CONSTRUCTION RISK MANAGEMENT THROUGH PREVENTIVE SAFETY TOOL: A COMPARATIVE ANALYSIS OF REGULATORY FRAMEWORKS AND TRENDS

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APRIL 2026

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A research project submitted in partial fulfilment of the requirement for the degree of

Master of Real Estate Development

Universiti Tunku Abdul Rahman

Faculty of Accountancy and Management

April 2026

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DECLARATION

I hereby declare that:

(1) This Research Project is the end result of my own work and that due acknowledgement has been given in the references to all sources of information be they printed, electronic, or personal.

(2) No portion of this research project has been submitted in support of any application for any other degree or qualification of this or any other university, or other institutes of learning.

(3) The word count of this research report is **18,593.**

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ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor, Dr. Goh Hong Lip, for his invaluable guidance, insightful ideas and continuous support. His expertise and encouragement have significantly contributed to the successful completion of this research.

I am also deeply thankful to my family members namely Azrain, Hariss and Sabrina for their unwavering support, patience and understanding throughout my journey in completing the Master in Real Estate Development programme. Their encouragement has been a constant source of strength.

This work is dedicated to my mother, Rokiah and my late father, Zainudin, whose belief in perseverance and self-confidence has inspired me to pursue and achieve my goals. They have shown me that with belief in oneself, anything is possible.

Finally, to Nadi Emily, I hope this achievement serves as a motivation for you to continuously strive towards your dreams, remembering always that the sky is the limit.

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LIST OF ABBREVIATION

BIM	Building Information Modelling
CBRisk	Case-based Reasoning System
CDM	Construction Design Management
CSV	Comma-Separated Values
DfS	Design for Safety
DRA	Design Review Assessment
DOI	Digital Object Identifier
DOSH	Department of Occupational Safety and Health
GISAT	Graphical Inherent Safety Assessment Technique
HIRA	Hazard Identification and Ranking
HSE	Health and Safety Executive
I2SI	Integrated Inherent Safety Index
ISI	Inherent Safety Index
KBRMS	Knowledge-based risk management systems
MOM	Ministry of Manpower, Singapore
OSH	Occupational Safety and Health
OSHCIM	Occupation Safety and Health Construction Industry (Management) Guideline 2017
PCWC	Principal Construction Work Contractor
PCWD	Principal Construction Work Designer

PtD	Prevention Through Design
RIS	Research Information Systems (RIS)
SLR	Systematic Literature Review
Scopus EID	Scopus Electronic Identifier
SweHI	Safety Weighted Hazard Index
UK	United Kingdom
WSH	Workplace Safety and Health Council

PREFACE

This research is inspired by the increasing need to rethink how safety is managed within the construction industry, particularly in shifting from traditional reactive practices to proactive, design-driven approaches. Despite continuous regulatory efforts, construction remains one of the most hazardous industries, indicating that existing safety practices are not sufficiently addressing risks at their source.

The introduction of the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024 in Malaysia presents a significant milestone in embedding preventive safety within the project lifecycle. This development has motivated the exploration of how regulatory frameworks, particularly in the United Kingdom and Singapore, have successfully operationalised design-stage risk management and how such approaches can be contextualised within the Malaysian setting.

In parallel, the rapid evolution of the construction industry—characterised by digital technologies such as Building Information Modelling, increasing adoption of sustainable design principles and the emergence of complex developments including data centres and smart facilities has introduced new dimensions of risk that extend beyond the construction phase into building operation and maintenance. These changes underscore the importance of integrating safety considerations throughout the entire lifecycle of a project.

This study therefore seeks to bridge the gap between research, regulation and practice by combining bibliometric analysis with comparative regulatory assessment. It is hoped that the findings will contribute to a more comprehensive understanding of preventive safety tools and support the advancement of a proactive, integrated and future-ready safety culture within the construction industry, particularly in Malaysia.

ABSTRACT

This study examines the role of preventive safety tools in enhancing construction risk management through a comparative analysis of regulatory frameworks and emerging research trends, with particular emphasis on Malaysia's Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024. Adopting a bibliometric analysis approach using Scopus-indexed publications (1991–2026), the study analyses 191 documents to identify publication trends, thematic evolution and knowledge gaps in design-stage safety practices. The findings indicate a clear global shift from reactive, site-based safety management toward proactive, design-driven approaches such as Design Review Assessment, Prevention through Design and Design for Safety, supported by digital technologies including Building Information Modelling. A comparative regulatory analysis of Malaysia, Singapore and the United Kingdom reveal significant disparities in legislative structure, duty-holder responsibilities and enforcement mechanisms, with more mature systems demonstrating stronger integration of design-stage risk management. Despite Malaysia's regulatory advancements, key challenges persist, including limited stakeholder awareness, insufficient technical capacity and weak alignment between regulatory intent and industry practice. The study highlights the need for stronger institutional support, standardised implementation frameworks and enhanced integration of digital tools to operationalise preventive safety effectively. Overall, the research contributes to bridging the gap between theory, regulation, practice and supports the development of a more proactive, design-oriented safety culture within the construction industry.

Keywords: Construction, Occupational Safety and Health, Risk Management, Design for Safety, Preventive Safety Tool, Regulatory Framework, Regulatory Trend

Subject area: K720-792 Property, K3661-3674 Public safety, K85-89 Legal research, K(520)-5582 Comparative law. International uniform law

CHAPTER 1

INTRODUCTION

1.1 Research Background

The construction industry is still regarded as one of the most hazardous sectors globally, especially when it comes to accident rates, the complicated stakeholder arrangements, as well as constant exposure to physical and environmental risks. Indeed, despite contributing to approximately 13.4% of the overall productivity (and employing close to 200 million workers), the sector registers a disproportionately high number of work-related deaths contributing to an estimated 30–40% of global work-related deaths (Zou et al., 2014). Malaysia has witnessed the same, with the construction industry consistently listed among the highest risk industries in terms of occupational fatalities despite continuous attempts at regulatory control (DOSH, 2022).

Historically, Malaysia has made steady progress in strengthening its regulatory framework in this area. One of the earlier initiatives was the introduction of the Occupational Safety and Health in Construction Industry (Management) Guidelines 2017, which provided a structured though largely voluntary approach to embedding proactive risk management across the entire project lifecycle (Che Ibrahim, C. K. I., & Belayutham (2019), A lifecycle-oriented approach to construction risk management emphasises the proactive identification, assessment and mitigation of risks before they materialise, rather than relying on reactive responses after incidents occur. This paradigm shift reflects a growing recognition that many construction hazards originate during the early stages of project planning and design. Consequently, stakeholders are encouraged to systematically evaluate potential risks at the outset and integrate appropriate control measures throughout the project lifecycle. Central to this approach are preventive safety concepts such as Prevention through Design (PtD) and Design for Safety (DfS), which prioritise the elimination of hazards at source and the reduction of risks through informed and deliberate design decisions (Hinze & Gambatese, 2003; Manuele, 2008).

By embedding Occupational Safety and Health (OSH) considerations within the design phase, this framework fundamentally transforms traditional safety management practices. Rather than treating safety as a downstream compliance requirement, it promotes an anticipatory and design-led strategy that enhances risk control effectiveness. This shift not only improves safety outcomes but also supports more efficient and cost-effective project delivery, as risks are addressed when intervention is most feasible. Overall, the integration of lifecycle thinking with preventive safety principles represents a critical advancement towards a more proactive, systematic and sustainable approach to construction risk management.

More fundamentally, this shift marks a turning-point away from a heavily guideline-based system, whose enforcement was often in the form of interpretation, to an established regulatory environment which imposes clear and enforceable safety requirements on all duty holders. By this approach, the expectation emerges that OSH must be tackled early, consistently and for the duration of the entire project – not an afterthought or a site issue.

A key aspect of this new framework is the clearer delineation of duties and accountability from the point of launch of a project to the completion of the project. Under the CDM Regulations 2024, duty holders, particularly clients, designers and contractors, are assigned particular responsibilities to ensure that risk management is not treated as activity downstream, but it is started early and continues throughout to completion of a project. In practise, this is a major change in the way that safety is controlled. Clients are placed as the direct engines of safety performance, and they have a higher expectation to drive decisions from the ground up. Such an approach consolidates the importance of incorporating safety considerations into the process of key project decision-making, and instead of postponing them to the construction phase where the options available for reducing the risk may be fewer (Ismail et al., 2023).

Significantly, the regulatory framework is committed to the systematic focus towards risk management at the design phase as a central element of OSH practice, particularly in the pre-construction period. This is accomplished through structured mechanisms, such as Design Review Assessment (DRA), guided by established principles such as Prevention through Design (PtD) and Design for Safety (DfS) (Hinze & Gambatese, 2003; Manuele, 2008; Ismail et al., 2023).

In light of the United Kingdom's successful system of coordination between roles such as Principal Designer and Principal Contractor, which is formally mandated, Malaysia's CDM Regulations 2024 adopt this approach and integrate design-stage responsibilities under the Principal Construction Work Designer (PCWD). This is a key advance for the sake of providing clear accountability at the design stage for safety, as opposed to diffusing it at a later stage in the project.

Through continuous risk management, enhancing stakeholder accountability, and embedding preventive safety practices early when it makes the most difference, especially in projects managed on behalf of a client from an integrated governance and operational perspective, it will bolster overall OSH performance.

Collectively, these frameworks point towards a broader shift in the way OSH works globally, from a traditionally reactive approach to one that is more proactive and design-led in risk management. It not only fits into these concepts, but is backed by empirical evidence that indicates that up to 60% of construction accidents trace back to design decisions. Such findings draw attention to the urgent need for regulation where early intervention (especially through CDM and DfS) plays a more significant role (Behm, 2005; Haslam et al., 2005). In this light, enhancing design-stage accountability is not merely a regulatory improvement, but is instead an essential step towards more impactful and sustainable OSH measures applied in construction projects.

Notably in the context of the Commonwealth, neighbouring Singapore has also recently made a step in this progressive direction, through the introduction of the Workplace Safety and Health (Design for Safety) Regulations 2015 (Singapore DfS Regulations 2015) (MOM, 2016). These regulations provide a clear, purposeful, formalised approach to preventive safety, most significantly via the application of DfS reviews. The requirement to appoint a DfS Professional, together with the maintenance of a DfS Register, allows for hazards and corresponding mitigation measures to be systematically identified, recorded and tracked across the various stages of a project. Contrasted with Malaysia's developing system, Singapore's approach is characterized by greater procedural formalisation and regulatory enforcement, particularly in embedding design-stage safety considerations into project delivery.

1.2 Research Problem

DfS and PtD are well established in literature; their application in the Malaysian construction sector is uneven. While regulatory provisions have developed over the years, they still fall short in providing the technical clarity and practical guidance needed to support effective integration of safety considerations at the design stage (Che Ibrahim et al., 2019; Manu et al., 2021).

In practice, this does not always translate to consistent application as per regulatory intent. Technical complexity, limited industry capability and varying levels of stakeholder awareness continue to present real constraints. For this reason preventive safety measures are often applied inconsistently, limiting their overall effectiveness in improving project safety outcomes.

A fundamental underlying challenge is the lack of a consistent, standardised framework to facilitate the application of preventive safety tools. In addition, this is challenging due to unclear roles and responsibilities among key stakeholders namely clients and designers with respect to design-stage risks. This lack of clarity in many of these settings, however, results in greater over-reliance on contractors and downstream controls, rather than encouraging earlier, more proactive intervention (Saifullah & Ismail, 2012; Che Ibrahim et al., 2019).

At the same time, digital technologies and knowledge-based systems in safety practices still are not yet well integrated. Building Information Modelling (BIM) has demonstrated great potential in supporting hazard identification and collaborative decision-making, however its application is often fragmented in many cases, which includes lack of standardisation in processes and alignment with regulatory requirements. As a result, its application in systematic and preventive risk management is not well exploited (Rafindadi et al., 2022).

These challenges highlight the wider gap in both knowledge and practice namely there is a lack of an integrated understanding about the interplay of regulatory frameworks, stakeholder roles and emerging technologies that collectively impact on the implementation of preventive safety tools. Bridging this gap is important to respond to the continued disconnect between regulatory intent and industry practice and the promotion of better, design-driven risk management strategies.

There is also a lack of empirical evidence in terms of how these constructs are actually implemented in relatively new regulatory environments, specifically under the CDM Regulations 2024. Yet, the adoption of this framework remains subject to systemic and operational constraints in Malaysia, such as limited stakeholder awareness, insufficient technical expertise in design-stage risk management and lack of localised guidance (Ismail et al., 2023). Organisational and industry-level factors can also exacerbate this pressure by way of inadequate designer competency, weak organisational commitment, insufficient training, and limited integration of safety considerations into procurement and early project planning processes (Che Ibrahim & Belayutham, 2020).

Accordingly, a clear gap remains between policy development and implementation of preventive safety tools like DRA, DfS and PtD. Furthermore, bibliometric evidence also suggests that research on regulatory implementation, design-stage risk management and preventive safety tools remains relatively limited in both volume and impact.

Here, a well-informed and comparative analysis of CDM-led regulatory regimes in Malaysia, Singapore and the United Kingdom is needed, in consideration of both the best practices and implementation challenges to improve and to help make use of best practices by way of designing and improving local context. This kind of analysis is crucial not merely to strengthen the regulatory system in Malaysia, but to ensure that preventive safety tools are effectively integrated into construction risk management systems. All in all, this study aims to contribute to the construction industry's more proactive, ordered, and design-oriented safety culture.

1.3 Research Objectives

With the proliferation of active, prevention-based techniques being employed progressively better in construction risk management, it is pertinent to elucidate the regulation of these procedures as well as the educational grounds justifying their effective implementation. Therefore, the research objectives of this study are:

1.3.1 To compare regulatory frameworks through a case study approach, evaluating the legislative structures, duty-holder responsibilities and DfS integration across Malaysia, Singapore, and the United Kingdom.

1.3.2 To systematically map the evolution of selected countries and Malaysian research regarding design review and construction safety by tracking relevant literature via bibliometric analysis.

1.4 Research Questions

In line with the research objectives, this study is guided by a set of structured research questions designed to provide a systematic inquiry into how design-stage risk management is governed and implemented.

1.4.1 How do the regulatory frameworks in Malaysia, Singapore and the United Kingdom differ in terms of legislative structure, duty-holder responsibilities and the integration of CDM principles, particularly in supporting design-stage risk management and preventive safety practices?

1.4.2 What are the publication trends, key research themes and emerging focus areas in global and Malaysian studies on design review and construction safety, as identified through bibliometric analysis?

1.4.3 What are the main knowledge gaps and underexplored areas in the existing literature on design-stage risk management, particularly within the Malaysian context, based on bibliometric mapping and thematic analysis?

1.5 Research Significance

Despite existing regulatory frameworks, OSH practices remain largely reactive and focused on the construction stage, even though many hazards originate during the design phase (Rafindadi et al., 2022). While preventive approaches such as CDM, DfS and DRA are increasingly promoted, gaps persist in aligning regulatory intent, academic research and industry implementation, particularly in Malaysia. This study is therefore significant in providing key insights and helping to close these gaps.

1.5.1 Academic Contribution

This study provides insight into the implementation of CDM Regulations 2024 and design risk management within the Malaysian context. A comparative analysis of regulatory frameworks in Malaysia, Singapore and the United Kingdom provides a useful basis for addressing gaps in the existing literature, particularly in understanding how preventive safety principles are embedded within different systems. More importantly, it helps to bridge the divide between research and practice by offering clearer insights into how design-stage safety tools can be effectively operationalised (Zou et al., 2014).

1.5.2 Industry Contribution

From an industry standpoint, this study provides practical insight into how DRA can strengthen risk management at the design stage, while reinforcing the importance of addressing hazards early when they are more manageable and cost-effective to mitigate (Rafindadi et al., 2022). It also brings to light key barriers to implementation, particularly in relation to stakeholder awareness and capability, which continue to hinder the effective translation of regulatory requirements into day-to-day practice.

Importantly, the findings also support the development of more effective and localised CDM guidance, enhancing the applicability of preventive safety practices in Malaysia. In doing so, the study contributes towards ensuring that such practices are not only conceptually understood but can be realistically implemented within the local construction context.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The following section provides a comprehensive and current review of literature on construction risk management through preventive safety tools, with a focus on comparative regulatory frameworks and emerging trends. It seeks at the same time to synthesize relevant theoretical and practical knowledge and determine important research gaps in Malaysia.

Construction developments involve shifting environments, multidimensional stakeholders, and complex work processes leading to a higher exposure to hazards (Jaafar et al., 2017). Workers often have to perform real-time decisions in settings where the uncertainty is pervasive at a time and place, which in turn require the use of experiential knowledge and informal channels of communication to mitigate risks (Saurin et al., 2008; Wadick, 2006). This reactive and adaptive way, however, is not enough to deal with systemic issues in OSH.

Research has consistently demonstrated that many construction accidents are rooted in inadequate planning, poor design decisions and lack of foresight during early project stages (Manu et al., 2021; Ning et al., 2018). For instance, Malekitabar et al. (2016) found that nearly 46.8% of construction accidents are linked to design-related factors, while European studies suggest that over half of workplace accidents originate from deficiencies in the project preparation phase (Martínez et al., 2018). These findings reinforce the argument that effective risk management must begin at the design stage, where the potential to influence OSH outcomes is greatest.

Prevention through Design (PtD) has emerged as one such solution to meet these issues. PtD, introduced by the National Institute for Occupational Safety and Health (NIOSH) in 2007, highlights the need for integrating safety concerns into the design components of facilities, equipment and processes (Vigneshkumar & Uma Maheswari, 2018). The term PtD also has its counterparts Design for Safety (DfS), Safety in Design (SiD) and Construction Hazard Prevention through Design (CHPtD), due to its common use among different contexts and design disciplines.

There is empirical evidence that the effectiveness of PtD for construction risk reduction has been found by empirically based practical analysis for the reduction of construction risks. Behm (2005) demonstrated that approximately 42% of construction fatalities could be linked to design-related issues, suggesting that these incidents could have been prevented through design modifications. Similarly, Driscoll et al. (2008) found that 37% of workplace fatalities were associated with design deficiencies. These findings highlight the critical role of designers in influencing safety outcomes and underscore the need for their active involvement in risk management processes.

2.2 Preventive Safety Tool

Hazard identification and risk assessment systems are a significant portion of the preventive safety tools developed to facilitate a systematic assessment of risks in the design phase. Tools like Hazard Identification and Ranking (HIRA), Safety

Weighted Hazard Index (SweHI) and Risk-Based Inherent Safety Index (RISI) have established frameworks for evaluating hazard severity, likelihood and consequences to facilitate decision-making and prioritization of risk mitigation measures. HIRA assesses fire, explosion, and toxicity hazards, while SweHI involves control provisions to more closely represent operational safety conditions (Khan & Abbasi, 1998; Khan et al., 2001). RISI takes this one step further, incorporating inherent safety principles into risk-based design decisions to lower both accident odds and accident-related outcomes across the design life cycle (Rathnayaka et al., 2014).

Related to these approaches, the principle of inherent safety focuses on removing hazards at their source in the early stages of design. Safety-based assessments, such as the Inherent Safety Index (ISI), Integrated Inherent Safety Index (I2SI), and Graphical Inherent Safety Assessment Technique (GISAT), are used to evaluate the safety performance in terms of toxicity, flammability and explosiveness, among others, to make comparison between the design options which are inherently safer (Ahmad et al., 2019). Although some of the aforementioned tools are useful in preliminary design and are improved using accident databases and simulation methods, the application of these tools in construction remains limited as these are heavily based in process engineering and not integrated with the dynamic construction data and real design workflow (Ahmad et al., 2019). These limitations reveal necessity of more integrated, context-adapted preventive safety tools that can bridge design-stage risk identification with practical implementation in construction environments.

In recent years, preventive safety tools have become one of the most important tools in modern construction risk management, changing the industry's approach from only reactive control measures to active hazard elimination throughout design and planning stages in the industry. The use of traditional knowledge-based safety best practices, which have depended heavily on experience, accident reports, and site-based interventions, is increasingly considered inadequate in complex construction environments (Rafindadi et al., 2022). Therefore, the adoption of preventive safety tools has gained traction to systematically integrate OSH considerations throughout a project lifecycle.

