abdul Rahman Farooq < >
Sent: Thursday, November 3, 2022 1:42 AM
To: Gambatese, John <
Subject: CHPtD: what designers should look at

[This email originated from outside of OSU. Use caution with links and attachments.]

Hi Dr hon J Gambatses,

I hope you are very well,

I had learned very much from your work in the CHPtD field.

Recently, have published a paper regarding 5 variable what designer should consider when implementing CHPtD (attached),

hope you have time to look at it and let me know if you agree with it.

many thanks

Abdul Farooq

Appendix 13 forty most used Process safety methods

The gathering of advantage and disadvantages of the 40 most used process safety methods based on HSL (2000) report

No.	Process safety method	Advantages of the method	Disadvantages of the method
1	**Hazard and operability study (HAZOP)**	• Systematic and comprehensive • Can be applied in post-design phases • Examines the consequences of the failure • Includes keywords and parameters • Makes recommendations for hardware, software, humans	• Time consuming and expensive • Need P&ID, drawing, reliability rate and other documents • Team needs experience and HAZOP training • Cannot be used for deviations with multi-failure causes
2	**What if? Analysis**	• Comprehensive preparation by collecting process drawings, process procedures, item specifications, etc. • Easy to apply • Can identify multi-failure hazards	• Time consuming • Need team experienced in working with the process
3	**Concept hazard analysis (CHA)**	• Can be used in the concept and design phases • Early elimination of major hazards • Easy and cheap • Can be combined with further study using data from previous incidents with similar processes	• Difficult to identify small or detailed hazards when details are not yet available

4	**Concept safety review**	• Good basis for further study • Set criteria for the project to comply with • Recommendations for development of inherent safety components	• Only major hazards • Only used in the concept phase
5	**Preliminary hazard analysis (PHA)**	• Used in concept and design phases • Considers specifications, material data, equipment specifications, inventory levels, and operation information in advance p7ID • Consequence driven, it looks at potential adverse outcomes • Facilitates building of fault tree analysis and event tree analysis	• Cannot identify causes, due to unavailability of information • Can identify major hazards only
6	**Fault tree analysis (FTA)**	• Clear step by step framework • Top down approach • Uses gates • Quantitative analysis • Graphical diagram demonstrates connections • Can be used in other sectors, such as finance, social, IT	• Time consuming and expensive • Need P&ID, drawing, reliability rate and other documents • Team needs experience and HAZOP training
7	**Cause–consequence analysis (CCA)**	• Examines causes and consequences • Quantitative evaluation of risk • Produces graphs demonstrating the	• Time consuming and expensive • Team must be experienced with the process

		relationship between causes and consequences • Can also be used in other sectors	
8	**Pre-HAZOP**	• Used in design and development phases • Used when details are too limited for full HAZOP study • Quick and cheap • Identifies which areas need further study	• Only major hazards can be identified
9	**Standards/codes of practice/literature review**	• Provides criteria for design and minimum safety considerations with which the design must comply • Provides guidance for authorities • Identifies why and how accidents happen in similar processes • Provides basis for more detailed process study method	• New processes or technology have limited LT or authority guidance • Time consuming • Need to check if the authority guidance applies to the particular process • Already incorporated in many other process study methods
10	**Functional integrated hazard identification (FIH)**	• Uses functions of the item to do early stage assessment in the concept and pre-design phases • Can assess a wide range of failures (e.g. hardware, software, process management)	• Time consuming • Requires intensive experience

11	**Checklists**	• Easy to use • No experience needed • Quick	• Cannot be used in early stages • Limited brainstorming and identification of issues not on the check list
12	**Critical examination of system safety (CEX)**	• Encourages innovation and inherent safety by design • If used in early phases, many hazards can be designed out • Can be a basis for further study such as FTA or CCA	• Requires experience with the process • Some hazards could be missed
13	**Method organised systematic analysis of risk (MOSAR)**	• Framework for systematically evaluating the process against hazards, consequences, preventative measures, reliability, human interaction • Uses HAZOP and other hazard identification techniques • Links severity with protection objective • Utilities barriers, technological barriers • Acceptability table for residual risk	• Time consuming • Same disadvantages as hazard edification method used in the framework
14	**Goal-oriented failure analysis (GOFA)**	• Creates a top-down diagram using FMEA and fault tree • Identifies failure goals, causes and analyses them further • Identifies failure mechanism and fault mode	• Time consuming • Requires experience with the process and failures • Only identifies hazards resulting from failures

