Designing a Knowledge-Based System to Facilitate the Process of Fall Risk Assessment in Construction

Thesis submitted in partial fulfilment of the
requirements for the degree of

Doctor of Philosophy

by

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2023

Dedicated to

My late mother, **C.Kalavathy,** who supported and encouraged me to complete this journey.

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Declaration

I hereby declare that the work presented in this thesis entitled "**Designing a Knowledge-Based System to Facilitate the Process of Fall Risk Assessment in Construction**" is my work and done under the guidance of Dr. Urmi Ravindra Salve, Associate Professor at the Department of Design, Indian Institute of Technology Guwahati, Assam, India. To the best of my knowledge, this material has not been submitted, either in whole or in part, for any degree or diploma at any University.

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Certificate

This is to certify that the work contained in this thesis entitled "**Designing a Knowledge-Based System to Facilitate the Process of Fall Risk Assessment in Construction**" submitted by C.Vigneshkumar to the Indian Institute of Technology Guwahati for the award of the degree of Doctor of Philosophy has been carried out under my supervision and this work has not been submitted elsewhere for any degree or diploma.

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Acknowledgment

First, I would like to express my gratitude to **Dr. Urmi Ravindra Salve**, my supervisor, for her insightful guidance and enthusiastic support. **Dr. Urmi R. Salve**, you and I developed a friendly relationship throughout this journey that inspired me to prove my capabilities to you and my desire to increase my knowledge and abilities. You constantly forced me outside of my comfort zone and helped me discover skills I didn't know I possessed. I appreciate your support, patience, and belief in me.

I am highly grateful to my doctoral committee members, **Prof. Debkumar Chakrabarti**, **Dr. Sharmistha Banerjee**, **Prof. L. Boeing Singh**, and **Dr. Abhishek Shrivastava**, for their constructive suggestions in improving my thesis work.

I sincerely thank the HOD, **Prof. Sougata Karmakar**, and **Prof. D. Udaya Kumar** for their support and encouragement throughout this study. I express my sincere thanks to the entire **faculty** and **staff** in the department of design and the academic affairs of the Indian Institute of Technology Guwahati for their help in the time of need.

My sincere gratitude goes out to the **Safety Managers** of construction projects who contributed greatly to this study; without their help, the work would not have been completed.

I want to thank **Vasundhara Srivastava**, PhD student at Hong Kong Polytechnic University, Hong Kong, and **my friends** and **colleagues** at the Indian Institute of Technology Guwahati for their support and assistance through constructive discussion.

I shall always be grateful to my family members; my father, **V.Chellappa**; sister, **C.Vidhya**; brother-in-law, **V.Ravikumar**; and nephews, **Mithran** and **Mithulan**, for their love and support. Last but not least, there would most likely be no achievement without the support and prayers of my late mother **C.Kalavathy**.

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ABSTRACT

Fall from height (FFH) accounts for several fatalities and injuries in the construction industry worldwide. Many researchers have proposed several approaches to enhance the safety performance of the construction industry by preventing falls. However, FFH continues to impact the construction sector. Yet, a practical approach is still lacking in the industry to prevent falls. This could be achieved through the fall risk assessment (RA) method. The entire safety procedures are likely to fail if RA fails, as this is one of the critical safety processes in the construction industry. But, the traditional method of RA fails to identify safety risks involved in construction activities due to a lack of experience and time. Some researchers recommended integrating the knowledge management (KM) concept into construction safety management to address these safety challenges. Unfortunately, few studies have attempted to integrate KM into safety in construction. Hence, this study focused on integrating KM into the safety planning to facilitate the process of RA in the Indian construction industry, focusing on preventing falls. This research was presented in traditional vertical formwork because the formwork jobs are highly influenced by working at heights, and its operations are associated with a high risk of falls.

From this perspective, this research study aimed to design a safety knowledge-based system to facilitate the fall RA process for vertical formwork activities to prevent falls. First, the study has used a qualitative approach to identify how KM strategies are employed in the RA process to prevent falls in construction companies. The results indicated that there was no systematic way of managing safety knowledge in construction during the fall RA process. Further, semi-structured interviews and surveys gathered the challenges that users (who perform RA) face during RA and their viewpoints to facilitate it. Through this, the study deduced that the users were looking for a platform where they could access safety knowledge for particular activities during the RA process. Based on the inputs from users, four activities that pose fall risks during formwork operations were identified through observation and surveys. The riskiest activities among them were analyzed using the occupational safety and health administration (OSHA) database. Then the Delphi survey was used to capture the construction experts' safety knowledge (i.e., activity risk levels, causes of fall, individual at risk, and preventive measures) of vertical formwork activities. Best safety practices for formwork operations were also captured through thorough document analysis. Based on the framework developed for the

knowledge-based system, a prototype was first developed to store and reuse the captured safety knowledge. The interface design of the prototype was evaluated through a cognitive walkthrough (CW) with five experts from different educational and industrial backgrounds. Based on the experts' feedback, the prototype's interface design was improved, and a web-based KM system was developed using PHP language programming. The developed system was evaluated in the real-life construction environment with 20 end-users based on three criteria: features, benefits, and challenges. The findings indicate that the proposed system offers numerous benefits to builders in (1) ensuring that end-users, regardless of their site location, have easy access to vertical formwork safety knowledge; (2) helping users with job site learning of safety RA skills; (3) effectively sharing safety knowledge; (4) facilitating the fall RA process on-the-job for safety heads; (5) helping to improve safety performance; and (6) saving time that is spent on RA.

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LIST OF ABBREVIATIONS

AFPS	Active Fall Protection System
AHP	Analytic Hierarchy Process
BAPP	Behaviors, Attitudes, Perceptions, And Performance
BIM	Building Information Modeling
BLS	Bureau of Labor Statistics
BN	Bayesian network
CFOI	Census of Fatal Occupational Injuries
CMS	Content Management System
CREDAI	Confederation of Real Estate Developers' Associations of India
CSR	Construction Safety Research
DfS	Design for Safety
ENR	Engineering News-Top Record
FCIS	Fatality and Catastrophe Investigation Summaries
FFH	Fall from Height
FPSDs	Fall Protection Supplementary Devices
FPSFHC	Fall Protection System for High-rise Construction
HR	Human Resources
HSE	Health and Safety Executive
ICTs	Information and Communication Technologies
ILO	International Labour Organization
KM	Knowledge Management
MCDM	Multiple Criteria Decision-Making Method
OSHA	Occupational Safety and Health Administration
OSV	On-site Visualization
PPE	Personal Protective Equipment
RA	Risk Assessment
RTI	Right to Information
SOPs	Safe Operating Procedures
UI	Usability Issues
VP	Virtual Prototyping

CHAPTER 1

INTRODUCTION

1.1 Background

Globally, with an annual budget of $10 trillion, the construction industry corresponds to 13 percent of the gross domestic product (GDP) (Barbosa et al., 2017). It also offers more employment opportunities for many young individuals in the global south (International Labour Organization (ILO), 2017). According to Fernando and Moodley (2018), a country with a non-Western cultural background is often labeled as a "developing" or "low-middle-income country" and is referred to as the "Global South." Despite its benefits, the construction industry contributes to poor safety performance (Safe Work Australia, 2019). According to global accident rates, compared to other sectors, construction fatalities and injuries were higher (Sousa et al., 2014). For instance, according to the Census of Fatal Occupational Injuries (CFOI; 2019), construction accounted for around 20% of worker fatalities in 2019. Unfortunately, due to high fatality rates, the reputation of the construction industry is notorious in many countries, including the U.K. (Health and Safety Executive (HSE), 2020), China (Shao et al., 2019), and Singapore (Ling et al., 2009).

According to Occupational Safety and Health Administration (OSHA; 2011), construction accidents are classified into the following groups: hit by objects, caught-in/between, falls from height (FFH), struck-by, collapse, incidents caused by lifting, electrocutions, and others in which, FFH accounts for a large number of fatalities and serious injuries in many countries (Kang, 2018; Samantha et al., 2021). For instance, FFH fatalities accounted for all worker deaths in U.K. construction in 2019 (HSE, 2020). In addition, researchers from many developed countries found that FFH was the main cause of deaths in the construction industry by examining the trends of fatal incidents (Aneziris et al., 2012; Kang et al., 2017; Zhong et al., 2020). More extreme cases have been recorded in developing countries compared to developed nations. For example, FFH fatalities were reported in more than half of overall accidents in the Chinese construction industry between 2004 and 2017 (Li et al., 2019). Likewise, in many developing nations, including Saudi Arabia (Abukhashabah et al., 2020), Brazil (Zlatar et al., 2019), and Malaysia (Ayob et al., 2018), similar situations have been recorded. From these statistics, it can be determined that the construction industry involves a significant risk of falls.

In India, the construction industry plays a key role in economic growth (Singh et al., 2021). The Indian economy is expected to rise from USD 2.6 trillion in 2019 to 9 trillion in 2030 (CREDAI, 2019). It is also expected that the Indian construction sector could contribute 13% of GDP by 2025 (CREDAI, 2019). Also, the construction sector is India's second-largest employer, employing around 50 million in 2012 (Patel and Jha, 2016a). Most of the construction workers are unskilled (Hasan and Jha, 2013), and due to poor safety standards (Patel and Jha, 2015) and labor scarcity (Hasan and Jha, 2013), the Indian construction industry does not place a premium on employee competence. The construction sector in India also faces challenges such as insufficient medical facilities, poor accident reporting methods, poor safety culture, and lack of implementation of safety regulations (Singh et al., 2021; Patel and Jha, 2016a; Vigneshkumar and Saravanamuthu, 2021), all of which contribute to the industry's poor safety culture, resulting in approximately 10,000 fatalities yearly (Patel and Jha, 2016b). Vigneshkumar et al. (2019) found that FFH accounts for 50% of overall construction accidents by analyzing accidents in the Indian construction sector during 2019-2020 using right to information (RTI) reports and local police records. Likewise, in many developing nations, similar situations have been reported (Pandit et al., 2020). When the underreporting of construction accidents in India and worldwide is considered, the actual fall accident rates will be significantly higher (Patel and Jha, 2016a). Although the government has enacted several safety regulations and recommendations, fall accidents in Indian construction (Chellappa and Salve, 2018) and in other developing nations construction sector continue to rise at an alarming rate (Awwad et al., 2016). Furthermore, the harmful nature of accidents in construction results in unintended consequences such as loss of work (Sunindijo and Zou, 2013) and project delays (Hu et al., 2000). In addition, fatalities cause serious financial damage to individuals and society (Liu and Tsai, 2012; Yuan et al., 2018).

Enhancing safety performance by preventing accidents is the current mantra in the construction industry worldwide (Zwetsloot et al., 2013). Hence, several approaches were proposed globally to prevent falls. In recent years, continuous efforts have been taken to improve construction safety situations (e.g.., Zuluaga et al., 2020; Lestari et al., 2019), but fall incidents continue to impact the construction sector (BLS, 2019; HSE, 2020). Though such studies proposed different methods of fall prevention, they were either too complicated to put into practice or didn't offer a clear plan for enhancing construction safety performance (Sanni-Anibire et al., 2020). Hence, there is currently a shortage of practical approaches to improve construction safety performance. The industry most likely lacks a straightforward, comprehensive, and still successful method. This can be achieved by using a fall risk assessment (RA) method. "The most critical safety process in construction is RA, since if it fails, all other procedures are likely to fail" (Manuele, 2013).

RA is a continuous holistic process at the core of construction safety planning and needs adequate planning, monitoring, and feedback (Celik and Gul, 2021). According to Bansal (2011), safety planning entails identifying and assessing potential safety risks associated with construction activities and drawing steps to control the risks via the RA process during the pre-construction phase. RA is a mandatory and knowledge-intensive process (Ding et al., 2016), usually carried out by safety heads/managers to prevent accidents (Ahmad et al., 2016). By recognizing all potential activity-based risks and recommending ways to avoid or reduce them, RA can be an effective method to analyze site operations, set up appropriate job procedures, and ensure that all people are trained (Chellappa et al., 2020). When carried out properly, RA can help decrease the number of workplace accidents and injuries, increase productivity, and lower workers' compensation costs (Mohammed et al., 2019). This systematic approach should be performed and renewed regularly by the philosophy of continuous improvement (Sanni-Anibire et al., 2020). It is referred to as risk management and, if necessary, making revisions. Considerable practical and theoretical knowledge is needed to execute the RA process (Ding et al., 2016). Nevertheless, RA faces significant challenges. For instance, RA heavily relies on the site members' experience. The fragmented nature of construction sites makes it difficult to draw on the expertise of different site members (Carter and Smith, 2006). Indeed, safety experts conduct the RA process based on their skills and safety knowledge, engineering drawings, standards, and regulations. (Chellappa et al., 2020). It is documented that such a process does not imitate real-life construction operations (Hadikusmo and Rowlinson, 2004; Ding et al., 2016). The conventional method of RA frequently fails to detect risks associated with an activity, either due to inadequate knowledge or a lack of time (Gadd et al., 2004), resulting in accidents (Albert et al., 2013). In many cases, workplace fatalities are caused by a failure to share and communicate critical knowledge (Li et al., 2018).

According to Carter and Smith (2006), challenges in construction safety could be eliminated by incorporating knowledge management (KM) into safety planning. Utilizing and transforming knowledge from different sources for continuous corporate improvement is the strategy of KM (Kamardeen, 2011). KM can assist in acquiring a company's expert knowledge from computer files or on the document or in people's heads and disseminating it in a problem-solving context or particular situation (Hadikusmo and Rowlinson, 2004). KM is viewed to improve organizations' efficiency and competitiveness (Javernick-will, 2012). Similarly, Hallowell (2012) stated that proper safety KM could improve the companies' ability to respond to safety challenges. According to Dong et al. (2018), safety knowledge is a justified belief that increases firms' ability to manage hazards to effectively attain an acceptable risk level. Lehtinen et al. (2005) pointed out that KM is essential in safety planning; hence: (1) resources of companies are not discarded, (2) information is kept as an organized entity, and (3) knowledge is readily available and accessible when and where it is needed. To create a better safety culture, organizations must create a systematic method to acquire and re-use safety knowledge among employees (Sherehiy and Karwowski, 2006). Some researchers (e.g., Carter and Smith, 2006; Kamardeen, 2011; Ding et al., 2016; Mohammed et al., 2019) proposed different approaches to integrating KM into construction safety planning. Unfortunately, there has been limited research on KM and safety in construction because most construction firms limit the minimum enforcement of their safety efforts (Hallowell, 2012). Given the above, this study focused on integrating KM into the safety planning to facilitate the process of RA, focusing on preventing falls in the Indian construction industry.

Construction involves numerous tasks and trades. Due to time constraints, it was practically difficult to include all the trades in this study. Therefore, this research was presented in the context of traditional vertical formwork (wall and column). Formwork is used as a mould and shaped into desired dimensions for concrete tasks. Up to 60% of the concrete structure’s overall cost can be covered by formwork operations (Hurd, 2005). Formwork used in construction often involves working at heights (Amrutha et al., 2014), and a high level of fall incidents are associated with its operations (López-Arquillos et al., 2014). Hence, safety and productivity are highly affected by formwork operations (Amrutha et al., 2014). According to Zambianchi (2007), the riskiest stage in terms of falls is preparing formwork for concrete structures. In addition, it is evident from the literature that preventing falls during formwork operations through RA from a KM perspective is an uncharted area. Hence, the goal of this research work was to collect evidence to answer the following research questions:

1. How are safety KM strategies employed in construction companies during the fall RA process?
2. What are the challenges encountered during fall RA and what knowledge do the users require for fall RA?

3. How should safety knowledge be represented while developing a knowledge-based system to facilitate the RA process focusing on preventing falls during vertical formwork?

4. How effective is the proposed system to perform fall RA?

1.2 Research Aim and Objectives

This research study aims to design a safety knowledge-based system to facilitate the process of RA, focusing on preventing falls during vertical formwork in construction projects. The following objectives are set to achieve this aim:

1. To identify the safety KM strategies employed by construction companies during the fall RA process

2. To identify the challenges faced by the users during fall RA and understand the safety knowledge needed by them for fall RA

3. To develop a knowledge-based system for representing safety knowledge by

    a. Identifying the activities that pose the risk of falls in vertical formwork

    b. Analyzing the fall trends in formwork operations

    c. Capturing the safety knowledge of formwork activities for fall RA

    d. Developing a system to store and reuse safety knowledge

4. To test and evaluate the knowledge-based system by potential end-users

1.3 Hypothesis

A safety knowledge-based system will enhance the fall RA process during vertical formwork operations.

1.4 Research scope

The knowledge-based system focused on the RA solutions most often applied in the Indian construction companies to benefit a larger community. The data collected concerns RA for vertical formwork operations in residential building construction, focusing on fall prevention and targeted safety heads/managers of the main contractors

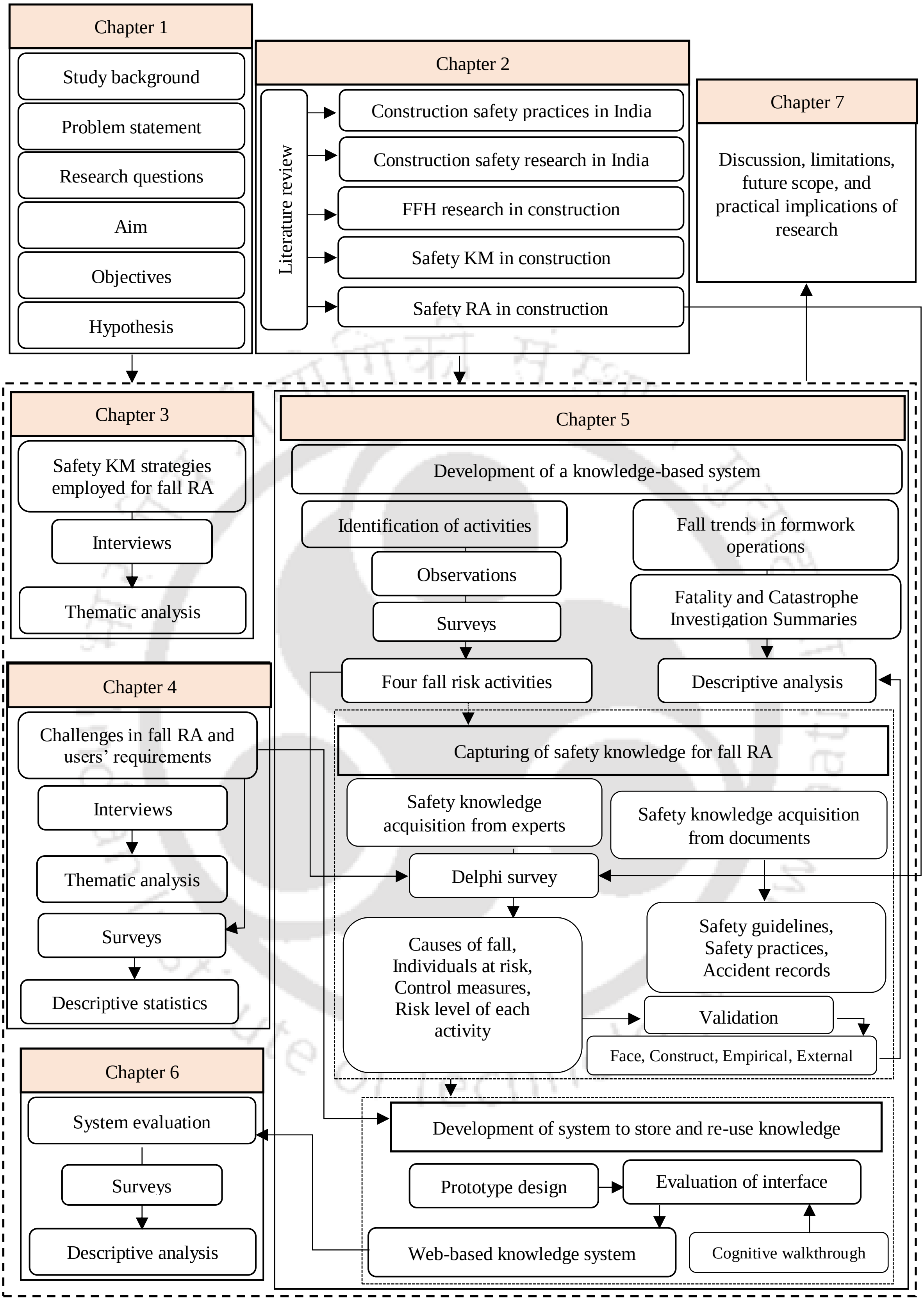


Figure 1.1 Thesis workflow and content of various chapters

1.5 Thesis structure

This thesis has been structured in seven chapters. The brief workflow of study is illustrated in Figure 1.1 and the summary of the chapters' contents is given below:

- **Chapter 1** discusses the study's background and purpose, research questions, aim and objectives, hypothesis, the study scope, and thesis structure.
- **Chapter 2** discusses the literature review findings. The review of literature is divided into five sections: (1) Safety context in Indian construction; (2) FFH in the construction industry; (3) RA in construction that includes the steps involved in it and methods used to conduct RA; and (4) Safety KM in construction: basic concepts, processes, benefits, and barriers.
- **Chapter 3** discusses the safety KM strategies employed in Indian construction companies to prevent accidents through thematic analysis.
- **Chapter 4** discusses the analysis of challenges that safety heads/managers face during RA and their requirements through thematic analysis and descriptive analysis.
- **Chapter 5** presents the activity involved in vertical formwork operations. This chapter also discusses the analysis of fall-related activity-based risks associated with formwork using the OSHA database. The fall-related safety knowledge of formwork operations required for RA captured from experts using the Delphi method is also discussed in this chapter. The developed knowledge-based system is presented in detail.
- **Chapter 6** details the validation of knowledge-based systems by real end-users through the survey.
- **Chapter 7** presents the study's findings and recommendations. This section covers the study's summary, significant research findings, implications, study limitations, and future scope of work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review conducted for this research is presented in this chapter. The two main topics, i.e., construction safety research (CSR) with particular reference to India and FFH research in construction worldwide, were systematically reviewed to identify the research gaps focusing on RA concerning KM. Scopus database was chosen to extract the documents for review due to its broader coverage (Chadegani et al., 2013). For CSR in India, the keywords used to search literature were "construction safety" OR "occupational health" OR "safety management' OR "construction accidents" OR "fall from height" OR "accident prevention" OR "ergonomics in construction" OR "India. Similarly, for FFH research, fall from height" OR "fall prevention" OR "fall accident" AND "construction fall safety" are the keywords used to search literature. For both the topics, only the journal articles published in the English language were selected. Initially, the journal articles found in the sample were 118 and 293, with the stated keywords. The abstract and title of each document were further screened to avoid any irrelevant documents in the sample. Finally, after careful refining, 64 and 83 documents were extracted and published during 2004-2019 and 2000-2018, respectively.

First, this chapter discusses the construction safety practice in India. This is followed by a discussion of a literature review on CSR in India. Next, the literature review on FFH research in construction worldwide is presented. The third section discusses the background of KM and the definition of safety knowledge, its link between safety, KM processes, and its barriers and studies carried out in the construction industry. The last section gives a detailed review of safety RA concepts and methods used in the construction domain. Lastly, the gaps are identified concerning FFH within the context of RA from the KM perspective.

2.2 Construction safety practice in India

The construction industry in India is largely acknowledged as a labor-intensive industry. Due to issues in safety laws enforcement, safety in Indian construction is poor (Bansal, 2011; Vigneshkumar et al., 2019). India has safety regulations such as The Building and other Construction Workers Safety and Welfare Act of 1996 and Factories Act 1948 for construction safety; however, only some are followed by construction organizations (Bansal, 2011). Although the National Building Code of India is set as national guidelines for regulating activities in Indian construction, many contractors push safety to the bottom priority level (Vigneshkumar et al., 2019).

According to Bansal (2011), many Indian contracting organizations still fail to enforce safety laws; new safety equipment and services are also being introduced. The construction workers are trained by safety professionals (Bansal, 2011), and through consultancies, large-scale contracting organizations started training their workers in recent years (Vigneshkumar et al., 2019). Safety professionals train workers on handling new equipment safely and explain precautions relating to threats such as falling hazards, fire, and electrocution (Bansal, 2011). To enhance safety performance in construction projects, such companies follow other developed countries' safety practices and regulations (Bansal, 2011).