One of the key underpinning concepts of preventive safety tools is Design Review Assessment (DRA) in general or, as PtD, DfS or any other construction hazard prevention through design. DRA focuses on the significance of OSH in early design and it allows hazards being removed or reduced before they ever become present on-site. This strategy falls within the hazard control hierarchy with emphasis on elimination and substitution above administrative controls and PPE, which is the elimination and substitution rather than administrative controls and personal protective equipment (Hardison et al., 2020). Empirical studies show that a significant proportion of construction accidents are caused by design-related factors (Behm, 2005) and therefore, upstream interventions are critical. Additionally, Szymberski's time–safety influence curve shows that the ability to influence safety outcomes is greatest in the conceptual and preliminary design phases, which further lends credence to the use of preventive tools in early phases of the project.

Beside theoretical models such as DRA, various technological and analytical preventive safety tools have been developed. Of these the Building Information Modelling (BIM) has emerged as a digital system that improves visualization, coordination and safety planning. It's known that BIM allows stakeholders to simulate construction processes, and to identify potential hazards and evaluate safety measures prior to physical construction (Rafindadi et al., 2022). Some studies have revealed that BIM-based safety training improves workers' hazard recognition and comprehension significantly over conventional methods, especially in interactive and visual learning environments to promote safety awareness (Rafindadi et al., 2022). Importantly, BIM provides advanced features in automated hazard detection, and facilitates four-dimensional scheduling for safety planning and integration with Augmented Reality and Virtual Reality for immersive training environments (Park & Kim, 2013; Li et al., 2015; Shen & Marks, 2016). Nonetheless, prior studies underscore certain limitations, such as absence of standardized BIM process flows and limited applicability in complex construction scenarios (Rafindadi et al., 2022).

Concurrently, information and digital-based risk management tools have been applied to mitigate risks and support preventive safety measures. Methods such as case-based reasoning systems (CBRisk) and knowledge-based risk management systems (KBRMS) utilize past data and expert knowledge to facilitate risk identification and decision-making (Amaechi et al., 2025). These frameworks allow the synthesis of knowledge maps, risk prediction models, and decision-support mechanisms that support project risk management throughout the construction lifecycle. Nevertheless, despite the promising potential, such tools face constraints related to scalability, data integration, and adaptability to a variety of dynamic and diversified project situations (Amaechi et al., 2025).

Although this research is growing on preventive safety tools in general there are a number of crucial gaps. First, many of the tools are largely built around identifying and assessing hazards with little focus on providing actionable design solutions or embedding safety suggestions into design workflows. Second, the adoption of such advanced technologies as BIM, Virtual Reality and Augmented Reality is uneven, especially in developing countries, where high implementation costs, limited technical expertise, and resistance to change stand in the way of the wide application of technologies (Bui et al., 2016; Marefat et al., 2019). Third, there are few standardized frameworks that combine several preventive safety tools and integrate them into a single, scalable tool that can be used across project phases and regulatory environments, limiting their utility for enabling holistic design-stage risk management (Ismail et al., 2021; Abueisheh et al., 2020).

To conclude, preventive safety tools are a new paradigm in construction risk management through the proactive mitigation of hazards during the design phase. These approaches, which include PtD, BIM-based systems, inherent safety assessment methods and knowledge-based tools, collectively provide improved OSH performance.

2.3 Historical Development

The development of construction risk management has evolved from reactive, site-based safety practices to more proactive, design-stage interventions. Traditionally, safety management in construction relied heavily on post-incident responses, training programs and compliance with safety procedures. However, such approaches have been widely criticised for their limited effectiveness in preventing accidents, particularly in complex and dynamic construction environments (Rafindadi et al., 2022).

A significant shift of introducing preventive safety concept has started to drive construction companies to consider on the elimination of hazards at the earliest stages of design rather than relying on protective measures during construction. As noted by Ahmad et al. (2019), “it is preferable to prevent hazards than to eliminate hazards after the accidents occur” (p. 275). This preliminary change of mindset is slowly supporting the established foundation for integrating safety into design processes.

In this research, Table 1 provides a comparative analysis of the construction sector occupational safety and health (OSH) performance in the United Kingdom, Singapore, and Malaysia after implementing design-based standards of safety. The United Kingdom operates under the CDM Regulations introduced in 1994 and revised in 2015, and Singapore, with its Design for Safety (DfS) Regulations 2015 enforced since 2016. Malaysia, on the other hand, has shifted from the voluntary

OSHCIM Guidelines (2017) to the CDM Regulations 2024 framework. According to the United Kingdom report, the fatality rate between 1.6 and 2.4 per 100,000 workers is much lower in the United Kingdom, while Singapore records slightly higher rates at around 2.7 per 100,000 workers. Unfortunately, in Malaysia, fatality rates are high and estimated between 10.7 and 12.8 per 100,000 workers. There are other reported statistics with far larger gaps seen in the aggregate mortality numbers: the United Kingdom has 51 construction-related fatalities in 2023/2024, Singapore records about 7 fatalities for a partial year in 2023, and in Malaysia this falls to 312 occupational fatalities across all sectors in 2020.

At long-term rate, the United Kingdom has seen a drastic reduction in construction fatalities, down almost 70% from 2001 to 2016. Singapore also shows a declining pattern with a drop in fatality rates from 4.4 to 2.7 per 100,000 workers. On the other hand, Malaysia is on an upward and fluctuating trajectory where construction deaths increased dramatically and even reported 20% rise in construction fatality rates. We found that construction is still a high-risk sector across the three countries, in terms of relative risk comparisons, with construction being one of the top major contributors to occupational fatalities in the United Kingdom and Singapore and construction-related deaths in Malaysia being 3.3 times that of the national average. Performance data on non-fatal injuries illustrates variation even further, with the United Kingdom recording around 47,000 injuries (approximately 2.4%), Singapore recording a substantial injury rate of 17.2 per 100,000 workers, and Malaysia recording 32,674 occupational accidents in 2020. For all jurisdictions, falls from height are the most common cause of death and injury, constituting 52 percent of deaths in the United Kingdom and 31 percent of injuries in Singapore, with comparable trends in Malaysia.

Design-based regulatory approaches have demonstrated impact in the United Kingdom, where CDM implementation has been linked to long-term declines in fatality rates, and Singapore, where DfS regulations have led to marked improvements. In contrast, Malaysia's reliance on voluntary guidelines early on has resulted in limited effectiveness prior to the enforcement of CDM Regulations 2024. With the United Kingdom showing a highly mature and well-enforced system of implementation, Singapore showing moderate but improving maturity, and Malaysia currently in an early transitional stage, they also differ significantly in the level of implementation maturity which has been observed.

There is a wider correlation as far as data on OSH outcomes are concerned, including between the maturity and mandatory enforcement of design-based safety regulations and the improved OSH result as a result, with countries where the longer-established and strictly enforced framework of design-based safety regulations exists, have significantly lower fatality rates and more consistent safety performance than those at the earlier phases of regulatory adoption.

Table 1: Comparative OSH Performance Post CDM Implementation: United Kingdom, Singapore and Malaysia

Indicator	**United Kingdom (CDM – Mandatory)**	**Singapore (DfS – Mandatory since 2016)**	**Malaysia (CDM 2024 – Emerging)**
Regulatory Framework	CDM Regulations (1994, revised 2015) (HSE, 2015)	Design for Safety Regulations (2016) (Ministry of Manpower [MOM], 2016)	OSHCIM (2017, voluntary) → CDM 2024 (DOSH, 2024; Che Ibrahim et al., 2019)
Fatality Rate (Construction)	~1.6 – 2.4 per 100,000 workers (HSE, 2023)	~2.7 per 100,000 workers (MOM, 2023)	~10.7–12.8 per 100,000 workers (CIDB, 2018; DOSM, 2022)
Recent Fatalities (Absolute)	~51 deaths (2023/24) (HSE, 2023)	~7 fatalities (2023, partial year) (MOM, 2023)	312 occupational fatalities (all sectors, 2020) (DOSM, 2022)
Trend Over Time	~70% reduction in fatality rate (2001–2016) (CIDB, 2018; HSE, 2017)	Declining trend (4.4 → 2.7 per 100k) (MOM, 2023)	Increasing / inconsistent trend (+20% construction fatality rate) (CIDB, 2018)
Relative Risk (vs All Industries)	Construction significantly higher than average (HSE, 2023)	Construction remains top contributor to fatalities (MOM, 2023)	~3.3× higher than national average (DOSM, 2022)
Injury Rate (Non-fatal)	~47,000 injuries (~2.4%) (HSE, 2023)	Major injury rate ~17.2 per 100,000 (MOM, 2023)	32,674 occupational accidents (2020) (DOSM, 2022)
Severity / Causes	Falls ≈ 52% of fatalities (HSE, 2023)	Falls ≈ 31% of injuries (MOM, 2023)	Falls cause of fatalities (DOSM, 2022)
Impact of Design-Based Regulation	Strong long-term fatality reduction linked to CDM (HSE, 2017; CIDB, 2018)	Improvement observed post-DfS implementation (MOM, 2023)	Limited impact pre-CDM 2024 due to voluntary adoption (Che Ibrahim et al., 2019; Ismail et al., 2023)
Implementation Maturity	Highly mature and enforced (HSE, 2015)	Moderately mature, improving (MOM, 2023)	Early-stage / transitioning (DOSH, 2024; Che Ibrahim et al., 2019)

Source: Compiled by the author(s) based on secondary data (HSE, 2015; 2017; 2023), (MOM, 2016; 2023), (DOSH, 2024), (CIDB, 2018), (DOSM, 2022) and relevant literature including Che Ibrahim et al. (2019) and Ismail et al. (2023).

Prior research in construction OSH mostly relied on qualitative case studies and descriptive analyses from the methodological perspective. More recent research, however, has used systematic literature reviews (SLR) and conceptual framework development to synthesise knowledge of various safety variables based on existing research and establish relationships between safety variables. The research has been found to be effective to enhance the in-depth analysis and transferability of insights to practical construction risk management scenarios (Rafindadi et al., 2022; Amaechi et al., 2025).

2.4 Recent Development

Recent development trends in construction risk management mirror an increased focus on preventive safety techniques, design-stage risk consolidation, and knowledge-based practices. Among the most noticeable factors is the growing realization that many construction hazards originate during early project phases, especially project planning and design. Studies have confirmed that decisions made during these stages significantly influence safety outcomes across the project lifecycle (Adaku et al., 2021; Manu et al., 2021).

This has led to the increasing relevance of PtD and DfS for developed and developing countries. However, research also shows that in developing countries, adoption of these concepts is inconsistent because of limitations in technical capacity, regulatory enforcement and industry awareness (Abueisheh et al., 2020).

As described, another major development is the growth of digital technologies, more specifically BIM, that enhances decision-making at the design stages. Research indicates that BIM-based training and hazard identification systems improve the understanding of safety risks among workers and contribute to more effective safety planning (Rafindadi et al., 2022). Nevertheless, BIM adoption remains limited in developing countries for many reasons such as lack of expertise, high implementation costs and absence of standardised processes.

With regard to theory, some recent research has adopted integrated and holistic models of safety management which use preventive safety tools and also organisational, behavioural and knowledge management perspectives. This is part of a wider trend from a technical solution-only focus to a socio-technical approach where human factors, communication and organisational learning are included in influencing OSH performance. It has been found that construction OSH is not solely dependent on regulatory compliance or technical systems, but also on dynamic workplace interactions, adaptive behaviours and shared learning processes among stakeholders (Zou et al., 2014).

2.5 Review of Previous on Preventive Safety Tools in Construction Industry

Previous bibliometric research has largely been limited to broader domains such as construction safety, sustainability, risk management and engineering management, rather than specific preventive safety tools. Such investigations traditionally use databases such as Scopus and Web of Science and employ tools like VOSviewer and Biblioshiny to study publication trends, citation networks and keyword co-occurrence (van Eck & Waltman, 2014; Aria & Cuccurullo, 2017).

For example, Rafindadi et al. (2022) conducted a systematic and bibliometric review of construction safety research. The results showed that there was an increasing emphasis on design-stage risk mitigation and digital safety tools. Safety research has evolved toward preventive approaches but remains heavily skewed toward developed countries; it has limited contextualisation in developing regions such as Malaysia.

Similarly, Manu et al. (2021) reviewed construction risk management literature and found that while design-related risk factors are widely acknowledged, their integration into formal project processes remains inconsistent. The study emphasised the need for stronger alignment between regulatory frameworks and design-stage safety practices.

Other bibliometric studies across related domains (e.g., sustainability, governance and engineering systems) have demonstrated the usefulness of bibliometric techniques in identifying publication growth trends, influential authors and thematic clusters, but often lack specificity in addressing construction safety from a preventive and regulatory perspective (Ahmi et al., 2025; Fayad et al., 2024).

The reviewed studies demonstrate that bibliometric and scientometric approaches are increasingly used to map research trends, identify knowledge gaps and structure the evolution of construction risk management literature. These studies collectively highlight the growing integration of digital technologies, knowledge management and preventive safety concepts within the construction domain. For instance, systematic and bibliometric analyses have been widely applied to identify thematic developments, research clusters and knowledge networks, thereby strengthening the analytical foundation of construction risk management research (Amaechi et al., 2025; Wei et al.; Ghaleb et al.; Ibrahim et al., 2022). In addition, recent studies emphasise the increasing role of digital tools and knowledge-based systems in advancing safety management practices (Rafindadi et al., 2022; Zhou et al., 2012).

Table 2 summarises key studies on construction risk management and preventive safety, their key areas of focus, methods, main findings, and limitations. A variety of approaches in each of the studies studied are mentioned, including bibliometric analysis, systematic literature reviews (SLR), conceptual frameworks, and digital or knowledge-based systems. These articles cover core areas; risk assessment techniques, stakeholder integration, BIM, and design-stage safety approaches, particularly PtD.

Overall, the table presents that there is a research focus on research trends to develop theoretical and conceptual frameworks and application of digital technologies for safety management. Although these contributions provide valuable insights into the evolution of construction safety research, a number of them reveal challenges in the field, including limited practical implementation, lack of integration with knowledge management systems, and difficulty of implementing the proposed tools across different project and regulatory contexts.

According to these studies, the gaps observed between theoretical advancement and the practical practices in the industries were much larger than the general trend even though advanced research was being applied on preventive safety. The gap is further highlighted in less developed countries, where challenges such as inadequate technical capacity, weak regulatory enforcement, and low stakeholder awareness still hamper successful utilization of preventive safety tools.

Findings from the studies reviewed focus on a growing significance for design-stage safety in determining the construction risk outcome, and the increasing incorporation of digital and knowledge-based tools to support decision making. But still, the literature consistently points to the requirements for more integrated, standardised, and practice-oriented approaches which really help bridge this divide between research and implementation in the real world as demanded by regulation.

Table 2: Summary of Previous Studies on DRA / DfS / DtS

Author(s)	**Study Focus**	**Methodology / Data Source**	**Key Findings**	**Limitations / Research Gap**
Wei et al. (2019)	Bibliometric analysis of construction project risk	Bibliometric analysis using indexed publications	Identified major research trends and thematic clusters	Did not incorporate knowledge management perspective
Khodabakhshian et al. (2023)	Risk management in construction projects	Systematic literature review (probabilistic and deterministic approaches)	Provided structured classification of risk assessment techniques	Excluded knowledge management dimension
Ghaleb et al. (2020)	Complexity in construction projects	Systematic literature review with bibliometric elements	Highlighted complexity factors influencing risks	Did not link to knowledge management or practical mitigation
Xia et al. (2018)	Stakeholder integration in risk management	Systematic literature review	Showed importance of stakeholder integration	Lacked comprehensive risk frameworks

Author(s)	Study Focus	Methodology / Data Source	Key Findings	Limitations / Research Gap
Amaechi et al. (2025)	Knowledge management in construction risk	Systematic literature review (SLR) with content analysis and knowledge mapping	Identified research trends, knowledge gaps, and thematic development in construction risk management	Need for more advanced knowledge management (KM) models and practical implementation strategies
Isah & Kim (2023)	Digital risk tool (ConRisk)	Knowledge-based system using Risk Knowledge Graph (RisKG) and KBRMS	Improved risk identification through knowledge-based systems and digital tools	Limited scalability and adaptability across projects
Yuzui & Kaneko (2025)	Risk analysis tools classification	Systematic review of 47 studies	Identified key tools such as FMEA, STAMP/STPA, Bayesian Network, Fault Tree, and Event Tree	Limited applicability and transferability to construction contexts

Author(s)	**Study Focus**	**Methodology / Data Source**	**Key Findings**	**Limitations / Research Gap**
Zhou et al. (2012)	Digital tools in construction safety	Literature review	Identified the role of BIM and visualization technologies in improving safety	Narrow focus on digital tools without broader integration
Hardison & Hallowell (2019)	Prevention through Design (PtD) trends and effectiveness	Review with scientometric elements	Evaluated effectiveness and evolution of PtD approaches	Limited dataset and lack of comprehensive global coverage
Ibrahim et al. (2022)	Scientometric analysis of PtD research	Scientometric / bibliometric analysis	Identified major research themes and publication trends in PtD studies	Limited linkage to practical implementation and industry adoption
Rafindadi et al. (2022)	BIM-based safety tools and conceptual framework development	Conceptual framework with literature synthesis and empirical validation	Demonstrated effectiveness of BIM in safety training, hazard identification, and design-stage risk mitigation	Lack of standardized BIM process flow and limited integration with real construction practices

Author(s)	**Study Focus**	**Methodology / Data Source**	**Key Findings**	**Limitations / Research Gap**
Zou et al. (2014)	Construction safety research and practice gap	Mixed-methods research with literature analysis	Highlighted gap between research outputs and industry practices; emphasised socio-technical safety approaches	Lack of systematic examination of knowledge application in practice
Manu et al. (2021)	Design-stage safety and PtD implementation	Thematic and empirical review	Identified strong linkage between design decisions and construction safety outcomes	Limited adoption and implementation in developing countries
Abueisheh et al. (2020)	PtD implementation in developing countries	Systematic literature review	Highlighted regulatory, technological, and knowledge barriers in PtD adoption	Significant research gaps in developing country contexts, including Malaysia

Author(s)	**Study Focus**	**Methodology / Data Source**	**Key Findings**	**Limitations / Research Gap**
Che Ibrahim et al. (2019)	OSHCI(M) guidelines and PtD in Malaysia	Regulatory and conceptual analysis	Introduced PtD-based guidelines to enhance stakeholder responsibility in Malaysia	Lack of enforcement and limited legal obligations for upstream stakeholders

Source: Developed by the author based on a synthesis of selected peer-reviewed journal articles and conference papers on preventive safety tools, Design for Safety (DfS), and Prevention through Design (PtD), including studies by Wei et al.; Khodabakhshian et al.; Ghaleb et al.; Xia et al.; Amaechi et al. (2025); Isah and Kim; Yuzui and Kaneko; Zhou et al. (2012); Hardison and Hallowell (2019); Ibrahim et al. (2022); Rafindadi et al. (2022); Zou et al. (2014); Manu et al. (2021); Abueisheh et al. (2020); and Che Ibrahim et al. (2019).

CHAPTER 3

RESEARCH METHOD

3.1 Introduction

This study takes a bibliometric analysis as a way to systematically analyse the development, trends as well as structure of knowledge associated with construction risk management, preventive safety tools, design-stage safety frameworks and in particular on CDM Regulations 2024. A bibliometric analysis facilitates quantitatively assessing the scientific literature based on publication patterns, citation structures and keyword relationships (Aria & Cuccurullo, 2017; van Eck & Waltman, 2014) and lays a reasonable foundation to locate research gaps and thematic elaboration.

The approach is intended to maintain transparency, replicability and analytical rigor, in line with accepted systematic research and bibliometric methodologies (Moher et al., 2010). It consists of four essential stages: search strategy, data collection, data cleaning and harmonization, and analytical tools.