		• Identifies components that require additional study • Uses practical knowledge to identify factors leading to component failures • Wide range of failures, including hardware software process human	
15	**Matrices**	• Comprehensive techniques identify materials used and their reactions and combinations • Identifies all plant constructed materials, operators and utilities used in process • Identifies energy source, use of land, air and water • Techniques can be used early in concept and design phases and can identify areas that need further study	• Only identifies hazards from two or more components together • Could miss some hazards due to early stage and scarcity of information available • Matrix can be confusing if not presented in clear, easy to understand way
16	**Inherent hazard analysis**	• Useful for concept and design phases • Breaks down the process into units and asks simple series of questions to eliminate hazards as much possible and investigate safer alternatives	• Limited information available due to early stage

17	**Safety audit**	• Also called process safety review, design review or loss prevention review • Involves planning in advance and determining scopes • Can be used in many phases during lifecycle • Flexible in determining depth and complexity • Detailed advanced planning • Action plans and follow up • Looks at various aspects, angles including management, behaviour, processes, and materials	• Time consuming and expensive if audit is detailed and in depth • Need aid of other techniques, such as risk assessment, checklist
18	**Failure mode and effect analysis (FMEA)**	• Description of the process and its parts and functions • Breaks down the process into functions, sections, block diagram • Studies each item in every section and determines the failure mode and consequences • Record of analysis, summary and recommendation	• Time consuming and expensive • Difficult to identify failures resulting from more than one item • Requires significant data on reliability rate of each item • Difficult to identify all failure modes
19	**Failure modes, effect and criticality analysis (FMECA)**	• Same as FMEA with two extra steps: (1) Determine the severity of the effects caused by the hazard; (2) Determine the frequency of the adverse events	• Same as FMEA

		• Ranking the hazard based on the critical level (severity x frequency)	
20	**Maintenance and operability study (MOP)**	• Useful for design phase focus on maintenance • Establishes a multi-disciplinary team (e.g. operation, maintenance, designers) • Uses and reviews the PI&D • Scrutinises each section of PI&D based on list of questions	• Only focuses on maintenance • Need highly experienced maintenance experts and designers
21	**Maintenance analysis**	• Identifies maintenance requirements based on series of questions • Identifies preventative measures and safety devices for each piece of equipment in the process • Identifies failures of each piece of equipment • Detection devices for failure mode identified	• Time consuming • Experience in repairs, process and equipment failure needed
22	**Sneak analysis**	• Sneak flow, sneak indications, sneak label, sneak energy, sneak reaction, sneak procedures or sequence • Investigates the path of each on the P&ID to identify failure and its consequences • Uses checklists	• Time consuming • Requires experience

23	**Reliability block diagram**	• Breaks the process into blocks and breaks each block into reliability blocks connected as a chain where output of first is input for second • Helps to identify parallel path to be used if a component fails and cannot operate • Helps to identify where safety instrument or device is needed • Visual presentation of the reliability of the process components	• Focuses on reliability only; other hazards not identified • Only fit for complex systems; not useful for simple processes
24	**Structural reliability analysis (SRA)**	• Identifies infrastructure and building structure failure of plant • Shows the safety margins of the infrastructure and the structure	• Only used for building and infrastructure; cannot identify process hazards
25	**Vulnerability assessment**	• Identifies effect of failure of item on adjacent items, including how much an accidents on one item (e.g. fire, leakage, explosion) can affect nearby items (e.g. debris, heat) • Uses 3D to present size, shape, location of each item • Great for determining safe spaces and design barriers	• Technique identifies secondary hazards from an accident; not suitable for identifying primary process hazards

