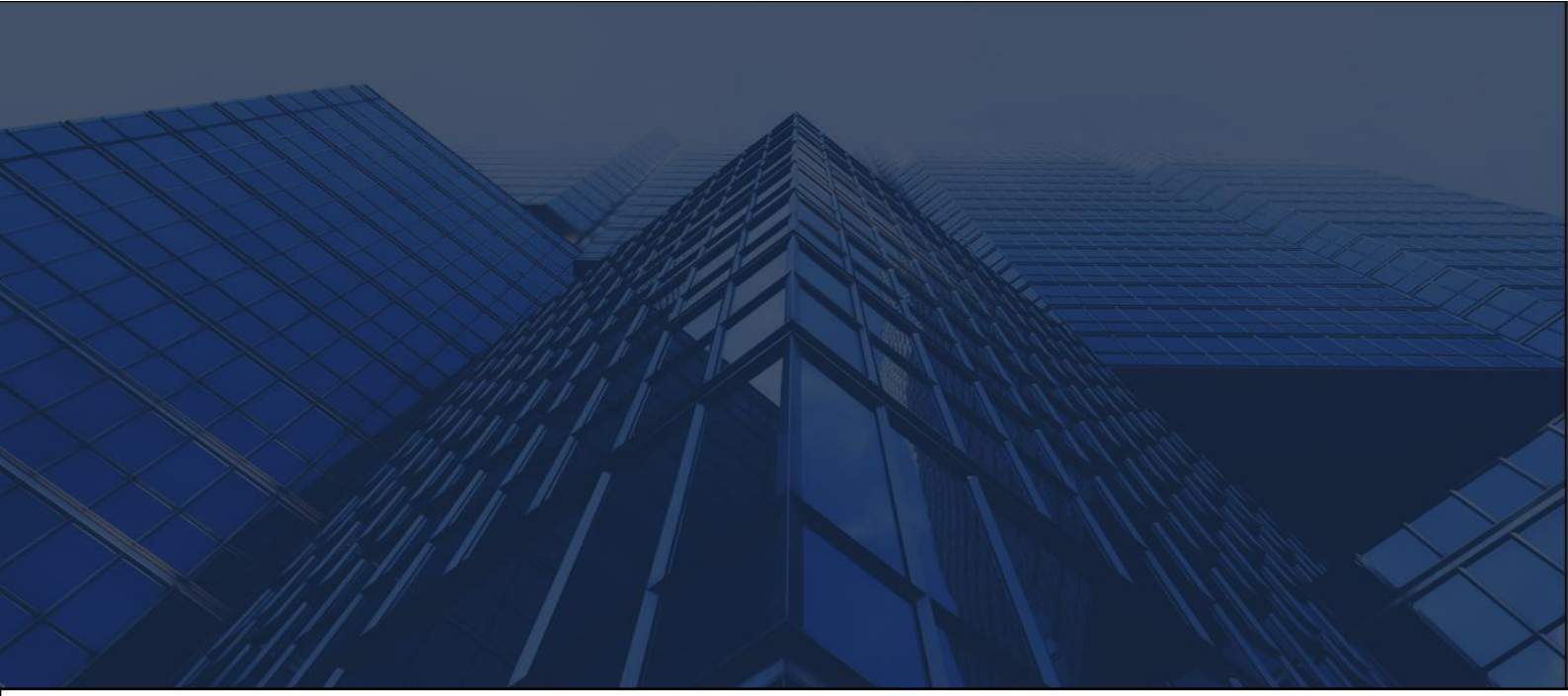

TECHNICAL RESEARCH PROCEEDINGS

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Acknowledgement

The Technical Research Proceedings of Institute of Quantity Surveyors Sri Lanka (IQSSL) are published annually in parallel to the Annual Technical Sessions to disseminate novel knowledge with the construction industry stakeholders and to encourage research in the field. In May 2024, the researchers were invited to submit their Research Papers on the main theme of "**Resilient Horizons: Reconceiving the Construction Industry Through Economic Recovery and Global Transformation"** covering 27 subthemes. A total of 18 research papers were received and 14 of them were selected after a comprehensive review process for the proceeding. The annual Technical Proceeding of IQSSL for this year has been scheduled to publish in parallel to the Annual General Meeting (AGM) 2024 of IQSSL and the IQSSL Annual Technical Sessions 2024. IQSSL Annual Technical Sessions and AGM 2024 of IQSSL will be held on 07 and 08 November 2024 respectively. All the submitted full papers were sent to at least two independent reviewers selected from the scientific committee for double-blind peer review. Reviewers provided constructive comments to the originality, significance, reliability, methodology, analysis and contribution of each paper. The Technical Research Proceedings is published for open access on the IQSSL official web site.

On behalf of Organizing Committee –Technical Session – 2024, I hereby acknowledge and highly appreciate all the authors who submitted valuable research papers. In addition, I thank all the members of the scientific review panel for their untiring commitment and dedication in providing comprehensive reviews. Furthermore, my sincere appreciation goes to the best paper award selection committee and conference coordinators.

Ch.QS Nimantha Manamgoda
Secretary
Organizing Committee –Technical Session – 2024
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THE NATURE OF CONTRACT TERMINATION BY PARTIES UNDER VARIOUS STANDARD FORMS OF CONSTRUCTION CONTRACTS

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THE NATURE OF CONTRACT TERMINATION BY PARTIES UNDER VARIOUS STANDARD FORMS OF CONSTRUCTION CONTRACTS

ABSTRACT