In practice, contracting companies appoint safety team members, including safety heads and junior safety officers, to manage safety at the site. Safety heads/managers usually conduct RA for each project by listing out all risky activities and control measures and handle it to junior safety officers in the form of safe operating procedures (SOPs) to ensure that safety measures are followed (Vigneshkumar et al., 2019). On the other hand, in India, the labor cost is cheap, and most of them are unskilled (Hasan and Jha, 2013), unaware of their rights (Bansal, 2011), and contracting organizations find it profitable. Many companies do not follow the code standards when enforcing safety laws on workers who are unaware of their rights (Bansal, 2011). This results in huge injuries and fatalities in Indian construction, which is 50 times higher than in the US construction industry (CIDC, 2005). In addition, one in 2,000 workers were injured or killed in Indian construction (Mahalingam and Levitt, 2007). This shows that construction safety practices still need to be improved in India.

2.3 Construction safety research in India

Various studies have been carried out covering multiple areas to enhance the Indian construction safety performance. According to Chen and Jin (2012), a safety program that connects safety training, management commitment, and education can improve safety performance. Factors influencing safety management programs in construction were examined through multiple studies. For example, nine critical factors that influence the success of a safety system in Indian construction were recognized and tested by (Rajaprasad and Chalapathi, 2015). Similar studies can be found in Ragul and Rathinakumar (2019), Nair and Vivek (2019), and Samuel and Munagala (2016). To prevent workers and employees from hazards, some studies (Rajaprasad and Chalapathi, 2016; Kumar et al., 2015) introduced a safety education program to educate them.

Also, the factors that influence safety climate and safety culture in Indian construction were identified (Patel and Jha, 2016b) and linked to measuring safety performance (Hasan and Jha, 2013; Patel and Jha, 2016a). Within the safety climate, workers were given more attention by the research community (Tabish and Jha, 2015). The relationship between KM and safety culture was addressed by some studies (Deepak and Mahesh, 2019; Deepak et al., 2019). For example, Deepak and Mahesh (2019) developed a knowledge-based safety culture for Indian construction companies (Deepak et al., 2019). In addition, the studies on safety culture were also focused on engineers and workers (Raja et al., 2016; Vidhyasri and Brahim, 2014).

Studies on applying information and communication technologies (ICTs) in Indian construction were limited. Bansal (2011) adopted geographical information system (GIS) during safety planning to forecast hazardous situations in construction projects. Similarly, Kumar and Bansal (2016, 2018) developed a method to select safe construction sites using GIS in hilly regions. In another study, on-site visualization (OSV) sensors were applied by Izumi et al. (2014) to visually represent the buildings to project team members and everyone around the site. Concerning hazard identification and risk mitigation, earlier studies focused on identifying health hazards (Neeharika et al., 2018) and accident causes (Gaganpreetkaur and Singhal, 2018). Some studies (e.g., Patel and Jha, 2017) adopted multiple criteria decision-making method (MCDM) techniques to classify and evaluate safety risks associated with activities. From the above-discussed studies, it is evident that few studies have been carried out in India targeting construction safety. In addition, it can be seen that no studies were carried out to prevent falls in construction. Hence, studies on fall prevention should be established in India, as FFH accounts for many accidents in Indian construction (Jain and Matharu, 2017; Vigneshkumar et al., 2019).

2.4 Fall from height in construction

FFH in construction has gained significant interest among researchers and has been extensively examined because of its severity and frequency (C and Salve, 2020). Early interest was primarily focused on identifying root causes and the factors contributing to falling accidents. For instance, Chi et al. (2005) developed a coding system that can recognize influential factors to fall and prevention measures. Many researchers (Huang and Hinze, 2003; Dong et al., 2012; Kang et al., 2017; Dong et al., 2017; Kang et al., 2018) from the construction safety domain used national statistical accident data to analyze fatal fall patterns in the countries including the Hong Kong, the U.S.A, and Taiwan. The factors such as individual characteristics, surfaces and platforms, workplace environment, organizational characteristics, and environmental conditions that influence FFH in construction workplace were analyzed using statistical tools by several researchers in terms of proportions, rates, and relationships (Nadhim et al., 2016). The efficiency of the fall prevention safety program was evaluated by Rivara and Thompson (2000) using the electronic database. Hung et al. (2013) and Evanoff et al. (2012) conducted studies targeting fall safety training programs for carpenters and subcontractors. Menzel and Shrestha (2012) and Evanoff et al. (2012) focused on increasing the safety behaviors of Latino workers and subcontractors, respectively.

For the past two decades, design for safety (DfS) concepts have played a significant role in minimizing or reducing accidents. To this extent, design suggestions were created by Behm (2012) for fall prevention measures in vegetated roofs. In another study, Fall Protection System for High-rise Construction (FPSFHC) was developed by Çeçen et al. (2013) with a set of design criteria. Some studies adopted ICTs, aiming at increasing site fall prevention (Zhang et al., 2013; Melzner et al., 2013; Zhang et al., 2015; Fang et al., 2018a; Fang et al., 2018b). In addition, virtual prototyping (VP), ontology web systems, 3D games, and algorithms were used by different researchers. For example, algorithms were developed to monitor and control fall hazards (Navon and Kolton, 2006) and smartphones to detect falls (Dzeng et al., 2014). In another study, 3D games were developed by Lin et al. (2018) to train construction workers in protecting them from falls. Using VP, cost-effective Fall Protection Supplementary Devices (FPSDs) were proposed by Zuluaga et al. (2018) to protect bridge maintenance workers from falls. An ontology was developed by Guo and Goh (2017) for managing safety knowledge among users regarding an active fall protection system (AFPS) (Goh and Guo, 2018).

Some researchers (Kurien et al., 2018; Jokkaw et al., 2017; Yang et al., 2016; Yang et al., 2017; Jebelli et al., 2016) targeted workers' safety behaviors, attitudes, perceptions, and performance (BAPP) to eliminate falls at construction sites. Worker’s characteristics were targeted by multiple studies, such as attitude (Dzeng et al., 2014), education (Huang and Hinze, 2003), experience (Hu et al., 2011), and demography (Gauchard et al., 2001).

Identifying and managing risks is an essential process in controlling falls. Sa et al. (2006) compared the risk factors of fall incidents among commercial and residential roofers to facilitate this process. Nguyen et al. (2016) developed a Bayesian network (BN) model to recognize the fall risks. Although these researches intended to reduce fall incidents by improving workers' and experts' safety knowledge in the construction industry, these interventions could eliminate or reduce some part of fall risks. An organized safety KM system is still needed to improve safety performance in many circumstances (Dong et al., 2018), where insufficient safety knowledge influences fall in construction projects (Nadhim et al., 2016). Despite the significance, no prior research identified safety KM trends in fall RA.

2.5 Safety knowledge management in construction

A company's most valuable asset is its knowledge. KM is important for a company's efficiency and performance (Tserng et al., 2016). Individuals can use KM to communicate their tacit knowledge and change it into explicit knowledge. Companies that successfully capture their employees' tacit knowledge outperform competitors (Hadikusmo and Rowlinson, 2004). In the construction sector, the KM's context and content change in the entire project life cycle (Park et al., 2010). KM entails the ability to transfer knowledge from one project to another in construction. KM initiatives are frequently implemented without the label of KM (Hon and Chan, 2014). According to Kamara et al. (2002), shifting individuals to other projects, intranets, contractual agreements, practice guidelines, usage of standards, and specific tasks such as post-project reviews are all examples of KM initiatives in the construction industry. However, these are organizational initiatives rather than dedicated KM strategies (Hon and Chan, 2014).

Safety knowledge is essential for effective safety management. To address construction safety challenges, many researchers have discussed the importance of safety knowledge (Hallowell, 2012; Zhang et al., 2015). Safety knowledge is categorized into two types: tacit and explicit. Explicit safety knowledge is described by Hadikusumo and Rowlinson (2004) as safety standards, safety guidelines, regulations, and accident reports. Accident reports are valuable resources for RA. Analyzing accident records in terms of probability and severity allows for improved resource allocation in terms of safety. Safety hazards with a high probability and serious impacts should be given more attention and resources. The minimal requirements for site safety are outlined in safety legislation, regulations, and guidelines. Meeting these requirements, however, is insufficient to ensure a safe working environment (Hon and Chan, 2010). Safety legislation in India is self-regulatory, and the legislation includes a rough outline only, leaving contracting firms with the ability to decide their safety practices.

Due to the complexity, unexpected accidents in construction often occur. Besides safety regulations, guidelines, and rules, safety management in construction also depends on the project's team members (Hadikusumo and Rowlinson, 2004). According to Sherehiy and Karwowski (2006), tacit knowledge is typically learned through a person's experience. Thus, it plays an essential role in deciding safety efficiency. Construction safety engineers' experience (i.e., tacit knowledge) is crucial in identifying hazards. For construction safety management, safety hazards recognition is critical (Carter and Smith, 2006). Sufficient actions and training cannot be implemented if management cannot identify possible safety risks (Hadikusumo and Rowlinson, 2004). Construction firms in developed countries may have an effective safety KM system to acquire, store, and disseminate tacit knowledge; however, this is quite impossible for most construction companies in developing countries like India to imitate. Therefore, more investigation is required into how construction companies in developing countries handle safety knowledge.

Safety KM processes include acquisition, storage, and transfer. Capturing, storing, and reusing knowledge offers ongoing direction on what has been learned and applies the lessons learned (Chua and Goh, 2004) that strengthen the capability to recognize and manage hazards. A construction company can acquire tacit knowledge through recruiting people from innovative organizations, from their internal employees, experience, participating in seminars, meetings, or conferences, or collaborating with others (Kululanga and McCaffer, 2001). Two methods exist to acquire tacit safety knowledge from safety experts (Hadikusumo and Rowlinson, 2004). Face-to-face conversations and using the computer software systems such as the design-for-safety-process (DfSP) tool, introduced by Hadikusumo and Rowlinson (2004); a decision support tool, ToolSHeD, developed by Cooke et al. (2008); a safety planning system for builders developed by (Kamardeen, 2011); and a web-based online platform, FPSWizard, designed by Goh and Guo (2018) to acquire tacit knowledge in a database.

Many barriers exist to implementing KM in a construction organization. For example, investments invested in project KM do not yield instant results. Because construction projects are scattered, it is difficult to capture tacit knowledge. Other barriers include time constraints, lack of KM budget, early retirement, inadequate information technology infrastructure, low acceptance of innovative ideas, and high turnover rates (Hallowell, 2012). According to Carrillo and Chinowsky (2006), low-profit margin, lack of standard work methods, and traditional culture make construction organizations reluctant to invest in KM supportive programs. Despite the importance of KM in construction, no studies have introduced KM into safety RA for fall prevention.

2.6 Safety risk assessment in construction

According to Zanko and Dawson (2011), RA is a method of identifying the sources of risks and determining the control measures before any accidents/injuries could happen. The RA process consists of the following steps: identifying hazards/accident causes, determining the individuals at risk, assessing risks and deciding on safety measures, and reviewing and updating the assessment, if necessary (HSE, 2020; Verma and Chaudhri 2016). Several RA methods have been proposed by researchers from the construction safety domain from different perspectives. For instance, Jannadi and Almishari (2003) developed a risk model using likelihood, severity, and exposure risk scores. Lee and Halpin (2003) developed a basic visual program using fuzzy inputs given by the users to generate a RA for typical construction activities. On the other hand, Sun et al. (2008) used AHP (analytic hierarchy process) to assess safety risks. A few studies evaluated safety risks involved in formwork operations (Hallowell, 2008; López-Arquillos et al., 2014). Hallowell and Gambatese (2009), assessed the overall safety risks for formwork activities, whereas, Lopez-Arquillos et al. (2014) evaluated safety risks for vertical formwork construction. To express the connections among construction components, hazard categories, and causes of hazards, Liu and Tsai (2012) proposed a fuzzy RA technique. More recently, Sanni-Anibire et al. (2020) conducted RA using a pairwise comparative method for Saudi Arabia construction companies.

This study used a two-dimensional risk scoring system method to assess risks. The RA equation is presented in Eq. (1). According to Eq. (1), a risk score is the product of severity and probability in which the magnitude of an event's possible consequence is known as severity and the average number of events per unit of time is known as probability. Severity is measured regarding the impact on the worker or company, and incidence rates measure probability.

$$\text{Risk Score} = \text{Probability (P)} * \text{Severity (S)} \tag{1}$$

Job hazard analysis, safety meetings, and safety inspections during construction are all common techniques of RA. These techniques are mostly used to identify risks. Intuition, perception, and word of mouth are commonly used to assess the relative severity of risks. Risk is reduced through activities such as site-specific safety plans, orientation and training, and toolbox talks (Hallowell and Gambatese 2008). This study offers an alternative way of evaluating fall risk by assessing the risks involved with each activity and defining risks on well-defined severity and probability scales. The 5-score severity and probability scales are described in Tables 2.1 and 2.2. Table 2.1 indicates the different levels of severity, from very low (level 1) to severe (level 5). For example, it can be seen in Table 2.1 that for a severity score of 4 (high severity level) – major first aid was required, and the worker could not return within three days. This means that if the individual is harmed and the worker might need major first aid, the worker cannot return to work within three days, then it falls under the category of severity level 4. Regarding probability level, the probability score increases when chances of risk increases. For instance, if the chances of risk are very frequent (almost certain), then the risk score increases and when the chances of risks are hardly ever (rare), then the risk score is low (refer to Table 2.2). Similarly, probability can be determined as rare (level 1) to almost certain (level 5). Once the risks are assessed, it is then to determine the zone of relative risks (Zhang et al., 2020). Five risk zones are associated with various magnitude levels, as indicated in Figure 2.1 and Table 2.3, ranging from insignificant to intolerable risks.

Table 2.1 Severity scale

Severity level	Description	Score
Very low	No health effect or injury or damage. No impact on work time	1
Low	Temporary discomfort or minor first aid is required. A worker can return to work within one day	2
Medium	Minor health effects. A worker could return within three days	3
High	Major first aid is required. A worker could not return within three days	4
Severe	Fatal or permanent disablement. A worker could not return to work	5

Table 2.2 Probability scale

Probability level	Description	Score
Rare	Only in exceptional situations	1
Unlikely	It could occur at some future time	2
Possible	It might happen at some point	3
Likely	Probably occur in most circumstances	4
Almost certain	Expected in normal circumstances	5

Risk Score (RS) = Probability (P) * Severity (S)					
VL= Very Low L = Low M = Medium H = High VH = Very High					
P	*RS = P * S*				
5	L	M	H	H	VH
4	L	M	M	H	H
3	L	L	M	M	H
2	L	L	L	M	M
1	VL	L	L	L	L
S	**1**	**2**	**3**	**4**	**5**

Figure 2.1 Risk matrix

Table 2.3 RA decision matrix

Risk score	Risk level	Description
1	Very low (insignificant risk)	If the risk's location falls under this zone (i.e., grey portion), there is no need to develop a set of controls to eliminate recognized risks and maintain track of the actions that must be completed.
2-6	Low (acceptable risk)	If the risk's location falls under this zone (i.e., blue portion), there is no need to develop a set of controls to eliminate recognized risks; however, the existing control measures should be maintained and monitored.
7-12	Medium (intermediate risk)	If the risk's location falls under this zone (i.e., yellow portion), actions must be performed to minimize the risks that have been identified.
13-20	High (significant risk)	If the risk's location falls under this zone (i.e., red portion), work should not begin until all identified risks have been eliminated. If an ongoing action exists, it should be halted, and if the risk to the work's continuation is there, emergency measures must be implemented.
25	Very high (intolerable or unacceptable risk)	If the risk's location falls under this zone (i.e., the orange portion), work should not begin until all identified risks reach an acceptable level. If an ongoing action exists, it should be halted, and activities should be avoided unless it is feasible to reduce the risks despite precautions.

According to Pei et al. (2018), the evaluated risks can be addressed in various ways, depending on the threshold value. Low risks can be acceptable if tracked regularly (Mohandes and Zhang, 2019). Aside from acceptance, transference is another treatment method (Liaropoulos et al., 2019). The relevant risks may be managed more controlled; nonetheless, they must be tracked regularly. (Fortunato et al., 2012). According to (Aven, 2016), if the magnitudes of the risks exceed the set threshold value, they must proceed to the mitigation stage, which involves two measures: mitigation and elimination. In light of these considerations, this study quantified the level of risk of activities based on Figure 2.1 and Table 2.3. Although some studies focused on RA for overall formwork activities in construction, no studies have addressed fall risks in vertical formwork activities (Lopez-Arquillos et al., 2014).

2.7 Summary

This chapter explores the concepts underlying the current research and aids in the identification of research gaps and the study's need. It was observed from the literature that no study had been conducted on Indian construction to prevent falls. Thus, there is a need to bring the focus on fall prevention in Indian construction. The chapter further explored that lack of safety knowledge is the major influencing factor that causes falls in the construction workplace. Studies targeting safety KM trends for fall prevention through the RA process are missing. Lastly, the literature on safety RA in construction was reviewed, and observed that no studies had been conducted to quantify safety risks associated with vertical formwork activities focusing on fall prevention. The key conclusion from this review is that there is a need to design a knowledge-based system to facilitate the process of RA for vertical formwork operations focusing on fall prevention in Indian construction.

CHAPTER 3

SAFETY KNOWLEDGE MANAGEMENT STRATEGIES EMPLOYED DURING FALL RISK ASSESSMENT PROCESS

3.1 Introduction

As addressed in the literature, RA heavily relies on individuals' experience, and lack of safety knowledge is the major factor influencing falls in construction. Due to this, the construction industry faces project delays, and the productivity of companies is adversely affected (Yuan et al., 2018). Therefore, interviews were conducted with safety professionals to understand how KM trends (acquisition, storage, and transfer) are employed in Indian construction companies during the fall RA process. This was done by conducting interviews with safety experts who had experience in the RA process. The qualitative data that emerged from interviews were analyzed through a coding procedure in ATLAS.ti. The second section of this chapter briefly describes the method used for data collection and analysis. Finally, this chapter's final section discusses the interviews' findings.

3.2 Methodology

According to Ahmed et al. (2016), qualitative research is the best approach for in-depth examinations of real-life behaviors. A qualitative approach was judged appropriate, given the study's emphasis on expert validation. One of the most successful techniques for implementing a qualitative strategy is to conduct interviews Oraee et al. (2022). According to Fellows and Liu (2008), interviews are a great way to learn in-depth details about an individual’s thoughts, feelings, and opinions. As this is the first study aimed at understanding the safety management in fall RA from KM perspectives in India, the researcher believes that interviews would be an effective way to lean in-depth details on safety KM strategies employed in construction companies.

Purposive sampling aims to select informed and helpful individuals with the subject under investigation (Guarte and Barrios, 2006). In qualitative research, samples are purposefully chosen (Marshall, 1996); hence, the companies and interviewees were chosen based on referrals and professional associations. The selected companies were large-scale contractors and all members of the CREDAI (Confederation of Real Estate Developers’ Associations of India) and actively participated in safety programs all over India. Safety heads/managers were the primary target group, and their participation was essential because they have experience with fall RA in construction projects.

It is evident from the literature that between 5 and 25 participants are well enough for interviews in a qualitative study (Saunders et al., 2017). Therefore, 20 safety heads/managers with relevant experience in the RA process in Indian construction were identified. These interviewees were contacted through their organizations. The companies' human resources (HR) departments were approached through e-mail with official letters following protocols. After following all protocols, interviewees were requested to participate in the interview through HR. Out of 20 identified interviewees, some were not interested in participating, and finally, eight safety experts from different companies participated in the study. It is noteworthy that the selected companies were the top contractors in India, and many other contractors followed the interviewed companies and executed safety practices (Chellappa et al., 2021). As the selected interviewees were similar to the studies that focused on construction safety (e.g., Hon et al., 2010; Hon et al., 2014; Kukoyi and Smallwood, 2017), the authors believed that eight sample size was adequate to provide a rich data to meet research objective.

Table 3.1 Respondents' backgrounds

Company	Interviewees' education	Interviewees' profession	Interviewees' experience (in years)
A	Masters (Safety)	EHS Senior Manager	23
B	B.Sc. (Safety)	Safety Manager	18
C	Diploma (Safety)	Safety Head	20
D	Diploma (Safety)	Safety Head	17
E	Diploma (Safety)	Safety Officer	9
F	PG Diploma (Safety)	Safety Head	18
G	Diploma (Safety)	Safety Head	13
H	Diploma (Safety)	EHS Senior Manager	15

EHS – Environmental Health and Safety

Face-to-face oral interviews were conducted. The interview guide had two sets of questions (see Annexure 1). The first set targets gathering background information from interviewees. The second set targeted to identify the KM trends in fall RA with questions: "Could you elaborate on the process of fall RA in construction? - How do you identify fall risks? How do you assess fall risks? How do you choose control measures to prevent falls? How is safety knowledge stored and re-used for fall prevention? What tools are used to store safety knowledge?". These questions were asked to understand better the interviewees' profiles and organizations that adopt safety strategies. The duration of data collection was for three months (November 2019 to January 2020), with each session lasting approximately one hour. All interviews were tape-recorded with the interviewee's permission and transcribed later. A basic assumption was that companies apply similar safety KM trends to different projects and project teams all over India. This was confirmed during the research process.

To ensure the interview results, the research team again contacted the companies and requested to be a part of their safety meetings after the interviews. Some companies agreed the researcher participate physically, and some made special arrangements for a researcher to attend through virtual mode. On the scheduled date and time, the researcher participated in each company's safety meeting and discussed the scope of research and past interview status with a group of experts to complement and validate the interview. During safety meetings, research-related documents such as data sources used for fall RA, RA worksheets, and tools used to share data were shown to the researcher that companies use during fall RA. Using this method, the researcher took experts' input, verified the interviews, and added meaning to the definitions of safety KM in fall RA. This increases and ensures the validity of this study's results.

The interview analysis was carried out by transcribing the recorded interviews and coding the transcripts to conclude the raw data gathered. The data was first transcribed and verified against audio recordings to make them ready for analysis. The researcher thoroughly examined the transcripts before beginning to interpret the data. This stage aimed to understand the critical points made by the interviewees and familiarize the researcher with the data. A careful reading of the data was required to examine each dimension with its questions to ensure no common themes or data patterns were repeated (Ryan and Bernard, 2000). Then, a thematic analysis was conducted to analyze interview data, facilitated by a Computer Assisted Qualitative Data Analysis Software (CAQDAS) known as ATLAS.ti. Braun and Clarke (2006) state that thematic analysis is “a process for identifying, assessing, and reporting patterns within data." For the qualitative data analysis, several CAQDAS programs are used, including Web QDA, XSIGHT, NU*DIST, NVivo, and ATLAS.ti (Watling et al., 2015). ATLAS.ti software could manage, structure, and make sense of rich-text data (McNiff, 2016). Numerous research has highlighted the widespread use of ATLAS.ti for qualitative analysis. The ability to search for patterns in words, codes, or attributes in ATLAS.ti enables researchers to do componential, taxonomic, and in-domain analyses (Leech and Onwuegbuzie, 2007). Hence, ALTAS.ti has been chosen to analyse interview data to understand the KM strategies employed in construction companies during the fall RA.

The coding procedure enables the extraction of information from the gathered unstructured data (Morse and Richards 2002). Coding the text makes it possible to access the significant concepts and evaluates what is occurring in the examined data (Saghatforoush, 2014). Three coding techniques: open, axial, and selective, were used following Strauss and Corbin's (1998) recommendation to identify emergent themes in the interview data. In open coding, line-by-line interview data was analyzed with references to various themes of interest being coded to particular nodes (Auerbach and Silverstein, 2003). The axial coding was performed with relevant references within the interview transcripts under the same category (Auerbach and Silverstein, 2003). Selective coding merges similar themes to avoid unnecessary theme duplication (Miles et al., 2013). To ensure that the process is not limited to a predefined group of categories, ATLAS.ti enabled the detection of new themes and reconsideration of themes during the analysis. Major themes and subgroups within the themes were used to categorize the content and the excerpts that fit into a certain theme. The themes derived from the thematic analysis of interview using ATLAS.ti was tabulated and listed in Tables 3.2-3.4.