26	**DEFI method**	• Computer program used to send failure inputs to equipment or components of the process system to determine the failure and reliability rate of the tested equipment/component • Supports other techniques by providing reliability rate data • Good for testing new equipment or component before installing it in the process	• Only tests one piece of equipment or component • Focuses on reliability and failure, not on hazards
27	**Computer hazard and operability study (CHAZOP)**	Software and program failure methods are not useful in construction; they identify failure or non-working functions of the software and how to fix them or find alternatives or solutions. The graphical representations of many of these techniques are helpful for understanding the relations between causes and consequences and also for visualising how data and activities flow through the control software program	
28	**Structured methods**		
29	**Structured English**		
30	**Specification language**		
31	**Structured analysis and design techniques (SADTs)**		
32	**State-transition diagrams**		
33	**Peti-nets**		
34	**Graphe de commande etat-transition (GRAFCET)**		
35	**Task analysis**	These techniques investigate the human errors that could occur during the operation and maintenance phase as a result of interaction between human and process. They require a detailed SOP, which is normally not available during the design phase; hence,	
36	**Hierarchical task analysis (HTA)**		
37	**Action error analysis (AEA)**		

38	**Human reliability analysis**	this technique is not useful for this thesis (because they are not fit for design phase)
39	**Pattern search method**	
40	**Predictive human error analysis (PHEA)**	
	Process hazard identification methods (techniques)	
	Hardware hazard identification	
	Control hazard identification (software)	
	Human hazard identification	

Appendix 14 Published paper

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CONSTRUCTIONS HAZARD PREVENTION THROUGH

DESIGN (CHPTD): ASSESSMENT OF FIVE VARIABLES

TO ENHANCE SAFETY AT CONSTRUCTION DESIGN

PHASE

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Globally, construction experience high rate of accidents due to many complex

challenges. Because of this situation, efforts are made to reduce and eliminate the

causes of these accidents starting from the design phase. The present study uses

series of questions to filter and analyse the current literature and identify potentially

unsafe conditions that can be influenced during the design phase and grouped

extracted accident causes into five domains: permanent structure, temporary structure,

building equipment/plant, building material, and building site environment. Based on

the themes that emerged, questionnaire survey was undertaken to measure how far

construction professionals agree with these domains. Of the 290 professionals that

responded to the survey, 86% agreed that each variable plays a role. Based on the

findings, designers are encouraged to consider these five domains during the design

phase to reduce hazards in all follow project phases and to consult construction teams.

Keywords: hazard, design phase, project life cycle, site environment, unsafe condition

INTRODUCTION

The construction site is one of the harshest working conditions and one of the most dangerous environments (Tunji-Olayeni, 2018), thus can lead to several safety and health issues. To understand the reasons behind the high rate of construction accidents, there is the need to have understanding around both latent and active factors associated with construction activities. Limited space, especially in big cities, the challenge of moving heavy plants on site as well as movement of various vehicles and storage of building materials, lift and position components, process and handle building materials and establishing temporary facilities, these makes tasks difficult and raises the likelihood of accidents occurring (Kim, Ryu and Kim, 2021).

In addition, the exposure to external conditions on construction site where workers must perform their duties outside under extreme condition such as cold, rain, mud, hot, aggressive wind, over and above that worker exposed to high noise level from machines and heavy plants, inhaling fume emitted from construction vehicles and generators are other factors associated with workplace accident. Consequently, of such external conditions, safety and health challenges exist that include frost bite, sunburn, slips and trips, asthma, falls, loss of hearing ability and breathing irritations (HSE, 2015).

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Cooke et al. (2008) identified working at different elevations, from deep underground to hundreds of metres above ground level, exposes construction workers to the risk of

falls from height, which is one of the main causes of fatality in the construction

industry. The use of temporary structures such as scaffolding, excavation equipment,

supporting beams or sheets, ladders, hoists, elevators, fences, and temporary stairs

where they are not properly installed and maintained can lead to collapse and

accidents on site (HSE, 2015).

In Search of accident causes and their contributions, HSE (2003) concluded on

factors, and causes of construction accidents, based on ConAc model (Figure 1) to

enable the active safety management on site.

Figure 1: ConAc model of accident causations, factors and influences

Previous studies also acknowledge decisions made during the design stage as likely to

have significant impact upon workers' safety during all subsequent building phases,

i.e., construction, occupation, maintenance, renovation and/or demolition (Hinze and

Gambatese, 1996, Williams1,998). While eliminating all causes of accidents right

from the construction design phase would be ideal, unfortunately this might not be

possible. Nevertheless, conscious of this fact, there are proof that a significant

percentage of accidents causes can be influenced during the design phase of a project.