Contracts offer stability, but contract termination can change a project's course. Contract terminations in the construction sector often stem from financial bankruptcy, failure to meet contractual obligations, or breaches by one party, leading to project delays, increased costs, and legal disputes that disrupt the construction process. Thus, this research aims to investigate the characteristics of contract termination by parties in different standard forms of construction contracts. This research employs a qualitative approach, utilizing a desk study to undertake a content analysis of the findings. The indicated findings relay that contract terminations in the construction industry are often caused by factors such as financial difficulties, poor project management, disputes over contract terms, or failure to meet project deadlines and quality standards. Contract terminations in the construction industry can lead to significant financial losses, project delays, legal disputes, and damage to the reputations of the parties involved. A structured approach to termination highlighted in the standard forms of contracts helps parties navigate the complex and often contentious process of contract termination, resulting in more equitable and efficient construction outcomes. This research provides insight into the provisional and practical implications of contract terminations under different standard forms of construction contracts.

Keywords: *Causes; Consequences; Contractor; Employer; Standard Forms of Contracts; Termination*.

INTRODUCTION

Construction contracts are essential for successfully executing construction projects by allocating risks among project stakeholders (Twyford, 2007). In the construction industry, contract formation is a routine occurrence that significantly affects project outcomes, leading to either successful project delivery or disputes resulting in wasted time and resources (Parchamijalal *et al*., 2021, p.74-104.) Thus, Standard Forms of Contracts (SFoC) are designed to establish a fair and standardized framework outlining the rights and obligations of all parties (Rameezdeen & Shiyamasuntharan, 2004). The rights and duties of the parties are often articulated in these documents, which serve as the foundation for legal relationships and obligations (Mitkus & Averkienė, 2019). Standard forms of contracts such as The Fédération Internationale des Ingénieurs-Conseils hereinafter referred to as (FIDIC 1999) and New Engineering Contract hereinafter referred as (NEC 3) play a significant role in this process by providing a framework for the allocation and standardization of these rights and obligations (Rameezdeen & Shiyamasuntharan, 2004). Standardized contracts, created by organizations such as FIDIC and NEC, are extensively used in the construction sector because they effectively handle typical concerns about contract termination, thus improving project management and minimizing the chances of conflicts (Gagula & Meškić, 2020; Terrell & Surace, 2016).