3.2 Search Strategy

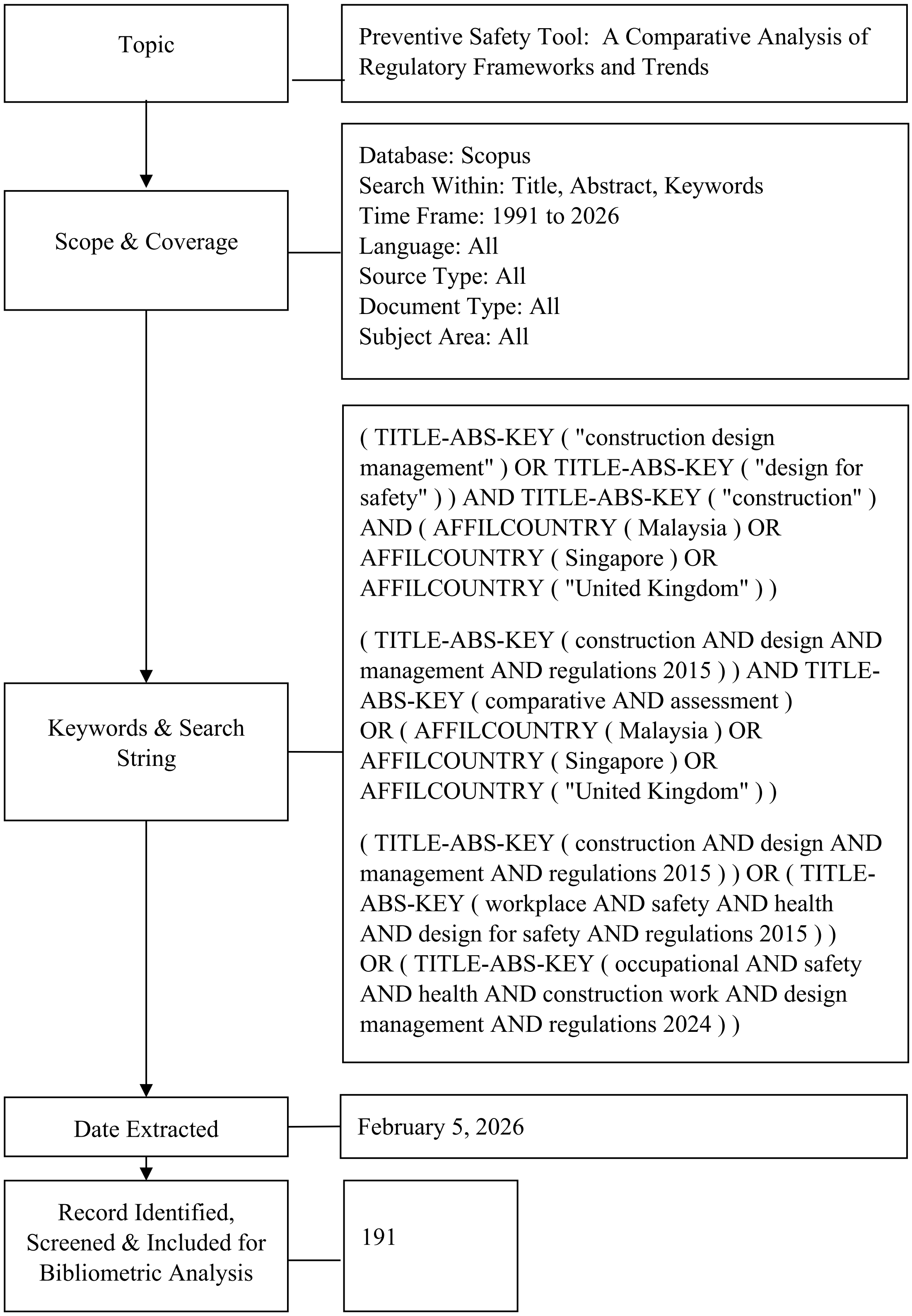
The search strategy was intended to ensure a systematic approach to the collection of relevant literature regarding construction risk management, preventive safety tools and design-stage regulatory frameworks, with particular attention to design for safety, safety preventive tool and CDM Regulations 2024.

The systematic search strategy using Scopus database is depicted in Figure 1. First steps involves the formulation of the search query where keywords for Construction (Design and Management) (CDM), Design for Safety (DfS) and regulatory frameworks in Malaysia, Singapore and the United Kingdom are formulated and improved. This is succeeded by screening and eligibility, using predetermined inclusion criteria, which includes peer-reviewed journal articles published between 2000 and 2025 to confirm that the literature chosen is relevant and appropriate.

After this the process of data cleaning and preprocessing is performed through Biblioshiny, an R-based bibliometric tool, in order to make the dataset more reliable through removing duplicates, standardisation of author names and keywords, and correction of metadata inconsistencies. The last step involves preparing the refined dataset for bibliometric analysis and visualisation using VOSviewer and biblioMagika, providing the overview of research trends, thematic patterns, and existing knowledge gaps within the domain.

In short, Figure 1 shows that the search strategy goes through a number of steps for identification followed by screening and inclusion. Scopus was chosen as the main database for peer-reviewed publications because it provides comprehensive coverage of published papers, and can be easily analyzed by bibliometric analysis tools. A systematic search was conducted with Boolean search terms on Title, Abstract, and Keywords (TITLE-ABS-KEY) fields ensuring both precision and relevance in the retrieved database records.

Figure 1. Flow Diagram of the Search Strategy



Source: Ahmi et al. (2025), Moher et al. (2009)

The search strategy was designed to create a focused and comparable overview across United Kingdom, Singapore, and Malaysia, incorporating search strings for regulatory keywords and contextual terminology variations. For regional comparability, the search was further narrowed, limiting author affiliations to those three countries to ensure that the dataset correlated with the investigation's comparative aim. In addition, the method considered variation in the terminology traditionally used in preventive safety research, acknowledging that terms like PtD, DfS and safety-in-design are often used interchangeably across regulatory and academic fields (Adaku et al., 2021; Manu et al., 2021). By adopting this approach, the dataset is enriched in breadth and inclusivity, which remains consistent with the study scope.

3.3 Search Limits and Criteria

In order to ensure consistency of the information, the study narrowed its scope to peer-reviewed journal articles, as well as to conference papers. This type of limitation of document type serves the purpose of anchoring the results in academically sound scholarship and not to introduce them to the existing literature without sufficient verification. In addition, only English papers were considered in our research for reasons of interpretation and the avoidance of mismatches due to translation or misinterpretation.

The period from 1991 to 2026 was specifically chosen for the purpose of documenting both the historical development and current trajectory of construction safety practices. Over the years this phase includes the early concept of CDM principles as well as more recent, forward-moving approaches to preventive safety as highlighted by the CDM Regulations 2024. Through looking on the long-term, the research is able to follow the trend of design-stage safety ideas and be aware of emergent findings.

These limits and criteria clearly outline the methodology behind the bibliometric analysis, which is one of the ways that we ensure the reliability of our findings and also encourage a well-rounded overview on trends, frameworks and research gaps in the area of preventive construction safety. The search route was consistent with the scope of the study, which was focused on regulatory frameworks and preventive safety tools.

3.4 Rationale for Search Strategy

The search terms have been defined according to the study aims; consequently, only specific search terms regarding CDM, DfS, and OSH frameworks were utilized to maintain conceptual clarity and exclude irrelevant literature. By providing more of a targeted selection, we develop better insight into how regulatory mechanisms and design-stage interventions contribute to construction risk management. Moreover, by integrating the keyword approach with geographical filtering, the findings are more relevant. Boolean operators (e.g. AND, OR) were used to narrow the search and identify studies focusing on the relevant themes, which enhances the efficiency of the screening and reduces data noise.

Thus, this methodological process guarantees reliable and applicable bibliometric data resulting in credible trend analysis while addressing gaps in localised and comparative regulatory research.

3.5 Data Collection

Data collection was performed systematically on the basis of Scopus as the only primary database, to provide consistency in indexing standards, citation metrics, as well as metadata structure. An initial review identified a broad set of 827 papers addressing construction safety, risk management and regulatory frameworks. The screening of the dataset according to predetermined inclusion and exclusion criteria is important to the study focus on preventive safety tools and design-stage risk management, and a final set of relevant studies was developed.

Then important bibliographic and analytical metadata were extracted from each published paper, such as author(s), title, year, source, keywords, abstract, and citation count. These variables underpin subsequent bibliometric analyses of publication trends, thematic development, authorship patterns, and citation impact. After that, the dataset was exported in Comma-Separated Values (CSV) and Research Information Systems (RIS) file formats to facilitate interoperability with many bibliometric tools and in turn to support more thorough data processing, mapping and visualisation.

Subsequently, data cleaning and preprocessing were carried out to strengthen data reliability. This involved removing duplicate entries, standardising author names and keywords, and correcting metadata inconsistencies. Finally, cross-checking procedures were also followed in order to get the data correct as well as removing any irrelevant entries which could have been excluded in order for integrity to be preserved.

Although Scopus provides high-quality and extensive coverage of peer-reviewed literature, its limitations still exist. Depending on a single database may introduce database bias, for example, by downplaying regional or non-indexed publications, such as some Malaysian-specific studies. Nonetheless, the approach used gives a good and reliable dataset, which can be used in bibliometric analysis, and is suitable to the practice of research.

3.6 Data Cleaning and Harmonization

A well-structured data cleaning and harmonization process was implemented prior to bibliometric analysis to optimize dataset accuracy, consistency and analytical reliability. Bibliometric data collected from Scopus are susceptible to the problem of inconsistencies like redundant entries, differences in the names of authors, and non-homogenized keyword terminology that could bias network-based inferencing methods such as co-authorship, citation, and keyword co-occurrence mapping (van Eck & Waltman, 2014).

The process of preprocessing consisted of four major steps. Duplicate records were first determined and subsequently removed based on unique identifiers including DOI, Scopus EID, and matching bibliographic details, to ensure that each publication was counted only once and the citation metrics were maintained. Second, author names and affiliations were standardized to help account for differences in naming conventions, which improved the accuracy of authorship attribution and analysis of collaboration networks. Third, keyword normalization was performed by collapsing synonymous and related terms together (e.g., “Prevention through Design” and “PtD”; “Design for Safety” and “DfS”) to further validate thematic mapping and clusters, as inconsistent terminology can lead to fragmented or misleading results (van Eck & Waltman, 2014). Finally, incomplete records were selectively reviewed, with relevant entries retained to balance data completeness and analytical value.

These approaches improved the overall reliability and robustness of the bibliometric analysis through a reduction in data inconsistencies leading to a better determination of research trends, collaboration patterns, and thematic development in the preventive construction safety field (van Eck & Waltman, 2014).

3.7 Tools

Two complementary bibliometric tools were used after data preparation. To perform network-based analysis, VOSviewer was selected; its support allowed visualization of co-authorship networks, keyword co-occurrence clusters, and citation relationships. This allows to find the patterns of collaboration, the prominent topics of research, and the intellectual structure in the construction safety research (van Eck & Waltman, 2014). Concurrently, biblioMagika was adopted for descriptive and performance analysis for statistical outputs such as annual publication trends, citation metrics, and leading contributors (authors, institutions, countries, and journals). As an Excel-based tool, it supports clear tabulation and graphical representation of bibliometric indicators that contribute to giving a macro-level overview of the development of the field (Donthu et al., 2021).

Scopus data combined with VOSviewer and biblioMagika allows for a more complete, multi-dimensional analysis providing quantitative performance metrics with visualizations using graph networks. This methodology improves the rigour and reliability of the study and allows a well-rounded assessment of research trends, collaboration structures, and thematic evolution in preventive construction safety, in accordance with the established best practices in bibliometric research (Donthu et al., 2021; van Eck & Waltman, 2014).

3.8 Regulatory Framework Analysis Methodology

Qualitative document analysis was used in this study to compare regulatory frameworks on design-stage risk management in Malaysia, Singapore and the United Kingdom. The specific countries selected in this regard were the United Kingdom serving as a mature benchmark, Singapore as a regionally advanced model, and Malaysia as an emerging system undergoing regulatory development.

To provide authenticity and reliability, authentic core regulatory data was collected from the official websites of the government and regulatory entities. The Malaysian framework was obtained specifically from the Department of Occupational Safety and Health (DOSH), United Kingdom from the Health and Safety Executive (HSE), and Singapore framework from Workplace Safety and Health (WSH) Council and Ministry of Manpower. Important documents are the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024 (Malaysia), Construction (Design and Management) Regulations 2015 (United Kingdom), and pertinent Design for Safety (DfS) regulations and directives from Singapore.

To support a structured and consistent comparative approach, the regulatory frameworks were analyzed against seven (7) criteria in order to provide structured and uniform comparisons. The criteria presented in Table 3 are based on well-established theory, empirical research, and professional legal analyses relating to construction industry nature. Under each criterion is a key concern and a dimension shown by literature to have an impact on regulatory interventions to be effective in managing OSH hazards at the design stage as a whole.

The legislative structure and scope are represented due to the fact that the legal structure of a regulatory policy determines its jurisdictional reach, enforceability, and applicability throughout the project lifecycle. As research indicates, comprehensive legislative coverage throughout the project lifecycle is absolutely necessary to achieve the systematic control of risks rather than episodic compliance (Lingard & Rowlinson, 2005). Legal scholars further argue that with a clearly defined statutory scope, there is less uncertainty and the regulatory framework is more effective (Hughes & Ferrett, 2020).

Duty-Holder Roles and Responsibilities is a core criterion as CDM-based frameworks fundamentally rely on the explicit allocation of duties among clients, designers, and contractors. Empirical studies show that unclear responsibility allocation is a major contributor to safety failures in construction projects (Manu et al., 2019). From a legal perspective, the principle of "duty holders" is central to modern safety regulations, ensuring accountability and enabling enforcement actions (HSE, 2015).

DRA / DfS / PtD Integration is justified, based on research showing early identification of risks and elimination of hazards during the design phase minimizes downstream risk. PtD literature consistently indicates that the incorporation of safety into design decisions leads to better and less expensive risk mitigation (Gambatese et al., 2005; Hinze & Wiegand, 1992). This criterion measures the degree to which regulatory regimes are operationalising principles of preventive safety.

The elements of **Design Review and Risk Assessment Mechanisms** were designed as formal processes like Design Risk Assessments (DRA) and structured safety reviews, which are the key instruments in the implementation of design-stage safety, come under the umbrella of the design process. Research shows structured review mechanisms enhance hazard identification, communication and documentation (Zhou et al., 2015). Such mechanisms are also seen by legal practitioners as evidence of due diligence in order to fulfil the statutory obligations.

Lifecycle Approach to Risk Management represents the transition from being reactive towards being proactive to manage the risk throughout the entire project lifecycle. Studies in the field of construction safety management emphasize that risks change over the life cycles of a project, design, construction, and maintenance, and with it, safety (Szymberski, 1997). Such a lifecycle-based paradigm is also in accord with global best practices in OSH governance.

Regulatory Compliance and Enforcement Measures are essential because legislation alone does not generate results in effectiveness in the absence of effective enforcement. The vast majority of the studies find that inspection regimes, penalties and active regulatory oversight can significantly affect compliance behaviour (Parker & Nielsen, 2011). It is worth emphasizing also in legal analysis that credibility of enforcement has a direct impact on industry compliance with safety obligations.

Guidance, Tools and Industry Support is supported by the understanding that in addition to regulatory frameworks, practical implementation resources must be available. There is evidence to suggest that guidance, training, and technical support increases industry's ability to act on challenging safety requirements (Goh & Chua, 2016). Without that support, well-designed regulations may struggle to be realized, especially in emerging regulatory environments.

In general, these criteria jointly imply a comprehensive and multidimensional approach to regulatory analysis that can encompass legal framework, stakeholder accountability, preventive design principles, procedural mechanisms, lifecycle integration, enforcement capacity and industry support systems. This synthesis with academic research and professional legal views underlines that the assessment model is comprehensive, robust and able to compare various jurisdictions.

Table 3: Criteria for Regulatory Analysis

No.	Criteria	Description
1	Legislative Structure and Scope	Examines the legal nature of the framework scope of application and extent of coverage across the project lifecycle.
2	Duty-Holder Roles and Responsibilities	Analyses the clarity, allocation and enforcement of responsibilities among key stakeholders in design-stage risk management.
3	Integration of DRA or DfS or PtD	Assesses how preventive safety principles are embedded within the regulatory framework
4	Design Review and Risk Assessment Mechanisms	Evaluates the presence and structure of formal processes such as DRA, safety reviews or risk assessments conducted at pre-construction stages.
5	Lifecycle Approach to Risk Management	Examines whether the framework adopts a lifecycle perspective, ensuring that safety considerations are integrated from project inception through design, construction and maintenance stages.
6	Regulatory Enforcement and Compliance Mechanisms	Considers the level of enforceability, including legal obligations, penalties, monitoring systems and the role of regulatory authorities in ensuring compliance.
7	Guidance, Tools and Industry Support	Assesses the availability of supporting guidelines, training provisions and technical resources that facilitate implementation by industry stakeholders.

These documents were systematically analysed, focusing on provisions related to design-stage risk management, duty-holder responsibilities, and preventive safety mechanisms. The findings of this analysis form the basis of the comparative discussion presented in Chapter 4.

CHAPTER 4

RESEARCH RESULTS

4.1 Introduction

The bibliometric results reveal a significant move towards more sophisticated and systematic methods, as bibliometric approaches, mixed-method approaches and systematic literature reviews (SLR) have taken on more prominence. These techniques allow for aggregation of voluminous research findings, to find thematic patterns and to facilitate knowledge network mapping among construction safety analyses. Together, they contribute a stronger and more evidence-based understanding of these phenomena, which serves as a building block for better risk management and for the development of preventive safety strategies (Amaechi et al., 2025; Rafindadi et al., 2022).

4.2 Results for Bibliometric Analysis

This section shows the results of bibliometric analysis on the 191 Scopus-indexed publications across 36 years to summarize the publication performance, citation indices, authorship patterns and keyword distribution.

Keywords co-occurrence, as for thematic coverage, results in that frequent terms will be: “construction”, “safety and health”, “prevention through design” and “design for safety” — also emerging topics such as “BIM”, “construction safety” and “Malaysia”. Indicators, (frequency of occurrence, total link strength, citation counts, and average publication year) are used to report these findings.

Authorship patterns are also reported through the number of contributing authors and average authors per publication, thus providing an overview of research participation. Together, these results provide the essential bibliometric characteristics of the dataset, providing a base for further interpretation in Chapter 5.

4.3 Bibliometric Performance and Citation Metrics of Selected Publications (1997–2023)

Bibliometric performance and citation metrics provide quantitative descriptions of publication and citation characteristics of the selected dataset. As stated, the dataset spans the time period from 1991 to 2026 with 191 publications covering 36 citable years and a total of 799 contributors. Among them, 157 publications have been cited.

As for citation numbers, the dataset has 3,710 citations, including a mean of 4.49 citations per paper, and 23.63 citations per cited paper. Average per-year citation is 106.00, and citation per author is 4.64. The average number of authors per paper is 4.18 which showed that it is a collaborative dataset.

Bibliometric indicators further include an h-index of 31, the number of publications listed that each acquired at least 31 citations, and g-index of 56, the cumulative citation level of strongly cited publications. The m-index of 0.861 reflects the trend of research impact across time. Also, citation sum in h-core is calculated as 3,487, indicating all citations of the core set of influential publications added up.

Table 4: Citation Metrics of Selected Publications by Year

Main Information	**Data**
Publication Years	1991 - 2026
Total Publications	191
Citable Year	36
Number of Contributing Authors	799
Number of Cited Papers	157
Total Citations	3,710
Citation per Paper	4.49
Citation per Cited Paper	23.63
Citation per Year	106.00
Citation per Author	4.64
Author per Paper	4.18
Citation sum within h-Core	3,487
h-index	31
g-index	56
m-index	0.861

Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

4.4 Keyword Co-occurrence and Bibliometric Performance Analysis of Selected Publications

Other bibliometric studies across related domains (e.g., sustainability, governance and engineering systems) have demonstrated the usefulness of bibliometric techniques in identifying publication growth trends, influential authors and thematic clusters, but often lack specificity in addressing construction safety from a preventive and regulatory perspective (Ahmi et al., 2025; Fayad et al., 2024).

The reviewed studies demonstrate that bibliometric and scientometric approaches are increasingly used to map research trends, identify knowledge gaps and structure the evolution of construction risk management literature. These studies collectively highlight the growing integration of digital technologies, knowledge management and preventive safety concepts within the construction domain. For instance, systematic and bibliometric analyses have been widely applied to identify thematic developments, research clusters and knowledge networks, thereby strengthening the analytical foundation of construction risk management research (Amaechi et al., 2025; Wei et al.; Ghaleb et al.; Ibrahim et al., 2022). In addition, recent studies emphasise the increasing role of digital tools and knowledge-based systems in advancing safety management practices (Rafindadi et al., 2022; Zhou et al., 2012). The keyword design appears in 44 documents, with a link strength of 140 and 705 citations, with an average publication year of 2018.205.