Gibb and Haslam (2004) investigated 100 accidents in the UK construction sector and

concluded that 47% of those accidents could have been avoided or reduced if different

decisions had been considered at the project design and planning stage. In addition,

Gambatese et., (2005) investigated 224 fatal accidents in the United States and found

that 42% could have been eliminated or reduced if designers had considered safety more during the project design phase. Furthermore, Driscoll et al., (2008) discovered

that 37% of the 210 fatal accidents studied in Australia had a direct correlation with

design issues, while another 14% had direct relationship with project design. To add

to this debate, the present study assessed the agreement level among construction

professionals regarding accident causes that can be influenced during the design

phase.

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METHODOLOGY

The present study reflected the approach by examining accident causes that designers

can influence during the design phase. Cross sectional study to measure

professionals' perception using a structured questionnaire developed on the role

played by permanent structure; temporary structure; building equipment; building

materials and prevailing site environmental condition in accident occurrence on site

was undertaken. Prior to collecting the participant response, the questionnaire was

tested among professionals and academic to ensure its accuracy and reliability and

based on the response analysed, further development of the questions was made to

ensure set objectives for each question is achieved. Thereafter the questionnaire was

hosted online, and link shared on several social media platforms (LinkedIn, Facebook

etc) after gaining approval of each gate keeper.

To measure whether these domains were accepted by the construction professionals,

the, survey question consisted of five sets of question for each domain, using Likert scale statements 1 = Strongly disagree, 2 = Agree, 3 = Undecided, 4 = Disagree and 5 = Strongly agree respectively. To ensure relevant participants only take part in the survey, as part of the inclusion criteria considered is that each participant must have (1) construction experience, (2) construction health and safety knowledge and (3) at least three years of experience working on medium or large construction projects.

At the end of the survey, 290 participants from 46 different countries completed the survey, the selection was based on the inclusion criteria rather than described.

At the end of the survey, data was analysed descriptively and inferentially to confirm or reject the following hypotheses:

Hypotheses

1. The professionals in construction agree that designers can influence the five domains identified in LT during the design phase
2. There is no difference between the views of professionals working in a narrow site space and those working in a wide site space regarding temporary structures
3. In terms of site environment conditions, there is no difference between the views of the professionals working on an urban project and those working on a rural project

Data Reliability Test

Data reliability was tested, to ensure consistency, by utilising Cronbach's alpha test, the data scored for each domain ranged between 0.64 to 0.83 (Table 1). Score exceeding 0.6 was considered reliable (Nunnally and Bernstein, 1994).

FINDINGS

Result for hypothesis 1

From the data analysis accident causes related to 'Building permanent structure' that can be influenced during the design phase, 97.6% of the participant either strongly agree or agree with the assertion, while the domain mean was 21.85, with a standard deviation of 3.46 (table 1). Result from variables that focused on 'Building temporary structure' show 97.9% either strongly agree or agree, while the domain total mean was 23.19, with a standard deviation of 3.09 demonstrating that that designer should place emphasis on safety around the erection of temporary structure on sites.

In addition, construction vehicles and equipment location on site was also positively viewed as the role of the designer (74.8%) to ensure adequate planning is considered at the design phase to help minimise incidence on site (18 ± 4.40). Concerning accident causes related to 'Building material' that can be influenced during the design phase, 97.6% of the respondents either strongly agree or agree that safe storage location of these materials considered at the design phase can influence site safety positively (Table 1).

Table 1: Domain means and standard deviations and Cronbach α

Result of hypothesis 2

Based on participants take on use of temporary structure on site, there was no significant difference found between in response on working in narrow site spaces (n=182, m=23.30, SD=2.66) and sites that has wide site spaces (n=97, m=23.15, SD=3.09). The outcome was t(277)=.417, p=.677 ns, which means that both groups share the same view, and hence the site space makes no difference on the need to ensure safety is guaranteed on both sides right at the design phase.

Result of hypothesis 3

Assessment regards participants assessment of safety around projects located in urban

and those in rural sites not significant different was found regards harsh environmental

conditions experienced t(276)=.262, p=.794 between groups (table 2)

Table 2: T-tests result for group work in urban and group work in rural projects

In addition, t-test was conducted to each of the five domains. From the result obtained

there was no significance difference between the group working in narrow site spaces

and the group working in wide site spaces (Table 3). Again, no significance found,

both groups have same view to all 5 domains.

The survey results demonstrate a high level of agreement among construction

professionals with all five domains. The reason for this could be that questions on the

survey related to challenges faced by professionals during one or more of the project

phases (design, construction, occupation, maintenance, and demolition).