As is the contract formation, contract termination is a crucial aspect in the construction industry, affecting various stakeholders involved in a project. Termination of contracts, defined as ending the agreement between the employer and contractor before project completion, can have significant implications (Riveros *et al*., 2022). Factors such as delayed design information and ambiguities in contract documents often contribute to disputes that may lead to contract termination (Artan, 2012). Understanding the termination process is essential, as emphasized in scholarly works focusing on the termination of construction contracts (Kelley, 2012; Terrell & Surace, 2016). One significant cause of contract termination is errors in contract documents, which can lead to misunderstandings and disputes (Dosumu *et al*., 2017). These errors often stem from issues such as incomplete design, defective materials, and changes in project scope, which are inadequately addressed in the contract conditions (Asadi, 2023). Additionally, the failure to address rework causes in construction contracts can result in conflicts and claims, ultimately leading to contract termination (Asadi *et al*., 2021). Legally, termination can lead to disputes, litigation, and significant financial liabilities,

particularly if the termination is found to be wrongful (Gould, 2018; Murdoch & Hughes, 2015). Financially, terminations can result in substantial costs, including demobilization, loss of profits, and potential project delays (Cushman & Carter, 2019; Ashworth, 2012). Operationally, terminations cause project disruptions, which can lead to delays and increased costs as new contractors take over incomplete work (Gould & Joyce, 2020). Reputational damage is also a concern, as both contractors and clients may face long-term harm to their industry standing and public trust (Hughes & Murdoch, 2015; Ashworth & Perera, 2018). The comparison of the FIDIC 1999 and NEC 3 contracts regarding termination by parties reveals significant differences in their approaches, frameworks, and implications for stakeholders involved in construction projects. FIDIC 1999 offers a structured contract termination process, outlining specific grounds for termination, such as failure to perform obligations, prolonged work suspension, or contractor insolvency. Termination is formal, requiring written notice and adherence to procedures, ensuring clarity and protection of both parties' interests (Heaphy, 2013; Tembo-Silungwe & Khatleli, 2017) whereas NEC 3 promotes collaborative contract management, encouraging parties to resolve issues collaboratively before resorting to termination, fostering mutual trust and cooperation (Lau *et al*., 2019). The 1999 edition of FIDIC's Red Book is widely recognized as the most widely used standard-form construction contract in international projects, demonstrating its widespread acceptance among international organizations and governments (Tanriverdi *et al*., 2021). On the other hand, NEC contracts, particularly NEC3, have gained traction in various regions, including the UK, Hong Kong, and South Africa, where they have been effectively applied in public works projects (Lau *et al*., 2019). FIDIC 1999 and NEC3 have been chosen for this paper due to their global prominence in the construction industry. FIDIC 1999 is widely used in international projects, while NEC3 is recognized for its collaborative approach, especially in the UK and Commonwealth countries. Given time constraints, focusing on these two forms allows for a relevant and efficient analysis within the paper's scope.

Understanding the nuances of contract termination within these SFoC is crucial for effective project management and risk mitigation. The long-term impacts of termination on project outcomes, stakeholder relationships, and industry practices, particularly in comparing standard forms of contracts (SFoC) for termination by parties, remain underexplored. Addressing this gap is crucial for developing contract provisions that mitigate negative outcomes and enhance pre-termination risk management, thereby improving the resilience and effectiveness of construction contracts. Consequently, the primary aim of this study is to examine the dynamics of contract termination by parties under different standard forms of construction contracts. This is achieved through a set of clearly defined objectives, which have been systematically addressed in the research.

OBJECTIVES:

- Identifying the causes of termination in different standard forms of contracts.
- Identifying the consequences of termination in different standard forms of contracts.
- Comparing the nature of the termination process in FIDIC 1999 and NEC3.

The scope of this research paper is confined to an examination of termination provisions by the respective parties as stipulated in the FIDIC 1999 and NEC3 contract framework.