3.3 Results and discussion

The information on the interviewee's role in construction projects, their work experience in construction safety, and their educational background is shown in Table 3.1. It can be seen in Table 3.1 that the interviewee's education ranged from diplomas to master's degrees in safety specialization and the average experience of interviewees in construction safety is 16.6 years. It was also observed from Table 3.1 that the interviewee's designation changes among different construction organizations, such as safety head, safety officer, and so on; however, their role in construction projects were performing RA.

The data gathered from the interviews were organized and summarized in Tables 3.2-3.4. The key elements of KM are listed in these tables that companies identified. The knowledge source (tacit or explicit) is typically held within each source, stored in each place, and disseminated by each communication mechanism. For example, the internal safety department file is a KM element in which A and B companies store safety knowledge related to fall RA. The knowledge type sources were categorized based on Hallowell's research (2012). The following is a brief discussion of the results of the safety KM processes (knowledge acquisition, including RA and control measures, knowledge storage, and knowledge transfer) performed by companies and the trends observed.

3.3.1 Capturing safety knowledge

For the acquisition of safety knowledge in companies, fifteen tacit and explicit knowledge sources were identified through the interview (see Table 3.2). These sources originate mostly from accident analysis, legislation and regulations, and self-inspections. The primary sources for acquiring safety knowledge among organizations were legislation and regulations (n = 8). Safety regulations were accessible from the National Safety Council, India, including The Factories act, 1948, The Building and other Construction workers act, 1996, and Occupational Health and Safety Council. Firms obtain external knowledge less often from trade publications (n = 2) and academic journals (n = 1). The construction companies' primary method of obtaining internal safety knowledge was accident analysis (n =8), followed by self-inspections (n = 6). Some companies follow their own regulatory system's safety practices, thus having a more designed knowledge acquisition system. Interviewee A revealed that

"We follow our company safety plan, which contains the list of activities and risk parameters of each exercise, which is already fixed. Fall risks will be identified, and our technical team members will be called to perform a risk assessment based on a new project's activities. Team members' input is essential in risk assessment and selecting preventive measures."

Likewise, Interviewee B stated that

"We get inputs from our companies' plan, which contains a safe work method statement where the activities are listed. The safety head then lists the hazards associated with each activity and calls technical team members to perform a fall risk assessment. It is a combined task in which the safety head and execution team members map all risky activities and control measures. Once both approve fall risk assessment, it is verified by work-in-charge and ready for communication."

Safety practices were limited in some organizations. In such organizations, safety depends on the executive staff members. For instance, Interviewee E revealed that *"…there is a safety plan, and safety meeting for individual projects, but the risk assessment sheet used for previous projects are being followed for new works based on a new project"*.

In the same line, interviewee G pointed out that

"We are following our fall risk assessment system, using the same from previous projects. If new projects involve some new activities, I will perform a risk assessment on my own, including evaluating risks and choosing control measures."

Interviewee C states, "*I carry out a fall risk assessment for which the risk of activities must be already listed from previous projects, and I only select the preventive measures based on my own experience according to the projects.*"

Similarly, interviewee (D) stated that

"The engineering team will give us the technical details, including activities of new projects. I will perform a risk assessment for each activity based on my previous experience, and sometimes I may consult with sub-contractors or other contractors."

According to interviewee H, *"Fall risk assessment is performed by me. In most cases, with my own experience, I conduct it. If I have to work on the new activity, I may contact other team members or use the internet to collect safety details related to that activity."*

Table 3.2 Capturing knowledge for fall RA

Sources	A	B	C	D	E	F	G	H	Total
Legislation and regulations	x	x	x	x	x	x	x	x	8
Company practices notes or safety plan	x	x	-	-	x	-	-	-	3
Sub-contractors	x	x	-	x	-	-	-	-	3
Internet	-	-	x	-	-	-	-	x	2
Intranet	x	x	-	-	-	-	-	-	2
Academic journals	x	-	-	-	-	-	-	-	1
Self-inspections	x	x	x	x	x	-	-	x	6
Safety meetings	x	x	-	x	x	-	-	x	5
Accident analysis	x	x	x	x	x	x	x	x	8
Safety stand-down	x	x	-	-	-	-	-	-	2
Informal discussions with other contractors	-	-	-	x	-	-	-	x	2
Trade publications	x	x	-	-	-	-	-	-	2
Team members/technical experts	x	x	-	-	-	-	-	x	3
Own experience	-	-	x	x	-	x	x	x	5
Pre-project procedure	-	-	x	-	x	-	x	-	3

x indicates the sources of knowledge for each company

Regular safety meetings and communication with contractors and sub-contractors could acquire tacit and explicit safety knowledge. This tacit knowledge facilitates the project members in evaluating the safety practices in construction related to falls, identifying possible safety risks, and planning coordination work. In work-at-height works, coordination is essential because it impacts the site workers and the public. Two companies believed that safety stand-down is prominent for capturing tacit knowledge. Unfortunately, most organizations have limited methods for their workforce to identify and acquire tacit knowledge.

3.3.2 Storing safety knowledge

Once knowledge is captured, it must be stored and transferred for better safety performance (Hallowell, 2012). Methods of fall-related safety knowledge storage were limited (see Table 3.3). Companies' safety plans (n = 8) and Job-hazard-analyses (JHAs) (n = 8) have an essential role in storing fall-related safety knowledge. The fall protection plan is another storing method of safety knowledge indicated by two companies. Individuals would be praised for assessing safety performance (Hallowell, 2012). Unfortunately, only two companies, A and B, introduce this method of storing tacit knowledge. The two companies adopted a unique data-entry system on their intranet, which is attributed to much of their achievement with the tacit fall-related safety knowledge. This method allows the organization to capture and store fall-related safety tacit knowledge by collecting diverse responses to particular safety circumstances and reporting recommendations for protection. The implication is that these companies would lose tacit knowledge with employees' exit. It can be seen in Table 3.3 that one company had a method to store the safety knowledge related to fall RA in a video format.

Table 3.3 Storing safety knowledge for fall RA

Knowledge storage	A	B	C	D	E	F	G	H	Total
Safety plan	x	x	x	x	x	x	x	x	8
Fall protection plan	x	x	-	-	-	-	-	-	2
JHA	x	x	x	x	x	x	x	x	8
Internal safety departmental file	x	x	-	-	-	-	-	-	2
Videos	x	-	-	-	-	-	-	-	1
Data entry and electronic feedback	x	x	-	-	-	-	-	-	2

x indicates the methods to store safety knowledge adopted in each company

3.3.3 Transferring safety knowledge

In the process of KM, knowledge transfer is the last step. The interviewees identified nine initiatives (see Table 3.4). The standard methods for transferring safety knowledge were toolbox talks, orientation and training programs, safety committees, employee communication, and professional interactions. Informal discussions among workers (n = 6) were an effective method to transfer tacit knowledge. Other ways to transfer safety knowledge among construction companies include bulletin boards (n = 3), safety information in the newsletter (n = 2), and addresses by the safety head/manager (n=2). Many organizations had no systematic methods for storing fall-related safety knowledge, with many initiatives to share safety knowledge. Observations revealed that, soon after knowledge was acquired, people in these companies either communicated or retained their knowledge.

Table 3.4 Transferring safety knowledge for fall RA

Transferring knowledge	A	B	C	D	E	F	G	H	Total
Address by safety head/manager	x	x	-	-	-	-	-	-	2
Toolbox talks	x	x	x	x	x	x	x	x	8
Informal communication with workers	x	x	x	-	x	x	-	x	6
Bulletin boards	x	x	-	x	-	-	-	-	3
Orientation and training sessions	x	x	x	x	x	x	x	x	8
Safety committee	x	x	x	x	x	x	x	x	8
Interaction with professionals	x	x	x	x	x	x	x	x	8
Communication among employees	x	x	x	x	x	x	x	x	8
Safety information in a newsletter	x	x	-	-	-	-	-	-	2

x indicates the methods to transfer safety knowledge adopted in each company

3.4 Summary

This chapter presents the findings from the analysis of safety KM trends adopted in Indian construction companies for fall RA. Semi-structured interviews were conducted among eight construction firms. The data were analyzed through a coding procedure in ATLAS.ti. The data collected was represented in word tables, which helped identify the trends across construction firms. The findings demonstrate that systematic safety KM was not commonly applied in construction firms. It was found that most organizations found an ineffective KM system for managing safety knowledge, especially tacit knowledge, which correlates with the results of Kamara et al. (2002). Legislation and regulations were the primary explicit knowledge gained by organizations. Contracting organizations were responsible for developing their safety plans and safety management systems. In most companies, such methods were prepared by explicit knowledge sources such as accident reports, regulations, etc. For instance, Interviewee C-H stated that the safety head conducted fall RA for any new project using the company's safety work method statement. Based on their experience, they choose the risk levels and control measures for any activities. This result relates with the past study conducted by Hadikusumo and Rowlinson (2004) that safety experts carry out the RA based on their own experiences with sources such as regulations and standards, which could not be adequate to prevent safety risks (Young, 1996; Dong et al., 2018). Usually, tacit knowledge is held in an individual's mind, and transferring it to other employees in the organization is quite difficult. Effective safety KM could improve the organization's safety performance (Hallowell, 2012). Since the construction process relies more on people, companies should use tacit knowledge to achieve better safety.

According to Hon and Chan (2014), construction practitioners (i.e., site engineers or managers) have the potential to recognize possible safety risks in the projects that will arise. However, there was no systematic method to capture the knowledge from site professionals. More often, site professionals are not loaded with site safety jobs. Other aspects of the project have to be addressed by site professionals. They cannot allot time to share tacit knowledge because of the tight project schedule. However, they are individuals with excellent knowledge of project safety to share.

Another key finding was that safety KM strategies should be implemented effectively and constantly applied across the firms and should contain various elements that support capturing, storing, and transferring. During safety storage, the elements that the interviewed companies typically ignored were tacit knowledge. It was recognized that continuous improvement requires effective safety knowledge storage and that even if knowledgeable employees leave the company, the safety knowledge can be transferred to new employees.

Tacit knowledge is essential in height work operations due to unexpected height works. ICTs have been used in construction projects to manage safety knowledge effectively (Hadikusumo and Rowlinson, 2004); however, such technologies are not widely designed for specific activities (Hon and Chan, 2014). Therefore, there is a need to design an effective safety KM to manage safety knowledge for fall RA. But before implementing such strategies, it is essential to understand the challenges that safety heads/managers face during RA and how the safety knowledge should be represented to users to facilitate the entire process of fall RA. According to Guo et al. (2013), any method or system that could not meet the user requirements would be ineffective. Hence, it is important to understand the user requirements to make any method/system effective. The next chapter discusses the user challenges they face during fall RA and their requirements to facilitate the process of fall RA in construction.

CHAPTER 4

CHALLENGES FACED BY THE USERS DURING FALL RISK ASSESSMENT AND SAFETY KNOWLEDGE REQUIRED BY THEM FOR FALL RISK ASSESSMENT

4.1 Introduction

The challenges faced by the users during fall RA and their requirements to facilitate the process of fall RA were identified and discussed in this chapter. Interviews followed by surveys were used to understand users' perspectives regarding the challenges they face during fall RA and their needs to facilitate the process in fall RA. The qualitative data that emerged from interviews were analyzed through a coding procedure in ATLAS.ti. Following the interviews, the identified challenges and user requirements were subject to a survey as a variable on a Five-point Likert Scale. Cronbach Alpha and Mean statistics were used in the survey analysis. The data collection and analysis methods are explained in detail in the second section of this chapter. Finally, the interview and survey findings are discussed.

4.2 Methodology

In this phase, a mixed-method approach - interviews followed by surveys were adopted to collect data. According to Fellows and Liu (2008), interviews are a great way to learn in-depth details about an individual’s thoughts, feelings, and opinions. In qualitative research, samples are purposely chosen to elicit rich information about a particular domain (Vasileiou et al., 2018). Therefore, a purposive sample methodology was used to select contracting companies and interviewees based on recommendations and professional associations. Purposive sampling aims to select informed and helpful individuals with the subject under investigation (Guarte and Barrios, 2006). Eight contracting companies involved in direct RA processes were targeted. These companies are large-scale contractors and members of the CREDAI and were actively participating in safety programs all over India. The assumption is that since these companies are the most well-known contractors in India's construction industry and participate actively in safety management programs across the nation, they will provide a direct and rich data source, improving data reliability.

Individuals who participated in the study were contacted through their organizations' HR departments with official letters by following protocols. The interviewees were designated based on their job duties and experience in the construction sector. In a qualitative analysis, Saunders et al. (2012) recommended interviewing between five and 25 people. To that end, five safety heads, one safety officer, and two safety managers from different contracting organizations participated in the interview.

The researcher used an interview guide to conduct the interviews. The interview guide used for this study can be seen in Annexure II. There were two sets of questions in the interview guide. The first set targets gathering background information from interviewees. The second set targeted understanding the users' challenges during the fall RA process and their opinions to enhance it. Eight (8) full interviews were conducted, and the profiles of the interviewees are shown in Table 3.1. The interviews lasted between 1 hr and 1.5 hrs. All interviews were tape-recorded with the interviewee's permission and transcribed later. Over four weeks in March and April 2020, the interviews were conducted. The interview analysis was carried out by transcribing the recorded interviews and coding the transcripts in ATLAS.ti to conclude the raw data gathered. This process was carried out as same as described in Chapter 3 (page 20) to identify the challenges faced by users and the safety knowledge required for fall RA. First, the researcher engaged himself by carefully reading the transcript to familiarize with the data. To make it simple for the researcher to specify himself observation, this was done. The next stage of a qualitative analysis is coding. Using the ATLAS.ti programme, the researcher collected and coded each data. Then, the researcher looks for all the themes and to achieve this, researcher highlighted significant pattern in the data that was pertinent to research question. All the coded data related to each theme was organized to complete this phase. Each theme was then reviewed and examined in relation to the coded extracts and the whole data sets to see whether they "work." Next the researcher would say if the topics create a compelling narrative. Finally, the researcher defines the theme and provided appropriate titles.

Surveys can map social problems and phenomena, whereas mapping refers to updating things (Denscombe, 2010). The main purpose of surveys is to collect information from a large population (i.e., people or organizations) at a specific period. Hence, the survey was used to identify the significant challenges faced by the users and prioritize the safety knowledge requirements they needed for fall RA. Once the interview data was analyzed, the identified challenges and requirements were subject to a survey as a variable on a Five-point Likert Scale (1=Strongly Disagree to 5=Strongly Agree). There were 15 scale items (variables) derived from challenges and user requirements. The questionnaire was examined by two professors with more than ten years of experience in survey data collecting, just like the semi-structured interviews. A revision was made in response to the feedback. Further, the questionnaire was tested with ten construction safety experts to improve the data validity (Saunders et al., 2012).

A web survey (see Annexure III) was built on a specified site to collect participants' responses and made available to participants via LinkedIn. At the start of the questionnaire, a filtering question was added to ensure that the participants were experienced in the RA process. Based on experience, participants were requested to rank the challenges and requirements for improving the fall RA process. Over nine weeks between April and June 2020, 84 questionnaires were returned. Of these, 33 were discarded due to invalid or missing data given by respondents. As a result, the analysis was conducted using 51 valid responses (see Table 4.1).

Table 4.1. Respondents background

Study variables	
Highest level of qualification	
Undergraduate degree	18 (35%)
Postgraduate degree	7 (14%)
Diploma	26 (51%)
Work experience (in years)	
Mean (SD)	13.7 (5.1)
Range	5-24
Position at work	
Safety manager	23 (45%)
Safety officer	13 (26%)
Safety head	15 (29%)

The response rate, in the end, was 60.71%. Cronbach Alpha and Mean statistics were used in the survey analysis (Hair et al., 1998). First, internal consistency was checked among the variables. The reliability of a Likert-based survey instrument was measured by Cronbach's alpha (Fellows and Liu, 2008). The results indicate that the variables were reliable indicators of challenges (α=0.716) and requirements for RA (α=0.817). Next, the mean statistics were employed to identify the most critical challenges faced by the users and their needs and compared them with interview results. A descriptive analysis was conducted on the usable returned survey using IBM SPSS Version 22.0.

4.3 Results and discussion

4.3.1 Findings from semi-structured interviews

Table 3.1 provides information on the interviewee's role in construction projects, their work experience in construction safety, and their educational background. It can be seen in Table 3.1 that the interviewee's education ranged from diplomas to master degrees in safety specialization and the average experience of interviewees in construction safety is 16.6 years. It was also observed from Table 3.1 that the interviewee's designation changes among different construction organizations, such as safety head, safety officer, and so on; however, their role in construction projects were performing RA.

The interviews' results are grouped into two key topics: challenges faced by the users during RA and users' requirements to facilitate the RA process. This is in line with the important aspects of RA stated in the introduction, with challenges corresponding to the first topic and the second topic corresponding to the main improvement area.

Challenges in fall RA

The study revealed six (6) challenges of the fall RA in construction projects. They were identifying the steps involved in each activity, identifying significant hazards, risk evaluation and scoring, selecting control measures, insufficient time to conduct, and working with insufficient data. Most respondents believed that identifying significant hazards is a major challenge they face during RA. One safety head, for instance, argued that:

"Identification of hazards in each activity is a major challenge. If there are any emerging hazards at the site, we need to call team members for their input to assess risks and select control measures. They are involved closely with activities and know the risks of each activity."

They mentioned that calling team members personally and conducting meetings are impossible, leading to project delays. Similarly, B stated that:

"RA is primarily generic. It may not be suited to site conditions every time because the building profile would be much different. The client may ask for specific building design changes so that fall RA will be changed accordingly. That is the first challenge that safety people face. During this time, we need to carry out RA again within a short period. It would be fine if we had adequate safety information for any activities. Otherwise, we need to look

for persons who have knowledge about specific activities and conduct meeting with them for doing fall RA."

Another safety head (F) added that:

"Day by day, we face a lot of activities and hazards. We have to look for safety knowledge. It is easy to handle if it is the same and repeats, but if something happens differently, it's a challenge. Work must be stopped here, and productivity may be affected."

Similarly, one safety manager stated that:

"I can say identifying hazards is a challenge. Although we have information about a particular activity, sub-activities hazards cannot be covered easily. For example, formwork is an activity, and we are provided with information about that activity, and we conduct RA. But, the sub-activities, i.e., erection, assembly, stripping, pouring, have different hazards and risks. Due to insufficient data or lack of information, we need to perform RA. Sometimes some professionals do not even consider sub-activities and commonly conduct RA altogether. This leads to accidents."

On the same line, another safety head pointed out that the scoring system used for evaluating the risks is also one of the challenges and identifying hazards. For example, C was of the view that:

"Usually, the risk scoring system differs from company to company. Here we use a simple frequency and severity scaling system. As the scaling rate increases, it takes more time to perform fall RA."

Safety professionals often do not get their support, pushing them to work without technical details. One safety head said that other team members' involvement is essential while performing RA. For instance, E argued that:

"Sometimes, we need to conduct fall RA without proper technical details. For example, the engineering team fails to provide details that cover work breakdown structures. So here we need to list the activities and perform RA based on our experience."

This was also echoed by interviewee D, who added that everyone considers the safety department solely responsible for the project's safety. In a country like India, safety professionals are overall in charge of safety, but we cannot alone solve the issues related to safety. Also, it is teamwork when it comes to RA; experts from different departments have different perspectives, which could help enhance the safety performance of companies. One safety manager (A) said that:

"As per the challenges, we get less time to conduct RA for each project. We have a proper system to conduct fall RA and call our team members with field experience to help in RA. Their inputs are also necessary for carrying out RA. However, it is time-consuming, and sometimes RA gets delayed due to team members' unavailability."

4.3.1.1 Users' requirements to facilitate the fall RA processes

The study revealed different requirements from users to facilitate the fall RA processes. They include a list of activities, other team members' involvement, causes of accidents, a platform to share safety knowledge, safety guidelines, past accident records, safety practices-case studies, a simple scoring system, and a list of control measures. One safety head believes sharing knowledge is essential among professionals, leading to better safety performance. For instance, B pointed out that:

"There is no common platform in the construction industry to share good safety practices, particularly about RA. Every industry has its idea and initiative for RA. As per their project budget and resource available, these are being installed. However, fall RA is not standard in the Indian construction sector."

Another safety head added that:

"It would be better to have a system where safety professionals can access safety information to carry out RA. It can be a closed system where information can be accessed among company group members, or it can also be an open system where anyone can access it. This could help us to retrieve information when and where we need it."

Similarly, one safety head (G) stated that:

"In many countries, documentation of construction projects is automated. The system should circulate a list of activities, possible accident causes, hazards, and control measures should be listed for each activity. We expect such systems to be implemented in India and ease our works in playing a role not only in fall RA but also in entire safety management from planning to execution."

Another safety head, D, echoed from a different perspective that:

"Other team members, especially engineers, should show their importance in safety. Although they know safety's importance, they do not show much interest in it. They can explain the work briefly, such as a list of activities, the possible hazards, and risks associated with each activity to safety people. Then it would be easy for us to conduct RA. Also, as it is challenging to conduct regular meetings, there should be a system where we can share safety information. This will minimize the working time."

According to some respondents, pertinent technical details from other team members and their input are important. Also, reviewing the best safety practices adopted in similar construction projects could enhance the RA process. One safety head, for instance, mentioned that:

"One should follow proper safety guidelines before conducting RA. The work statement is more important to understand the activities, and I look for team members' input. They can give more information about hazards associated with each activity."

Another safety head (E) stated that:

"An essential requirement is technical details. If management provides sufficient activity information, it will be easy for me to conduct fall RA. Also, information about best safety practices implemented in similar projects will help us understand the current safety scenario and take adequate steps to control risks."

A added that:

"A person has to analyze the incidents that are repeatedly happening deeply. There must be different causes of incidents. Even after providing safety measures, many incidents happen at the site. There should be a thorough understanding of the causes of accidents/incidents. Past accident records will provide information about the causes of accidents. Also, reviewing and understanding safety practices adopted in many projects that address those causes will help conduct fall RA."

Risk evaluation is one of the essential tasks in RA. If the risks are not appropriately evaluated, adequate control measures cannot be provided, leading to an accident. Therefore, there should be equal importance in selecting a rating system, also stated by the safety head. For instance, C pointed out that:

"We are looking for a rating system that should reduce the time we spend in fall RA. A simple rating system is needed, and if it is computerized, we will welcome that system."

4.3.2 Findings from survey

4.3.2.1 Respondent's characteristics

Overall, most of the respondents were safety managers (45%), with the remainder being safety heads (29%) and safety officers (26%). Out of 51 respondents, most were diploma holders (51%) whose experience in construction safety ranges from five to twenty-four. Table 4.1 shows the complete background information.

4.3.2.2 Challenges faced and user requirements to facilitate the fall RA process

The reliability and descriptive statistics were accomplished by using Arithmetic Means. The individual Mean is computed by multiplying the total number of respondents by the sum of the individual respondents' ranks for each question. The results of reliability and descriptive statistics are shown in Table 4.2.

Table 4.2 Challenges and user needs

Variables	Mean	SD
Challenges (α=0.716)		
Identifying the steps involved in each activity	4.01	.70
Identifying significant hazards	4.52	.50
Risk evaluation and scoring	3.52	.50
Selecting control measures	3.27	.45
Insufficient time to conduct	2.50	.50
Working with insufficient data	3.25	.82
Requirements (α=0.817)		
List of activities	4.70	.46
Other team members' involvement	4.66	.47
List of causes of accidents	4.58	.77
System to access/share safety knowledge	4.64	.48
Safety guidelines	4.47	.78
Past accidents records	4.41	.85
Safety practices-case studies	4.39	.67
Simple scoring system	4.54	.59
List of control measures	4.52	.54

Approximately a mean of 4 (agree) was attained from Table 4.2 for identifying significant hazards and steps involved in each activity for challenges. This indicates that participants agree that identifying hazards and steps associated with particular activity during the RA process were the key challenges faced, followed by a risk evaluation and scoring; and selection of control measures. Users working with insufficient data and time were the challenges that obtained relatively lower ratings.

Users' requirements were obtained to address the challenges and facilitate the process of fall RA. It can be seen in Table 4.2 that a list of activities, other team members' involvement, and a system to access/share safety knowledge were more significant variables, followed by a list of accident causes, a simple scoring system, and a list of control measures. Safety practices, accident records, and safety guidelines obtained lower ratings which indicate that they were the least important to the users for fall RA. The results show the importance of challenges and users' requirements stated by respondents below in descending order.