All keywords are reported based on bibliometric indicators including number of documents, total link strength, citation counts, and average publication year, providing a structured representation of their presence and connectivity within the dataset.

Table 5: Publication by Keywords

Keywords	**Links**	**Total link strength**	**Documents**	**Citations**	**Norm. citations**	**Avg. pub. Year**	**Avg. citations**	**Avg. norm. citations**
construction	58	619	191	3362	196	2019.663	17.420	1.013
Safety and Health	57	402	147	1659	108	2018.143	11.286	0.734
prevention through design	40	468	141	3147	166	2021.426	22.319	1.178
design for safety	32	474	130	3141	143	2022.669	24.162	1.098
malaysia	35	338	95	1417	98	2021.958	14.916	1.033
construction safety	34	200	75	2603	94	2020.960	34.707	1.254
construction industry	35	129	65	3042	99	2017.985	46.800	1.521
safety	29	198	63	2371	81	2018.095	37.635	1.291
BIM	26	94	47	1281	63	2021.191	27.255	1.330
design	18	140	44	705	42	2018.205	16.023	0.945
accidents	22	78	30	489	26	2018.500	16.300	0.853
safety management	16	47	28	1712	75	2019.107	61.143	2.690
designer	12	115	28	691	39	2019.679	24.679	1.402
construction management	19	86	27	546	27	2019.667	20.222	1.017
risk management	17	58	25	216	13	2018.440	8.640	0.501
engineer	11	76	22	834	40	2019.682	37.909	1.800

Keywords	Links	Total link strength	Documents	Citations	Norm. citations	Avg. pub. Year	Avg. citations	Avg. norm. citations
competence	10	77	22	351	20	2019.455	15.955	0.928
procurement	5	12	20	260	14	2013.200	13.000	0.699
organisation	10	76	19	24	12	2021.421	1.263	0.612
developing countries	8	79	19	276	15	2022.895	14.526	0.793
CDM regulations	9	35	19	209	15	2010.474	11.000	0.793
project management	14	43	18	214	16	2018.444	11.889	0.868
construction projects	16	42	18	458	42	2022.500	25.444	2.343
survey	7	71	16	193	13	2023.812	12.062	0.826
united kingdom	10	34	15	620	23	2012.467	41.333	1.528
OSHCIM	7	46	14	76	8	2023.571	5.429	0.560
safety in design	6	35	14	275	15	2020.214	19.643	1.048
scientometric review	8	40	13	440	26	2022.692	33.846	1.984
management	4	16	13	182	10	2012.923	14.000	0.769
tripartite collaboration	5	41	12	7	10	2025.583	0.583	0.833
sustainable construction	11	30	12	212	22	2022.333	17.667	1.807
sustainability	5	20	11	292	16	2020.273	26.545	1.432
social sustainability	7	28	11	424	45	2023.364	38.545	4.135
education	6	28	11	222	14	2021.455	20.182	1.235

Keywords	Links	Total link strength	Documents	Citations	Norm. citations	Avg. pub. Year	Avg. citations	Avg. norm. citations
project performance	11	35	11	194	13	2019.818	17.636	1.148
enforcement	7	41	11	3	0	2023.273	0.273	0.028
industrialized building system	6	13	11	178	10	2019.455	16.182	0.870
safety performance	9	22	10	238	16	2021.200	23.800	1.625
health	8	24	10	227	11	2003.900	22.700	1.139
building developers	7	35	10	100	6	2020.400	10.000	0.576
systematic literature review	11	29	10	1161	41	2021.800	116.100	4.079
virtual reality	7	17	10	60	8	2023.900	6.000	0.751
OSHA	6	23	9	15	12	2023.000	1.667	1.282
design for OSH	5	26	9	101	6	2019.889	11.222	0.649
china	7	39	9	74	8	2024.556	8.222	0.849
academic	5	45	9	198	12	2022.000	22.000	1.289
causal loop diagram	5	45	9	198	12	2022.000	22.000	1.289
industry 4.0	9	27	9	324	32	2023.000	36.000	3.559
competency	6	32	9	280	16	2020.667	31.111	1.788
directive 92/57/eec	5	21	9	498	16	2016.667	55.333	1.729
integrated project delivery (ipd)	3	24	8	48	5	2023.000	6.000	0.619
architectural perspective	3	24	8	48	5	2023.000	6.000	0.619

Keywords	**Links**	**Total link strength**	**Documents**	**Citations**	**Norm. citations**	**Avg. pub. Year**	**Avg. citations**	**Avg. norm. citations**
sustainable development	6	16	8	217	13	2021.125	27.125	1.568
regulatory	5	40	8	8	6	2025.000	1.000	0.769
capabilities	5	40	8	8	6	2025.000	1.000	0.769
risk communication	5	12	8	266	6	2017.500	33.250	0.769
project life cycle	5	22	8	154	18	2023.125	19.250	2.225
ontological framework	3	24	8	48	5	2023.000	6.000	0.619
safety training	4	17	8	42	2	2021.625	5.250	0.308
collaboration	7	29	8	51	3	2023.875	6.375	0.374
compliance	5	19	8	3	0	2024.625	0.375	0.038
safety engineering	3	24	8	16	2	2024.000	2.000	0.205
visualisation	5	14	8	30	4	2008.750	3.750	0.515
thematic analysis	5	24	8	1218	34	2020.250	152.250	4.258
ageing	4	13	8	356	10	2014.375	44.500	1.270
uk	5	15	7	152	6	2011.571	21.714	0.909
collective impact framework	3	21	7	7	10	2026.000	1.000	1.429
dynamic capabilities	6	42	7	14	11	2025.000	2.000	1.538
organisational management	6	42	7	14	11	2025.000	2.000	1.538
leadership	7	16	7	187	7	2017.429	26.714	0.976

Keywords	**Links**	**Total link strength**	**Documents**	**Citations**	**Norm. citations**	**Avg. pub. Year**	**Avg. citations**	**Avg. norm. citations**
case study	7	16	7	95	6	2021.571	13.571	0.881
construction 4.0	5	12	7	292	45	2024.571	41.714	6.372
construction design management	4	16	7	424	12	2016.429	60.571	1.732
fatality	6	26	7	27	2	2022.143	3.857	0.320
factor analysis	5	13	7	96	8	2019.714	13.714	1.119
artificial intelligence	5	10	6	50	9	2023.333	8.333	1.545
automation	4	10	6	476	25	2022.333	79.333	4.247
principal	4	12	6	126	5	2015.000	21.000	0.793
safety risk	3	6	6	76	16	2023.667	12.667	2.640
augmented reality (ar)	4	10	6	26	3	2023.333	4.333	0.447
structural equation modeling	2	5	6	121	8	2022.667	20.167	1.390
internet of things	6	14	6	200	19	2022.667	33.333	3.238
health and safety plan	4	12	6	60	5	2022.500	10.000	0.810
concept application	3	18	6	210	12	2022.000	35.000	2.051
design management	2	6	6	99	4	2020.500	16.500	0.609
organisational capability	3	18	6	0	0	2022.000	0.000	0.000
indicator	7	21	6	60	2	2019.500	10.000	0.256
corporate social responsibility	3	9	6	327	7	2011.000	54.500	1.141

Keywords	Links	Total link strength	Documents	Citations	Norm. citations	Avg. pub. Year	Avg. citations	Avg. norm. citations
safety interventions	3	18	6	84	5	2022.000	14.000	0.820
unions	4	12	6	54	4	2007.000	9.000	0.662
building design	3	18	6	84	5	2022.000	14.000	0.820
industry-level interventions	3	18	6	84	5	2022.000	14.000	0.820
inherent safety	1	6	6	87	3	2015.000	14.500	0.504
knowledge	4	15	6	45	3	2023.000	7.500	0.571
preliminary design	1	6	6	87	3	2015.000	14.500	0.504
assessment	8	19	5	185	6	2017.600	37.000	1.289
occupation	0	0	5	160	11	2014.400	32.000	2.228
ptd	4	20	5	0	0	2019.000	0.000	0.000
malaysian construction industry	2	6	5	2	0	2019.000	0.400	0.011
framework	3	11	5	42	2	2022.000	8.400	0.492
small to medium-sized enterprises	4	12	5	117	6	2010.400	23.400	1.216
safety commitment	4	20	5	5	0	2020.000	1.000	0.057
pre-construction	5	12	5	3	0	2022.200	0.600	0.042
critical success factors	4	14	5	36	3	2021.800	7.200	0.500
construction sector	3	8	5	173	9	2019.400	34.600	1.790
corporate sustainability	1	2	5	68	6	2021.800	13.600	1.201

Keywords	Links	Total link strength	Documents	Citations	Norm. citations	Avg. pub. Year	Avg. citations	Avg. norm. citations
construction safety performance	5	15	5	95	5	2020.800	19.000	1.095
incidents	5	12	5	36	6	2009.400	7.200	1.280
neural network	4	10	5	384	15	2017.200	76.800	2.975
integration	4	9	5	54	2	2019.600	10.800	0.309
design considerations	4	20	5	15	2	2023.000	3.000	0.310
construction safety management	2	10	5	60	4	2021.000	12.000	0.834
visualization technology	2	10	5	60	4	2021.000	12.000	0.834
client	2	10	5	0	0	2025.000	0.000	0.000
duties	2	10	5	0	0	2025.000	0.000	0.000
training	6	15	5	34	3	2019.800	6.800	0.637
risk assessment	6	17	5	110	11	2023.000	22.000	2.271
fatal occupational accidents	3	15	5	0	0	2021.000	0.000	0.000
falls accidents during design	3	15	5	0	0	2021.000	0.000	0.000
challenges	6	11	5	2	2	2025.000	0.400	0.308
ergonomics	4	13	5	2	0	2013.400	0.400	0.007
workers	5	13	5	0	0	2016.600	0.000	0.000
gaza strip	3	15	5	15	12	2025.000	3.000	2.308
client role	3	15	5	15	12	2025.000	3.000	2.308

Keywords	Links	Total link strength	Documents	Citations	Norm. citations	Avg. pub. Year	Avg. citations	Avg. norm. citations
corporate responsibility	2	8	5	178	7	2018.400	35.600	1.325
planning and design phase	3	15	5	15	12	2025.000	3.000	2.308

Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

4.5 Annual Publication Trends and Citation Performance of Selected Publications (1991–2026)

This section presents the annual distribution of publications and citation performance of the selected dataset from 1991 to 2026, based on key indicators including total publications (TP), number of contributing authors (NCA), number of cited publications (NCP), total citations (TC), citations per paper (C/P), citations per cited paper (C/CP), and bibliometric indices (h-index, g-index, and m-index).

The results indicate that publication activity started at a low level in the early years, with only one publication in 1991 and sporadic output from 1994 to 2014, with annual total publications (TP) tending to be lower than five. The citation counts varied between years during this period with selected years in 2005 and 2014 yielding higher total citations (TC) than other initial years.

There is a noticeable increase in publication output from 2015 onwards. The number of publications increases to 7 in 2015 and again to 11 in 2016, alongside greater numbers of contributing authors (NCA) and cited papers (NCP) in 2016. The h-index in 2016 was also 6, reflecting the number of publications that achieved at least six citations within that year.

From 2019 onwards we always see higher publication outputs, 13 publications in 2019 and 20 in 2020. This upward trajectory continues with 13 publications in 2021 and peaks with 26 publications in 2022. During these years, the dataset also records higher values of NCA, NCP, and total citations (TC), along with increased values of bibliometric indices such as h-index and g-index.

In the more recent years, including 2023 to 2025, publication output remains relatively high, ranging between 17 to 18 publications annually, with corresponding variations in citation counts and bibliometric indicators. The year 2026 records 3 publications at the time of data extraction. Overall, the Table 6 reports the yearly progression of publication output, citation counts, authorship contribution, and bibliometric indices, providing a chronological overview of the dataset's bibliometric characteristics across the study period.

Table 6: Publication by Year

Year	TP	NCA	NCP	TC	C/P	C/CP	h-index	g-index	m-index
1991	1	2	1	0	0.00	0.00	0	0	0.000
1994	2	2	2	14	7.00	7.00	2	2	0.061
2001	1	2	1	11	11.00	11.00	1	1	0.038
2003	3	6	1	15	5.00	15.00	1	3	0.042
2005	3	5	2	786	262.00	393.00	3	3	0.136
2006	1	2	1	106	106.00	106.00	1	1	0.048
2007	2	3	2	18	9.00	9.00	2	2	0.100
2008	4	12	2	107	26.75	53.50	3	4	0.158
2009	6	15	4	16	2.67	4.00	2	4	0.111
2010	4	6	3	135	33.75	45.00	3	4	0.176
2011	2	5	2	3	1.50	1.50	1	1	0.063
2012	4	11	3	115	28.75	38.33	3	4	0.200
2013	3	6	2	51	17.00	25.50	2	3	0.143
2014	2	6	2	153	76.50	76.50	2	2	0.154
2015	7	19	4	34	4.86	8.50	3	5	0.250
2016	11	30	8	364	33.09	45.50	6	11	0.545
2017	5	18	4	140	28.00	35.00	3	5	0.300
2018	2	10	2	109	54.50	54.50	2	2	0.222
2019	13	57	10	242	18.62	24.20	7	13	0.875
2020	20	111	20	301	15.05	15.05	8	17	1.143
2021	13	47	11	163	12.54	14.82	7	12	1.167
2022	26	109	25	447	17.19	17.88	14	20	2.800
2023	17	86	10	75	4.41	7.50	6	8	1.500

2024	18	81	18	291	16.17	16.17	7	17	2.333
2025	18	121	14	12	0.67	0.86	2	2	1.000
2026	3	27	3	2	0.67	0.67	1	1	1.000
(blank)					0.00	0.00			0.000
Grand Total	**191**	**799**	**157**	**3710**	**4.49**	**23.63**	**92**	**147**	

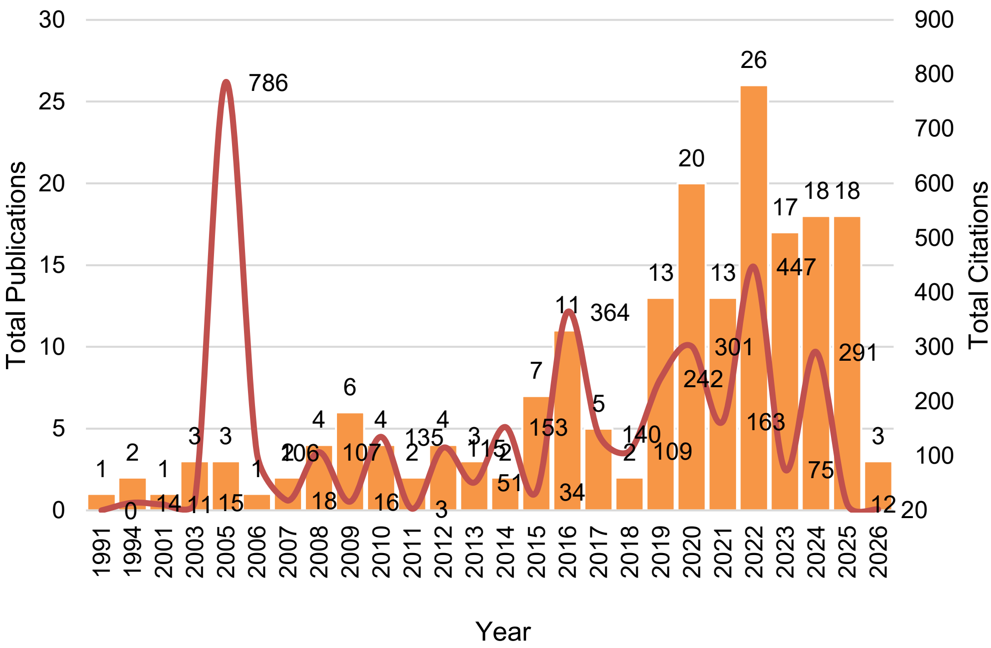
Note: TP=total number of publications; NCA=Number of contributing authors; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; g=g-index; m=m-index. Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

Figure 2 is the overall distribution of total publications and number of citations in the years 1991−2026. Bars represent total publications (TP) by year, and the line represents the total citations (TC) for each year.

Publications per year ranged between 1 and 4 between 1991 and 2014. Citation values for this era differ from one year to another and have been recorded as 0 (1991), 14 (1994), 11 (2001), 15 (2003), 786 (2005), 106 (2006), 18 (2007), 107 (2008), 16 (2009), 135 (2010), 3 (2011), 115 (2012), 51 (2013), and 153 (2014). From 2015 onward, the number of annual publications rises, 7 publications included in 2015, 11 in 2016, 5 in 2017, 2 in 2018, 13 in 2019, 20 in 2020, 13 in 2021, 26 in 2022, 17 in 2023, 18 in 2024, 18 in 2025, and 3 in 2026 respectively. They are 34 (2015), 364 (2016), 140 (2017), 109 (2018), 242 (2019), 301 (2020), 163 (2021), 447 (2022), 75 (2023), 291 (2024), 12 (2025), and 2 (2026).

The publication counts and citation values for each year are shown on the figure to show a chronological comparison of these two indicators for the whole of the study period.

Figure 2: Total Publications and Total Citations by Year



Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

4.6 Cumulative Growth of Publications Over Time (1997-2023)

The Figure 3 presents the cumulative total number of publications over time from 1991 to 2025, illustrating the progressive accumulation of publications across the study period. The horizontal axis represents the publication year, while the vertical axis shows the cumulative total number of publications. Two lines are displayed: a solid line representing the cumulative publication count and a dotted line indicating the general growth pattern.

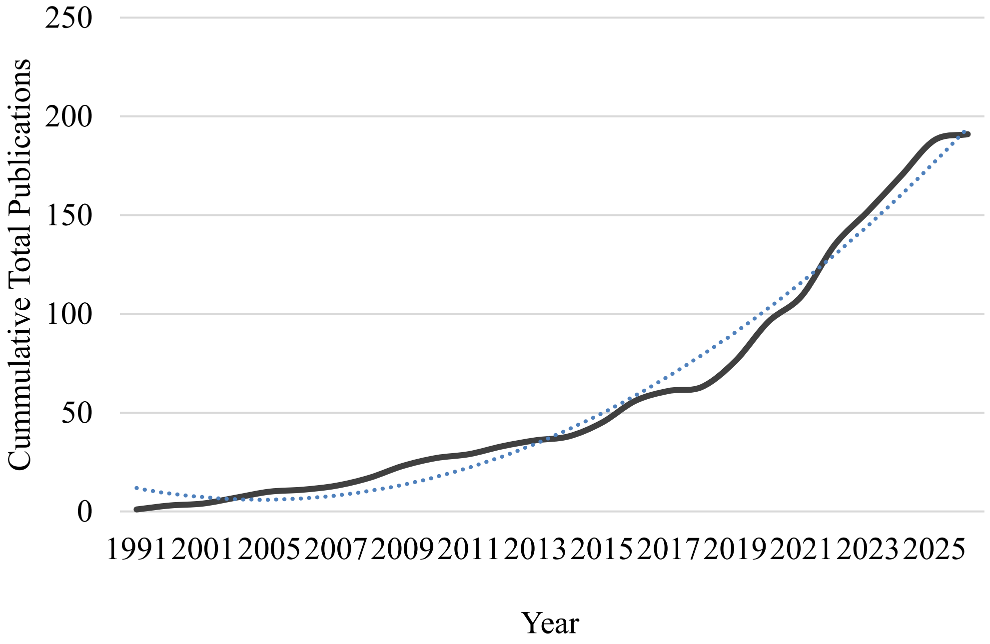
The cumulative number of publications gradually expands from 1 publication in 1991 to around 10 publications in the early 2000s. The cumulative total increases further, reaching just about 30 in 2010 and about 40 in 2013.

From 2015 onwards there is a much more rapid rise in the cumulative count, from around 50 publications in 2015 to approximately 60 in 2016 and 80 by 2018. The total continues to grow, reaching around 100 publications by 2020 and approximately 130 publications by 2021.

In the later years, the cumulative number increases further to around 160 publications by 2022 and approaches approximately 190 publications by 2024–2025. The dotted line follows a similar upward trajectory, indicating the overall pattern of cumulative growth across the years.

Taken together, the findings suggest that, the figure displays the cumulative progression of publication output over time, showing the total number of publications accumulated year by year within the dataset.