Outcome of the result show that 97.6% of the participant agrees that building design,

type, size, shape, and permanent components influence safety, whether during

construction, maintenance, or demolishing phases, which confirms the findings of

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previous studies (Gambatese et., 2005; Heinz and Gambatese 1996; Lingard et al.,

2015; Manu et al., 2012, Driscoll 2008; Gibb and Haslam 2004; Toole 2005).

Table 3: T-tests for group work in narrow site space and group work in wide site space

However, Gambatese et al. (2013) and Lingard et al. (2015) found that current

practice of architect and designers tend to be focus on safety of the end user (occupier)

but neglect that of worker during the construction and other phases, with both confirming that designers can influence safety during subsequent construction phases.

In accordance with the literature, the survey findings also confirm that permanent structures can be influenced by the designers during the design phase as designers can select the shape, size, and permanent components of the building and in many (if not most) projects the designers determine the exact specifications of these permanent structures. Hence, permanent structures and its components are directly influenced by designers during the design phase.

It was evident that the survey respondents affirmed that consideration for design of site layout, scaffold, barriers, material storage, excavation, space for welfare facilities, fences and closing-for-openings can increase safety and reduce accidents during construction work. However, in practice such consideration is left to the main contractors which most often becomes secondary issues that can lead to accidents as a result of poor location or missing temporary structures. Therefore, an opportunity exists where the architect together with the main contractor could design these components, to help reduce number of hazards during the construction, maintenance, and demolishing phases.

NIOSH (2013) recognise that designers have the potential to influence the temporary structure during the design phase, further adding on the present study result that demonstrates site space whether it is narrow or wide does not make any difference as professionals who worked in narrow site space provided the same level of agreement as the group who work in wider site space. From these results it can be concluded that planning and designing temporary structure during design phase, in cooperation with construction team, will reduce the hazards of construction work on site. Nonetheless, it worth mentioning that designers in some country avoid getting involved in construction site activities and its layout to avoid legal responsibility (Saunders et al., 2016).

Considering the level of acceptance (74.8%) among the participants that designers can play role in selecting plant/equipment and its locations on site, with advance technology such as BIM and VR (virtual reality), the designers can visualise the movements of plant and equipment on the virtual simulation space during the design phase, which will help to determine location and vehicles/plants specification that fit the job. This may reduce many unnecessary hazards during construction phase. In addition, while environmental condition such as weather, lighting, wind, rain can cause accidents during the construction, maintenance, or demolishing phases, it is argued that such factors should be taken into consideration during the design phase of

the project as it will help minimise incidence on site. Based on the outcome of the study designers are tasked to consider site environmental conditions and what impact it will have on construction workers, building material, plant, or equipment.

It is important to consider safety hazards throughout all phases of the project, from the design to the demolition, or even more comprehensively, from the idea to recycling.

Each permanent section of the building will go through all project phases. Therefore, designers during the design phase consider factors described as the five domains of the present study to help with planning design and decision. In addition, these domains are viewed important as it will help strengthen CHPtD delivery during the project execution.

While in practice, designers are likely not to have answers to many of the above questions on their own, due to lack of construction experience and safety knowledge (Toole 2005; Hecker et al., 2005; Gambatese 2008), thus the need to consult other teams who are involved with constructing, maintaining, or demolishing the building, including safety professional teams and carefully consider these teams' input during the design phase.

In addition, the study advances the current effort by earlier study in the adopt of CHPtD as a means of preventing workplace accident on construction. The study opened on the need for designers to consider safety related issues right at the project design phase and a means of ensuring latent risk are identified and safety considerations considered during the project lifecycle. Hence the need for consideration of manageable factors in our case; that will guarantee a realistic projectsafety efforts has been considered at the design phase to help with forecasting and evaluating potential safety risks at the pre-construction stage of every project (Gangolells et al., 2010).

CONCLUSIONS

Based on the survey outcome it is possible to conclude that unsafe conditions, which designers can influence during the design phase of construction projects, will fall into one or more of the following five domains: Permanent structure, Temporary structure, building equipment/plants, Building material and Site environment. Designers should

consider these five domains throughout building project phases, and it is vitally

important to seek advice from other project teams, including safety professionals to

enhance safety considerations throughout construction project lifecycle.

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