LITERATURE REVIEW

STANDARD FORMS FIDIC 1999 AND NEC3

Construction contracts are legal instruments that regulate the relationships between the parties, facilitate the management of projects with many stakeholders, and comply with regulatory obligations therefore utilizing standard forms of contract (SFoC) improves project delivery efficiency, minimizes conflicts, and ensures clarity. As they are critical in their role in defining the scope of work and the responsibilities of each party, these contracts typically include specifications, contract data, and construction drawings, which outline the client's requirements and expectations (Gunawardena, 2006). FIDIC contracts are widely recognized in the construction industry for their emphasis on timely communication and dispute resolution, which are essential for managing complex construction projects effectively (Sümer & Arditi, 2022; Chan & Chan, 2017; Yabar-Ardiles, 2023). The NEC contracts are recognized for fostering collaboration and flexibility, promoting effective project management by encouraging mutual trust and cooperation hence they are designed to accommodate changes in project scope, making them particularly suitable for dynamic environments. The latest NEC Engineering and Construction Contract (ECC) emphasizes proactive risk management and early warning systems to prevent disputes, reflecting lessons learned from earlier versions (Chan & Chan, 2017; Yabar-Ardiles, 2023).

TERMINATION CONTRACT

Parties enter a contract hoping that the contract would be terminated through its natural course which is performance as per the agreed items in the contract (Elliot & Quinn, 2013). But it is also a probability that it would not always be the case. Termination of a contract is simply to end the contract before the respective obligations are fulfilled, which means that the duty to perform no longer exits. Gould (2018) summarizes the most common classifications of contract terminations initiated by the parties in the construction industry as Termination at Convenience (Party terminates the contract through provisions in the contract) and Termination at Cause (Party terminating the contract for a breach through standard forms of contract provisions) and Termination through mutual agreement (Parties terminating the contract through mutual agreement).

CAUSES AND CONSEQUENCES OF CONTRACT TERMINATION BY EMPLOYER AND CONTRACTOR AS PER FIDIC 1999 & NEC3

Payment provisions, liquidated damages, and delay in performance, breach of contract, communication gaps are crucial causes in construction contracts that, if not properly managed, can lead to termination (Rosli *et al*., 2022). Under FIDIC 1999, specific clauses outline the conditions under which a contractor and employer may terminate the contract. For instance, if the employer fails to make timely payments, the contractor is entitled to suspend work and potentially terminate the contract (Hyari, 2022). In contrast the NEC3, is designed to promote collaboration and proactive management of risks by early warning systems to communicate and mitigate risks (Amoah & Nkosazana, 2022; Wilsoncroft, 2009). Termination of a construction contract can have significant consequences, including project delays, increased costs, and potential claims for damages from the contractor, especially if the termination is unjustified (Aliaj, 2022; Gagula & Meškić, 2020). Contractors may face financial instability and loss of income, leading to deteriorating relationships and ongoing disputes that complicate future collaborations (Çela, 2015; Yao *et al*., 2021). Both FIDIC and NEC3 provide dispute resolution mechanisms, such as adjudication and arbitration, which are crucial to avoid prolonged disputes and escalating legal costs (Dąbrowska, 2019; Daradkeh, 2016).

METHODOLOGY

Qualitative methodologies are ideal for exploratory research, particularly in emerging markets, where existing theories may not fully explain observed phenomena, leading to the development of new theoretical frameworks (Willig, 2012). The iterative nature of qualitative research enables continuous refinement of research questions and methods, thereby enhancing the depth and relevance of the findings (Au-Yong-Oliveira, 2024). Therefore, this research adopts a qualitative approach to deeply explore and understand the complexities and nuances of the subject matter.

This study occupies a document review since document reviews enable researchers to analyze contracts, and related documentation, highlighting the importance of understanding termination clauses within standard forms of contracts, particularly in construction projects, for practical implications (Cárdenas *et al*., 2017). The study compares standard forms of contracts, namely FIDIC 1999 and NEC3, emphasizing the significance of understanding different contractual frameworks to effectively evaluate termination provisions, alongside journal paper reviews to provide a comprehensive understanding of the termination process in the industry. Content analysis can uncover broader trends in literature as content analysis is not merely a descriptive tool but a rigorous method that enables researchers to derive empirical knowledge from qualitative data (Krippendorff, 2019). Therefore, this study employs Content Analysis to systematically interpret and understand the qualitative data collected.