Challenges faced by users

1. Identifying significant hazards
2. Identifying the steps involved in each activity
3. Risk evaluation and scoring
4. Selecting control measures
5. Working with insufficient data
6. Insufficient time to conduct

Users' requirements to facilitate the fall RA process

1. List of activities
2. Other team members' involvement
3. System to access/share safety knowledge
4. List of causes of accidents
5. Simple scoring system
6. List of control measures
7. Safety guidelines
8. Past accidents records
9. Safety practices-case studies

4.4 Summary

This chapter presents the challenges faced by users during the fall RA process and their opinions on facilitating it. Using interviews and surveys, 15 variables were identified as the challenges faced by the users during RA (6 variables) and users' requirements to facilitate RA processes (9 variables). The data that emerged through the interviews were analyzed through a coding procedure in ATLAS.ti. Following the semi-structured interviews, the identified challenges and gathered requirements were subject to a survey as the variables. The data collected through surveys were analyzed using mean statistics. It was found that identifying significant hazards and the steps involved in each activity are the major challenges users face during RA, which correlates with the results of Carter and Smith (2006).

In most cases, users had to prepare RA with insufficient information about the particular activity. This is one of the major reasons that users could not address any significant hazards, as indicated by A, D, and E. Selecting appropriate control measures for risks was also one of the users' challenges. Safety professionals do not have experience handling site activities compared to site professionals and, thus are unaware of the risks involved in construction activities (Chellappa et al., 2020). The result also indicates that the risk evaluation scoring system was challenging to understand and perform. This is because different companies follow different risk scoring systems, as mentioned by interviewee C. Safety experts from other companies cannot easily adapt to a new system (Chellappa et al., 2020). It was also evident from the survey results that users face challenges when they work with insufficient data and time. Interviewee E reported that they were supposed to conduct RA with insufficient technical data provided by the engineering team. During this stage, users had to conduct RA based on their experience, which is hard to list the potential hazards and preventive measures.

Everyone involved in projects is responsible for safety, and organizations should not only rely on the safety team for project safety performance. In most countries, including India, management still thinks the safety team is only responsible for project safety (C et al., 2019). Management should also support the safety team and professionals by giving sufficient time to conduct RA and providing sufficient technical details involving a list of RA activities. These findings are largely attributed to the project-based structure of the construction sector (Forcada et al., 2013). While construction is a knowledge-based industry (Zerjav et al., 2012), safety knowledge is scattered among employees and workers (Woo et al., 2004). Safety experts face challenges such as identifying hazards, identifying steps involved in activities, and selecting control measures during RA, as they do not have experience handling construction activities (Hadikusmo and Rowlinson, 2004). In this case, the safety knowledge of practitioners can potentially address these challenges involved in construction activities (Chellappa et al., 2020).

To facilitate the process of fall RA, users' requirements were gathered. The findings show that adequate technical details about a particular activity, such as a list of activities, causes of accidents, control measures, safety guidelines, past accident records, and safety practices-case studies, could facilitate the process of RA. Along with other team members, safety knowledge is needed to carry out RA by the users. According to Hadikusmo and Rowlinson (2004), practitioners such as site engineers, site managers, foremen, and so on have adequate knowledge of the risks involved in particular activities. Hence, their input during RA is much needed to prevent accidents. The results also indicated that users were looking for some online system where they could access and share safety knowledge for RA. For instance, Interviewee B pointed out that an online system where users can access and share safety knowledge was needed. It could be either a closed system where only company employees can access it or an open system where anyone can access it. According to Interviewee H, such a system could reduce the time of performing RA and project delays. Therefore, it is evident from this chapter that adopting an online system involving technical details on particular activity with a simple risk rating system that contains practitioners' safety knowledge could facilitate the RA process. However, it is essential to understand how safety knowledge of particular activity should be represented in an online system before proposing it. The next chapter discusses knowledge-based system development for safety knowledge representation.

CHAPTER 5

DEVELOPMENT OF A KNOWLEDGE-BASED SYSTEM FOR REPRESENTING SAFETY KNOWLEDGE

5.1 Introduction

This chapter presents the third objective of the research, where the knowledge-based system to facilitate the fall RA was developed. In section 1.1, it is mentioned that this research presents the context of traditional vertical formwork, and hence the knowledge-based system that represents safety knowledge targets vertical formwork operations. Therefore, to develop a knowledge-based system to facilitate the fall RA process of vertical formwork, first, the formwork activities that pose the risk of falls at the construction site have been identified through observation and surveys. Four activities that pose a risk of falls during formwork operations were identified. Followed by the fall trends in vertical formwork activities were analyzed using construction accidents reported in the OSHA database, a regulatory agency in the USA. Next, the safety knowledge needed for fall RA such as risk level of activities based on the height of work, causes of falls, individuals at risk, and control measures, were captured from the experts through Delphi surveys and literature. Surveys were conducted with another nine experts to validate the findings obtained through Delphi surveys. First, a framework was developed to understand the activity flow and resources involved in the fall RA process for developing a knowledge-based system. Then, the framework was converted into a web-based safety fall RA system, which created a web-based fall RA system architecture. Followed by a web-based prototype was designed using a content management system (CMS), and five evaluators from different academic backgrounds were allowed to access the prototype to evaluate the interface design through a cognitive walkthrough (CW). Finally, the evaluator's feedback was taken into account, the prototypes' interface design was improved, and a web-based KM system to store and re-use the safety knowledge captured for fall RA was developed using a programming language.

5.2 Identifying the formwork activities that pose the risk of falls

5.2.1 Methodology

The researcher started by observing working teams in the field who were actively involved in formwork operations. The field observation's main goal was to produce a preliminary list that would subsequently be validated in a survey by construction experts. Four projects in the southern part of India were visited for field observations. The projects ranged from Rs 50 crores to 150 crores in multi-story buildings. The formwork construction methods differed from one site to the other, while all projects entailed new construction. All projects used traditional form components, i.e., plywood. In total, the research team observed 192 working hours, resulting in the documentation of 12 different formwork activities, four of which pose a risk of falls. The observation phase was completed when no new activity was observed within stipulated working hours. It was considered that adequate repetition had been attained once this requirement was reached.

A sample size of 8 industry experts currently employed in South India was invited in person by the researcher to participate in the survey with the list of four fall risk activities and descriptions. Three practitioners refused, and five accepted the invitation and agreed to participate. All the experts had more than five years of experience in construction and were engaged in formwork activities. Participants were instructed to go through the list of activities and its description and choose one of the following options: (1) double-check that the list is complete and that nothing is missing or wrong; (2) add new activities with a brief description if any; (3) remove ineffective activities if any; or (4) modify the labels or descriptions of activity if needed.

5.2.2 Findings

Four activities that pose the risk of falls were identified and described during the field observation. The industry experts reviewed and validated the activities and their descriptions, as indicated previously. The description of activities was refined during the review process. The findings of the field observation are summarized in Table 5.1, including names of activities and descriptions.

Table 5.1 Description of activities

Activity name	Description
Assembly	Assembling the formwork panels using brackets, nail guns, etc.
Erection	Installation of forms at a height that required fall protection
Concrete pouring	Pouring concrete, compacting it manually or with vibrator
Stripping	After curing of concrete, remove the forms and supporting falsework

It's worth noting that the fall risks defined for activities listed in Table 5.1 only apply to activities carried out exactly as indicated. Following the definition of the activities, the next phase was to analyze the fall trends in formwork operations.

5.3 Analysis of fall trends in formwork operations

5.3.1 Methodology

First, the database containing vertical formwork fall incidents information was to be identified. The data from OSHA Fatality and Catastrophe Investigation Summaries (FCIS) database was used first due to its reliable source. Some data were missing and not updated in the OSHA database after 2016. Hence, the documented reports from OSHA between 1995 and 2015 were used in this study to analyze and understand the fall trends, such as the severity of activities, the height of falls, and their causes in formwork activities. The accident reports were retrieved from the database using the keyword "concrete formwork." Initially, 526 reports were found, and with a further filter using keywords such as "vertical formwork" and "fall from height", 203 reports were retrieved from the database. The research flowchart is illustrated in Figure 5.1.

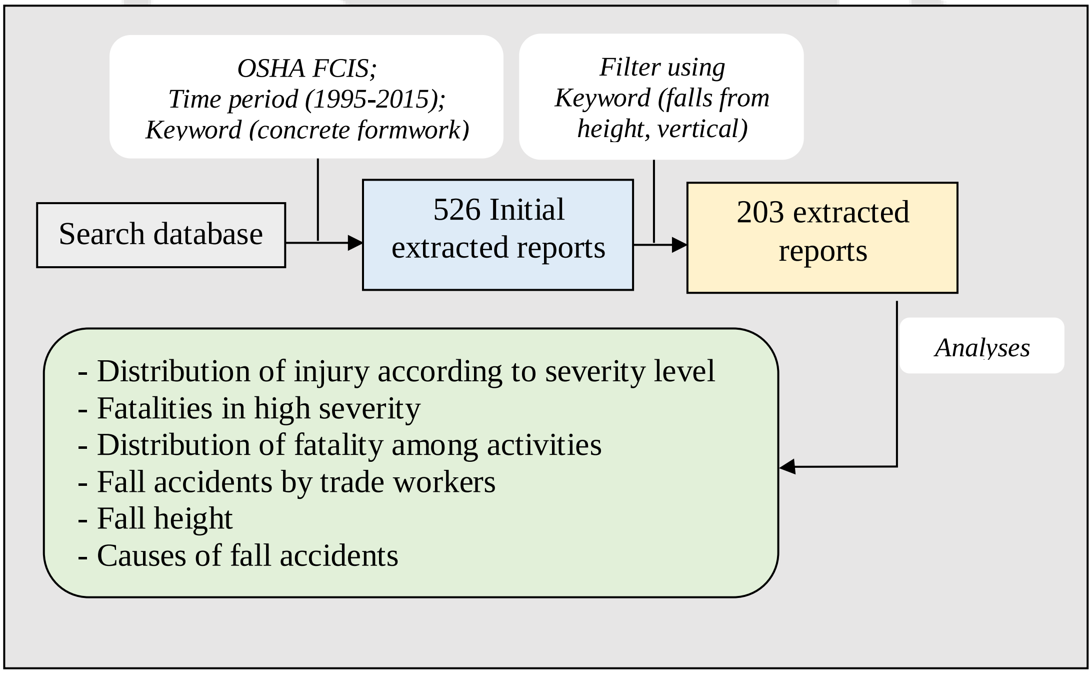


Figure 5.1 Research process flowchart

5.3.2 Data Analysis

In five different criteria, the retrieved data are summarized: (1) injuries severity, (2) the activity of the formwork being carried out at the time of the occurrence, (3) trade workers involved in each activity when the fall occurred, (4) height of fall, and (5) causes of fall. Based on the severity level set forth by Dharmapalan (2011), the severity of the incident was classified. Dharmapalan (2011) established four severity levels: Near miss: no injuries; low severity: temporary pain; medium severity: results in medical action; and high severity: fatality or permanent disability. Based on studies conducted by Amrutha et al. (2014) and Hallowell (2008) and findings from section 5.2, the formwork activities that pose the risk of falls, the formwork activities are classified, namely assembly, erection, concrete pouring, and stripping. In case the injured worker was not connected for formwork operations, they are identified, and it is named the "other" category. The activity not stated in the report was under the "not specific" category.

5.3.2.1 Distribution of injury according to severity level

It was identified from retrieved reports that erection activity poses a high risk of falls, followed by panel stripping. Additionally, these two activities tend to have medium severity of falls. Other activities, such as concrete pouring and assembly, have a low severity of falls in formwork operations. Notably, no activity falls under the category of a near miss. The injury distribution is shown in Figure 5.2.

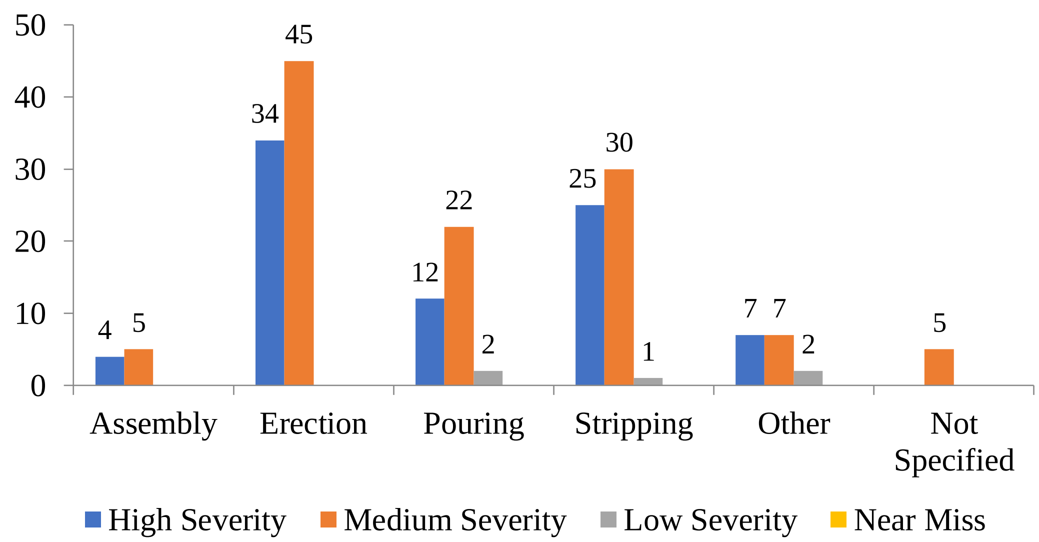


Figure 5.2 Injury distribution of activities

5.3.2.2 Distribution of fatality among activities

Regarding the distribution of fatalities in formwork activities, stripping has the highest fatalities, followed by panel erection and pouring (see Table 5.2). The 'other' category describes accidents in which the worker engaged in the accident was conducting some tasks entirely outside of any concrete forming activities. The 'not specified' category includes the number of events in which the specific event cannot be determined due to a lack of information in the report.

Table 5.2 Fatalities distribution in formwork activities

Activities	Fatalities	Percent
Assembly	4	6
Erection	21	32
Pouring	11	17
Stripping	22	34
Other	7	11
Not specified	0	0
Total	65	100

5.3.2.3 Fall accidents by trade workers

Trade workers who are exposed to falls during formwork were also examined. Only 137 trade workers were identified out of 203 events due to missing data. From Table 5.3, it can be seen that carpenters are often associated with falls during formwork, followed by concrete laborers. Also, it can be found that most workers tend to fall during stripping and erection activities.

Table 5.3 Fall incidents by type of trade

Activities	Trade workers (count)				
	Concrete Labor	Carpenter	Finisher	Metalworker	Supervisor
Assembly	2	3	-	1	5
Erection	20	34	-	1	-
Pouring	9	2	5	1	1
Stripping	16	17	2	1	3
Other	5	2	2	-	1
Not specified	1	2	-	1	-
Total	53	60	9	5	10

5.3.2.4 Fall height

Fall incidents by height are illustrated in Table 5.4. Fifty-one cases were found to have complete data about fall height out of 203 events. It can be seen that within the elevation between 0 to 9.1 m (30 ft), 77% of falls occurred. Elevation of a project could be considered one of the riskiest aspects. According to OSHA regulation (CFR1926), fall protection must be enforced at an elevation above 1.83m.

5.3.2.5 Causes of fall accidents

Fall causes can be found only in 105 cases due to the unavailability of data. It was found that improper platform/opening (30%) accounts for many fall incidents, followed by deck form collapse and objects (21%). Table 5.5 shows that inappropriate and inadequate fall protection personal protective equipment (PPE) contributed to 8% of falls.

Table 5.4 Fall incidents by height

Activities frequency	Fall height [m (ft)] (count)					
	0-3.0 (10)	3.0-6.1 (10-20)	6.1-9.1 (20-30)	9.1-12.2 (30-40)	12.2-15.2 (40-50)	>15.1 (>50)
Assembly	1	2	-	-	-	1
Erection	4	7	6	1	1	4
Pouring	1	2	1	-	-	-
Stripping	2	7	6	1	-	1
Other	1	-	-	-	-	2
Not specified	-	-	-	-	-	-
Total	9	18	13	2	1	8

Table 5.5 Distribution of causes of falls during formwork

Activities	Causes of fall accidents (count)						
	Unguarded or unsupported platform/ uncovered opening	Inappropriate /no fall arrest system or PPE	No guardrails/toe board/slipped	Loss of balance	Carelessness of worker/lack of training	Hit by moving objects/fall over/ deck form collapse	Not known
Assembly	1	3	-	-	1	-	4
Erection	12	9	4	7	5	5	39
Pouring	5	-	2	3	2	9	15
Stripping	10	3	4	5	4	4	26
Other	2	1	-	-	-	1	12
Not specified	-	-	1	1	-	1	2
Total	30	16	11	16	12	20	98
Percent	15	8	6	8	6	10	47

5.3.3 Findings

Observing trends from past events will indicate which safety risks are most common on the construction site. Hence, fall trends during formwork operations were studied within multiple dimensions. It was found that panel erection and stripping significantly impact fall compared to panel assembly and concrete pouring. During formwork operations, it was also found that fall occurs at less than 9.1 m (30ft). In the context of trade workers, carpenters and concrete laborers are at high risk during formwork operations, and among activities, stripping is the most vulnerable activity to trade workers. Also, it was found that management negligence is responsible for 15% of falls in formwork operations. It should be noted that the OSHA data do not include in-depth event details, i.e., event time, exact location, etc.

5.4 Capturing the safety knowledge of formwork operations

5.4.1 Safety knowledge acquisition from experts

A Delphi research technique was adopted to capture the safety knowledge for fall RA associated with four formwork activities. The Delphi method is a multi-round, organized, and interactive survey approach for gathering information from a group of experts on a specific subject (Belton et al., 2019). One of the key reasons why the Delphi technique was chosen for this study is because of this. The Delphi method's framework is mostly consistent from study to study; however, the details of how the procedure is carried out may change (Alomari et al., 2018). In general, the procedure seeks anonymous evaluation from selected experts over numerous rounds, which removes some of the bias that could be expected (Hallowell and Gambatese, 2010). The elimination of bias is the second reason for employing this strategy in the current study. Although Delphi replies are subjective, the refining criteria for participant selection can make it a more accurate approach than traditional surveys (Alomari et al., 2018). It should be noted that risk perception or recognition is an inherently unpredictable effort, ensuring that the method's findings are subjective. In most risk perception studies, experts rate the potential risks based on probability and severity (Alomari et al., 2018; Mohandes and Zhang, 2019).

The Delphi technique is a group method based on obtaining group consensus (Karakhan et al., 2021). Establishing consensus (i.e., the convergence of viewpoints towards a high level of agreement) among group responses reduces bias and increases the trustworthiness of Delphi results (Hallowell and Gambatese, 2010). The amount of consensus within the group is determined by statistical measurements such as interquartile range and standard deviation after each round of the Delphi process (Hallowell and Gambatese, 2010; Karakhan et al., 2021). The Delphi method has several advantages, one of which is that it is an iterative process. The participant gets many opportunities to respond to the same question (Alomari et al., 2018). The current study, which evaluates risk perceptions based on expert decisions, benefits from the iterative nature. The repetitive structure of the process allows individuals to adjust their responses after seeing those of other participants, reducing personal bias (Belton et al., 2019). There are disadvantages to the Delphi technique and the benefits listed. Because it is a lengthy procedure, some individuals may not be able to participate in all rounds. As a result of this flaw, researchers are forced to abandon incomplete answers (Tymvios and Gambatese, 2016). In the Delphi method, it is also essential that the panelists are chosen carefully and are qualified experts on a particular topic (Sierra et al., 2016). The panel members were selected with great care in this study, as described in the next section of this article.

Over the past decades, the Delphi method has been widely employed in construction management studies (e.g., Hallowell and Gambatese, 2010; Sierra et al., 2016; Mayo and Issa, 2016; Karakhan et al., 2020; Karakhan et al., 2021) to generate trustworthy research outcomes. For instance, for selecting procurement systems for projects, Chan et al. (2001) developed a multi-attribute model using the Delphi method and an expert panel of eight. In the same line, with the panel of 22 construction experts, Yeung et al. (2009) identified the key performance metrics determining the construction project's success in Australia. Gharaibeh (2014) investigated the cost overruns caused in construction projects and developed cost-effective solutions to controlling project costs using a Delphi method with a panel of 15 experts. More recently, Karakhan et al. (2021) used the Delphi method to identify and determine the level of influence of indicators for assessing diversity, equity, and inclusion of the construction workforce with a panel of 16 experts.

This study used the Delphi approach to capture the safety knowledge from experts for fall RA such as riskiest activities based on height, causes of falls, people at risk during vertical formwork, and measures to prevent falls. The following sections describe the procedure for selecting and qualifying expert panelists.

5.4.1.1 Panel members

As previously noted, the Delphi processes' success relies heavily on the panel members' qualifications. The researchers employed a three-step method to select a highly qualified panel of experts for the current study. Lopez-Arquillos et al. (2014) suggested that industry practitioners were targeted in the Delphi panel. Bringing a panel of experts from the industry ensures that the panel's feedback is practically sound and widely recognized across the industry (Karakhan et al., 2021).

First, to decide if a practitioner is eligible for participation on the Delphi panel, the researchers relied on their individual opinion in the selection process. The research team used different ways to identify possible participants. The selection of participants relied on each participant's job and position within their firm regarding human resources management and their education, profession, and engagement in the industry. The only individual who worked and was located in India during the study period was selected for participation. Following a thorough search for suitable participation, a list of 53 experts was produced. The researchers contacted the 53 individuals who had been identified, explained the study to them, and invited them to participate. The Delphi panel's participation depended on the qualification results from the second round of the selection procedure. Twenty-four of the 53 participants volunteered to join the panel if they were judged to be qualified experts.

Second, an email was sent to the 24 individuals interested in participating in the study. The email requested information on their qualifications, education, and work experience, among many other items. The goal of gathering this information was to decide if the individuals were qualified to participate on the panel as experts. For this purpose, Hallowell and Gambatese's (2010) point-system qualification approach was used. Several construction management researchers adopted this point system, including Karakhan et al. (2021), endorsed by Delphi methodologists (Belton et al., 2019). The qualification point-system process includes criteria for the year of professional experience, educational background, professional registration, committee membership, research publications, and overall contributions to the profession, all of which are used to decide whether an individual is a construction expert. As listed in Table 5.6, each criterion is given a different weighting. According to previous researchers' recommendations (e.g., Lopez-Arquillos et al., 2014), if an individual scores 11 points or more across multiple criteria, they are supposed to be an expert.

Table 5.6 Point system qualification system

Criteria	Weight
Registration in professional body	3 points (each)
Experience in years	1 point (each)
Member of a committee	1 point (each)
Chair of a committee	3 points (each)
Publications (in the safety domain)	Books (4 points each) Book chapters (2 points each) Peer-reviewed journal articles (2 points each) Conference articles (0.5 points each)
Technical degree	BE (4 points) ME (+2 points) Ph.D. (+4 points)

Out of the 24 people who initially expressed an interest in participating in the study, the information was provided by 16 (66.67%) relating to the qualification criteria listed in Table 5.7. All participants scored more than 11 points after gathering and evaluating the information provided and were thus regarded as qualified experts. The expert panelists' qualification data are listed in Table 5.7. The table shows that most panelists achieved scores higher than the 11-point threshold. Even the four panelists who received the lowest score (16 points) are well qualified, having acquired an undergraduate degree and having worked in the field for more than six years. Every member has a Bachelor's or Master's degree in a technical field. In the construction industry, formwork activities have a high technical profile. As a result, this criterion is essential because prior specialized training is required to construct a practical evaluation. As Belton et al. (2019) advised, the researcher requested the participants to declare their experience in subjects such as construction site safety, formwork activities, and work-at-height practices to guarantee that all panelists are experts on the topic. All of the panelists said they were directly involved in attempts to manage site safety and monitor construction processes as part of their jobs. The panelists also had distinct features and qualifications that made them valuable and relevant to the research. Nine of the panelists were members of a safety committee and have more than ten years of experience addressing safety issues in the construction industry. Finally, engaging industry participants boosts confidence in the panel's responses and guarantees that any results are both practical and scientific. A panel of 16 experts is within the recommended range indicated by prior studies (Kamaruzzaman et al., 2019; Karakhan et al., 2021).