Figure 3: Cumulative Growth of Publications Over Time (1997-2023)



	Cumulative Publication Count
	General Growth Pattern

Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

4.7 Country-wise Distribution and Bibliometric Performance of Publications

Across the analysis, Table 7 reports the distribution of publications and associated bibliometric distribution of publications by country, together with their corresponding bibliometric performance indicators.

Malaysia records the highest total publications (TP = 409), with 11 contributing authors (NCA), 327 cited publications (NCP), and a total of 3,717 citations (TC). The citation per paper (C/P) is 9.09, while citation per cited paper (C/CP) is 11.37. The country also records an h-index of 32, g-index of 60, and m-index of 1.778.

The United Kingdom reports 213 publications, with 9 contributing authors and 165 cited publications, accumulating 3,536 total citations. The C/P is 16.60 and C/CP is 21.43, with an h-index of 36, g-index of 59, and m-index of 1.000.

The United States contributes 27 publications with 24 authors and 26 cited papers, generating 1,367 citations. The C/P is 50.63 and C/CP is 52.58, with an h-index of 16, g-index of 27, and m-index of 0.667.

Australia records 18 publications, 10 contributing authors, 15 cited papers, and 530 citations, with a C/P of 29.44 and C/CP of 35.33. The h-index is 9, g-index is 18, and m-index is 0.600.

Other countries reported include Ghana (TP = 16, TC = 102), Spain (TP = 14, TC = 527), China (TP = 10, TC = 28), Portugal (TP = 5, TC = 8), and the United Arab Emirates (TP = 4, TC = 360). Additional contributions are recorded from New Zealand, Iraq, Pakistan, Jordan, Lithuania, Saudi Arabia, and Indonesia, each with smaller publication counts ranging from 1 to 3 publications. It is also noted that Singapore is not listed in the publication by countries table, despite its relevance to the study context.

Table 7: Publications by Countries

Country	**TP**	**NCA**	**NCP**	**TC**	**C/P**	**C/CP**	***h***	***g***	***m***
Malaysia	409	11	327	3717	9.09	11.37	32	60	1.778
United Kingdom	213	9	165	3536	16.60	21.43	36	59	1.000
United States	27	24	26	1367	50.63	52.58	16	27	0.667
Australia	18	10	15	530	29.44	35.33	9	18	0.600
Ghana	16	NR	15	102	6.38	6.80	7	10	2.333
Spain	14	2	14	527	37.64	37.64	9	14	0.474
China	10	11	2	28	2.80	14.00	2	5	0.400
Portugal	5	2	5	8	1.60	1.60	2	2	0.125
United Arab Emirates	4	NR	4	360	90.00	90.00	4	4	1.333
New Zealand	3	4	3	28	9.33	9.33	2	3	0.250
Iraq	2	NR	2	80	40.00	40.00	2	2	0.222
Pakistan	2	2	2	41	20.50	20.50	2	2	0.667
Jordan	2	16	1	3	1.50	3.00	1	1	0.500
Lithuania	1	NR	0	0	0.00	0.00	0	0	0.000
Saudi Arabia	1	5	1	18	18.00	18.00	1	1	0.333
Indonesia	1	51	1	1	1.00	1.00	1	1	0.143

Note: TP=total number of publications; NCA=number of contributing authors; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

4.8 Key Publications and Citation Impact in Preventive Safety and Construction Risk Management

This section presents the top 20 highly cited publications in the field of preventive safety and construction risk management, based on total citations (TC) and citations per year (C/Y). The table provides details including authors, publication year, article title, source title, and corresponding citation metrics.

The listed publications span from 1994 to 2025 and are published across various sources, including journals, conference proceedings, and technical series such as *Safety Science*, *Journal of Engineering, Design and Technology*, *Journal of Safety Research*, *IEEE Transactions on Engineering Management* and *IOP Conference Series: Materials Science and Engineering*.

In terms of citation counts, the publication by Behm (2005) records the highest total citations (TC = 390) with a citation per year (C/Y) of 17.73. Another highly cited publication is by Balasubramanian et al. (2024), with 90 total citations and a C/Y of 30.00. Other publications with notable citation counts include Ahmad et al. (2019) with 28 citations (C/Y = 3.50), Asmone et al. (2022) with 14 citations (C/Y = 2.80), and Ammad et al. (2021) with 12 citations (C/Y = 2.00).

Some entries, including Ahmad et al. (2009), Asbury (2009), and Belayutham et al. (2019), are recorded with zero citations at the time of data extraction.

The citation per year (C/Y) values range from 0.00 to 30.00, reflecting the annualized citation rates of the publications. The table also includes recent publications (e.g., 2024 and 2025), which show lower citation counts or zero citations, consistent with the time of publication and data extraction.

In an overall form, Table 8 lists the main publications and citation metrics, which contributes to a structured evaluation of how the top 20 highly cited work is distributed in the data.

Table 8: Top 20 Key Publications and Citation Impact in Preventive Safety and Construction Risk Management

No.	Author(s)	Title	Source Title	TC	C/Y
1	Abas, N.H.; Abd Rahman, R.; Mohammad, H.; Rahmat, M.H. (2020)	Designer's Confidence and Attitude towards Designing-for-Construction-Safety (DfCS) Implementation	IOP Conference Series: Materials Science and Engineering	5	0.71
2	Abas, N.H.; Blismas, N.; Lingard, H. (2016)	Knowledge-based energy damage model for evaluating Industrialised Building Systems (IBS) occupational health and safety (OHS) risk	MATEC Web of Conferences	4	0.36
3	Adaku, E.; Ankrah, N.A.; Ndekugri, I.E. (2021)	Prevention Through Design: Clientsâ€™ Pre-construction Health and Safety Arrangements	Lecture Notes in Networks and Systems	1	0.17
4	Adaku, E.; Ankrah, N.A.; Ndekugri, I.E. (2022)	Prevention through design: conceptual models for the assessment of a principal designerâ€™s skills, knowledge and experience	Journal of Engineering, Design and Technology	9	1.80
5	Ahmad, A.; Bahari, I.; Mohd Zain, M.F.; Jaafar, A.; Mat Piah, O. (2009)	Construction accident in relation to safety factor in design - A proposed model	0	0	0.00
6	Ahmad, S.I.; Hashim, H.; Hassim, M.H.; Rashid, R. (2019)	A graphical inherent safety assessment technique for preliminary design stage	Process Safety and Environmental Protection	28	3.50
7	Alder, W.A.T.; Perkins, J. (2003)	The use of a safety case approach to support decision making in design	Institution of Chemical Engineers Symposium Series	1	0.04

No.	Author(s)	Title	Source Title	TC	C/Y
8	Amaechi, C.V.; Reda, A.; Beddu, S.B.; Mohamed, D.B.; Syamsir, A.; Ahmed Ja'e, I.; Ullah, S.; Deng, D.; Huang, B.; Wang, C.; Ju, X. (2025)	A systematic literature review on knowledge management for project risk management in construction	Journal of Building Engineering	0	0.00
9	Ammad, S.; Alaloul, W.S.; Saad, S.; Altaf, M.; Alawag, A.M.; Ali, M. (2021)	Building Information Modelling (BIM) and Occupational Safety in Infrastructure Projects	0	12	2.00
10	Anderson, J. (2010)	Briefing: Regulations to improve construction health and safety	Proceedings of Institution of Civil Engineers: Management, Procurement and Law	4	0.24
11	Ariffin, H.L.; Mohd, N.I.; Lim Carmen, N.N.S.; Kidam, K.; Mohammad, M.; Ali, K.N.; Mustaffa, N.E.; Rohani, J.M.; Abdullah, S.; Mat Ali, N.B.; Fetri, M.S.A.M. (2020)	Occupational safety and health in construction industry management (OSHCIM) implementation - Academician's perspectives	IOP Conference Series: Materials Science and Engineering	2	0.29
12	Arifin, K.; Juhari, M.L.; Aiyub, K. (2024)	A systematic literature review on occupational accident factors in the rail construction industry: lessons learned from a quarter-century of studies globally	International Journal of Injury Control and Safety Promotion	2	0.67
13	Asbury, S. (2009)	The CDM regulations: What difference have they made to construction safety?	Building Engineer	0	0.00

No.	Author(s)	Title	Source Title	TC	C/Y
14	Asmone, A.S.; Goh, Y.M.; Lim, M.S.H. (2022)	Prioritization of industry level interventions to improve implementation of design for safety regulations	Journal of Safety Research	14	2.80
15	Balasubramanian, S.; Shukla, V.; Islam, N.; Manghat, S. (2024)	Construction Industry 4.0 and Sustainability: An Enabling Framework	IEEE Transactions on Engineering Management	90	30.00
16	Barrie, A.; Rohani, J.M.; Kidam, K.; Mohammad, M.; Binti Sarbini, N.N.; Kamarden, H.; Ali, K.N.; Ariffin, H.L.; Mohd, N.I.; Mustaffa, N.E.; Abdullah, S.; Fetri, M.S.A.M.; Ramuseren; Ali, N.M. (2020)	Risk Assessment of Design Components of Building Construction	IOP Conference Series: Materials Science and Engineering	2	0.29
17	Barrie, A.; Rohani, J.M.; Redzuan, N. (2020)	Risk estimation of construction activities of buildings	AIP Conference Proceedings	1	0.14
18	Behm, M. (2005)	Linking construction fatalities to the design for construction safety concept	Safety Science	390	17.73
19	Belayutham, S.; Che Ibrahim, C.K.I.; Hussain, A. (2019)	Shaping the future of prevention through design (PTD) practice in the Malaysian construction industry	0	0	0.00
20	Bishop, D. (1994)	The professionals' view of the Health and Safety Commission's draft Construction (Design and Management) Regulations	Construction Management and Economics	7	0.21

Source: Generated by the author(s) using biblioMagika® (Ahmi, 2024)

4.9 Keyword Co-occurrence Network Analysis

Figure shows a network visualization of author keyword co-occurrence using VOSviewer. Nodes in the network represent keywords. Lines between nodes indicate the co-occurrence links and their thickness measures the strength of the connections. The colours in the dataset indicate clusters of related keywords.

Several colours signify clusters of related keywords in the dataset. In the network's central part are some prominent keywords, such as construction industry, safety and health, accident prevention, and construction safety. These nodes are bigger and connected to lots of links around multiple other keywords.

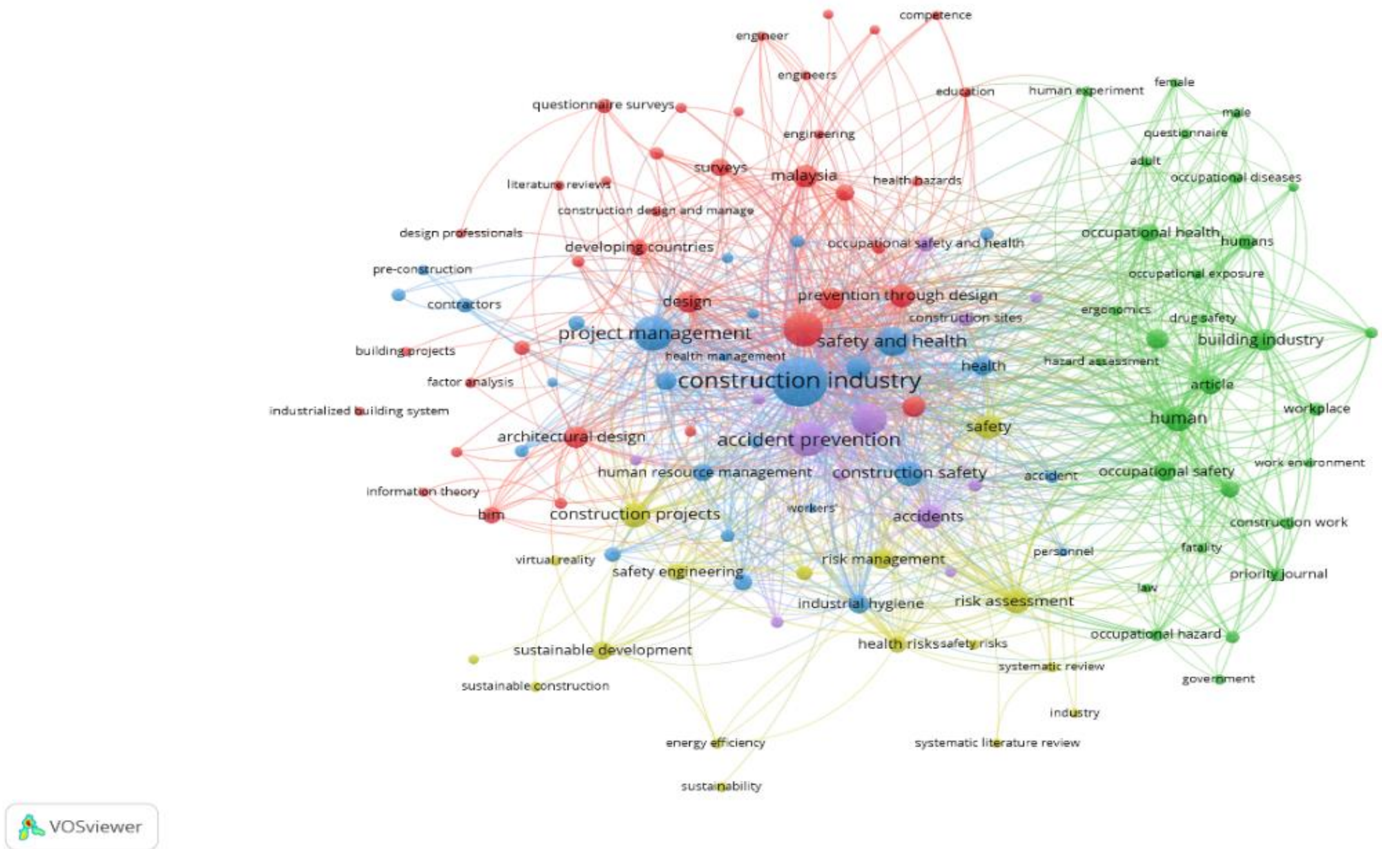
Several prominent keywords appear in the centre of the network such as construction industry, safety and health, accident prevention, and construction safety. These nodes are larger in size and connected to multiple other keywords through numerous links.

The network is divided into multiple clusters. The red cluster includes keywords such as prevention through design, design, Malaysia, surveys and developing countries. The green cluster contains keywords such as human, occupational health, building industry, workplace, and occupational safety. The blue cluster includes terms such as *project management*, *construction projects*, *architectural design*, and *contractors*. The yellow cluster features keywords such as *risk management*, *risk assessment*, *industrial hygiene* and *sustainable development*.

Additional keywords appearing in the network include *BIM*, *virtual reality*, *safety engineering*, *accidents*, *health*, *workers* and *construction sites*. These keywords are positioned across different clusters and connected through multiple co-occurrence links.

In general, the Figure 4 displays the relationships among author keywords based on their co-occurrence, showing node size, link connections and clustered groupings within the dataset.

Figure 4: Network Visualization of the Co-occurrence Analysis of the Author Keywords



Source: Generated by the author(s) using VOSviewer (van Eck & Waltman, 2014)

4.10 Keyword Overlay Visualization Analysis

Figure 5 presents an overlay visualization of author keyword co-occurrence generated using VOSviewer. Each node represents a keyword, with node size indicating frequency of occurrence, and links representing co-occurrence relationships between keywords. The colour of each node corresponds to the average publication year, based on the colour scale displayed in the figure.

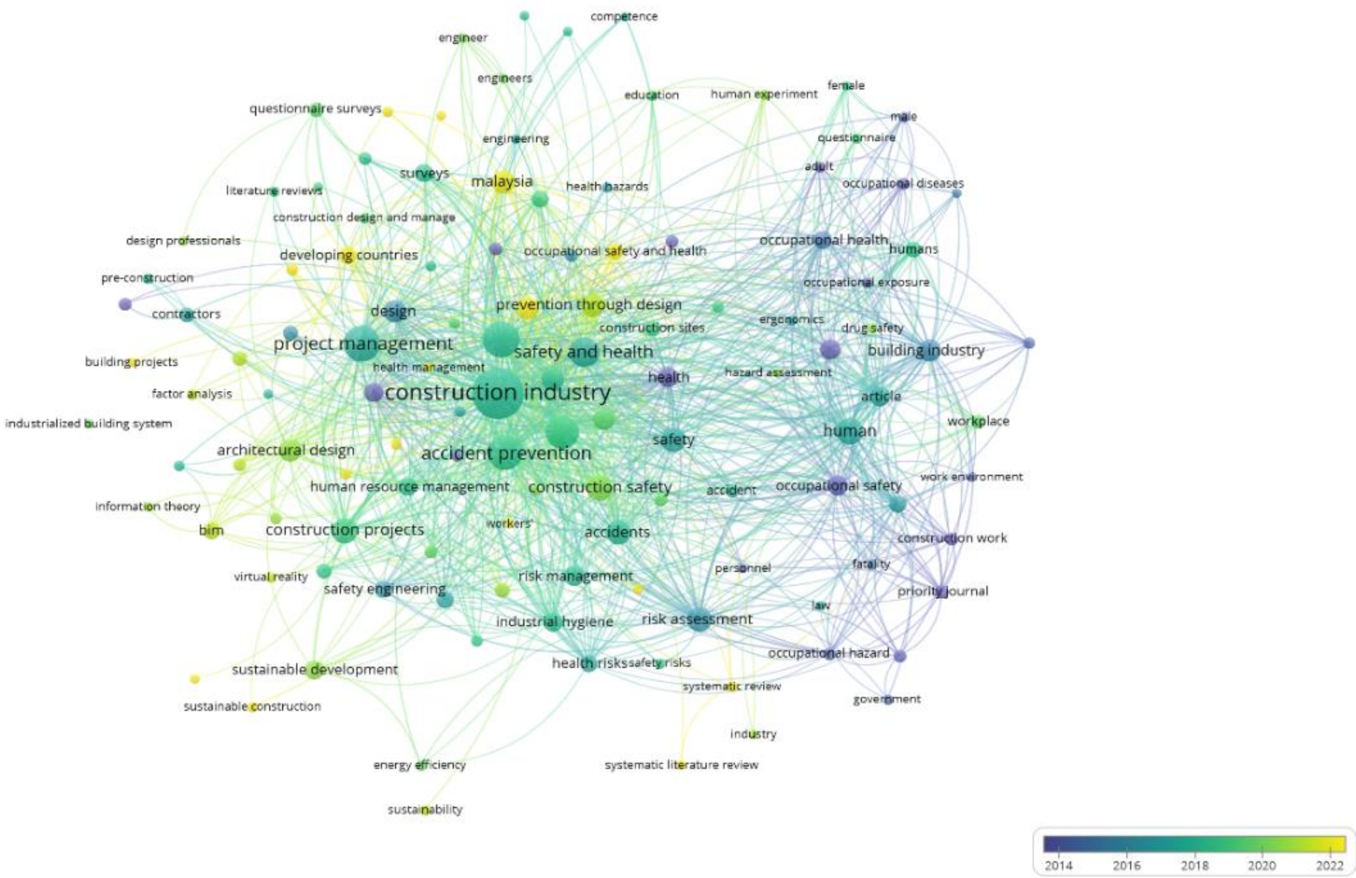
The colour variation follows a gradient ranging from blue to yellow. Blue-coloured nodes represent earlier average publication years, approximately around 2014 to 2016. Green-coloured nodes are mid-range publication years, between 2017 and 2019. Yellow-coloured nodes indicate more recent average publication years, approximately from 2020 to 2022.

Darker blue tones of the keywords also reflect the earlier published years in terms of publication methods (occupational diseases, questionnaire, building industry). Green-coloured keywords include construction industry, safety and health, accident prevention, and construction safety, which correspond to mid-range publication years. Yellow tones for keywords are systematic review, sustainable development, construction 4.0, and risk assessment, denoting more recent average publication years.

Other keywords you can see throughout the network are prevention through design, Malaysia, design, project management, human, occupational safety, workplace, construction projects, architectural design, BIM, virtual reality, industrial hygiene, and energy efficiency. The keywords spread out at different colour scales and are interconnected via multiple co-occurrence links.

Based on the outcomes, the figure shows the relationship with co-occurrence of author keywords and the average years of publication associated with them, as the colors transition from blue (earlier) to yellow (more recent).