FINDINGS

The findings of this document review, which employed both a review of two standard forms of contracts namely FIDIC 1999 and NEC3 and related journal publications in the area. Findings provide a comprehensive analysis of the causes, consequences, and processes associated with contract termination under the FIDIC 1999 and NEC3 frameworks and their applicability in the construction industry through the journal paper reviews.

CAUSES OF TERMINATION IN DIFFERENT STANDARDS FORMS OF CONTRACTS: TERMINATION BY EMPLOYER VS CONTRACTOR

As outlined in Table 1, a document review was conducted to systematically identify the causes of contract termination from the perspectives of both the employer and the contractor. This analysis involved a comprehensive review of the FIDIC 1999 and NEC3 contract frameworks, utilizing document review methods. Additionally, the study incorporated a journal paper review to capture the industrial perspectives and contextualize the findings within current industry practices and scholarly discourse.

Table 1: Comparison of Causes of Contract Terminations for Termination by Employer and Termination by Contractor under FIDIC 1999, NEC 3 and Journal Findings.

Document Review of Cause of Termination; FIDIC 1999 vs NEC 3					**Literature Review**
Cause of Termination	**FIDIC 1999**		**NEC 3**		**Journal Paper Review**
	Termination by Employer (FIDIC 1999)	**Termination by Contractor (FIDIC 1999)**	**Termination by Employer (NEC 3)**	**Termination by Contractor (NEC 3)**	**Remarks**
Non-Performance / Failure to Proceed	Clause 15.2: Contractor fails to proceed with	Clause 16.2: Employer fails to pay or interferes	Clause 91.2: Contractor fails to proceed or	Clause 91.4: Employer does not pay	*Non-performance and delays are common grounds for termination*

	works or abandons the site.	with the works.	abandons the project.	certified amounts.	*across various contract types, cited as a leading cause (Stannard,2018; Riveros et al.,2022).*
Financial Default	Clause 15.2: Contractor's insolvency or bankruptcy.	Clause 16.2: Employer's insolvency or bankruptcy.	Clause 91.2: Contractor's insolvency.	Clause 91.4: Employer's insolvency.	*Financial difficulties of either party often lead to termination, as highlighted in various studies on construction disputes (Lee, H, and Choi, I, 2003).*
Serious Breach of Contract	Clause 15.2: Repeated or serious breaches of contract by the Contractor.	Clause 16.2: Serious breach by Employer, especially concerning payment.	Clause 91.2: Contractor commits a major breach of the contract.	Clause 91.4: Employer breaches contract terms, particularly regarding payment.	*Significant breaches, particularly related to payment, are commonly cited in research as grounds for termination (Riveros, Ruiz, Mesa, & Guevara, 2022).*
Failure to Provide Site Access	Not specifically covered; can be inferred under failure to proceed (Clause 15.2).	Clause 16.2: Employer fails to provide site access or impedes work.	Clause 91.2: Indirectly under failure to proceed by Employer.	Not directly addressed; implied under failure to proceed.	*Denial of site access is frequently mentioned in research as a significant cause for contractor-initiated termination (Surahyo,2018)*
Suspension of Works by Contractor	Clause 15.2: Employer may terminate if the Contractor unjustifiably suspends work.	Clause 16.2: Contractor suspends work due to Employer's default (e.g., non-payment).	Clause 91.2: Employer may terminate if the Contractor suspends work unjustifiably.	Clause 91.4: Contractor suspends work due to Employer's non-payment or breach.	*Suspension of works, particularly for non-payment, is commonly highlighted in studies as a cause for termination by the contractor (Surahyo,2018; Matu et al.,2021)*
Health and Safety Violations	Clause 15.2: Contractor breaches health and safety obligations.	Not directly addressed.	Clause 91.2: Contractor fails to maintain health and safety standards.	Not directly addressed.	*Termination due to health and safety violations is increasingly discussed in research, though less common as a primary cause (Othman,2012).*