5.4.1.2 Survey

As part of the Delphi process, a questionnaire was created as the data collection tool (see Annexure IV). The purpose of the questionnaire was to capture safety knowledge from the expert panel about the causes of falls and the population at risk during formwork activities, as well as to weigh probability and severity levels using the previously provided probability and severity scales and fall preventive measures.

A pilot study was conducted with two industry practitioners who were not part of the Delphi panel before being sent to the panel. The questionnaire was updated based on the comments received from the pilot testing, and it was then forwarded to the expert panelists for feedback. The experts were given access to a web survey produced on a specific site to collect expert responses. After collecting data for the period mentioned above, the web survey expired. Four rounds of questionnaires were used, and the panelists were unaware of the identities of the other panelists. The research team managed the survey independently and preserved confidentiality throughout the procedure.

Table 5.7 Qualification data of the expert panel

Panelist	Technical degree	Experience (years)	Professional registration	Journal articles	Conference articles	Member of a committee	Book chapter	Total	Number of achievement categories
1	BE	9	1	0	0	0	0	16	3
2	BE	13	0	0	0	1	0	18	3
3	BE	16	1	0	0	1	0	24	4
4	BE	25	1	0	0	0	0	32	3
5	ME	23	0	0	0	0	0	29	3
6	ME	14	0	0	1	0	0	20.5	4
7	BE	10	1	0	0	1	0	18	4
8	BE	18	1	2	1	1	0	30.5	6
9	BE	16	1	0	0	0	0	23	3
10	BE	11	0	0	0	1	0	16	3
11	BE	11	1	0	0	1	0	19	4
12	ME	7	0	1	2	0	0	16	5
13	BE	9	0	0	0	1	1	16	4
14	BE	13	1	0	0	0	0	20	3
15	BE	27	1	0	0	1	0	34	3
16	ME	15	1	0	2	1	0	26	6

The panelists were asked to indicate the causes of falls and the population at risk during formwork activities in the first round of the Delphi process to analyze and improve workplace safety. Risky activities, individual characteristics, site conditions, management/organization, agents, and weather/environmental conditions influence falls during formwork. All indicated causes of falls and population risks were given to the panelists during the second round. They were asked if they agreed that the causes of falls and the population at risk stated in the first round were essential constructs for RA. The panelists were asked to weigh the probability and severity levels using the previously provided scales in the third round. In the fourth round, the panelists were asked to list each activity's fall risk control measures to prevent falls in the construction workplace.

5.4.1.3 Results of Delphi survey

5.4.1.3.1 Round 1

The activity descriptions in Table 5.1 were given to the Delphi panel. The panelists were asked to indicate the causes of falls and persons at risk in the survey's first phase to facilitate the RA process. There were two primary questions asked. The panelists were asked to indicate the causes of falls in the first question and who could be at risk of falling during each formwork activity in the second. All of the panelists completed the questionnaire, and they all provided feedback. The panelists identified a total of 106 causes and 12 people who will be at risk of falling after gathering and analyzing the responses. The study team reviewed the responses for consistency in phrasing, grouping like answers, removing incomplete input, and so on. For example, unsuitable fall protection systems, inappropriate fall arrest systems, and no personal protective equipment (PPE) were all grouped under the heading of inappropriate/no usage of the fall protection system. The list of causes of falls was reduced to 29 by grouping similar terms: 7 causes for panel assembly, panel erection, and stripping, and eight causes for concrete pouring. However, the list of persons at risk remains the same, consisting of 12 individuals, each with three. Table 5.8 lists the common causes of falls, the population at risk of falling, and their frequency. It should be noted that while all of the mentioned activities have similar causes of falls and populations at risk of falling, their influence on falling may differ, as detailed in the following sections.

5.4.1.3.2 Round 2

In the second round, the panelists were asked if the 27 causes and 12 populations should be kept as an essential construct for RA in construction projects. Thirteen panelists (81%) participated in the second round, out of 16 who participated in the first round. Table 5.9 summarizes the results from the second round. Based on the findings in Table 5.9, most of the panelists indicated all causes of falls and persons at risk to be retained. The majority in this study is defined as more than half of the individuals agreeing or disagreeing. Several Delphi studies have adopted the 50% rule in the past (Von der Gracht, 2012; Allen et al., 2019; Karakhan et al., 2021).

Table 5.8 Causes of falls and population at risk of falls indicated by the expert panel (n=16)

Activity	Causes of fall	Frequency	Population at risk	Frequency
Assembly	Inappropriate/ no fall arrest system or PPE	16	Carpenter	13
	Unsuitable ladder	7	Helper	7
	Inattention /Inexperience of users	6	Fitter	3
	Improper /unguarded edges/platform	4		
	Slippery or slopped surface	3		
	Hit by moving objects	1		
	Loss of balance	1		
Erection	Inappropriate/ no fall arrest system or PPE	16	Carpenter	11
	Improper /unguarded edges/platform	13	Labor	9
	Unsuitable floor covering	9	Fitter	3
	Inattention/Inexperience of users	7		
	Hit by moving objects	4		
	Loss of balance	4		
	Slippery or slopped surface	3		
Concrete pouring	Inappropriate/ no fall arrest system or PPE	16	Labor	16
	Improper /Unguarded edges/ platform	12	Finisher	8
	Inattention/ Inexperience of users	7	Supervisor	3
	Hit by moving objects	6		
	Unsuitable floor covering	9		
	Loss of balance	5		
	Slippery or slopped surface	4		
	Deck form collapse	3		
Stripping	Inappropriate/ no fall arrest system or PPE	16	Carpenter	8
	Loss of balance	7	Labor	6
	Improper /Unguarded edges/platform	12	Supervisor	2
	Inattention/Inexperience of users	4		
	Unsuitable floor covering	8		
	Slippery or slopped surface	3		
	Hit by moving objects	2		
Total	29 causes are indicated	207	12 population are indicated	89

Table 5.9 Panel responses regarding retention of causes of fall and population at risk (n=13)

Activity	Causes of fall	Retain (count)		Retain (%)		Population at risk	Retain (count)		Retain (%)	
		Yes	No	Yes	No		Yes	No	Yes	No
Assembly	Improper /unguarded edges/platform	13	0	100	0	Carpenter	13	0	100	0
	Inappropriate/ no fall arrest system or PPE	13	0	100	0	Helper	11	2	85	15
	Unsuitable ladder	13	0	100	0	Fitter	12	1	92	8
	Inattention /Inexperience of users	13	0	100	0					
	Loss of balance	11	2	85	15					
	Slippery or slopped surface	13	0	100	0					
	Hit by moving objects	7	6	54	46					
Erection	Hit by moving objects	11	2	85	15	Carpenter	12	1	92	8
	Inappropriate/ no fall arrest system or PPE	13	0	100	0	Fitter	10	3	77	23
	Improper /unguarded edges/platform	13	0	100	0	Labor	9	4	69	31
	Unsuitable floor covering	13	0	100	0					
	Loss of balance	8	5	62	38					
	Slippery or slopped surface	7	6	54	46					
	Inattention/Inexperience of users	13	0	100	0					
Concrete pouring	Improper /Unguarded edges/platform	13	0	100	0	Labor	13	0	100	0
	Hit by moving objects	11	2	85	15	Finisher	9	4	69	31
	Inattention/ Inexperience of users	13	0	100	0	Supervisor	7	6	54	46
	Loss of balance	9	4	69	31					
	Unsuitable floor covering	13	0	100	0					
	Inappropriate/ no fall arrest system or PPE	13	0	100	0					
	Slippery or slopped surface	7	6	54	46					
Stripping	Inappropriate/ no fall arrest system or PPE	13	0	100	0	Carpenter	13	0	100	0
	Unsuitable ladder	13	0	100	0	Labor	8	5	62	38
	Improper /Unguarded edges/platform	13	0	100	0	Supervisor	7	6	54	46
	Slippery or slopped surface	8	5	62	38					
	Loss of balance	13	0	100	0					
	Hit by moving objects	7	6	54	46					
	Inattention/Inexperience of users	13	0	100	0					
	Unsuitable floor covering	13	0	100	0					

5.4.1.3.3 Round 3

All thirteen panelists who took part in the second round participated in the third round. In this round, the panelists were also asked to weigh the probability and the severity based on working height for each activity using a scale provided in Tables 2.1 and 2.2. The panelists' responses were gathered and evaluated to establish the relative weights of the probability and severity of each activity. The severity of the fall changes based on working height, i.e., the severity of the person falling from 12m will be higher than the person falling from 6m. Therefore, the working height of each activity was divided based on the literature (Huang and Hinze, 2003; Kang et al., 2017). A standard deviation was used to measure the consensus of the responses (i.e., the responses are within an acceptable degree of dispersion), as suggested by Hallowell and Gambatese (2010) and Kamaruzzaman et al. (2019). A standard deviation of 1.64 or less, according to earlier studies (e.g., West and Cannon, 1988; Rogers and Lopez, 2002), suggests an acceptable degree of dispersion among the responses. Therefore, in this study, the standard deviation of the responses was less than 1.64, and the consensus was considered achieved for all.

For assessing the fall risk, the experts multiplied the probability and severity ratings for each activity, and their mean values were considered, according to Hallowell and Gambatese (2009). The product of the probability and severity ratings indicates the risk scores for the activities. For instance, the risk score for the assembly activity for a working height of more than 15m can be determined by the probability and severity values (i.e., 2 x 4). The summary of the quantified risk score is shown in Table 5.10. The relative risk level was determined based on Figure 2.1 and Table 2.3 once the fall risks were assessed. The appropriate risk zone based on working height for each activity is tabulated in Table 5.10.

Due to the specific guidelines are given to the Delphi panelists, the gathered fall risk values through the Delphi method are constrained in the following ways:

- Regardless of the size, location, safety record, etc., the values represent the average for all companies in the sector.
- The risk values represent the average amount of fall risk which might happen if no fall prevention measures are undertaken.
- The risk values represent the construction professional’s judgments, not the empirical data.

- The risk values are generic; therefore, they don't consider extreme project conditions or organizational cultures.

Table 5.10 Probability and severity of each activity

Activity	Working height	Risk score (P x S)	Risk zone
Assembly	<3 m	3.69	L (Blue)
	3.1-6.1 m	5.92	L (Blue)
	6.2-9.1 m	8.07	M (Yellow)
	9.2-12.1 m	9.07	M (Yellow)
	12.2-15m	10.53	M (Yellow)
	>15m	11.92	M (Yellow)
Erection	<3 m	8.07	M (Yellow)
	3.1-6.1 m	10.92	M (Yellow)
	6.2-9.1 m	13.46	H (Red)
	9.2-12.1 m	15.76	H (Red)
	12.2-15m	16.61	H (Red)
	>15m	18.46	H (Red)
Concrete pouring	<3 m	5.23	L (Blue)
	3.1-6.1 m	8.30	M (Yellow)
	6.2-9.1 m	11.84	M (Yellow)
	9.2-12.1 m	13.30	H (Red)
	12.2-15m	14.84	H (Red)
	>15m	15.46	H (Red)
Stripping	<3 m	7.01	M (Yellow)
	3.1-6.1 m	10.69	M (Yellow)
	6.2-9.1 m	13.00	H (Red)
	9.2-12.1 m	15.92	H (Red)
	12.2-15m	19.07	H (Red)
	>15m	19.38	H (Red)

Note: P = Probability; S = Severity

5.4.1.3.4 Round 4

Liaropoulos et al. (2019) point out that once a significant safety risk is identified, assessed, and evaluated, appropriate preventive measures must be devised to complete a thorough RA. The fourth phase of the Delphi process was to thoroughly determine practicable and productive preventive measures for all of the evaluated fall risks. The outcomes of analyses carried out in the study were then provided to the panelists. Then a list of existing control measures recommended in the literature was also provided. The panelists were asked to indicate the number of fall preventive measures to prevent falls based on their newly defined zones. Participants were also asked to suggest additional preventive measures if any. All thirteen panelists who took part in the second round participated in this round. The panelists indicated 104 fall preventive measures after gathering and analyzing the responses. Like round one, the responses were reviewed for consistency in phrasing, grouping like answers, removing incomplete input, and so on. The list of preventive measures was reduced to 53 by grouping similar terms: 7 fall preventive measures for panel assembly, 15 preventive measures for panel erection and stripping, and 16 measures for concrete pouring. The fall preventive measures for each activity associated with vertical formwork construction can be found in Annexure VII. It should be noted that some of the fall preventive measures can be similar to other activities.

5.4.1.4 Validation of Delphi results

The researcher aimed to (1) identify the causes of falls during vertical formwork activities; (2) understand the individuals who might be at risk of falls during vertical formwork activities; (3) assess the fall risks for each activity associated with vertical formwork using Eq. (1); and (4) list out the fall preventive measures to reduce fall at the worksite during data analysis. The data were merged to achieve these objectives with each activity.

To achieve the third objective, the data were combined by multiplying the probability and severity to calculate the overall risk score. The product of the probability and severity values corresponds to the overall fall risks, as indicated in the literature. It can be seen in Table 5.11 that the highest fall risk activities are stripping followed by erection in which, all of which come under the red zone after a certain working height (>6.2 m). The data indicated that panel assembly is the lowest fall risk activity among others. Table 5.10 shows that the overall causes that could influence falls during formwork activities are inappropriate/ no fall arrest system or PPE, hit by moving objects, and improper /unguarded edges/platforms. One of the major causes that influence falls during assembly and panel stripping is using an unsuitable ladder to work. During these activities, carpenters/fitters may require ladders to assemble or remove panels, and due to the use of unsuitable or improper ladders at the site, falls could occur. Also, it can be seen in Table 5.10 that carpenters are at high risk of falls during assembly, erection, and panel stripping. Followed by labor during erection, concrete pouring, and stripping and fitter during assembly and erection are at high risk of falls. Apart from workers, supervisors are also at high risk of falls during concrete pouring and stripping. This is the fact that when supervisors visit formwork activities to inspect the concrete condition during pouring and monitor the panels' conditions while stripping, they are at high risk of falls. To prevent such falls on the construction sites, preventive measures were suggested for each activity by construction experts, as can be seen in Annexure VII. The overall data from this study were combined for each activity using MS Excel to give a fall RA worksheet for vertical formwork to prevent falls at the site.

Generally, there are several types of validations to examine the goal of determining the degree to which the current study's findings are relevant to reality. According to Lucko and Rojas (2010) and Karakhan and Gambatese (2017), validation is of four types in the construction safety research domain: face, construct, empirical, and external validations. Concerning the face validity, the current study is valid owing to the domain expert's participation, according to the criteria proposed by Karakhan and Gambatese (2017). Further, as mentioned by Blayse and Manley (2004), the experts chosen were involved in various phases throughout the entire process (i.e., causes of fall and population at risk of fall, RA, and control measures), making the face validity of the ongoing research particularly strong. To ensure the research's construct validity, the senior experts were contacted to have structured questionnaires pilot tested before being distributed at various stages. This stage was essential in ensuring that the research met its set goals in the end. Therefore, as Ling (2002) points out, this research has strong construct validity since the outcomes obtained after each step was completely consistent with what they were trying to achieve.

When it comes to empirical validity, the results must be compared to real-life situations (Branford, 2007). Amruta et al. (2014) and Chellappa and Salve (2022) reported that erection and stripping activities have high risks of falls during formwork activities in construction projects compared to other activities due to increased exposure to fixing and removing panel-oriented tasks. Likewise, management negligence (e.g., inappropriate/ no fall arrest system or PPE and improper /unguarded edges/platform) were the major influencing factor to falls during formwork activities, as emphasized in section 5.3. Additionally, section 5.3 reported that carpenters and general workers (i.e., concrete laborers) were exposed to high risks of falls during formwork activities in construction projects. The conclusions of this study were consistent with the findings of other studies, as seen by the elaborations offered on comparable studies stated above.

To determine external validity, 12 qualified experts were contacted who met the same criteria as the Delphi method. Out of 12, 9 experts agreed to participate in the validation. The average experience of construction experts is 16.4 years. It's worth noting that the experts selected for the study's validation were from construction firms in Chennai, and they were all involved in the formwork practices. Firstly, the activity descriptions in Table 5.1 were given to the experts.

Along with, a questionnaire containing a list of causes of falls and people who might be at risk of falls to each activity was given to them. The experts were asked to confirm if the identified causes and individuals are influenced to fall during vertical formwork. Experts were also asked to indicate additional causes and individuals if any.

Additionally, no new causes or people were introduced. Second, the designed questionnaire to calculate the probability and severity of each activity was given to the experts. Third, the fall preventive measures were gathered by interviewing experts one after the other. The survey with the experts was done one after the other to obtain a thorough list of fall prevention strategies relevant to each activity. Doing so, a thorough list of applicable and useful measures is obtained. The questionnaire used for validation can be seen in Annexure V.

Once the survey was completed, the researchers compared the validated results with the original findings. It was observed that all the causes of falls (those were previously considered critical by Delphi panelists) were found to be sufficiently critical. Also, it was observed that both Delphi findings and validation results show the same results regarding the individuals at risk of falling. Therefore, the experts for validation confirmed 100% of the overall causes, and individuals who might be harmed are recognized as critical by the Delphi panelists, indicating consistency and similarity between the obtained results. In terms of the risk scores obtained, there was not a statistically significant difference (i.e., between the Delphi findings and validation results; $p\text{-value} > 0.05$), indicating an adequate agreement, according to the researcher Chan et al. (2009). The researchers believed that the findings were valid and reliable as the data reported are consistent with the Delphi findings.

5.4.2 Best safety practices for vertical formwork

Following the safety knowledge acquisition of vertical formwork for fall RA from experts, the safety knowledge for vertical formwork was also captured through document analysis to identify best safety practices for formwork operations. Working at height regulations, guidelines in India and other published articles internationally related to formwork operations were rigorously examined. These include the Factories act, 1948 (GOI, 2017), Guide to the Safety, Health and Welfare at Work (General Application) Regulations 2007, part 4: Work at Height (HSE, 2008), Industry Guide for Formwork (Safework, 2012), and Guide to Safety Procedures for Vertical Concrete Formwork (SSFI, 2016), Hallowell and Gambatese (2009), Amruta et al. (2014), López-Arquillos et al. (2014), and Barbosa et al., (2014).

5.5 Developing a system to store and reuse safety knowledge

5.5.1 Knowledge-based fall RA framework

A framework was developed for the knowledge-based fall RA, as shown in Figure 5.3. The basic activity flow and resources involved in the fall RA process are illustrated in the framework.

- The safety knowledge base, which includes work-at-height safety regulations, guidelines, accident records, and research publications, is an essential component of knowledge-based fall RA. It includes the activity-based risk levels, hazards/causes of falls, individuals at risk, and fall preventive measures. When new knowledge emerges, a dedicated knowledge worker updates this knowledge base regularly.
- Knowledge-based fall RA entails analyzing the variables, retrieving safety knowledge, developing fall RA, and putting it into action on the job site.
- The scope of the project and the type of activity to be performed are situational variables. These variables are thoroughly studied for each activity, and potential causes of falls and fall preventive measures are drawn from the knowledge base. These result in the creation of a fall RA worksheet or fall prevention plan (FPP) for the vertical formwork.
- The FPP is applied and monitored on-site. If any cause or preventive measures are discovered, they should be documented and considered for updating in the knowledge base.

5.5.2 Web-based safety RA system development

The above model was converted into a web-based system to get the most out of the proposed knowledge-based fall RA strategy that

- offers a structured and widely accessible repository for safety knowledge,
- allows for the recording and storage of activity-based hazards/causes of falls and control measures in easily retrievable and exploitable formats,
- enables safety experts from a contractor's various project sites to use the safety knowledge base.

5.5.3 System modeling

- Figure 5.4 depicts the web-based fall RA system architecture and distinguishes the various systems' practical components. The system is built based on 3-tier architecture with three logical layers: a user side, a middle layer, and a server side. The server and user sides are connected through the middle layer and have an access knowledge base.
- The main functional set of the system's interface is the safety knowledge retrieval and update sets. After completing the access authentication process, users from construction sites can access the knowledge retrieval system. The knowledge retrieval set enables users from various locations to access activity-based hazards/causes of falls, at-risk populations, and risk control measures for activities. This knowledge would help the safety director with intensive fall prevention.

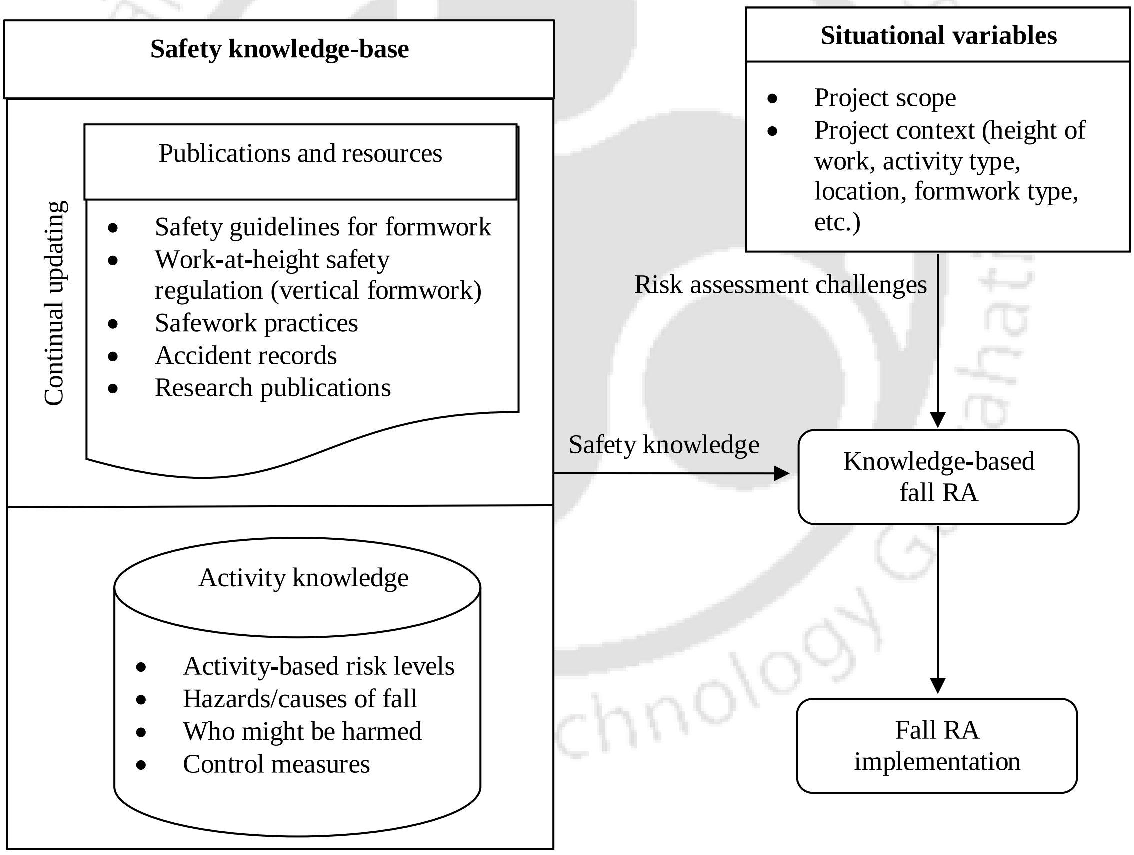


Figure 5.3 Knowledge-based fall RA framework

Figure 5.5 shows how safety knowledge related to fall RA is stored in the knowledge base as a tree structure. Wall and column are the two types of vertical formwork, and these tasks are further divided into subtasks or job operations. For these subtasks, relevant hazards/causes of falls, individuals at risk, and fall prevention measures are mapped. In the knowledge base, knowledge about fall hazards/causes, individuals at risk, and fall prevention measures is stored in textual and tabular formats.

The proposed fall RA systems' user navigational flowchart is shown in Figure 5.6. The Index Page connects the user to retrieve safety knowledge about fall RA. The Login Page is where the user begins using the system. The user is granted access to the Index Page once the authentication has been verified; otherwise, the user is advised to register.