Figure 5: Overlay visualization of the co-occurrence analysis of the author keywords



Source: Generated by the author(s) using VOSviewer (van Eck & Waltman, 2014)

4.11 From Reactive to Preventive Safety: Evolution of Construction Safety Research Themes Through Keyword Analysis

Table 9 displays the keyword-based classification of construction safety research themes and divides content into three categories in time (older keywords pre-2016, transitional keywords 2016–2019, and newer keywords post-2019) in three columns: category, keywords, and interpretation. The initial category, referred to as foundational themes, consists of construction industry, safety and health, accident prevention, occupational safety, occupational health, human, workplace, building industry, construction work, risk assessment, industrial hygiene, and accidents, and the interpretation column identifies these with the usual safety management emphasis on reactive features, compliance and incident-based analysis. The second category, transitional keywords, consists of risk management, construction safety, project management, human resource management, safety engineering, ergonomics, occupational exposure, health risks, and safety culture; a shift to formal and systematic approaches to safety management including its organizational and behavioural components can be detected through the table. The third category, more recent keywords, includes terms such as prevention through design (PtD), design, BIM, virtual reality, sustainable construction, sustainability, developing countries, Malaysia, questionnaire surveys, education and competence and the interpretation column refers to them as an indicator that preventive and proactive paradigm, including design-stage interventions, digital technologies and sustainability integration in addition with the alignment with the contemporary frameworks such as CDM and DRA. In other words, the table explicitly presents the keyword distribution in each time-bound category and corresponding descriptions of the research focus pertaining to the grouping.

Table 9: Evolution of Research Themes in Construction Safety: A Keyword-Based Classification

Category	Keywords	Interpretation
Older Keywords (Pre-2016 / Foundational Themes)	construction industry, safety and health, accident prevention, occupational safety, occupational health, human, workplace, building industry, construction work, risk assessment, industrial hygiene, accidents	Represent traditional safety management focus—reactive approaches, compliance, and incident-based analysis. These form the core foundation of construction safety research in Malaysia.
Transitional Keywords (2016–2019)	risk management, construction safety, project management, human resource management, safety engineering, ergonomics, occupational exposure, health risks, safety culture	Reflect a shift toward more structured and systematic safety management approaches, incorporating organizational and behavioural dimensions.
Newer Keywords (Post-2019 / Emerging Themes)	prevention through design (PtD), design, BIM, virtual reality, sustainable construction, sustainability, developing countries, Malaysia, questionnaire surveys, education, competence	Indicate a proactive and preventive paradigm—focusing on design-stage interventions, digital technologies, and sustainability integration. Strong alignment with modern frameworks like CDM and DRA concepts.

Source: Developed by the author(s) based on bibliometric analysis of the Scopus dataset using VOSviewer and biblioMagika® (Ahmi, 2024).

4.12 Keyword Density Visualization of Research Themes in Construction Risk Management and Preventive Safety

The Figure 6 presents a keyword density visualization generated using VOSviewer, illustrating the distribution and concentration of author keywords within the dataset. In this visualization, colours represent the density of keyword occurrences, where brighter colours (yellow) indicate higher concentrations, and darker colours (green to blue) indicate lower concentrations.

The highest density areas (yellow zones) are observed around keywords such as construction industry, safety and health, project management, and accident prevention. These keywords appear prominently at the centre of the map and are surrounded by closely related terms.

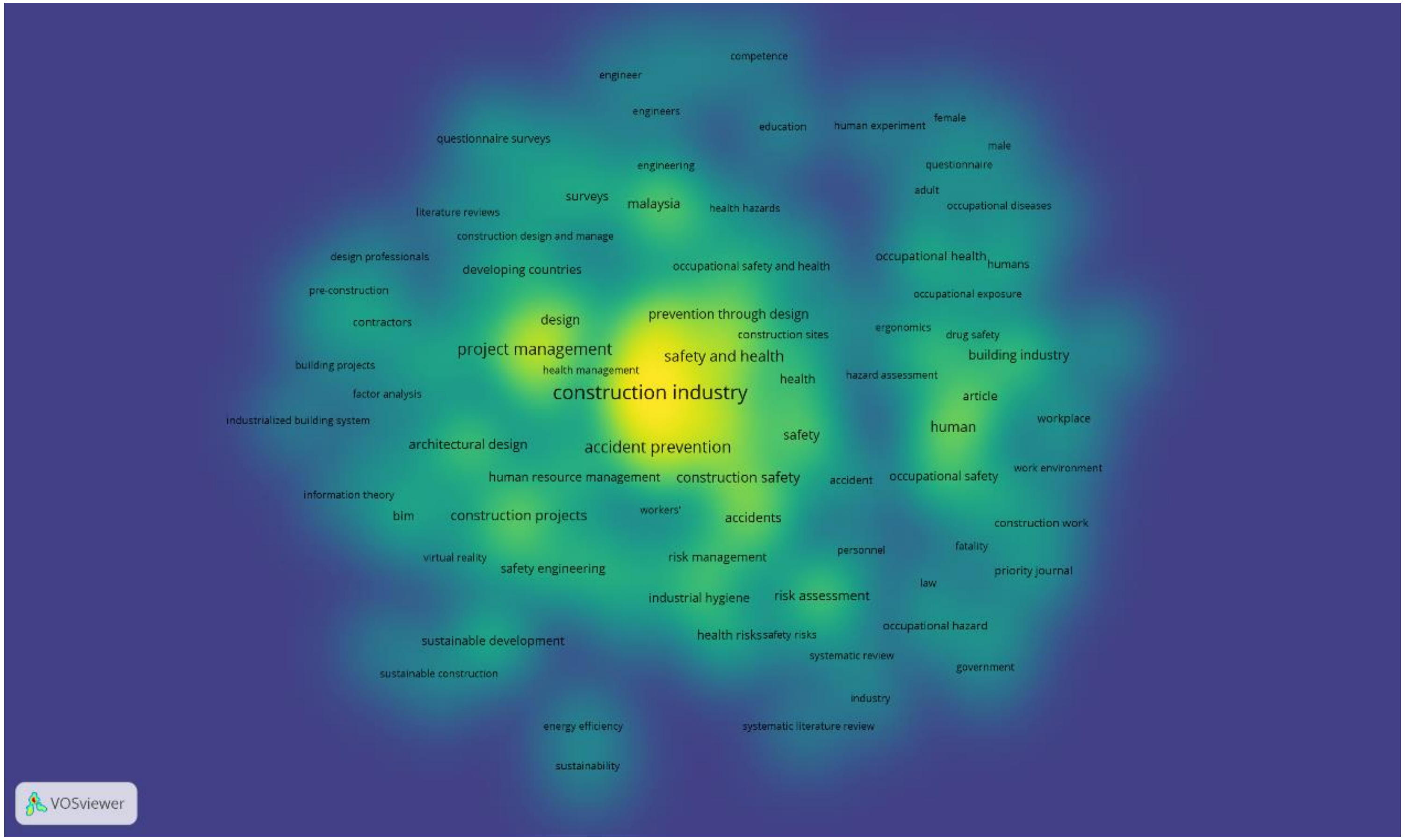
Moderate density areas (green zones) include keywords such as construction safety, human, building industry, design, prevention through design, risk management, and construction projects. These keywords are distributed around the central region and connected to multiple surrounding terms.

Lower density areas (blue zones) are observed at the outer regions of the map, where keywords such as sustainable development, sustainability, energy efficiency, systematic literature review, government, law, occupational hazard, and industrialized building system are located. These keywords appear more dispersed and are positioned further from the central cluster.

Additional keywords visible across the visualization include *BIM*, *virtual reality*, *safety engineering*, *architectural design*, *occupational health*, *workplace*, *ergonomics*, *education*, and *Malaysia*. These are distributed across varying density levels within the network.

When viewed collectively, the figure displays the concentration and spatial distribution of keywords, highlighting areas of high, moderate and low density based on their frequency and co-occurrence within the dataset.

Figure 6: Keyword Density Visualization Analysis



Source: Generated by the author(s) using VOSviewer (van Eck & Waltman, 2014)

4.13 Case Study: Comparative Analysis of CDM and DfS Regulatory Frameworks in the United Kingdom, Singapore and Malaysia

This section presents a comparison outlined in Table 10 of regulatory frameworks in the United Kingdom, Singapore, and Malaysia across key aspects related to construction safety and design-stage risk management. The comparison is structured based on regulatory approach, legal basis, applicability, duty-holder roles, and implementation mechanisms.

The United Kingdom adopts a comprehensive lifecycle framework under CDM 2015, covering design, construction, and handover stages. Singapore applies a design-focused approach under the DfS regime, with emphasis on eliminating risks at the design stage. Malaysia's CDM 2024 reflects a similar lifecycle structure to the United Kingdom, covering all project phases.

The legal foundations vary from one country to another. The UK framework is based on the Health and Safety at Work etc. Act 1974, Singapore under the Workplace Safety and Health Act, while Malaysia is under OSHA 1994 (Act 514).

In terms of applicability, the United Kingdom and Malaysia frameworks are applicable to all construction projects, with the United Kingdom including additional requirements for notifiable projects. There are regulations under the DfS which apply predominantly to large-scale projects having a contract value of SGD 10 million or more, as stipulated by Singapore statute.

In the United Kingdom, for duty-holder responsibilities, the client is accountable for project arrangements, resources, and appointments. The developer is responsible for removing design risks and coordinating the DfS process in Singapore. In Malaysia, the client must guarantee appropriate time, funding, resources, and safety arrangements.

In terms of design responsibilities, the United Kingdom assigns a Principal Designer (PD) to manage the pre-construction phase; in Malaysia, a Principal Construction Work Designer (PCWD) carries out similar functions. Singapore does not have such a direct function, although a professional in the DfS can be employed to assist the developer.

For construction roles in the United Kingdom, a Principal Contractor (PC) has been designated to manage the construction phase, whereas Malaysia has the Principal Construction Work Contractor (PCWC), which is similar. In Singapore, contractors perform general functions but do not have a centralised role equivalent to the United Kingdom system.

These frameworks cover the management of design risk, including procedures to eliminate or control risks during the design stage. The client or developer in all three systems is required to provide pre-construction information. In both the United Kingdom and Malaysia, a construction phase plan is mandatory, while in Singapore, the focus is primarily on design-stage processes.

Strict documentation requirements involve a Health and Safety File in the United Kingdom, a Design-for-Safety Register in Singapore, and a Safety and Health File in Malaysia. Mechanisms for conducting design reviews differ: Singapore requires formal DfS review meetings, while the United Kingdom and Malaysia rely on coordination through designated roles without a specified formal meeting requirement.

Notification requirements in the United Kingdom and Malaysia are established based on project duration and the size of the workforce, while Singapore does not outline an equivalent threshold. Competency requirements are present in all three frameworks — the duty holder is required to have the requisite skills, knowledge, and experience.

In the United Kingdom, worker engagement is mandated through the Principal Contractor and PCWC in Malaysia, although it is not explicitly emphasised in Singapore's DfS regulations. For domestic clients, both the United Kingdom and Malaysia provide mechanisms for transferring duties, whereas this is not specifically highlighted in Singapore.

Enforcement of the United Kingdom system is by the Health and Safety Executive (HSE), Singapore by the Ministry of Manpower (MOM), and Malaysia by the relevant authority, with provisions including fines of up to RM500,000 and potential imprisonment.

Table 10: Comparison of Construction Safety Regulatory Frameworks: UK CDM 2015, Singapore DfS 2015 and Malaysia CDM 2024

Aspect	**UK (CDM 2015)**	**Singapore (DfS 2015)**	**Malaysia (CDM 2024)**
Regulatory Approach	Comprehensive lifecycle CDM (design → construction → handover)	Design-focused (DfS) – strong emphasis on eliminating design risks	Mirrors UK CDM structure with full lifecycle coverage
Legal Basis	Health and Safety at Work etc. Act 1974	Workplace Safety and Health Act	OSHA 1994 (Act 514)
Applicability Threshold	Applies to all construction projects (with additional rules for notifiable projects)	Applies mainly to large projects (≥ SGD 10M contract sum)	Applies to all construction projects
Key Duty Holder (Client / Developer)	Client responsible for project arrangements, resources, and appointments	Developer responsible for eliminating design risks and coordinating DfS process	Client responsible for time, funds, resources, and safety arrangements
Primary Design Role	Principal Designer (PD) – manages pre-construction phase and coordination	No PD equivalent; Developer leads DfS, may appoint DfS professional	Principal Construction Work Designer (PCWD) – equivalent to UK PD
Construction Role	Principal Contractor (PC) – manages construction phase	Contractor has general duties; less centralised than UK	Principal Construction Work Contractor (PCWC) – mirrors UK PC
Design Risk Management	Mandatory application of general principles of prevention during design	Strongest emphasis: eliminate or reduce design risks at source	Same principle as UK – eliminate or control risks during design

Aspect	UK (CDM 2015)	Singapore (DfS 2015)	Malaysia (CDM 2024)
Pre-Construction Information	Must be provided by client to designers/contractors	Required via information sharing by developer	Mandatory provision by client
Construction Phase Plan	Required before construction begins	Not explicitly required (focus is design stage)	Mandatory and similar to UK
Health & Safety File / Register	Health & Safety File required and maintained	Design-for-Safety Register (focus on residual risks)	Safety & Health File required (equivalent to UK)
Design Review Mechanism	Coordination via PD (no formal review meeting requirement)	Mandatory DfS review meetings	Coordination via PCWD (no formal meeting requirement specified)
Notification Requirement	Required if >30 days & 20 workers OR >500 person-days	No equivalent notification threshold	Required if >30 days OR >500 person-days
Competency Requirements	Duty holders must have skills, knowledge, experience, organisational capability	Developer must ensure competent designers and contractors	Same as UK with explicit competency requirement
Worker Engagement	Mandatory consultation and engagement by Principal Contractor	Not explicitly emphasised in DfS regulations	Mandatory engagement by PCWC
Domestic Client Treatment	Duties transferred to contractor/PD	Not specifically emphasised	Similar transfer mechanism as UK
Enforcement & Penalties	Enforced by HSE; compliance-based	Enforced by MOM; compliance-focused	Stronger penal provisions (fines up to RM500,000 & imprisonment)

Source: Compiled by the author based on regulatory documents from the Health and Safety Executive (HSE), United Kingdom; Ministry of Manpower (MOM) and Workplace Safety and Health Council (WSH Council), Singapore and Department of Occupational Safety and Health (DOSH), Malaysia.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Discussion of Major Findings

This study presents a broad view of the evolution of the research and practice of construction safety with respect to both prevention and design-stage approaches. Combining bibliometric analysis with a comparative review of regulations, the findings demonstrate a paradigm shift away from reactive, site-based safety measures toward proactive, design-led, and regulation-driven frameworks. This paradigm shift is in line with industrial trends towards early risk recognition, the integration of life cycle safety, and knowledge-based risk management (Hardison & Hallowell, 2019; Zhou, Irizarry, & Li, 2021).

5.1.1 Maturation of the Research Field

It highlights the continued growth, the increasing collaborative approach, and the formation of a more stable and well-structured body of knowledge in the field of research. Although a main group of influential studies still dominate the literature, newer research highlights a growing emphasis on preventive safety and design-stage risk management. This trend reflects that construction safety is no longer considered an operational issue, but a strategic consideration integrated across the project lifecycle, underpinned by developments in risk management practices and knowledge integration (Amaechi et al., 2025; Hardison & Hallowell, 2019).

Nonetheless, the uneven effects of research seem to indicate that the field is still at a stage of consolidation. These specific areas, such as regulatory integration and design-stage implementation, are important for further depth and empirical validation, which are essential in this paper. This is particularly noticeable within emerging contexts like Malaysia, as existing literature continues to be sparse and fragmented, thus emphasising the need for more localised studies and practical implementation frameworks to connect theories with practice (Zou et al., 2014; Ismail, Rahim, & Yusof, 2023).

5.1.2 Shift Toward Design-Stage and Preventive Safety

A particularly relevant finding that emerged as being present in all of the analyses is the tendency towards design-stage risk management. Modern terminology, like Prevention through Design (PtD), Design for Safety (DfS) and Design Risk Assessment (DRA), is more often associated with a transformation in attitudes towards safety from managing risks on-site to eliminating them at source (Ahmad et al., 2019; Hardison & Hallowell, 2019). This trend parallels findings that indicate early design interventions can significantly reduce construction hazards and contribute to broader success in terms of safety (Rafindadi et al., 2022).

This transition is facilitated through an increasing association between safety and the project management process, as well as the organisational processes and digital technologies. Building Information Modelling (BIM) and similar tools provide better coordination, hazard visualisation, and informed decision-making during the early stages of a project (Rafindadi et al., 2022; Zhou, Irizarry, & Li, 2021). Thus, effective safety management increasingly depends on early-stage decision-making, interdisciplinary collaboration, and structured planning, rather than relying on reactive compliance measures during construction (Zou et al., 2014).

5.1.3 Increasing Integration and Interconnectivity of Research Themes

The findings further demonstrate that construction safety research continues to become intertwined. Yet, while traditional safety themes persist, they correlate much more closely with new digitalisation (e.g., Building Information Modelling [BIM]), sustainability, and lifecycle management issues. Such trends are also in line with prevailing research documenting the adoption of digital technologies and knowledge management systems for construction risk management, enabling more holistic and data-driven approaches to safety (Amaechi et al., 2025; Zhou, Irizarry, & Li, 2021).

This is indicative of growing attention to a comprehensive view of safety within construction, rather than working in a vacuum. In particular, the embedding of BIM and lifecycle thinking will enable safety perspectives to be embedded throughout design, construction and operational phases, leading to better coordination and long-term risk management (Rafindadi et al., 2022; Marefat et al., 2019). To this end, this research supports the view that Design Risk Assessment (DRA) should not be seen as one resource or an isolated process but as part of a wider system which encompasses design processes, risk management strategies and regulatory compliance frameworks and provides for a more effective and sustainable measure of safety (Hardison & Hallowell, 2019).

5.1.4 Emerging Role of Technology and Lifecycle Thinking

Technology and lifecycle considerations, meanwhile, are getting more pressing with respect to construction safety. Digital technologies, integrated with contemporary building practices, mirror the industry's response to growing project complexity, especially in the development of smart facilities, advanced infrastructure, and sustainable buildings (Zhou, Irizarry, & Li, 2021). Building Information Modelling (BIM) and equivalents improve visualisation, coordination, and enable early hazard identification at all stages of a project, thereby allowing more effective decision-making at every step of a project (Rafindadi et al., 2022).

This evolution highlights the need for safety beyond the construction phase to extend to operation, maintenance, and long-term asset performance. Lifecycle-based approaches recognise that risks emerge from both construction and the utilisation and maintenance of facilities, necessitating continuous safety integration across all project phases (Marefat et al., 2019). Such a holistic approach with an emphasis on prevention measures is recommended in line with lifecycle risk management, as preventive safety concepts like Design Risk Assessment (DRA) should be incorporated in these concepts, allowing safety considerations to be embedded from design through to asset operation and end use (Hardison & Hallowell, 2019).

5.1.5 Global Influence and Local Implementation Gaps

The country-level analysis shows that research on construction safety is globally distributed, but its influence remains concentrated in more mature research environments with well-established regulatory systems and industry practices (Lingard & Rowlinson, 2020). In comparison, Malaysia highlights increasing research but still shows a noticeable gap in research impact and practice uptake.

This mirrors challenges highlighted in the literature as they relate to the inability of literature to translate into practice, often due to lack of localized study, poor guidance, and capability gaps among stakeholders (Ismail, Rahim, & Yusof, 2023; Azis, Abdul Rahman, & Ismail, 2022).

This indicates that while there is a sound theoretical base for preventive safety, especially in the domain of design-stage risk management, applying preventive safety in the industry is a difficulty to resolve. This persistent disjointedness between research, regulatory frameworks, and practices on site has been acknowledged as one of the major issues of health and safety for construction in this era (Zou et al., 2014). Thus, there is a critical requirement for greater coupling between research, regulation, and deployment, notably for the advancement of Design Risk Assessment (DRA) in practice with real projects.

5.1.6 Regulatory Effectiveness Depends on Implementation Capacity

Regulations only do part of the work, and really what matters is implementation, the analysis reveals. Effective safety systems are those that bring safety into the project early, especially at the design stage, clearly define who is responsible for what, enforce the rules consistently, and ensure that industry players have the right skills and knowledge. While Malaysia's CDM 2024 is a strong step forward, the extent of its influence will depend on how well these components function in practice, especially in building stakeholder capability, strengthening enforcement, and ensuring design-stage safety is actually applied on the ground.