Illegal or Unlawful Acts	Clause 15.2: Contractor engages in illegal activities related to the contract.	Not specifically addressed but can be implied under serious breach.	Clause 91.2: Contractor engages in unlawful activities.	Not specifically addressed but can be implied under serious breach.	*Engaging in illegal activities is acknowledged in research as a potential, though rare, ground for termination (Laxsana, Abiramy & Fayasa,2023).*
Prolonged Suspension of Works	Clause 8.11: Employer may terminate if Contractor suspends work without justification.	Clause 8.11: Contractor may terminate if Employer suspends works without justification.	Clause 91.2: Contractor suspends works unjustifiably.	Clause 91.4: Employer suspends works without justification.	*Prolonged suspension is recognized as a common ground for termination, especially in complex projects (Surahyo, 2018; Matu et al., 2021)*
Failure to Appoint/Pay Subcontractors	Not directly covered; may fall under serious breach or failure to proceed.	Not directly addressed.	Not directly covered; implied under failure to proceed or serious breach.	Not directly addressed.	*Failure to appoint or pay subcontractors is less commonly addressed but still relevant in complex projects, as noted in some studies (Bolton et al., 2022).*
Termination at Convenience	Clause 15.5 (Termination for Employer's Convenience). The Employer may terminate the contract at any time for convenience by giving notice to the contractor without needing to provide reasons	Not Applicable	Clause 90.2 (Employer's Right to Terminate)) The employer can terminate the contract at any time for any reason by giving notice to the contractor.	Not Applicable	*FIDIC 1999 and NEC3 link contractor termination to employer failures FIDIC allows termination for non-compliance with contractual obligations, while NEC3 allows termination for persistent delay These provisions empower contractors to terminate contracts (Fawzy et al.,2018)*

The causes for termination in the construction industry are identified through journal paper review findings of numerous papers indicating the recurring causes namely non-performance and financial defaults, which are addressed through specific clauses in FIDIC 1999 and NEC 3. These issues reflect the high stakes of maintaining progress and financial solvency in construction projects. Serious breaches of contract, such as payment defaults and failures to adhere to agreed-upon standards, are also a prominent cause of termination. While FIDIC 1999 and NEC 3 provide robust frameworks for managing contract terminations, practical challenges and emerging issues in the industry often extend beyond these contracts. Non-performance,

financial defaults, and serious breaches of contract remain the common causes of termination, but as the industry evolves, more nuanced issues like health and safety violations, prolonged suspensions, and subcontractor management are becoming more prominent in discussions of contract termination.

CONSEQUENCES OF TERMINATION IN DIFFERENT STANDARDS FORMS OF CONTRACTS, TERMINATION BY EMPLOYER VS CONTRACTOR

As outlined in Table 2, a document review was conducted to systematically identify the consequences of contract termination from the perspectives of both the employer and the contractor. This analysis involved a comprehensive review of the FIDIC 1999 and NEC3 contract frameworks, utilizing document review methods. Additionally, the study incorporated a journal paper review to capture the industrial perspectives and contextualize the findings within current industry practices and scholarly discourse.

Table 2: Comparison of Causes of Contract Terminations for Termination by Employer and Termination by Contractor under FIDIC 1999, NEC 3 and Journal Findings.