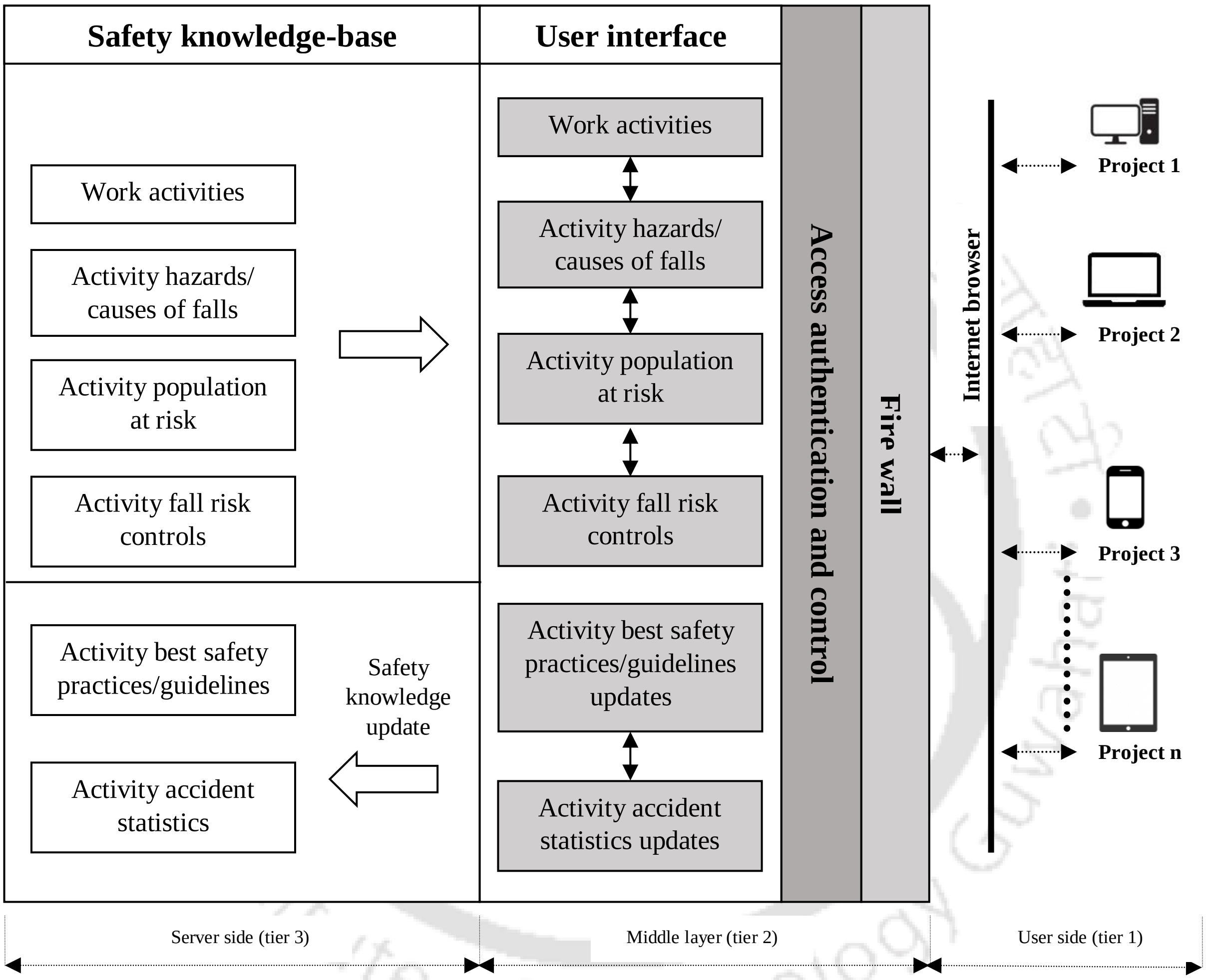


Figure 5.4 Web-based fall RA system architecture

5.5.4 Prototype development

A prototype was developed by using a CMS. CMS software enables users to create and manage dynamic websites using built-in tools and templates (Kamardeen, 2011). According to Robertson (2003), using a CMS can provide various benefits such as greater consistency, support for decentralized authoring, reduced site maintenance, greater capacity for growth, reduced duplication of information, increased security, and a streamlined authoring process. Therefore, it was decided to create the proposed system's prototype using a CMS. Justinmind is a CMS that academicians and corporates can use to create dynamic websites and e-business solutions. Justinmind, being a web development tool, can be downloaded from the Internet and installed on personal computers for a website's development and testing purposes. Justinmind was used to create a prototype of the proposed fall RA system.

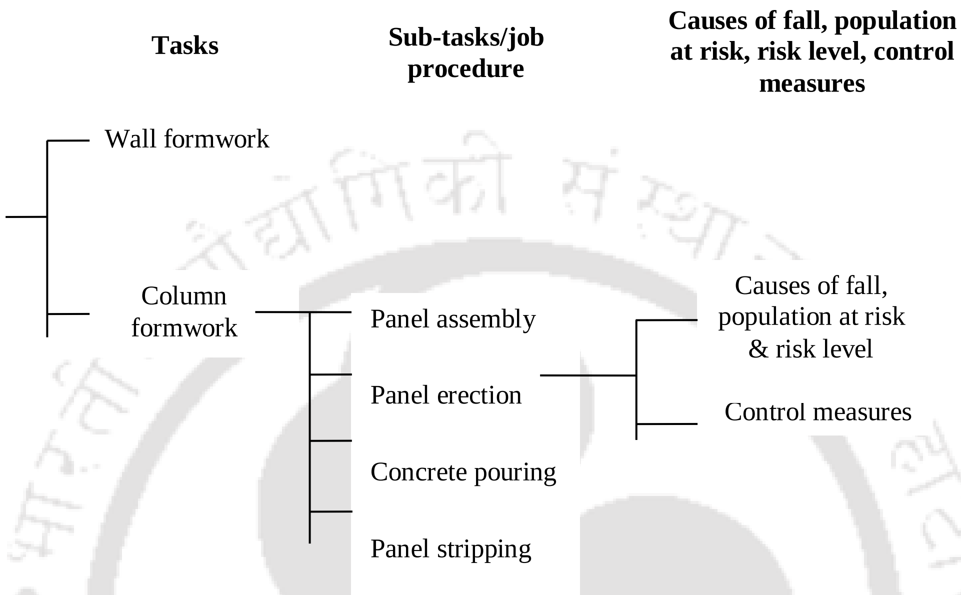


Figure 5.5 Knowledge representation tree

5.5.4.1 The working mechanism of Justinmind

There are two elements to a Justinmind website: the front-end and the back-end. Users can use the components on a website's front end. The back-end is the section of the website where it is created, edited, and maintained. Justinmind saves website content as articles on the backend, including graphics, written content, and/or footage added to the webpage. The website's articles are clustered in divisions and topics. An article must belong to a category and a section simultaneously. Before adding content (articles) to individual pages on the website, it's critical to organize and create the website's first sections and categories. On the website backend, Justinmind also provides uncategorized content for static pages. Justinmind has a word processor with a visual editing interface for producing and editing material in articles. Another significant component of Justinmind is the menu manager, which aids in creating website navigational menus.

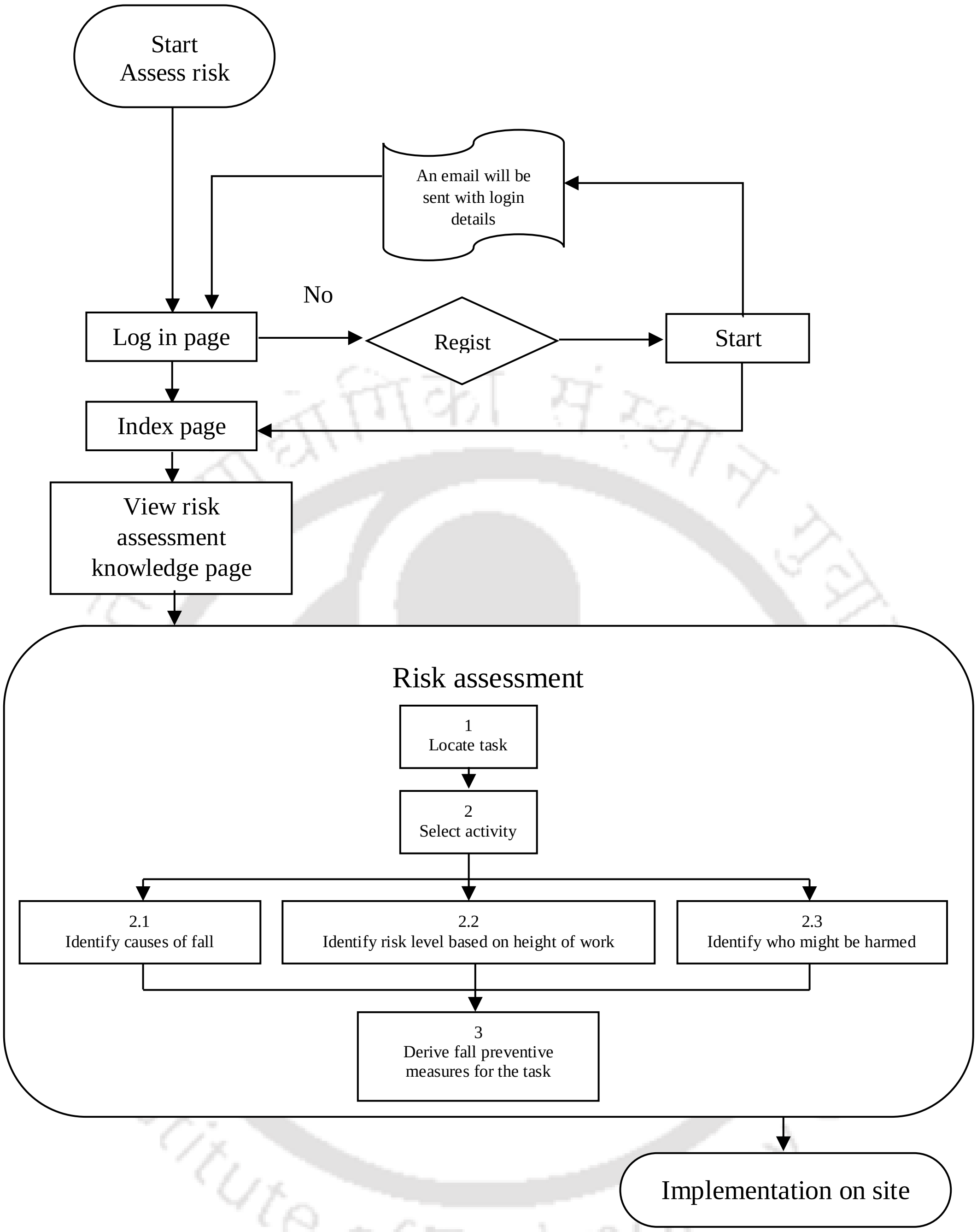


Figure 5.6 Knowledge-based fall RA flowchart

5.5.4.2 Development of a prototype

The suggested system's ultimate goal was to create a comprehensive fall RA system for vertical formwork. As a result, when the website was planned, it was determined to include three major sections. Following that, categories for the fall RA were determined. For each job procedure, one article was dedicated to describing the causes of falls, individuals at risk, activity risk level, and fall prevention strategies, and this information was presented in text and table formats. Figure 5.7 and 5.8 represents the front-end and back-end of the web-based system.

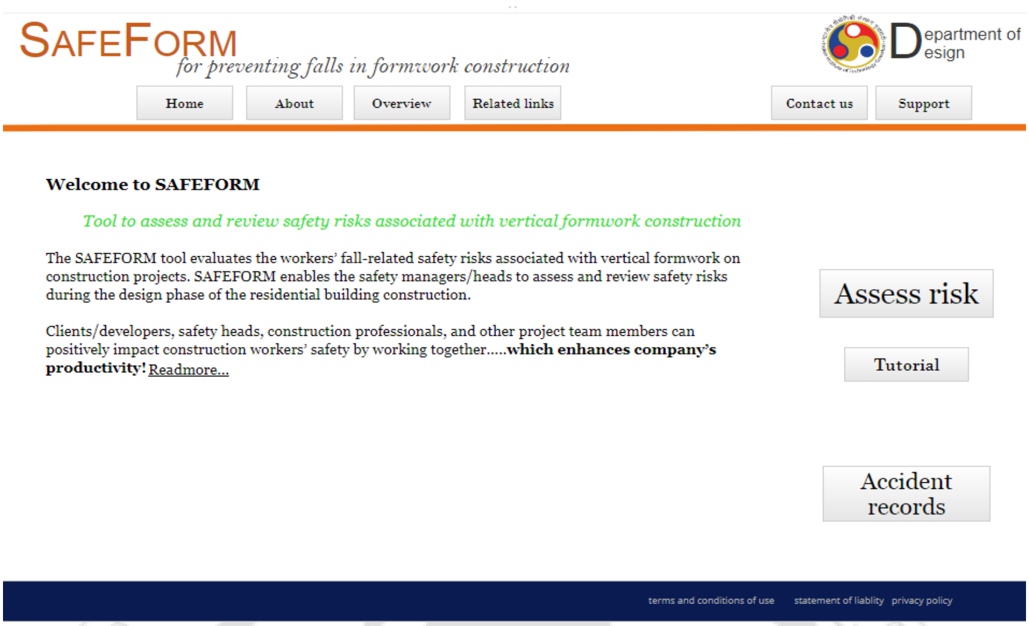


Figure 5.7 Front-end of the prototype

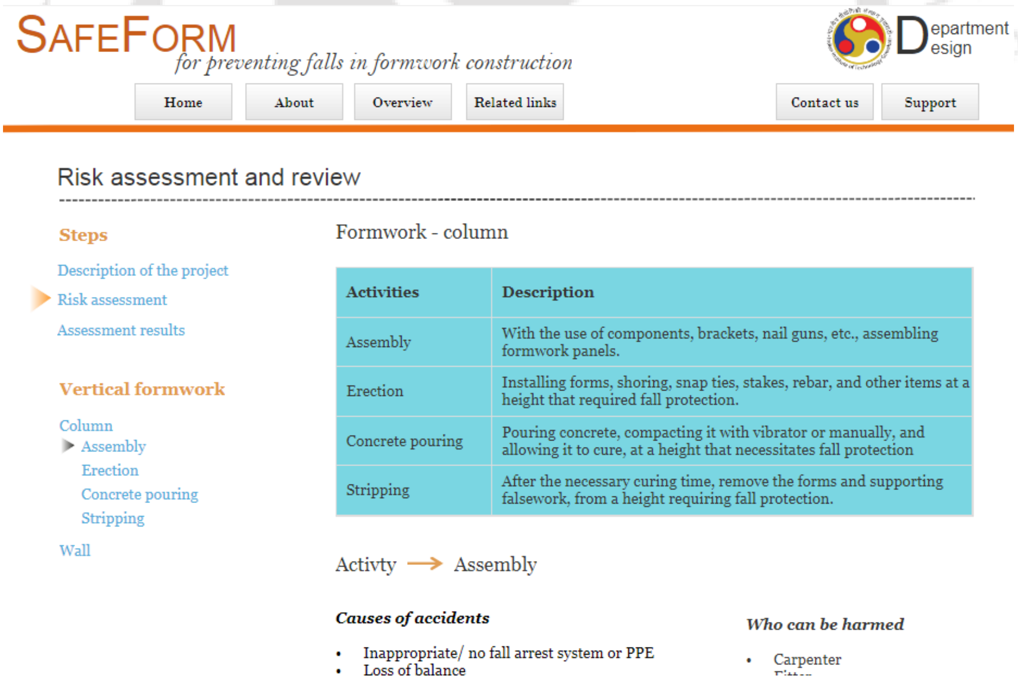


Figure 5.8 The back-end of the prototype

5.6 Evaluation of the system's interface design

5.6.1 Methodology

The prototype was named SAFEFORM, and its usability was evaluated utilizing the CW evaluation method at construction companies in southern India.

5.6.1.1 Evaluation through a cognitive walkthrough

It is commonly acknowledged that usability testing is essential to the success of interactive applications. According to Jaspers (2009), several usability inspection methods exist, such as heuristic evaluation, guideline review, think-aloud, and CW. Among these, the CW offers a more organized method directed by a list of user tasks and questions (Beuscart-Zéphir et al., 2005). CW is a method of evaluating the usability of tasks with a linear path (Zapata et al., 2014). It is a group-based method based on theories of explorational learning proposed by Lewis et al. (1990). In CW, based on users' contextual knowledge, the assessors imitate users' cognitive processes by tracking the activity sequence used to complete specified tasks (Jaspers, 2009). The assessors examine the user interface and the simplicity with which each step is completed by beginner users (Farzandipour et al., 2021). The quality of results is significantly influenced by the assessors' ability to put themselves in the users' position (Zapata et al., 2014). Therefore, in this research, the CW was used to evaluate the interface design of the prototype.

5.6.1.2 System and target users

At the time of this research, SAFEFORM was not implemented in any construction projects. Safety heads/managers were targeted who perform fall RA in construction projects.

5.6.1.3 Task scenario

A scenario was chosen based on the most significant and common fall RA tasks for formwork activities where the prototype will be used. This scenario, which included identifying safety hazards/causes of falls, identifying individuals at risk, evaluating activity-based risks, selecting the height of work, and selecting fall preventive measures, was created based on the opinions of eight safety heads/managers working in the safety department of construction projects and was then confirmed by the project heads. Users' goals and the action sequence to complete specified tasks were all defined for each task. The scenario that was chosen was given below

> You have been working in the RA process for many years. You have heard the great news about the new RA web-based tool, SAFEFORM, for vertical formwork construction and how the system helped colleagues and friends facilitate the process of RA. You have opened the SAFEFORM webpage. You opened the SAFEFORM because you need to understand the work-at-height safety risks involved in activities (assembly, erection, concrete pouring, stripping) of vertical formwork (i.e., column and wall). First, you need to enter project details to assess and review the risks of fall-related vertical

formwork activities. Before proceeding to RA, you need to update the project details you have given previously. Then, you need to assess and review risk levels at different heights of erection (for wall) and stripping (for column) activities involved in formwork. Once you finish the RA, you should close the project. Suppose you wish to quit the RA in between, you can do it. So, you know the RA is a challenging task and not easy to gather information about a particular activity. Now, you will begin your journey by learning and using SAFEFORM.

5.6.1.4 Evaluators

According to Khajouei et al. (2018), 3-5 evaluators are sufficient for CW evaluation, and therefore, in this study, five evaluators were selected from different educational backgrounds through random sampling. The evaluators have included two junior safety engineers, one graphic designer, one project engineer, and one construction engineering and management faculty with an average experience of 6.4. The junior safety engineers had experience in the RA process; however, unlike safety heads/managers, they were not the users.

5.6.1.5 Identification of usability issues

The evaluators had a 1-hour session to determine the usability problems in SAFEFORM. Using the SAFEFORM user interface, the evaluators individually conducted tasks sequentially to perform the evaluation. Therefore, based on users' experience, evaluators put themselves in real users' positions. If a problem emerged after a task was completed, evaluators were allowed to report back from the users' perspective. As an observer, the researcher was present next to the evaluators during the evaluation period and made notes on the evaluators' comments, queries, understanding of the exact location of usability problems in SAFEFORM, and detailed explanations of usability problems. After completing the evaluation procedure, assessors evaluated their lists and, if necessary, updated or revised a comment.

5.6.2 Findings

After merging the issues and removing the repeated ones, five usability issues were found. Table 5.11 shows the list of usability problems identified and discussed in the following paragraphs. While coming to the RA window, the button for selecting "wall formwork" and "column formwork" was given in the same window. The evaluator mentioned that once the user finishes some trade, for example, wall formwork, they must return to select the other trade. Therefore, the evaluator recommended providing a link to the "wall" under "steps" in the RA window to access "wall formwork" to indicate that the button is going to allow the user to assess the risk in wall formwork.

Table 5.11 List of usability issues identified by the evaluators based on usability attributes

S. No	Usability issues (UI)	Evaluators' comments
UI-1	Activities for both wall and column formwork are given in the same windows	Use separate windows for wall and column formwork
UI-2	The option for deleting any selected activities in the final stage is missing	There should be a separate delete button for each activity in the final stage
UI-3	The user has to start from the beginning for editing an activity instead of editing a particular activity that they are willing to do	Keep the edit button for each selected activity in the final stage so that users can edit the activities whichever they want
UI-4	The user may not prefer the print button, as the entire information about formwork is visualized as a worksheet	The print button can be renamed as generate a worksheet
UI-5	There is no logout button in the RA window	Include the logout button in the RA window throughout all RA steps in the same way

Evaluator pointed out that if the user feels in the final stage of completing RA that they need to edit or delete any activity from the selected list of activities, they have to return to the RA window to make changes or unselect the particular activity from the trade. In another two similar cases, UI-2 and UI-3, there is no option to edit or delete any activity from users' selected list of activities before completing the RA process. Hence, the evaluator suggests providing a separate button, "edit" or "delete," for each activity in the final stage before completing the RA. The fourth usability issue (UI-4) was that once the RA is completed, the user may not prefer the "print" button to transmit the knowledge from system to paper as the entire information about vertical formwork was visualized as a worksheet as same as used in the construction site. Hence, the evaluator advised renaming the "print" button as "generate worksheet" to reduce ambiguity and facilitate system learnability.

The major usability issue indicated by most of the evaluators in SAFEORM was the missing "logout" button. Evaluators pointed out that if the user wants to take a break during the RA process or they feel to continue RA after some time, then there is no option to log out of the window; rather, they have to close the entire window. So, evaluators suggested keeping the “logout” button through all RA steps. Users can continue their work by logging in with the same credentials they used to register for RA in SAFEFORM.

5.7 Development of a knowledge-based system

The findings from section 5.6.2 indicated that the system interface should be redesigned using icons familiar to users, providing clear terminology and doing an action following the users' expectations cannot only reduce the ambiguity but also reduce the memory load of users and the system learning time and enhance the users' efficiency. And hence, taking evaluators' feedback into account, the interface design of a prototype was improved, and a web-based safety KM for fall RA was created using PHP programming language. The example of the source code of the knowledge-based system is shown in Figure 5.9. Being a web-based tool, the user can access the system anywhere and anytime on personal computers, tablets, laptops, and Smartphones. Figure 5.10 shows the front end of the knowledge-based system. In the front end, the system describes the overview of the system, publications related to SAFEFORM, safety regulations and safety practices for vertical formwork operations, how to use SAFEFORM, and accident statistics of formwork activities. The user can start performing the fall RA by clicking the assess risk tab on the front end.

```
<!doctype html>
<html>
<head>
<meta charset="utf-8">
<meta name="viewport" content="width=device-width, maximum-scale=1">
<title>SafeForm</title>
<link rel="icon" href="img/logo.png" type="image/png">
<link href="css/bootstrap.min.css" rel="stylesheet" type="text/css">
<link href="css/style.css" rel="stylesheet" type="text/css">
<link href="css/font-awesome.css" rel="stylesheet" type="text/css">
<link href="css/animate.css" rel="stylesheet" type="text/css">
  <style>
h1{
  font-size: 32px;
  color:#df0031;
}
h1 span { font-size: 42px; }
.subhead::first-letter {
  initial-letter: 2;
  font-size:34px;
}
</style>
</head>
<body>
```

Figure 5.9 Knowledge-based systems’ source code example

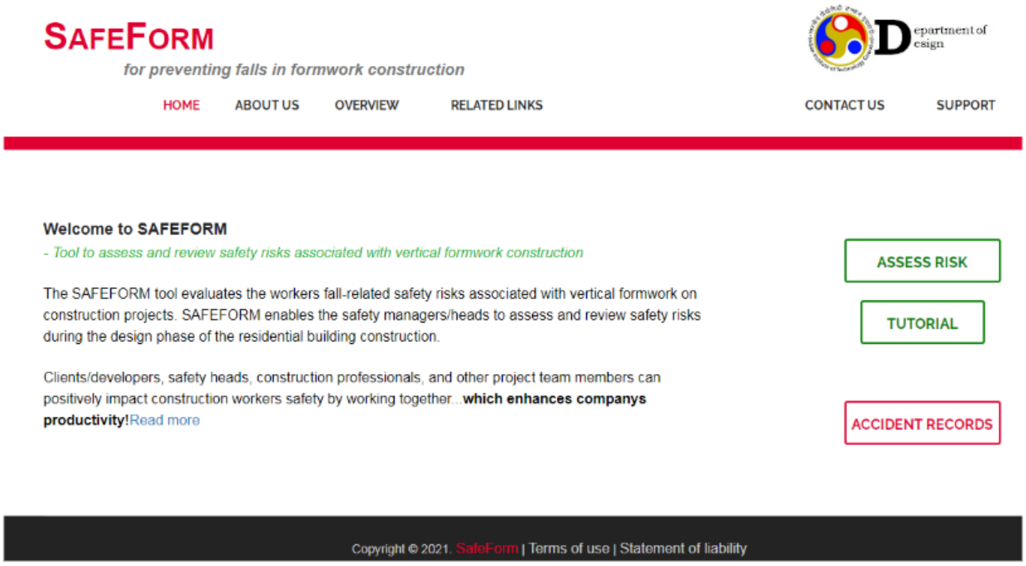


Figure 5.10 Front-end of the knowledge-based system

The user can start performing the fall RA by entering the project details and their mail IDs (see Figure 5.11). Once the users enter the RA page, they can start selecting the trade for which they want to perform fall RA. At this stage, the user can select the activity involved in any trade. For instance, Figures 5.12 and 5.13 shows the vertical formwork activity "panel erection" under the trade "column." Once the activity is selected, the causes of falls/hazards involved will be visualized along with the individuals who might be harmed during that activity. The user has to choose the height of work to be carried out and select the appropriate control measures from the list that will be already visualized in SAFEFORM.