5.1.7 Overall Synthesis

Together, these results suggest that construction safety is experiencing a clear paradigm shift, toward an approach that is anticipatory, holistic, and design-oriented. The safety design domain is still rooted in long-held safety practices, but continues to evolve with advancements in digital technologies, regulatory developments, and increased focus on lifecycle risk management (Hardison & Hallowell, 2019; Zhou, Irizarry, & Li, 2021). This change mirrors the increasing awareness that good safety has to be implemented in an early stage of a project, not reactively performed during construction.

The implications for this investigation are hence clear. First, Design Risk Assessment (DRA) is in line with the current developments in research and industry practice, particularly with the accelerating adoption of design-stage risk management such as Prevention through Design (PtD) (Ahmad et al., 2019). Second, its effective adoption in Malaysia necessitates not only regulatory backing, but also substantial enhancement of the skills of the stakeholders involved, cross-cutting coordination, and practical application, as reported in capacity gaps within the industry (Azis, Abdul Rahman, & Ismail, 2022). Third, developing a strong integration of design processes, regulation, and on-site enforcement is key for reaching significant and sustainable safety gains, especially in bridging the gap between policy intent and practice (Zou et al., 2014).

When weighed together, the findings suggest that the future of construction safety lies in shifting risk management upstream into the design stage, with rigorous regulation and strengthened industry capacity. Such a paradigm is further illustrated by evidence based on early-stage approaches and digital tools including BIM for hazard identification and safety enhancements (Rafindadi et al., 2022). As so, promoting DRA within the Malaysian context does more than only pose the regulatory requirement; it is a needed advance of more effective preventive and lifecycle-oriented construction safety.

5.2 Implications of the Study

5.2.1 Theoretical Contributions

This study adds to the literature by integrating bibliometric analysis with comparative regulatory evaluation and, consequently, provides a more focused and structured picture of the evolution of preventive safety and construction risk management over time. Instead of focusing solely on research trends, the research situates them within the broader context of regulatory development, revealing how theory, policy, and practice are increasingly interconnected in shaping safer construction environments (Amaechi et al., 2025; Zou et al., 2014).

One of the main contributions to our work is to show that the development of the keywords is representative of the changing direction of research. The movement away from traditional, reactive safety themes to design-stage safety approaches, digital tools, and sustainability signals the advent of more proactive, integrated, and lifecycle-based safety in practice. This tendency aligns with studies suggesting an increasing use of Prevention through Design (PtD) and digital technologies, like Building Information Modelling (BIM), for early-stage hazard identification and safety planning (Rafindadi et al., 2022; Ahmad et al., 2019). Additionally, the alignment of these developments with regulatory frameworks such as CDM confirms the value in implementing safety within both design processes and governance structures (Lingard & Rowlinson, 2020).

These insights offer an important view of future research that suggests a future of interdisciplinary approaches that draw from design, technology, regulation, and organisational behaviour for a better integration of design and technology in future work. This has been especially concerning given that a gulf between regulatory intent and actual implementation (Zou et al., 2014) is still evident in construction safety literature as evidenced by the failure of this domain to make significant or systemic improvements. In future research on emergent contexts including

Malaysia this framework can be supplemented by developing more tailored models, applied tools and methods of working to improve both the efficiency of design-stage risk management and the adoption process of the sector (Azis, Abdul Rahman, & Ismail, 2022).

Generally, this study complements the theoretical grounding of preventive safety studies by mapping the research subject into real-world regulatory concerns, while also providing a future-looking perspective on how the field may keep evolving to solve the emerging challenges of industry and to respond to technical developments (Hardison & Hallowell, 2019; Zhou, Irizarry, & Li, 2021).

5.2.2 Practical and Policy Implications

Findings have practical bearing for the policymakers, regulators, and industry practitioners, in that they show how preventive safety may be more practically performed rather than considered as a concept. By combining research of bibliometric trends and comparative regulatory frameworks, the paper draws our attention to the need for a coordinated and systematic approach to increasing the safety of construction – that starts very early in the construction lifecycle and is backed by clearly defined systems, roles, and enforcement mechanisms (Amaechi et al., 2025; Zou et al., 2014).

From a policy perspective, the report also reveals improved design-stage risk management with a clear delineation of responsibilities for clients, designers, and contractors. It is based on the Prevention through Design (PtD) principles which focuses on early hazard elimination and the introduction of a well-planned safety during project development (Ahmad et al., 2019). Regulators should therefore not take a broad approach, but establish clear guidelines, specific tools or measures to ensure uniform application of the applicable legislation. This is particularly relevant in emerging contexts, namely Malaysia, where the transition to CDM 2024 necessitates not just regulatory congruence, but also improved industry readiness, competency and institutional capacity (Azis, Abdul Rahman, & Ismail, 2022).

From an industry perspective, the results reinforce the crucial role of rigorous mechanisms such as design reviews, as well as the application of digital tools including Building Information Modelling (BIM) to promote early identification of hazards and an interdisciplinary approach. There is solid evidence that BIM approaches make a remarkable contribution to improving safety planning, hazard visualisation and training effectiveness, which enhances overall project safety performance (Rafindadi et al., 2022). Meanwhile, enhancing the competencies, training, and awareness of stakeholders remains important to embed preventive safety as an integral aspect of the project delivery (Zhou, Irizarry, & Li, 2021) rather than regarding it as a compliance issue.

For policymakers and practitioners, the study also provides important implications in guiding future policy development and practice by showing priority areas for improvement. It underlines the need for localised development of guidelines, improved enforcement, and stronger alignment between regulatory intent and actual implementation, which has been acknowledged as a continuing issue facing construction safety for years (Zou et al., 2014). Finally, for both researchers and practitioners, the findings provide a clearer pathway for advancing preventive safety—practical, integrated, and responsive to the increasing complexity of modern construction projects (Hardison & Hallowell, 2019).

5.3 Limitations of the Study

There are several limitations that must be recognized in this research. First, only the Scopus database is included in the analysis and such data coverage, known as the Scopus database with its comprehensive coverage of peer-reviewed literature, however, does not extend to all the relevant publications especially those indexed

in other databases such as Web of Science or Google Scholar as well as local and industry-based databases (Amaechi et al., 2025). Consequently, despite the robustness of the database, the general coverage of this dataset could be limited.

Second, bibliometric analysis is inherently dependent on available metadata, which may contain inconsistencies even after data cleaning and standardisation. Variations in author names, keyword usage, and indexing practices can influence the accuracy of mapping research trends and relationships, potentially affecting the interpretation of findings (Zou et al., 2014).

Third, the regulatory analysis in this study is based on document review, which enables structured comparison across different frameworks but may not fully capture actual implementation practices. In reality, discrepancies often exist between policy intent and industry application, influenced by factors such as organisational behaviour, stakeholder competency, and enforcement capacity (Zhou, Irizarry, & Li, 2021; Azis, Abdul Rahman, & Ismail, 2022).

5.4 Recommendations for Future Research

Building on these limitations, several directions for future research can be identified. First, expanding the dataset to include additional databases such as Web of Science or Google Scholar would enhance the breadth of coverage and improve the robustness of the analysis, as multi-database approaches are commonly recommended in systematic literature reviews to capture a more comprehensive body of knowledge (Amaechi et al., 2025).

Based on these limitations, several avenues for future research on data analysis could be drawn. First, widening the approach of the dataset to include additional databases like Web of Science or Google Scholar could widen the coverage from scope of data and add significant rigour to the analysis, which is consistent with a multi-database approach for systematic literature reviews to allow more comprehensive body of knowledge to be collected (Amaechi et al., 2025).

Furthermore, further developments could add empirical data on case studies, interviews, and industry surveys out among document-oriented studies. This approach as well as the previous ones would give more insight into how preventive safety measures are practised in real project environments and serve to link the research practice gap noted as a recurring problem in construction safety research studies (Zou et al., 2014).

Moreover, there is strong potential for further research on digital tools and emerging technologies. BIM (Building Information Modelling), AI, and knowledge-based systems are several prominent domains where design-stage risk management can be augmented and existing processes for risk identification can be improved. Previous studies have already demonstrated the effectiveness of BIM for visualisation, coordination, and early risk detection; however, further research is required to understand how such technologies can be systematically integrated into existing regulatory frameworks and industry practices (Rafindadi et al., 2022; Zhou, Irizarry, & Li, 2021).

In summary, it can be concluded that not only should new theoretical concepts be developed for future research but also their operationalisation need to be taken into consideration. This is particularly relevant in the Malaysian context, where implementation of preventive safety is challenging not only in terms of adopting preventive safety approaches but also operationalising them into its industry environment through improved competency, guidance, and implementation strategies (Azis, Abdul Rahman, & Ismail, 2022).

5.5 Conclusion

These findings further highlight the evolution of construction safety, focusing on preventive and design-stage approaches, both of which are key areas in this FYP. This study illustrates a trend from traditional, reactive safety practices towards more structured, design-led, and regulation-driven approaches through bibliometric analysis as well as comparative regulatory review. This shift aligns with wider trends in construction safety research and practice highlighting the importance of early hazard identification and lifecycle-based methods for risk management (Hardison & Hallowell, 2019; Zhou, Irizarry, & Li, 2021). It also shows that jurisdictions like the United Kingdom, Singapore, and Malaysia incorporate preventive safety as part of well-defined responsibilities, legal frameworks, and early design-stage interventions (Health and Safety Executive [HSE], 2015; Ministry of Manpower [MOM], 2016; Department of Occupational Safety and Health [DOSH], 2024).

Yet, the study acknowledges that the construction industry today is increasingly complex. New development trends such as data centres, smart warehousing and sustainable buildings offer new types of risks that transcend the construction phase. This emphasizes the need to consider safety throughout the project lifecycle, including operation and maintenance phases, in response to long-term performance, system integration and user safety as critical concerns (Marefat et al., 2019).

The new CDM Regulations 2024 in Malaysia and the associated Occupational Safety and Health Master Plan (OSHMP) 2021–2025 represent a progressive push towards improving preventive safety measures and adherence to international standards (DOSH, 2021, 2024). Nevertheless, for mechanisms like Design Risk Assessment (DRA) to be put into place, industry readiness should be higher. Enhancing stakeholder competence, consistency in enforcement, and adopting digital techniques such as Building Information Modelling (BIM) has all contributed to improving design-phase decision making and hazard detection (Rafindadi et al., 2022; Azis, Abdul Rahman, & Ismail, 2022).

In conclusion, the research indicates that to promote construction safety in general and construction safety with DRA in particular, a more comprehensive and future-oriented approach is needed. Through closer integration of regulatory frameworks, design practices and technological tools in the project lifecycle, Malaysia has an opportunity to improve its ability to address risks at earlier stages and more effectively, according to modern construction safety theories and global standards (Lingard & Rowlinson, 2020; Hardison & Hallowell, 2019).

REFERENCES

Abas, N. H., Blismas, N., & Lingard, H. (2014). *Knowledge-based energy damage model for evaluating industrialised building systems (IBS) occupational health and safety (OHS) risk.* MATEC Web of Conferences from https://doi.org/10.1051/matecconf/20144704015

Abas, N. H., Blismas, N., & Lingard, H. (2016). *Knowledge-based energy damage model for evaluating industrialised building systems (IBS) occupational health and safety (OHS) risk.* MATEC Web of Conferences, 47, 04015, from https://doi.org/10.1051/matecconf/20164704015

Abas, N. H., Abd Rahman, R., Mohammad, H., & Rahmat, M. H. (2020). *Designer's confidence and attitude towards designing-for-construction-safety (DfCS) implementation*. IOP Conference Series: Materials Science and Engineering, 713, 012045, from https://doi.org/10.1088/1757-899X/713/1/012045

Abueisheh, Q., Manu, P., Mahamadu, A.M., Cheung, C. (2020). Design for safety implementation among design professionals in construction: The context of Palestine. *Safety Science*. 128 (April), 104742 https://doi.org/10.1016/j.ssci.2020.104742.

Adaku, E., Ankrah, N.A., Ndekugri, I.E. (2021*). Prevention though Design: Conceptual models for the assessment of a principal designer's skills, knowledge and experience.*

Adaku, E., Ankrah, N. A., & Ndekugri, I. E. (2022). Prevention through design: Conceptual models for the assessment of a principal designer's skills, knowledge and experience. *Journal of Engineering, Design and Technology,* 20(3), 595–623, from https://doi.org/10.1108/JEDT-07-2020-0278.

Ahmad, A., Bahari, I., Mohd Zain, M. F., Jaafar, A., & Mat Piah, O. (2009). Construction accident in relation to safety factor in design: A proposed model. *Journal of Design and Built Environment*, 5(1), 27–36.

Ahmad, S. I., Hashim, H., Hassim, M. H., & Rashid, R. (2019). A graphical inherent safety assessment technique for preliminary design stage. *Process Safety and Environmental Protection,* 130, 275–287, from https://doi.org/10.1016/j.psep.2019.08.024

Ahmad, N., Mohd Shariff, A., & Zaini, D. (2019). A graphical inherent safety assessment technique for preliminary design stage. *Process Safety and Environmental Protection*, 123, 274–288.

Ahmi, A. (2025). Leveraging bibliometrics and AI: Empowering Islamic studies scholars to uncover emerging topics and navigate diverse perspectives. In *Proceeding of the International Summit on Science, Technology, and Humanity (ISETH)* (pp. 137–144).

Alder, W. A. T., & Perkins, J. (2003). The use of a safety case approach to support decision making in design. *IChemE Symposium Series*, 149, 807–813.

Amaechi, C. V., Reda, A., Beddu, S. B., Mohamed, D. B., Syamsir, A., Ja'e, I. A., Ullah, S., Xiaopeng, D., Huang, B., Wang, C., & Ju, X. (2025). A systematic literature review on knowledge management for project risk management in construction. *Journal of Building Engineering,* 114, 114261, from https://doi.org/10.1016/j.jobe.2025.114261.

Ammad, S., Alaloul, W. S., Saad, S., Altaf, M., Alawag, A. M., & Ali, M. (2021). *Building Information Modelling (BIM) and occupational safety in infrastructure projects*. 2021 International Conference on Data Analytics for Business and Industry (ICDABI), from https://doi.org/10.1109/ICDABI53623.2021.9655832

Anderson, J. (2010). Briefing: Regulations to improve construction health and safety. *Proceedings of the Institution of Civil Engineers: Management, Procurement and Law,* 163(3), 97–98, from https://doi.org/10.1680/mpal.2010.163.3.97

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, 11(4), 959–975, from https://doi.org/10.1016/j.joi.2017.08.007

Ariffin T., H. L., Mohd, N. I., Lim, C. N. N. S., Kidam, K., Mohammad, M., Ali, K. N., Mustaffa, N. E., Rohani, J. M., Abdullah, S., Mat Ali, N. B., & Fetri, M. S. A. M. (2020). *Occupational safety and health in construction industry management (OSHCIM) implementation – Academician's perspectives.* IOP Conference Series: Materials Science and Engineering, 849(1), 012017, from https://doi.org/10.1088/1757-899X/849/1/012017

Arifin, K., Juhari, M. L., & Aiyub, K. (2024). A systematic literature review on occupational accident factors in the rail construction industry: Lessons learned from a quarter-century of studies globally. *International Journal of Injury Control and Safety Promotion,* 31(4), 644–659, from https://doi.org/10.1080/17457300.2024.2409634

Asmone, A. S., Goh, Y. M., & Lim, M. S. H. (2022). Prioritization of industry level interventions to improve implementation of design for safety regulations. *Journal of Safety Research*, 82, 352–366, from https://doi.org/10.1016/j.jsr.2022.06.011

Asbury, S. (2009). The CDM regulations: What difference have they made to construction safety? *Building Engineer,* 84(5), 14–16.

Azis, N. A., Abdul Rahman, H., & Ismail, Z. (2022). Implementation challenges of design for safety in Malaysian construction projects. *Built Environment Journal*, 19(1), 23–35.

Balasubramanian, S., Shukla, V., Islam, N., & Manghat, S. (2024). Construction Industry 4.0 and sustainability: An enabling framework. *IEEE Transactions on Engineering Management,* 71, 1–16, from https://doi.org/10.1109/TEM.2021.3110427

Barrie, A., Rohani, J. M., Kidam, K., Ismail, M., Sarbini, N. N., Kamarden, H., Ali, K. N., Tajul Ariffin, H. L., Mohd, N. I., Mustaffa, N. E., Abdullah, S., Fetri, M. S. A. M., Ramuseren, & Mat Ali, N. (2020). *Risk assessment of design components of building construction.* IOP Conference Series: Materials Science and Engineering, 884, 012046 from https://doi.org/10.1088/1757-899X/884/1/012046

Barrie, A., Rohani, J. M., & Redzuan, N. (2020). Risk estimation of construction activities of buildings. *AIP Conference Proceedings,* 2217(1), 020001, from https://doi.org/10.1063/5.0004435

Behm, M. (2005). Linking construction fatalities to the design for construction safety concept. *Safety Science*, 43(8), 589–611, from https://doi.org/10.1016/j.ssci.2005.04.002

Bishop, D. (1994) The professionals' view of the Health and Safety Commission's draft Construction (Design and Management) Regulations. *Construction Management and Economics*, 12(4), 365–72.

Bui, N., Merschbrock, C., Munkvold, B.E. (2016). A Review of Building Information Modelling for Construction in Developing Countries. *Procedia Eng*. 164 (1877), 487–494, from https://doi.org/10.1016/j.proeng.2016.11.649

Che Ibrahim, C. K. I., & Belayutham, S. (2019). *Guidelines on OSHCIM and PtD implementation in Malaysia.*

Che Ibrahim, C. K., Belayutham, S., & Mahamadu, A.-M. (2019). Investigating the barriers to safety in design in the Malaysian construction industry. *Journal of Engineering, Design and Technology*, 17(4), 1–18.

Che Ibrahim, C. K. I., Belayutham, S., Azmi, E. A., & Hussain, A. (2019). *Exploring the knowledge of prevention through design (PtD) among Malaysian civil and structural designers.* IOP Conference Series: Materials Science and Engineering, 615, 012031, from https://doi.org/10.1088/1757-899X/615/1/012031

Che Ibrahim, C. K., & Belayutham, S. (2020). Barriers to implementation of safety in design in the Malaysian construction industry. *Engineering, Construction and Architectural Management,* 27(10), 3053–3072.

Che Ibrahim, C. K. I., Belayutham, S., & Mohammad, M. Z. (2020). Prevention through design (PtD) education for future civil engineers in Malaysia: Current state, challenges, and way forward. *Journal of Professional Issues in Engineering Education and Practice*, from https://doi.org/10.1061/(ASCE)EI.2643-9115.0000030

Che Ibrahim, C. K. I., Belayutham, S., Mohammad, M. Z., & Ismail, S. (2021). Development of a conceptual designer's knowledge, skills, and experience index for prevention through design practice in construction. *Journal of Construction Engineering and Management, from* https://doi.org/10.1061/(ASCE)CO.1943-7862.0002234

Che Ibrahim, C. K. I., Manu, P., Belayutham, S., Mahamadu, A. M., & Antwi-Afari, M. F. (2022). Design for safety (DfS) practice in construction engineering and management research: A review of current trends and future directions. *Journal of Building Engineering*, 52, 104352, from https://doi.org/10.1016/j.jobe.2022.104352

Che Ibrahim, C. K. I., Belayutham, S., Manu, P., Mahamadu, A. M., & Cheung, C. M. (2022). Knowledge, attitude and practices of design for safety (DfS): A dynamic insight between academics and practitioners in Malaysia. *Safety Science*, 146, 105576, from https://doi.org/10.1016/j.ssci.2021.105576

Che Ibrahim, C. K. I., Belayutham, S., Awuzie, B. O., & Oke, A. E. (2022). Analysis of designers' Prevention through Design (PtD) competence in the construction industry: A study of Malaysia, Nigeria, and South Africa. *Safety Science,* 150, 105710, from https://doi.org/10.1016/j.ssci.2022.105710

Construction Industry Development Board (CIDB). (2018). *Securing improvement in the health and safety performance of Malaysia's construction industry*. CIDB Malaysia.

Construction Industry Development Board (CIDB). (2018). *Construction safety and health statistics.* CIDB Malaysia.

Department of Occupational Safety and Health (DOSH). (1994). *Occupational Safety and Health Act 1994 (Act 514).* Ministry of Human Resources Malaysia.