Document Review of Consequences of Termination; FIDIC 1999 vs NEC 3					**Literature Review**
Consequences	**FIDIC 1999**		**NEC 3**		**Journal Paper Review**
	Termination by Employer under FIDIC 1999	**Termination by Contractor under FIDIC 1999**	**Termination by Employer under NEC3**	**Termination by Contractor under NEC 3**	**Remarks**
Relevant Clauses	Clause 15.2 (Termination by Employer)	Clause 16.2 (Termination by Contractor)	Clause 91.2 (Termination by Employer)	Clause 91.4 (Termination by Contractor)	Termination by the parties often leads to significant financial and time overruns in projects and sour relationships.
Consequences on Payment	Employer may withhold or reduce payments for work done before termination (FIDIC 1999, Cl. 15.6).	Contractor is entitled to payment for work done and demobilization costs (FIDIC 1999, Cl. 16.4).	Employer can withhold payment; compensation events may be triggered (NEC 3, Cl. 93.1).	Contractor entitled to payment for work done and demobilization costs (NEC 3, Cl. 94.1).	*Withholding payments can exacerbate disputes, leading to prolonged arbitration as highlighted by Serpell and Torres (2023) and by Miller, (2014)*
Consequences on Completion	Employer can engage others to complete the work; delays could result in LDs (FIDIC 1999, Cl. 15.4).	Contractor must cease work, removing equipment and materials (FIDIC 1999, Cl. 16.3).	Employer can complete the work or hire others; Contractor may face penalties (NEC 3, Cl. 91.2).	Contractor must remove equipment, and materials; further work ceases (NEC 3, Cl. 91.4).	*Completion delays are common, and the hiring of alternative contractors usually results in quality issues (Odeh & Battaineh,2022; Jung et al.,2021)*
Impact on Subcontractors	Employer may assume direct responsibility	Subcontractors may seek compensation from the	Employer may require subcontractors to continue	Subcontractors may claim compensation from the	*Subcontractors face uncertainty, and the risk of litigation increases,*

	for subcontractors (FIDIC 1999, Cl. 15.2).	Contractor (FIDIC 1999, Cl. 16.2).	or terminate their contracts (NEC 3, Cl. 91.2).	Contractor (NEC 3, Cl. 91.4).	*as noted in research by Bolton et al., (2022) and by Haron and Arazmi, (2020)*
Dispute Resolution	Disputes resolved via the DAB or arbitration (FIDIC 1999, Cl. 15.6, Cl. 20.4).	Disputes resolved via the DAB or arbitration (FIDIC 1999, Cl. 16.4, Cl. 20.4).	Disputes resolved under adjudication or arbitration (NEC 3, Cl. W1/W2).	Disputes resolved under adjudication or arbitration (NEC 3, Cl. W1/W2).	*Dispute resolution is often lengthy, with outcomes favoring the employer due to contract terms (Yates,2011).*
Return of Performance Security	Employer can call upon the performance bond or security (FIDIC 1999, Cl. 15.2).	Performance security should be returned to the contractor (FIDIC 1999, Cl. 16.2).	Employer may retain performance security or bonds (NEC 3, Cl. 91.2).	Performance security should be returned to the contractor (NEC 3, Cl. 91.4).	*Performance securities are frequently contested, leading to additional legal costs (Hassan & Adnan,2018).*
Effect on Claims	Employer's claims for defects or delays are still valid post-termination (FIDIC 1999, Cl. 15.6).	Contractor may still claim for unpaid work or damages (FIDIC 1999, Cl. 16.4).	Employer retains the right to claim for defects or delays (NEC 3, Cl. 93.1).	Contractor may claim for unpaid work or demobilization costs (NEC 3, Cl. 94.1).	*Claims post-termination are complex, with both parties seeking compensation, leading to further legal entanglements (Shen et al., 2017)*

The analysis of the consequences of contract terminations under FIDIC 1999 and NEC 3 reveals several critical points. The consequences in termination in the construction industry are identified through journal paper review findings of numerous papers indicating that both contracts expose contractors and employers to significant financial risks, especially regarding payment withholding and performance securities. Termination often leads to project completion delays, particularly when new contractors are brought in, resulting in quality issues. Subcontractors are vulnerable during contract terminations, facing uncertainty and an increased likelihood of litigation. Dispute resolution mechanisms provided by both contracts are often lengthy and may favour the employer, leading to additional costs. The post-termination period is complex, with legal challenges as both parties seek to claim for outstanding issues. In summation, it is noted that in both the standard forms of contracts clear contract terms and effective practical mechanisms are crucial to mitigate post-termination conflicts.

COMPARISON OF THE NATURE OF THE PROCESS OF TERMINATION IN DIFFERENT STANDARD FORMS OF CONTRACT

As detailed in Table 3, through the previous findings in the above tables, the similarities, and differences in the termination processes between FIDIC 1999 and NEC3 were examined from both the employer's and contractor's perspectives. This analysis entailed a thorough review of key aspects such as the grounds for termination, notice requirements, procedural obligations, and financial adjustments following termination.