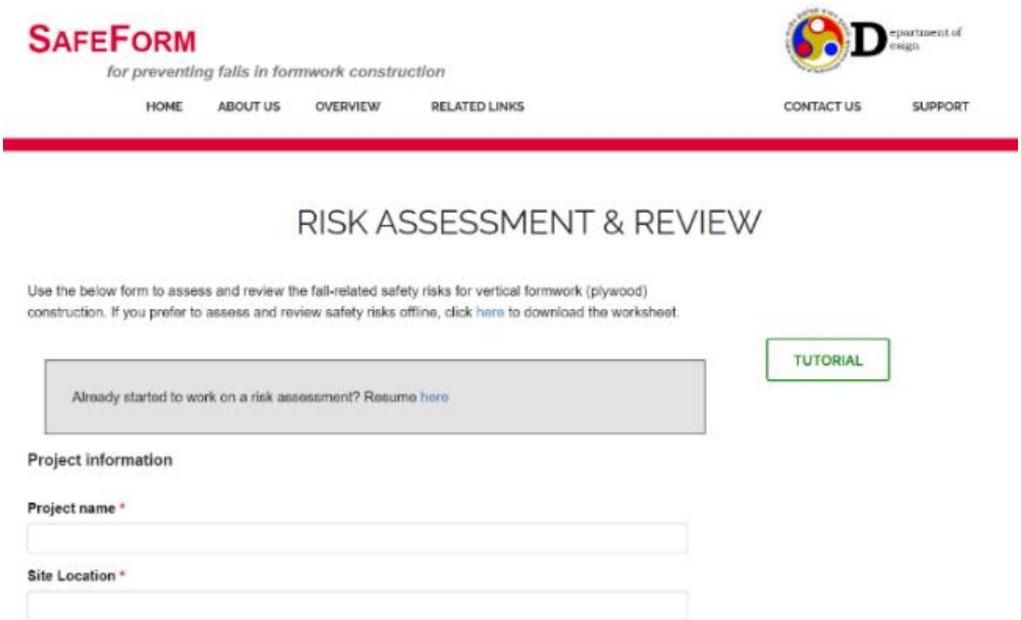


Figure 5.11 The page display of fall risk assessment

Once the user finishes performing RA, the entire result will be displayed on the final page (see Figure 5.14). Here the user can modify the list of activities by adding or rejecting them. The user can finally generate the worksheet and printing option and forward it to the management team for approval.

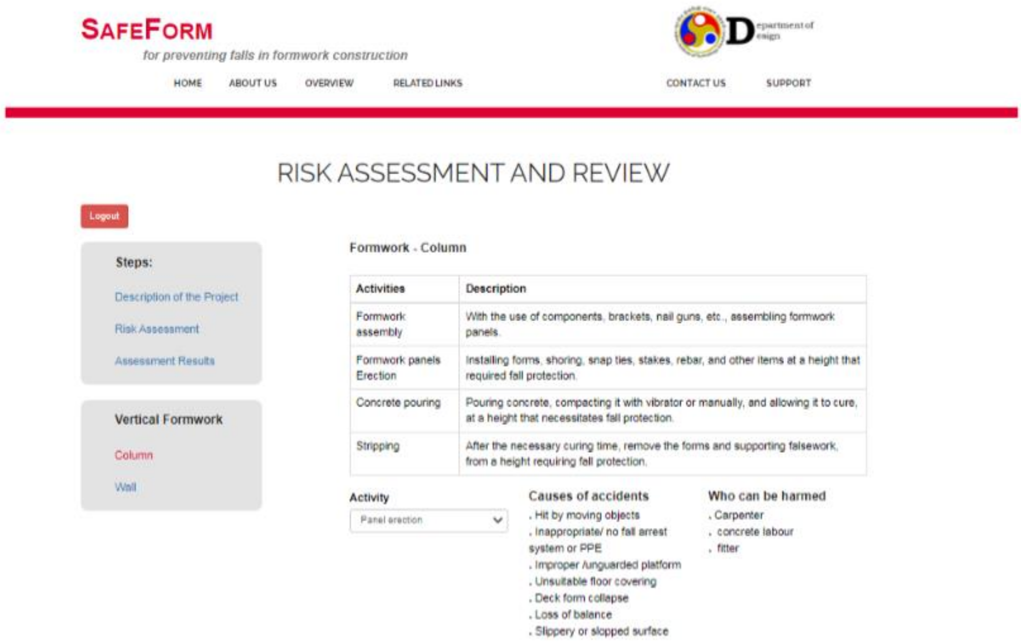


Figure 5.12 The page display of trade (column) for vertical formwork activities

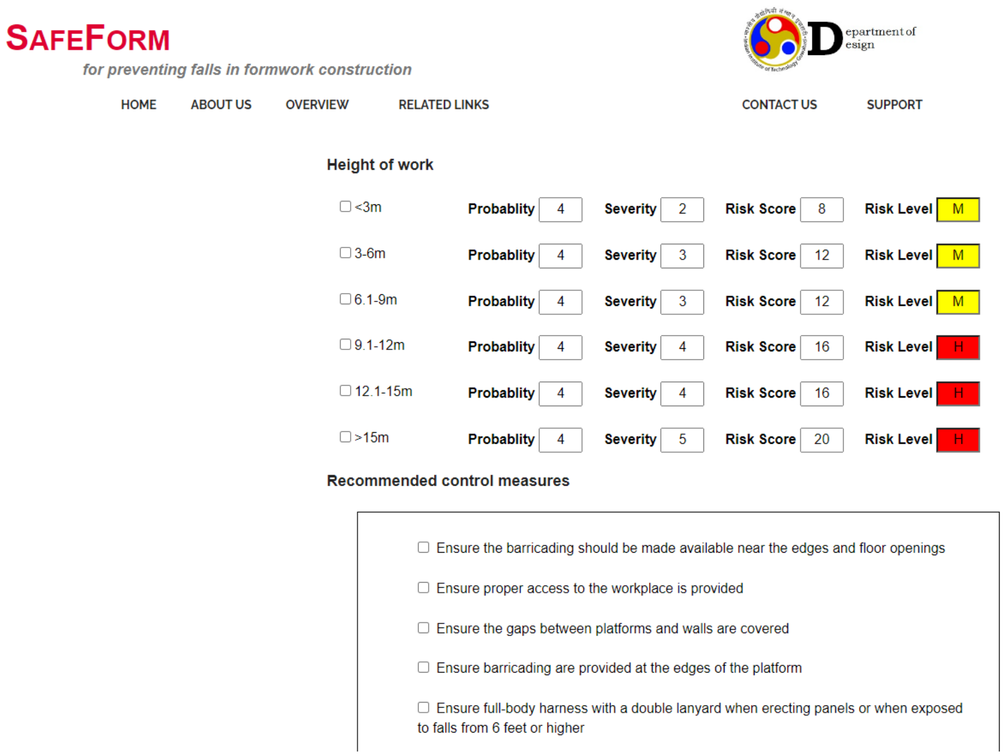
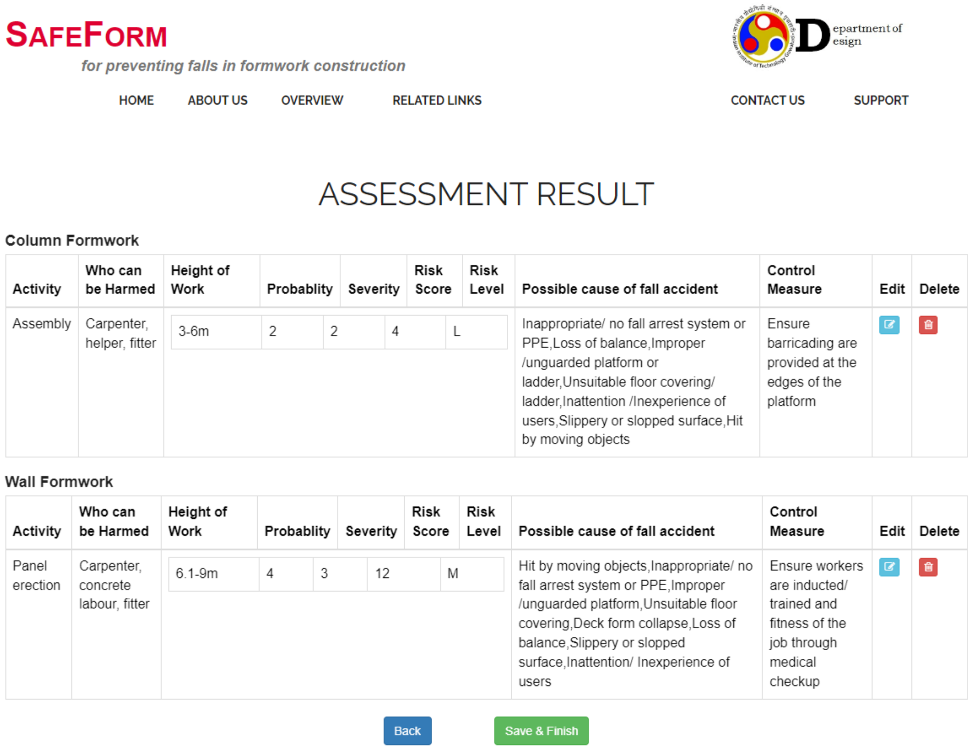


Figure 5.13 The page display of risks scores and control measures for panel erection


SAFEFORM

for preventing falls in formwork construction

HOME ABOUT US OVERVIEW RELATED LINKS CONTACT US SUPPORT

ASSESSMENT RESULT

Column Formwork

Activity	Who can be Harmed	Height of Work	Probablity	Severity	Risk Score	Risk Level	Possible cause of fall accident	Control Measure	Edit	Delete
Assembly	Carpenter, helper, fitter	3-6m	2	2	4	L	Inappropriate/ no fall arrest system or PPE,Loss of balance,Improper /unguarded platform or ladder,Unsuitable floor covering/ ladder,Inattention /Inexperience of users,Slippery or slopped surface,Hit by moving objects	Ensure barricading are provided at the edges of the platform		

Wall Formwork

Activity	Who can be Harmed	Height of Work	Probablity	Severity	Risk Score	Risk Level	Possible cause of fall accident	Control Measure	Edit	Delete
Panel erection	Carpenter, concrete labour, fitter	6.1-9m	4	3	12	M	Hit by moving objects,Inappropriate/ no fall arrest system or PPE,Improper /unguarded platform,Unsuitable floor covering,Deck form collapse,Loss of balance,Slippery or slopped surface,Inattention/ Inexperience of users	Ensure workers are inducted/ trained and fitness of the job through medical checkup		

Back Save & Finish

Figure 5.14 The page display of fall RA results

5.8 Summary

This chapter aimed to design a knowledge-based system to represent safety knowledge for fall RA focused on vertical formwork activities. First, the activities that pose fall risks during formwork operations were identified through observation and surveys. The results indicated that panel assembly, erection, concreting pouring, and stripping are the four activities that pose a risk of falls during vertical formwork operations. Then, the riskiest activities and fall trends in formwork were analyzed using the OSHA database. Followed by the knowledge of formwork for fall RA was captured from construction experts through the Delphi survey. The findings show that panel erection and stripping were the high-risk activities related to falls and in terms of individuals, carpenters and laborers were at high risk of falls. Best safety practices for formwork operations were also captured through thorough document analysis. The captured knowledge was combined for each activity in MS Excel, and a framework was developed to store and re-use the knowledge. Then, based on the framework, a prototype was developed using CMS, and its interface design was evaluated through CW. Based on experts' feedback, the prototype's interface design was improved, and a web-based KM system was developed using PHP language programming. The next chapter discusses the testing and evaluation of the prosed knowledge-based system.

CHAPTER 6

EVALUATION OF KNOWLEDGE-BASED SYSTEM

6.1 Introduction

System evaluation is a crucial step in ensuring the quality of research outcomes. This is often done at the end of the research process. To evaluate the knowledge-based system developed from this research study, a survey was conducted with 20 potential end-users who carry out RA in Indian construction projects. The conclusions of the evaluation of the knowledge-based system established as a result of this study are presented in this chapter. This chapter is categorized into four sections. The second section outlines the research approach utilized for system evaluation, while the third and fourth sections explain the outcomes and chapter summary, respectively.

6.2 Methodology

The research hypothesis was validated after evaluation of a knowledge-based system which was carried out to confirm that the system had fulfilled the defined research objectives. The knowledge-based system evaluation included the following objectives:

- To show that the knowledge-based system's idea and principles may handle the challenges faced by fall RA, as detailed in Chapter 3 of the report.
- To determine the system's utility for its intended users.
- To show how incorporating KM into RA can help to
    - reduce site fall incidents and
    - facilitate on-the-job learning for less-experienced safety professionals
- To get feedback and suggestions for future upgrades and enhancements.

To meet these objectives, a demonstration of a live presentation to potential end-users would benefit the proposed systems' features and functionality. Next, they would be asked to fill out a questionnaire in which they would be able to express their thoughts on various systems aspects. Twenty South Indian construction industry representatives participated in the system evaluation part. According to Cooke et al. (2008) and Kamardeen (2011), 10 to 20 sample sizes would be adequate to evaluate the web-based system. Hence, the researcher believed that a 20-

sample size was adequate to evaluate the proposed knowledge-based system for this study research. It is noteworthy to mention that out of eight individuals who participated during the interview phase, five validated the proposed system.

6.2.1 Questionnaire design

To ensure that the evaluation exercise' objectives stated above are achieved successfully, a questionnaire was designed. There were four sections to the questionnaire (see Annexure VI). The participant's information was gathered in section 1. The effectiveness of the system was evaluated in section 2. System benefits and organizational learning were examined in section 3. Finally, section 4 attempts to evaluate how the proposed knowledge-based system could help address the challenges faced by the users during fall RA. Participants were also allowed to provide additional comments in sections 2–4.

6.3 Results and discussion

Overall, most of the respondents were safety heads (45%), with the remainder being safety managers (30%) and safety officers (25%). Out of 20 respondents, most were undergraduate degree holders (40%), and all respondents' experience in RA ranges from ten to twenty-four. Table 6.1 shows the complete participant's background. The participant's level of safety competency in Table 6.1 indicates that they had sufficient knowledge and expertise to evaluate the proposed system.

Table 6.1 Users characteristics

Study variables	
Highest level of qualification	
Undergraduate degree	9 (45%)
Postgraduate degree	5 (25%)
Diploma	6 (30%)
Work experience (in years)	
Mean (SD)	15.2 (4.2)
Range	10-24
Position at work	
Safety manager	6 (30%)
Safety officer	5 (25%)
Safety head	9 (45%)

Tables 6.2-6.4 illustrate the survey participants' level of agreement with the system on various criteria. The following numerical points were assigned to the rating scales to determine the degree of agreement for each criterion: 1- Agree, 2- Disagree. Subsequently, Krippendorff's

alpha was used to compute the inter-rater reliability among the raters. The results show that the inter-rater reliability among the raters was relatively high (features of SAFEFORM, $\alpha = 0.790$; benefits of SAFEFORM, $\alpha = 0.802$; challenges addressed by SAFEFORM, $\alpha = 0.855$), according to Krippendorff (2011). The following are the results for the various sections of the questionnaire:

6.3.1 Knowledge-based systems' functional features

The participants' level of agreement with the effectiveness of the SAFEFORM is shown in Table 6.2. Three participants disagreed with variables number two and six. They mentioned that although the system provides possible control measures, it can suggest which measures should be mandatory for a particular risk. And for variable six, participants mentioned that based on the nature of the construction site, the causes of falls are not updatable, and the system cannot help reduce the accidents significantly. Five participants disagreed with variables number three and six. Regarding variable three, participants pointed out that the system did not illustrate enough practices and could be useful if such practices target Indian construction. However, the agreement level for all the variables was more than or equal to 75%, showing that the proposed knowledge-based system is an effective fall RA method.

Table 6.2 SAFEFORM effectiveness

S.No	Functional features of SAFEFORM	Agree (%)	Disagree (%)
1.	To assist fall RA, SAFEFORM is an excellent way to emphasize the causes of falls and activity risks involved in vertical formwork.	100	0
2.	SAFEFORM is an effective tool for describing appropriate control measures.	85	15
3.	The system that has been presented is an effective way of recommending the best safety practices.	75	25
4.	The strategy described is a useful and instructive tool for the RA process.	100	0
5.	SAFEFORM has the potential to reduce the number of falls that occur.	100	0
6.	If the SAFEFORM system is expanded to include safety knowledge regarding the causes of falls, risks, and best practices for vertical formwork in construction, it could drastically reduce on-site fall accidents.	85	15

6.3.2 Knowledge-based system benefits

Table 6.3 shows the participants' level of agreement with the benefits of the SAFEFORM. In this section, the fourth variable was contested by three participants. According to the explanation, "construction practitioners always prefer paper-based offices and chances of rejecting computer-based work." However, 86 percent of those polled thought the idea was sound. Another participant disagreed that the web-based solution would increase on-site safety performance. It mentions that the system is not industry-enforced, although it demonstrates risks and directions to use them. Senior management should require its application on the job to gain the system's benefits. The remaining participants, on the other hand, believe that the suggested technique has the potential to improve site safety performance.

Table 6.3 SAFEFORM benefits

S.No	Benefits of SAFEFORM	Agree (%)	Disagree (%)
1.	SAFEFORM summarizes safety knowledge from different sources (causes of falls, the population may be harmed, formwork guidelines, safety practices, etc.) and stores it in a central location in simple and easy-to-understand formats.	100	0
2.	SAFEFORM could make safety knowledge related to vertical formwork readily available and affordable to users at any site location.	100	0
3.	SAFEFORM has the potential to reduce the amount of time spent on RA.	100	0
4.	SAFEFORM does not require any prior training or software abilities, but it does require a basic understanding of how to use web browsers.	85	15
5.	Overall, SAFEFORM could be a useful tool for sharing safety knowledge.	100	0
6.	Overall, SAFEFORM might be a good method to make the RA process easier for safety heads in the workplace.	100	0
7.	Overall, SAFEFORM could help improve safety performance	95	5

6.3.3 Challenges addressed by the knowledge-based system

The participants' level of agreement with the challenges addressed by SAFEFORM is shown in Table 6.4. Variable number two was contested by two participants. The reason was that although the system visualizes the safety knowledge needed for fall RA, it restricts them from using only available safety knowledge in the system. Four participants disagreed with variable six, stating that the new knowledge related to activity cannot be updated. All participants agreed that the proposed system was understandable and could reduce the time of work that they spent on the RA process. Also, all participants agreed that the system provides the list of activities involved in formwork operations and assists users in developing an effective fall prevention plan by assessing the risks involved in each associated activity.

Table 6.4 Challenges addressed by SAFEFORM

S.No	Challenges addressed	Agree (%)	Disagree (%)
1.	SAFEFORM could help safety heads and safety teams to develop better fall prevention plans	100	0
2.	SAFEFORM could provide safety managers with the skills they need to conduct effective RA.	90	10
3.	SAFEFORM summarizes safety knowledge related to vertical formwork from experts, as well as various guidelines, and literature, and makes it simple for safety heads to understand and apply, despite their tight schedules and work pressures.	100	0
4.	The scoring system for RA in SAFEFORM is understandable and easy to use	100	0
5.	SAFEFORM provides a list of activities involved in vertical formwork which could enhance the users to evaluate risks associated with them	100	0
6.	SAFEFORM could provide a standardized method for managing safety knowledge related to RA	75	25

6.4 Summary

Evaluation of the final knowledge-based system was conducted through a survey with 20 potential end-users who had experience in RA in Indian construction projects. The respondents were asked to rate the system based on three criteria: features, benefits, and challenges, using dichotomous variables. The statistical analysis of the responses revealed that the raters' inter-reliability was rather high. Based on the findings, it can be determined that the proposed system offers numerous benefits to builders in (1) ensuring that end-users, regardless of their site location, have easy access to vertical formwork safety knowledge; (2) helping users with job site learning of safety RA skills; (3) effectively sharing safety knowledge; (4) facilitating the fall RA process on-the-job for safety heads; (5) helping to improve safety performance; (6) saving time that is spent on RA, and (7) assisting in developing better fall prevention plans.

CHAPTER 7

OVERALL SUMMARY AND CONCLUSION

7.1 Summary

This research aimed to develop a knowledge-based system to facilitate the fall RA for vertical formwork in Indian construction projects. The factors influencing FFH in construction and the potential impact of KM on the construction industry were identified from the literature for this research work. A mixed-method approach was adopted, and the data collection and analysis were carried out in different stages to accomplish the research objectives. First, to identify the safety KM strategies employed in construction companies during the fall RA process for fall prevention, eight interviews were conducted and analyzed through a coding procedure in ATLAS.ti. To achieve the second objective, interviews and surveys were adopted. The data that emerged through the interviews were analyzed through the coding procedure in ATLAS.ti. The data collected through surveys were analyzed using mean statistics. Next, to develop a knowledge-based system, the activities that pose fall risks during formwork operations were identified through observation and nine surveys with construction practitioners. Then, the riskiest activities and fall trends in formwork were analyzed using the OSHA database. Followed by the knowledge of formwork for fall RA was captured from 13 construction experts through the Delphi survey. Best safety practices for formwork operations were also captured through thorough document analysis. Then, based on the framework, a prototype was developed using CMS, and its interface design was evaluated through CW with five experts from different backgrounds. Based on their feedback, the interface design of the prototype was improved, and a web-based KM system was developed using PHP language programming. Then, to accomplish the last objective, the evaluation exercise was conducted through a survey with 20 potential end-users with experience in construction safety. The data were analyzed using mean statistics.

7.2 Major findings

In the development of the knowledge-based system, four research objectives were achieved. The following are the key conclusions drawn from each objective:

- Although many researchers have discussed the importance of incorporating KM into safety planning, the KM strategies in the RA process were uncharted. Hence, the first attempt made in this research work was to understand how such KM strategies are employed in Indian construction companies during the RA process for fall prevention. The trends observed in this study indicated an inadequacy of safety KM within companies, particularly a systematic way of managing safety knowledge, especially tacit knowledge. However, there are efforts from some companies to capture tacit knowledge and acceptable safety practices.

- Various researchers developed the KM system to facilitate the process of OHS planning; however, such approaches did not target the real-life challenges that safety heads/managers face during fall RA in construction. Hence, the second objective was designed to understand users' challenges during the fall RA process and to gather their requirements to address those challenges. It was evident from the research study that identifying significant hazards and steps involved in activities is the major challenge users face during RA. Safety professionals face such challenges as they do not have experience handling construction activities. Therefore, the safety knowledge of practitioners involved in construction activities is needed to address these challenges. The users suggested that sufficient technical details such as a list of activities, a list of causes of accidents, control measures, safety guidelines, past accident records, and safety practices-case studies could facilitate the RA process. Moreover, some users are looking for a platform where they can access data related to RA.