Department of Occupational Safety and Health (DOSH). (2022). *Occupational accident statistics Malaysia.* Ministry of Human Resources Malaysia.

Department of Occupational Safety and Health (DOSH). (2024). *Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024.* Ministry of Human Resources, Malaysia.

Department of Occupational Safety and Health. (2021). *Occupational Safety and Health Master Plan 2021–2025 (OSHMP 2021–2025).* Ministry of Human Resources Malaysia.

Department of Statistics Malaysia (DOSM). (2022). *Statistics of occupational accidents and fatalities in Malaysia.* DOSM Malaysia.

Department of Statistics Malaysia (DOSM). (2022). *Statistics on causes of death,* DOSM Malaysia.

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, 133, 285–296.

Driscoll, T., Harrison, J., Bradley, C., Newson, R. (2008). The role of design issues in work related fatal injury in Australia. *Journal of Safety Research,* 39, 209–214.

Ghaleb, M., et al. (2020). Complexity in construction projects: A systematic literature review. *Engineering, Construction and Architectural Management,* 27(6), 1–20.

Fayad, A., et al. (2024). *Integrated reporting and corporate disclosure: A bibliometric review of trends, themes, and future research directions*. Meditari Accountancy Research.

Goh, Y. M., & Chua, D. K. H. (2016). Knowledge, attitude and practices for design for safety: A study on civil and structural engineers. *Accident Analysis & Prevention*, 93, 260–266, from https://doi.org/10.1016/j.aap.2015.06.010

Hardison, D., & Hallowell, M. (2019). Construction hazard prevention through design: Review of perspectives, evidence, and future objective research agenda. *Safety Science*, 120, 517–526, from https://doi.org/10.1016/j.ssci.2019.08.001

Hardison, D., Hallowell, M., Littlejohn, R. (2020). Does the format of design information affect hazard recognition performance in construction hazard prevention through design reviews? *Safety Science* 121, 191–200.

Haslam, R. A., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., Atkinson, S., & Duff, R. (2005). Contributing factors in construction accidents. *Applied Ergonomics*, 36(4), 401–415.

Hinze, J., & Gambatese, J. (2003). Factors that influence safety performance of specialty contractors. *Journal of Construction Engineering and Management,* 129(2), 159–164.

Hughes, P., & Ferrett, E. (6th ed.) (2020*). Introduction to health and safety at work: For the NEBOSH National General Certificate in Occupational Health and Safety*.

Hussain, A., Che Ibrahim, C. K. I., Belayutham, S., Manu, P., & Nazruddin, M. A. (2023). *OSHCIM: A study on Malaysian OSH regulatory capabilities readiness in the design phase.*

Hussain, A., Che Ibrahim, C. K. I., Belayutham, S., Kidam, K., & Mat Ali, N. (2017). *Occupational safety and health regulator readiness in the design phase: Views from Malaysia.*

Health and Safety Executive. (2015). *Managing health and safety in construction (CDM 2015).* UK Government.

Health and Safety Executive (HSE). (2015). *Construction (Design and Management) Regulations 2015.*

Health and Safety Executive (HSE). (2015). *Managing health and safety in construction: CDM Regulations 2015. UK Government.*

Health and Safety Executive (HSE). (2017). *Health and safety at work: Summary statistics.*

Health and Safety Executive (HSE). (2023). *Construction statistics in Great Britain, 2023. UK Government.*

Ibrahim, M. H., Roy, M. H., Ahmed, Z., & Imtiaz, G. (2022). An investigation of construction risk management research: A bibliometric analysis. *Sustainability,* 14(3), 1234, from https://doi.org/10.3390/su14031234

Isah, M. A., & Kim, B.-S. (2023). Development of knowledge graph based on risk register to support risk management of construction projects. *KSCE Journal of Civil Engineering,* 27(7), 2733–2744, from https://doi.org/10.1007/s12205-023-2886-7

Ismail, N. F., Hanid, M., Ye, K. M., Ab Wahab, L., Mohamed, O., & Leman, A. P. (2022). Development of theoretical framework for improving implementation of design management within Malaysian construction industry. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 28(3), 248–263, from https://doi.org/10.37934/araset.28.3.248263

Ismail, N. A. A., Baharun, B. N. B., Adnan, H., Maisham, M., & Mahat, N. A. A. (2022). *BIM capabilities towards better safety climate in the Malaysian construction industry*. IOP Conference Series: Earth and Environmental Science, 1067, 012070, from https://doi.org/10.1088/1755-1315/1067/1/012070

Ismail, Z., Rahim, F. A., & Yusof, A. M. (2023). Implementation of CDM regulations in Malaysia: Issues and challenges. *Journal of Construction Policy,* 12(1), 55–70.

Jaafar, M. H., Arifin, K., Aiyub, K., Razman, M. R., Ishak, M. I. S., & Samsurijan, M. S. (2017). Occupational safety and health management in the construction industry: a review. *International Journal of Occupational Safety and Ergonomics,* 1-14.

Jaafar, M. H., Arifin, K., Aiyub, K., Razman, M. R., & Kamaruddin, M. A. (2017). *Human Element as the Contributing Factor Towards Construction Accidents from the Perspective of Malaysian Residential Construction Industry.* Paper presented at the International Conference on Applied Human Factors and Ergonomics.

Jaffar, N., Tharim, A. A., & Shuib, M. (2011). Factors of conflict in construction industry: a literature review. *Procedia Engineering*, 20, 193-202.

Ismail, R., Rahim, A., & Yusof, N. (2023). *Construction safety research and implementation in Malaysia.*

Khan, F. I., & Abbasi, S. A. (1998). Techniques and methodologies for risk analysis in chemical process industries. *Journal of Loss Prevention in the Process Industries.* 11(4), 261–277.

Khan, F.I., Abbasi, S.A. (1998). Inherently safer design based on rapid risk analysis. *Journal of Loss Prevention in the Process Industries.* 11, 361–372.

Khan, F.I., Sadiq, R., Veitch, B. (2004). Life cycle iNdeX (LInX): a new indexing procedure for process and product design and decision-making. *Journal of Cleaner Production.* 12, 59–76.

Khan, F., Rathnayaka, S., Ahmed, S. (2015). Methods and models in process safety and risk management: past, present and future. *Process Safety Environment Protection.* 98, 116–147.

Khan, E.A., Syeda, S.R. (2022). Chemical substitution in processes for inherently safer design: pros and cons. *Pure and Applied Chemistry.* 94, 889–899.

Khan, F.I., Amyotte, P.R. (2004). Integrated inherent safety index (I2SI): a tool for inherent safety evaluation. *Process Safety Progress.* 23, 136–148.

Khan, F.I., Amyotte, P.R. (2005). I2SI: a comprehensive quantitative tool for inherent safety and cost evaluation. *Journal of Loss Prevention in the Process Industries.* 18, 310–326.

Khodabakhshian, A., Puolitaival, T., & Kestle, L. (2023). Deterministic and probabilistic risk management approaches in construction projects: A systematic literature review and comparative analysis. Buildings, 13(5), 1312. https://doi.org/10.3390/buildings13051312.

Li, H.; Lu, M.; Chan, G.; Skitmore, M. (2015). Proactive training system for safe and efficient precast installation. *Automation in Construction.* 49, 163–174.

Lingard, H., & Rowlinson, S. (2005). *Occupational health and safety in construction project management.* Spon Press.

Lingard, H., & Rowlinson, S. (2020*). Occupational health and safety in construction project management (2nd ed.).* Routledge.

Malekitabar, H., Ardeshir, A., Sebt, M.H., Stuoffs, R. (2016) Construction safety risk drivers: A BIM approach. *Safety Science* 82, p.445-455, from https://doi.org/10.1016/j.ssci.2015.11.002

Manuele, F. A. (2008). *Prevention through design: Addressing occupational risks in the design and redesign processes.* Wiley.

Manu, P., Mahamadu, A.M., Phung, V.M., Nguyen, T.T., Ath, C., Heng, A.Y.T., Kit, S.C. (2018). Health and safety management practices of contractors in South East Asia: A multi country study of Cambodia, Vietnam, and Malaysia. *Safety Science* 107, 188–201, from https://doi.org/10.1016/j.ssci.2017.07.007.

Manu, P., Poghosyan, A., Agyei, G., Mahamadu, A.M., Dziekonski, K. (2021). Design for safety in construction in sub-Saharan Africa: a study of architects in Ghana. *International Journal of Construction Management*. 21 (4), 382–394, from https://doi.org/10.1080/15623599.2018.1541704.

Manu, P., Poghosyan, A., Mahamadu, A.M., Mahdjoubi, L., Gibb, A., Behm, M., Akinade, O.O. (2019). Design for occupational safety and health: key attributes for organisational capability. *Engineering, Construction and Architectural Management.* 26 (11), 2614–2636, from https://doi.org/10.1108/ECAM-09-2018-0389.

Manu, P., Poghosyan, A., Mshelia, I.M., Iwo, S.T., Mahamadu, A.M., Dziekonski, K. (2019). Design for occupational safety and health of workers in construction in developing countries: a study of architects in Nigeria. *International Journal of Occupational Safety and Ergonomics* 25 (1), 99–109, from https://doi.org/10.1080/10803548.2018.1485992.

Marefat, A., Toosi, H., & Hasankhanlo, R. M. (2019). A BIM approach for construction safety: Applications, barriers and solutions. *Engineering, Construction and Architectural Management,* 26(9), 1855–1877, from https://doi.org/10.1108/ECAM-01-2017-0011

Martinez-Rojas, M., Martín Antolín, R., Salguero-Caparr´os, F., Rubio-Romero, J.C. (2020). Management of construction Safety and health plans based on automated content analysis. *Automation in Construction,* 120, 103362.

Ministry of Manpower. (2016). *Workplace Safety and Health (Design for Safety) Regulations.* Singapore Government.

Ministry of Manpower (MOM). (2023). *Workplace safety and health report 2023.* Singapore Government.

Mohd, N. I., Tajul Ariffin, H. L., Abdul Hamid, M. H., Kidam, K., Ismail, M., Ali, K. N., Mustaffa, N. E., Rohani, J. M., Sabrini, N. N., Abdullah, S., Mat Ali, N., & Fetri, M. S. A. M. (2020). *Occupational safety and health construction industry management (OSHCIM): Current practice in Malaysia.* IOP Conference Series: Materials Science and Engineering, 849, 012012, from https://doi.org/10.1088/1757-899X/849/1/012012

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine*, 6(7), e1000097, from https://doi.org/10.1371/journal.pmed.1000097.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G. (2010). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *International Journal of Surgery.* 8 (5), 336–341, from https://doi.org/10.1016/j.ijsu.2010.02.007

Ndekugri, I., Ankrah, N.A., Adaku, E. (2021). The design coordination role at the pre-construction stage of construction projects. *Building Research & Information*, from https://doi.org/10.1080/09613218.2021.1971061.

Ning, X., Qi, J., Wu, C. (2018). A quantitative safety risk assessment model for construction site layout planning. *Safety Science.* 104, 246–259, from https://doi.org/10.1016/j.ssci.2018.01.016.

Park, C.S.; Kim, H.J. (2013). A framework for construction safety management and visualization system. *Automation in Construction,* 33, 95–103.

Parker, C., & Nielsen, V. L. (2011*). Explaining compliance: Business responses to regulation.* Edward Elgar Publishing.

Rafindadi, A. D., et al. (2022). *BIM-based framework for hazard identification and safety improvement.*

Rafindadi, A. D., Shafiq, N., & Othman, I. (2022). A conceptual framework for BIM process flow to mitigate the causes of fall-related accidents at the design stage. *Sustainability*, 14(20), 13025, from https://doi.org/10.3390/su142013025

Rafindadi, A. D., Napiah, M., Othman, I., & Musa, M. (2022). Integration of design for safety (DfS) and building information modelling (BIM) in construction projects: A systematic review. *Safety Science*, 147, 105617, from https://doi.org/10.1016/j.ssci.2021.105617.

Rathnayaka, S., Khan, F., & Amyotte, P. (2014). Risk-based inherent safety index. *Process Safety and Environmental Protection*, 92(6), 1–10.

Saifullah, N. M., & Ismail, Z. (2012). Integration of safety in design in Malaysian construction projects. *Procedia Engineering,* 20, 1–10.

Saurin, T. A., Formoso, C. T., & Guimarães, L. B. (2008). Safety and production: An integrated planning and control model. *Construction Management and Economics,* 26(2), 159–169.

Shen, X.; Marks, E. (2016). Near-miss information visualization tool in BIM for construction safety. *Journal of Construction Engineering*. 142, 04015100.

Szymberski, R. T. (1997). Construction project safety planning. *Tappi Journal,* 80(11), 69–74.

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics,* 84(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

van Eck, N. J., & Waltman, L. (2014). Visualizing bibliometric networks. In Y. Ding, R. Rousseau, & D. Wolfram (Eds.), *Measuring scholarly impact (pp. 285–320).* Springer.

Vigneshkumar, C., Uma Maheswari, J. (2018). *Prevention Through Design: A Concept Note for Preventing Accidents/Injuries to Construction Workers.* (December 2017), 3–10. doi: 10.1007/978-981-10-6328-2_1.

Wadick, P. (2006*). Learning Safety in the Building Industry*. CFMEU– Construction and General Division NSW Branch <http://www.cfmeu-constructionnsw.com.au/pdf/pwreslearnsafetybldgind.pdf> (accessed 04.01.11).

Wadick, P. (2006). Safety culture in construction: Theory and practice. *Construction Management Journal*, 12(3), 45–55.

Wei, X., et al. (2019). Bibliometric analysis of construction risk management research. Engineering, *Construction and Architectural Management*, 26(5), 1–15.

Xia, N., Zou, P. X. W., Griffin, M. A., Wang, X., & Zhong, R. (2018). Towards integrating construction risk management and stakeholder management: A systematic literature review and future research agendas. *International Journal of Project Management, 36*(5), 701–715. https://doi.org/10.1016/j.ijproman.2018.03.006

Yuzui, T., & Kaneko, F. (2025). Toward a hybrid approach for the risk analysis of maritime autonomous surface ships: A systematic review. *Journal of Marine Science and Technology.* https://doi.org/10.1007/s00773-024-01040-0

Zhou, W., Irizarry, J., & Li, Q. (2021). Applying advanced technologies for safety management in construction. *Automation in Construction*, 122, 103–115.

Zhou, Z., Irizarry, J., & Li, Q. (2021). Applying advanced technologies to improve construction safety management: A review. *Automation in Construction,* 126, 103650. https://doi.org/10.1016/j.autcon.2021.103650

Zou, P. X. W., & Sunindijo, R. Y. (2013). Skills for managing safety risk in construction. *Journal of Construction Engineering and Management,* 139(11), 04013016.

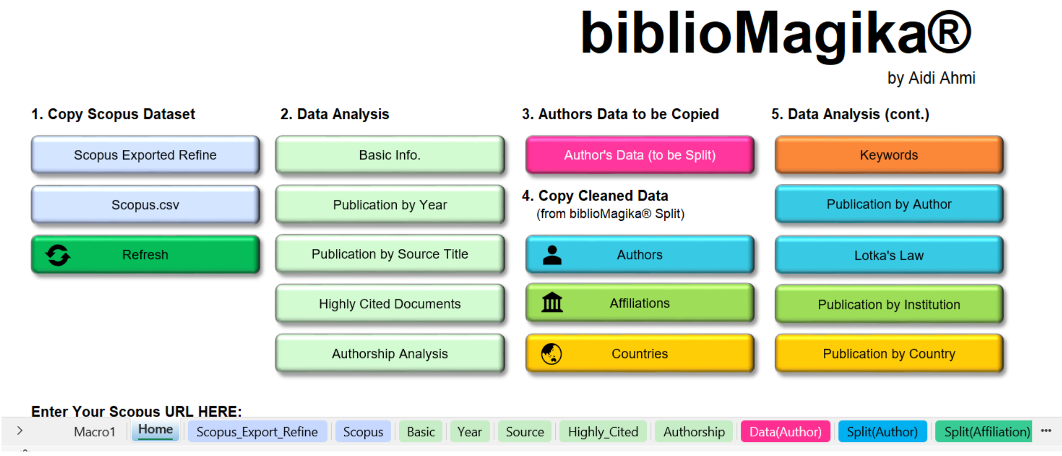
Zou, P. X. W., et al. (2014). *Bridging the gap between construction safety research and practice.*

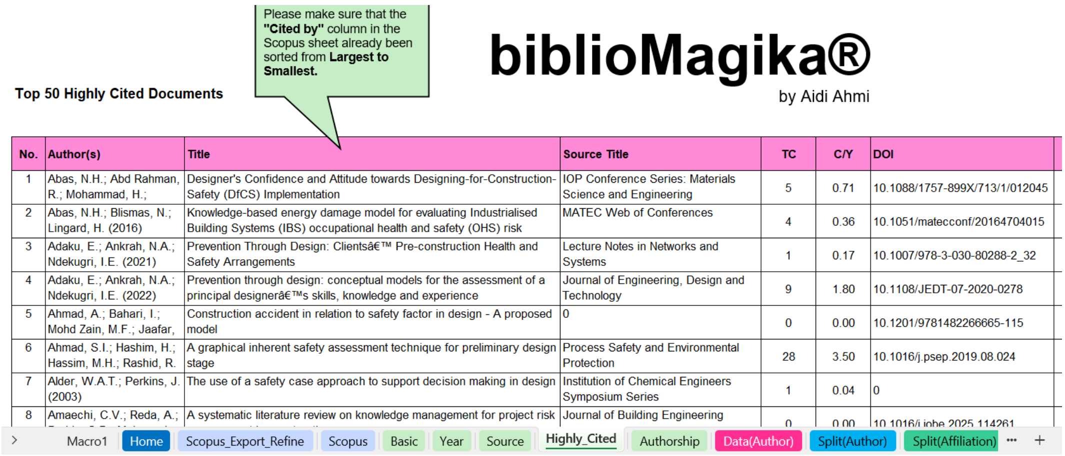
Zou, P. X. W., Sunindijo, R. Y., & Dainty, A. R. J. (2014). A mixed methods research design for bridging the gap between research and practice in construction safety. *Safety Science,* 70, 316–326. https://doi.org/10.1016/j.ssci.2014.07.005

Zou, P. X. W., Zhang, G., & Wang, J. (2014). Understanding the key risks in construction projects in China. *International Journal of Project Management,* 32(1), 1–12.

Appendices

Data Analysis Method





No.	Author(s)	Title	Source Title	TC	C/Y	DOI
1	Abas, N.H.; Abd Rahman, R.; Mohammad, H.;	Designer's Confidence and Attitude towards Designing-for-Construction-Safety (DfCS) Implementation	IOP Conference Series: Materials Science and Engineering	5	0.71	10.1088/1757-899X/713/1/012045
2	Abas, N.H.; Blismas, N.; Lingard, H. (2016)	Knowledge-based energy damage model for evaluating Industrialised Building Systems (IBS) occupational health and safety (OHS) risk	MATEC Web of Conferences	4	0.36	10.1051/matecconf/20164704015
3	Adaku, E.; Ankrah, N.A.; Ndekugri, I.E. (2021)	Prevention Through Design: Clientsâ€™ Pre-construction Health and Safety Arrangements	Lecture Notes in Networks and Systems	1	0.17	10.1007/978-3-030-80288-2_32
4	Adaku, E.; Ankrah, N.A.; Ndekugri, I.E. (2022)	Prevention through design: conceptual models for the assessment of a principal designerâ€™s skills, knowledge and experience	Journal of Engineering, Design and Technology	9	1.80	10.1108/JEDT-07-2020-0278
5	Ahmad, A.; Bahari, I.; Mohd Zain, M.F.; Jaafar,	Construction accident in relation to safety factor in design - A proposed model	0	0	0.00	10.1201/9781482266665-115
6	Ahmad, S.I.; Hashim, H.; Hassim, M.H.; Rashid, R.	A graphical inherent safety assessment technique for preliminary design stage	Process Safety and Environmental Protection	28	3.50	10.1016/j.psep.2019.08.024
7	Alder, W.A.T.; Perkins, J. (2003)	The use of a safety case approach to support decision making in design	Institution of Chemical Engineers Symposium Series	1	0.04	0
8	Amaechi, C.V.; Reda, A.;	A systematic literature review on knowledge management for project risk	Journal of Building Engineering	0	0.00	10.1016/j.jobe.2025.114261