- The third objective was to develop a knowledge-based system to address these challenges by capturing the safety knowledge of vertical formwork from construction experts for fall RA. First, the activities that pose fall risks during formwork operations were identified, i.e., assembly, erection, concrete pouring, and stripping. Then, the knowledge of formwork for fall RA, i.e., activity-based fall risk levels, hazards/causes of fall, individuals at risk, and control measures, were captured from construction experts. The findings indicated that panel erection and stripping are the high-risk activities related to falls and in terms of individuals, carpenters and laborers were at high risk of falls. This was validated by comparing with secondary data gathered from the OSHA database. The captured knowledge was combined for each activity in MS Excel, and a framework was developed to store and re-use the knowledge. Then, using CMS, a prototype was developed based on the framework, and the interface design issues were improved based on expert feedback. Finally, using PHP language programming, a web-based KM system was developed.

- The research study validated the knowledge-based system based on benefits, features, and challenges. Overall findings indicated that the proposed system could enhance fall prevention by facilitating fall RA for vertical formwork in Indian construction.

7.3 Limitations and future scope

This study includes several limitations. First, the proposed system focused on traditional vertical formwork (i.e., plywood) in the context of residential building projects in India. Second, the study targets fall risk activities involved in vertical formwork in construction, and the study findings focused on the RA process to prevent them in Indian construction projects. Next, the proposed system focused only on the end-users, i.e., safety heads/managers of construction projects involved in the RA process. Finally, the safety knowledge of vertical formwork activities represented in the proposed system was designed in a static way

Although this research work developed a knowledge-based system for preventing falls in Indian construction organizations, it could be applied in a similar context in other countries to increase its usefulness and enhance the performance of overall construction safety worldwide. Also, safety knowledge of other formwork activities, such as slab or beam focusing on FFH and other formwork materials, including aluminum and steel, could be incorporated into this system to develop a systematic RA tool for formwork operations targeting falls in construction. Such a system should be evaluated against the real-life environment to enhance the overall safety performance of formwork operations in India and other countries with similar environment.

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ANNEXURE I

SEMI-STRUCTURED INTERVIEWS

Safety KM strategies followed in construction firms to prevent fall injuries/accidents during fall risk assessment

General information

1. Tell us your name, your role in this company, and how long you have been working in this company.
2. What are the sectors being serviced by your company and tell me the location of your company headquarters?
3. What is your company size?

Strategies employed for fall prevention

1. Elaborate on the process that you carry out to conduct a fall risk assessment in detail.
2. How do you identify hazards/causes of falls? What sources do you use to identify hazards? Explain in detail.
3. How do you assess potential risks? Explain in detail.
4. How do you choose control measures? Explain in detail.
5. Will you get advice/suggestions from other practitioners while conducting risk assessment? If yes, then during which part?
6. How do you store safety knowledge related to fall risk assessment?
7. What strategies are being followed to disseminate the stored knowledge?

ANNEXURE II

SEMI-STRUCTURED INTERVIEWS

Challenges that user faces and their opinions to enhance the process of fall RA in construction

1. Tell us your name, your role in this company, and how long you have been working in this company.
2. What are the sectors being serviced by your company and tell me the location of your company headquarters?
3. What is your company size?
4. Why sometimes do safety professionals (users) develop ineffective fall risk assessments?
5. What are the challenges that you face during fall risk assessment? Explain in detail.
6. What you don’t like about current strategies followed by your company during fall risk assessment?
7. Previous project documents are sufficient for conducting RA. Are you agree with this statement? If no, then why?
8. How to enhance the entire fall risk assessment process? What are your requirements? Explain in detail.
9. Your any other thoughts on the fall risk assessment process. If any.

ANNEXURE III

WEB-SURVEY TEMPLATE

Fall risk assessment in construction: Challenges and User Requirements

Dear safety professionals,

I am Mr. C. Vigneshkumar, a research scholar working under the supervision of Dr. Urmi R. Salve in the Department of Design, Indian Institute of Technology Guwahati, Assam, India. We are researching understanding the challenges in fall risk assessment fall (RA) and user (safety professionals) requirements to enhance the fall (RA) process towards preventing construction accidents in India. We would greatly appreciate it if you could share your thoughts by answering the questions below. We estimate that it will take you about 10 minutes to finish the survey. Your responses will be kept confidential; the information will only be used for aggregated statistical analysis and will not be shared with anyone outside the study team.

If you have any questions about this study, please contact C. Vigneshkumar, DoD, Indian Institute of Technology Guwahati, Surjyamukhi Road, North, Amingaon, Guwahati, Assam 781039 (Tel.: +91-9600878893)

Thank you so much for taking the time to take part in this vital research.

Sincerely,

C. Vigneshkumar

Research Scholar, Department of Design

Are you engaged and experienced in fall RA during the pre-construction stage? If yes, please fill out this form. Others may ignore it.

1. Designation:
2. Higher level of qualification:
3. Experience in the Construction Industry:
4. What are the most important tasks you need to perform in fall RA?

- ☐ Identifying hazards/causes of fall
- ☐ Evaluating risks
- ☐ Choosing control measures
- ☐ Implementation and review records
- ☐ All of the above

5. Listed below are some of the challenges in fall RA. Rate through 1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5-strongly agree with scale.

Challenges	1	2	3	4	5
Identifying the steps involved in each activity					
Identifying significant hazards					
Risk evaluation and scoring					
Selecting control measures					
Insufficient time to conduct					
Working with insufficient data					

6. Listed below are the strategies to enhance fall RA. Rate through 1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5-strongly agree with scale.

User requirements	1	2	3	4	5
List of activities					
Other team members' involvement					
List of causes of accidents					
System to access/share safety knowledge					
Safety guidelines					
Past accidents records					
Safety practices-case studies					
Simple scoring system					
List of control measures					

ANNEXURE IV

WEB-BASED DELPHI SURVEY TEMPLATE

Capturing the safety knowledge of vertical formwork for fall risk assessment

Round 1

Section 1: General information

1. Age:
2. Highest Technical Degree:
3. Designation:
4. Year of professional experience:
5. Professional registration (e.g., Licensed Architect (LA), Professional Engineer (PE), Safety Expert (SE)):
6. Author of the book(s) (if yes, mention how many):
7. Author of the article(s) in reputed Journals (if yes, mention how many):
8. Conference presentation, If any:
9. A faculty member at an accredited university:
10. Member of a committee:
11. Chair of a committee:

Section 2: Safety knowledge of vertical formwork construction

Riskiest activities posed to fall during vertical formwork operations (the listed activities were validated through construction experts)

Activity name	**Description**
Assembly	Assembling the formwork panels using brackets, nail guns, etc.
Erection	Installation of forms at a height that required fall protection
Concrete pouring	Pouring concrete, compacting it manually or with vibrator
Stripping	After curing of concrete, remove the forms and supporting falsework

12. Among these, which activity has more risks of falls?
13. List out the causes of falls for each activity.
14. List out the individuals who might be at fall risk during each activity operation.

Round 2

Below are the listed causes of falls during formwork operations indicated by experts in the first round of the survey. According to you list out the causes of falls that should be retained.

Activity	Causes of fall	Retain	
		Yes	No
Assembly	Improper /unguarded edges/platform		
	Inappropriate/ no fall arrest system or PPE		
	Unsuitable ladder		
	Inattention /Inexperience of users		
	Loss of balance		
	Slippery or slopped surface		
	Hit by moving objects		
Erection	Hit by moving objects		
	Inappropriate/ no fall arrest system or PPE		
	Improper /unguarded edges/platform		
	Unsuitable floor covering		
	Loss of balance		
	Slippery or slopped surface		
	Inattention/Inexperience of users		
Concrete pouring	Improper /Unguarded edges/platform		
	Hit by moving objects		
	Inattention/ Inexperience of users		
	Loss of balance		
	Unsuitable floor covering		
	Inappropriate/ no fall arrest system or PPE		
	Slippery or slopped surface		
Stripping	Inappropriate/ no fall arrest system or PPE		
	Unsuitable ladder		
	Improper /Unguarded edges/platform		
	Slippery or slopped surface		
	Loss of balance		
	Hit by moving objects		
	Inattention/Inexperience of users		
	Unsuitable floor covering		

Below are the listed individuals who might be at risk of falls as indicated by experts in the first round of the survey. According to you who should be retained for each activity.

Activity	Population at risk	Retain	
		Yes	No
Assembly	Carpenter		
	Helper		
	Fitter		
Erection	Carpenter		

	Fitter		
	Labor		
Concrete pouring	Labor		
	Finisher		
	Supervisor		
Stripping	Carpenter		
	Labor		
	Supervisor		

Round 3

Listed below are the activities that pose fall risks during formwork operations. For the "Injury Severity Level" and "Injury probability Level" fields, using your experience and judgment, indicate, for a single worker or work crew, "how frequently an injury occurs and how much severe it would be while performing each construction activity" using the following frequency scales. Please note, that the severity rating should be given based on working height.

Severity level	Description	Score
Very low	No health effect or injury or damage. No impact on work time	1
Low	Temporary discomfort or minor first aid is required. A worker can return to work within one day	2
Medium	Minor health effects. A worker could return within three days	3
High	Major first aid is required. A worker could not return within three days	4
Severe	Fatal or permanent disablement. A worker could not return to work	5

Probability level	Description	Score
Rare	Only in exceptional situations	1
Unlikely	Could occur at some future time	2
Possible	It might happen at some point	3
Likely	Probably occur in most circumstances	4
Almost certain	Expected in normal circumstances	5

Activity	Probability	Working height	Severity
Assembly		<3 m	
		3.1-6.1 m	
		6.2-9.1 m	
		9.2-12.1 m	
		12.2-15m	
		>15m	
Erection		<3 m	
		3.1-6.1 m	

		6.2-9.1 m	
		9.2-12.1 m	
		12.2-15m	
		>15m	
Concrete pouring		<3 m	
		3.1-6.1 m	
		6.2-9.1 m	
		9.2-12.1 m	
		12.2-15m	
		>15m	
Stripping		<3 m	
		3.1-6.1 m	
		6.2-9.1 m	
		9.2-12.1 m	
		12.2-15m	
		>15m	

Round 4

Riskiest activities posed to fall during vertical formwork operations (the listed activities were validated through construction experts)

Activity name	**Description**
Assembly	Assembling the formwork panels using brackets, nail guns, etc.
Erection	Installation of forms at a height that required fall protection
Concrete pouring	Pouring concrete, compacting it manually or with vibrator
Stripping	After curing of concrete, remove the forms and supporting falsework

Indicate the fall preventive measures for each activity to prevent falls during formwork operations:

ANNEXURE V

DELPHI VALIDATION SURVEY TEMPLATE

Validating the captured safety knowledge of vertical formwork for fall risk assessment

Section 1: General information

Age:

Highest Technical Degree:

Designation:

Year of professional experience:

Professional registration (e.g., Licensed Architect (LA), Professional Engineer (PE), Safety Expert (SE)):

Author of the book(s) (if yes, mention how many):

Author of the article(s) in reputed Journals (if yes, mention how many):

Conference presentation, If any:

A faculty member at an accredited university:

Member of a committee:

Chair of a committee:

Riskiest activities posed to fall during vertical formwork operations (the listed activities were validated through construction experts)

Activity name	**Description**
Assembly	Assembling the formwork panels using brackets, nail guns, etc.
Erection	Installation of forms at a height that required fall protection
Concrete pouring	Pouring concrete, compacting it manually or with vibrator
Stripping	After curing of concrete, remove the forms and supporting falsework

Below are the listed causes of falls during formwork operations indicated by experts. Are you agree with the list? If you find any missed causes, please indicate……….

Activity	Causes of fall	Confirmation	
		Yes	No
Assembly	Improper /unguarded edges/platform		
	Inappropriate/ no fall arrest system or PPE		
	Unsuitable ladder		
	Inattention /Inexperience of users		

	Loss of balance		
	Slippery or slopped surface		
	Hit by moving objects		
Erection	Hit by moving objects		
	Inappropriate/ no fall arrest system or PPE		
	Improper /unguarded edges/platform		
	Unsuitable floor covering		
	Loss of balance		
	Slippery or slopped surface		
	Inattention/Inexperience of users		
Concrete pouring	Improper /Unguarded edges/platform		
	Hit by moving objects		
	Inattention/ Inexperience of users		
	Loss of balance		
	Unsuitable floor covering		
	Inappropriate/ no fall arrest system or PPE		
	Slippery or slopped surface		
Stripping	Inappropriate/ no fall arrest system or PPE		
	Unsuitable ladder		
	Improper /Unguarded edges/platform		
	Slippery or slopped surface		
	Loss of balance		
	Hit by moving objects		
	Inattention/Inexperience of users		
	Unsuitable floor covering		

Below are the listed individuals who might be at risk of falls as indicated by experts. Are you agree with the list? If you find any missed individuals, please indicate……….

Activity	Population at risk	Confirmation	
		Yes	No
Assembly	Carpenter		
	Helper		
	Fitter		
Erection	Carpenter		
	Fitter		
	Labor		
Concrete pouring	Labor		
	Finisher		
	Supervisor		
Stripping	Carpenter		
	Labor		
	Supervisor		

Listed below are the activities that pose fall risks during formwork operations. For the "Injury Severity Level" and "Injury probability Level" fields, using your experience and judgment, indicate, for a single worker or work crew, "how frequently an injury occurs and how much severe it would be while performing each construction activity" using the following frequency scales. Please note, that the severity rating should be given based on working height.

Severity level	Description	Score
Very low	No health effect or injury or damage. No impact on work time	1
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Severe	Fatal or permanent disablement. A worker could not return to work	5

Probability level	Description	Score
Rare	Only in exceptional situations	1
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Activity	Probability	Working height	Severity
Assembly		<3 m	
		3.1-6.1 m	
		6.2-9.1 m	
		9.2-12.1 m	
		12.2-15m	
		>15m	
Erection		<3 m	
		3.1-6.1 m	
		6.2-9.1 m	
		9.2-12.1 m	
		12.2-15m	
		>15m	
Concrete pouring		<3 m	
		3.1-6.1 m	
		6.2-9.1 m	
		9.2-12.1 m	
		12.2-15m	
		>15m	
Stripping		<3 m	
		3.1-6.1 m	

		6.2-9.1 m	
		9.2-12.1 m	
		12.2-15m	
		>15m	

Indicate the fall preventive measures for each activity to prevent falls during formwork operations:

ANNEXURE VI

SYSTEM VALIDATION SURVEY TEMPLATE

Section 1: Participants' information

Educational background:

Experience in construction safety:

Section 2: Effectiveness of the system

Listed below are statements about the effectiveness of the system. Rate through 1-Agree or 2-Disagree.

S.No	Functional features of SAFEFORM	Agree	Disagree
1.	To assist fall RA, SAFEFORM is an excellent way to emphasize the causes of falls and activity risks involved in vertical formwork.		
2.	SAFEFORM is an effective tool for describing appropriate control measures.		
3.	The system that has been presented is an effective way of recommending the best safety practices.		
4.	The strategy described is a useful and instructive tool for the RA process.		
5.	SAFEFORM has the potential to reduce the number of falls that occur.		
6.	If the SAFEFORM system is expanded to include safety knowledge regarding the causes of falls, risks, and best practices for vertical formwork in construction, it could drastically reduce on-site fall accidents.		

Do you have any comments about its effectiveness? If yes, mention……………

Section 3: System benefits

Listed below are statements about the benefits of the system. Rate through 1-Agree or 2-Disagree.

S.No	Benefits of SAFEFORM	Agree	Disagree
1.	SAFEFORM summarizes safety knowledge from different sources (causes of falls, the population may be harmed, formwork guidelines, safety practices, etc.), and stores it in a central location in formats that are simple to understand and use.		
2.	SAFEFORM could make safety knowledge related to vertical formwork readily available and affordable to users at any site location.		

3.	SAFEFORM has the potential to reduce the amount of time spent on RA.		
4.	SAFEFORM does not require any prior training or software abilities, but it does require a basic understanding of how to use web browsers.		
5.	Overall, SAFEFORM could be a useful tool for sharing safety knowledge.		
6.	Overall, SAFEFORM might be a good method to make the RA process easier for safety heads in the workplace.		
7.	Overall, SAFEFORM could help improve safety performance		

Do you have any comments about its benefits? If yes, mention……………

Section 4: Challenges addressed by the system

S.No	Challenges addressed	Agree (%)	Disagree (%)
1.	SAFEFORM could help safety heads and safety teams to develop better fall prevention plans		
2.	SAFEFORM could provide safety managers with the skills they need to conduct effective RA.		
3.	SAFEFORM summarizes safety knowledge related to vertical formwork from experts, as well as various guidelines, and literature, and makes it simple for safety heads to understand and apply, despite their tight schedules and work pressures.		
4.	The scoring system for RA in SAFEFORM is understandable and easy to use		
5.	SAFEFORM provides a list of activities involved in vertical formwork which could enhance the users to evaluate risks associated with them		
6.	SAFEFORM could provide a standardized method for managing safety knowledge related to RA		

Do you have any comments about the challenges addressed? If yes, mention……………

ANNUXURE VII

DELPHI RESULS

Fall preventive measures for vertical formwork activities

Assembly	• Ensure ladders are set up according to manufacturer's instructions and that they are on level stable ground • Ensure full-body harness when bolting panels or when exposed to falls from 6 feet or higher • Ensure proper anchorage point for fixing of safety harness • Ensure proper illumination if work carried out at night • Ensure the barricading should be made available near the edges and floor openings • Ensure only authorized personnel in the stripping area • Ensure workers are provided with proper PPE
Erection	• Ensure the barricading should be made available near the edges and floor openings • Ensure proper access to the workplace is provided • Ensure the gaps between platforms and walls are covered • Ensure barricading are provided at the edges of the platform • Ensure full-body harness with a double lanyard when erecting panels or when exposed to falls from 6 feet or higher • Ensure proper anchorage point for fixing of safety harness • Ensure the working platform are made as per the methodology • Ensure the unwanted materials are kept away from the edge of the platform • Ensure the safety screens are provided at the bottom level from the place of working • Ensure proper illumination if work carried out at night • Ensure only authorized personnel in the erection area • Ensure close supervision should be deployed during panel erection • Ensure workers are permitted to work at height before starting the task • Ensure workers are inducted, trained, and fitness of the job through medical checkup • Ensure the platform with adequate space for working • Ensure workers are provided with proper PPE
Pouring	• Ensure the formwork system advice and pour methods • Ensure close supervision should be deployed while concrete pouring • Ensure the barricading should be made available near the edges and floor openings • Ensure proper access to the workplace is provided • Ensure the gaps between platforms and walls are covered • Ensure barricading are provided at the edges of the platform • Ensure full-body harness with a double lanyard when erecting panels or when exposed to falls from 6 feet or higher • Ensure proper anchorage point for fixing of safety harness • Ensure the working platform are made as per the methodology • Ensure the safety screens are provided at the bottom level from the place of working

	• Ensure proper illumination if work carried out at night • Ensure workers are provided with appropriate PPE • Ensure workers are permitted to work at height before starting the task • Ensure workers are inducted, trained, and fitness of the job through medical checkup • Ensure the platform with adequate space for working • Ensure concrete and loose materials are cleared
Stripping	• Ensure the barricading should be made available near the edges and floor openings • Ensure proper access to the workplace is provided • Ensure the gaps between platforms and walls are covered • Ensure barricading are provided at the edges of the platform • Ensure full-body harness with a double lanyard when erecting panels or when exposed to falls from 6 feet or higher • Ensure proper anchorage point for fixing of safety harness • Ensure the working platform are made as per the methodology • Ensure the unwanted materials are kept away from the edge of the platform • Ensure the safety screens are provided at the bottom level from the place of working • Ensure proper illumination if work carried out at night • Ensure close supervision should be deployed during panel stripping • Ensure workers are permitted to work at height before starting the task • Ensure workers are inducted, trained, and fitness of the job through medical checkup • Ensure the platform with adequate space for working • Ensure workers are provided with proper PPE • Ensure concrete and loose materials are cleared • Ensure ladders are set up according to manufacturer's instructions and that they are on level stable ground

APPENDIX

PUBLICATIONS

Journal papers - published and in press

- Vigneshkumar, C., & Salve, U. R. Exploring barriers to effective safety risk assessment in Indian construction projects, *Proceedings of the Institution of Civil Engineers – Management, Procurement and Law,* ahead of print. *https://doi.org/10.1680/jmapl.22.00053*
- Vigneshkumar, C., & Salve, U. R. (2022). Safety knowledge management practices in Indian construction, *Journal of Information and Knowledge Management*, 21(4), 2250049. https://doi.org/10.1142/S0219649222500496
- Chellappa, V., & Salve, U. R. (2022). Analysis of workers' fall accidents due to formwork operations. *Proceedings of the Institution of Civil Engineers - Forensic Engineering, 175*(1), 1–6. https://doi.org/10.1680/jfoen.21.00006
- Chellappa, V., Srivastava, V., & Salve, U. R. (2021). A systematic review of construction workers' health and safety research in India, *Journal of Engineering, Design and Technology, 19(6),* 1488-1504. https://doi.org/10.1108/JEDT-08-2020-0345
- Chellappa, V., Salve, U. R., Li, R. Y. M., & Liias, R. (2020). A knowledge-based approach for enhancing fall prevention in the construction industry. *Journal of Statistics and Management Systems*, *23*(2), 373–378. https://doi.org/10.1080/09720510.2020.1736320
- Vigneshkumar, C., & Ravindra Salve, U. (2020). A scientometric analysis and review of fall from height research in construction. *Construction Economics and Building*, *20*(1). https://doi.org/10.5130/ajceb.v20i1.6802

Journal papers – under review

- Vigneshkumar, C., & Salve, U. R. Fall risk assessment for vertical formwork construction, *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, ASCE Publication, USA (second revision (minor); IF: 3.084).
- Vigneshkumar, C., & Salve, U. R. Safety knowledge management in the Indian construction projects focusing on Fall Risk Assessment, *Knowledge and Process Management,* Wiley Publication, USA.
- Vigneshkumar, C., & Salve, U. R. Safety knowledge-based system to assess fall risk for vertical formwork construction, *KSCE Journal of Civil Engineering*, Springer, Korea.

Conference papers published

- Chellappa, V., & Salve, U. (2021). Designing a Knowledge-based Safety Risk Assessment System for Vertical Formwork Construction. in *XXXIIIrd Annual International Occupational Ergonomics and Safety Conference*, Virtual. pp 91-97. https://doi.org/10.47461/isoes.2021_091.

- Chellappa, V., & Ravindra Salve, U. (2021). Understanding the fall-related safety issues in concrete formwork. *E3S Web of Conferences*, *263*, 02007. https://doi.org/10.1051/e3sconf/202126302007
- Vigneshkumar, C., Li, R. L. M., Liias, R., & Salve, U. (2019). Developing a database to capture, store and share fall-related safety knowledge to enhance fall prevention in construction industry. in *proceedings of the 19th International Conference on Construction Applications of Virtual Reality (CONVR2019),* Bangkok, Thailand, pp. 152-159.

Papers published in book chapters

- Vigneshkumar, C., Salve, U.R. (2022). End-Users' Opinions to Enhance the Process of Hazard Identification and Risk Assessment (HIRA) in Construction Projects. In: Ginzburg, A., Galina, K. (eds) Building Life-cycle Management. Information Systems and Technologies. Lecture Notes in Civil Engineering, vol 231. Springer, Cham. https://doi.org/10.1007/978-3-030-96206-7_48.
- Vigneshkumar, C., Salve, U.R. (2022). *SAFEFORM:* A Prototype of Safety Knowledge Management for the Construction Companies. In: Ginzburg, A., Galina, K. (eds) Building Life-cycle Management. Information Systems and Technologies. Lecture Notes in Civil Engineering, vol 231. Springer, Cham. https://doi.org/10.1007/978-3-030-96206-7_29.
- Vigneshkumar, C., Salve, U.R. (2022). Science Mapping to Visualize the Factors Influencing Workers' Fall from Height in Construction Projects. In: Chakrabarti, D., Karmakar, S., Salve, U.R. (eds) Ergonomics for Design and Innovation. HWWE 2021. Lecture Notes in Networks and Systems, vol 391. Springer, Cham. https://doi.org/10.1007/978-3-030-94277-9_35.