Table 3: Similarities and Differences in the process of termination in FIDIC 1999 and NEC 3 through the perspectives of termination by employer and termination by contractor.

Aspect	FIDIC 1999	NEC3	Remarks
Grounds for Termination	**By Contractor:**	**By Contractor:**	
	Sub-Clause 16.2 allows termination if the employer fails to pay, interferes with payment certificates, or fails to perform obligations.	Clause 91.6 allows termination for non-payment or prolonged suspension of works.	**FIDIC 1999**: Clearly defined, specific grounds for both employer and contractor. The process is prescriptive, focusing on specific breaches like non-payment or failure to proceed. **NEC3**: Broader and more flexible grounds, allowing for termination based on general principles like non-payment or prolonged suspension. Less specific than FIDIC but more adaptable.
	By Employer:	**By Employer:**	
	Sub-Clause 15.2 allows termination for defaults such as failure to proceed with works, defective work, or contractor insolvency.	Clause 91.1 allows termination for reasons such as failure to proceed regularly and diligently, or contractor insolvency.	
Notice Requirements	Notices must be served before termination:	Clause 90.1 requires issuing a notice before initiating termination procedures.	FIDIC 1999: Specific sub-clauses outline the need for notice before termination, emphasizing formal procedures. NEC3: Clause 90.1 provides a straightforward notice requirement, with a focus on clarity and communication before termination.
	Sub-Clause 15.1 (Employer)		
	Sub-Clause 16.1 (Contractor)		
Consequences of Termination	**By Contractor:**	Clause 93.2 outlines payments due after termination, varying by the reason for and outcome of the termination.	**FIDIC 1999**: Consequences are clearly defined with specific sub-clauses detailing payments and financial adjustments based on the reason for termination. **NEC3**: More flexible consequences, with an emphasis on negotiated outcomes and varying payments based on termination reasons.
	Sub-Clause 16.4 addresses payments post-termination.		
	By Employer:		
	Sub-Clause 15.4 covers payments following termination by the employer.		
Nature of the Contract	Prescriptive and traditional, with a distinct separation of responsibilities between employer, contractor, and Engineer.	Collaborative and flexible, emphasizing cooperation with mechanisms like Early Warning and Compensation Events to prevent disputes.	**FIDIC 1999**: Traditional and prescriptive, emphasizing the clear separation of roles and responsibilities. **NEC3**: Collaborative, with a focus on cooperation and flexibility, aiming to prevent disputes through proactive management mechanisms.
Detailed Grounds for Termination	Provides specific grounds under Sub-Clause 15.2, such as abandonment of works or failure to comply with notices.	Offers broader categories under Clause 91.2, including failure to provide performance	**FIDIC 1999**: Provides specific, detailed grounds for termination, including breaches and contractor defaults. **NEC3**: Offers broader categories for termination, with a

Aspect	FIDIC 1999	NEC3	Remarks
		bond or rectify defects.	less rigid approach, making it adaptable to different scenarios.
Procedural Requirements	Detailed steps, particularly involving the Engineer's role in certifying defaults and requiring prolonged failure before termination.	Less formal, relying on project management procedures, with early warnings and risk registers to address issues pre-termination.	**FIDIC 1999**: Involves detailed procedures, particularly around the Engineer's role, requiring sustained issues before termination is allowed. **NEC3**: Less formal, relying on collaborative project management tools like early warnings and risk registers to manage potential termination issues.
Financial Adjustments Post-Termination	Extensive assessments by the Engineer, including potential deductions for costs incurred due to termination.	Flexible approach, allowing negotiated settlements post-termination, especially under Clause 90.2 (mutual agreement).	**FIDIC 1999**: Involves extensive assessments and potential cost deductions, with a formalized approach to financial settlements. **NEC3**: Allows for more flexible, negotiated settlements, particularly where termination is mutually agreed upon.
General Summation	FIDIC 1999 is more rigid and prescriptive, with a clear, formalized process for termination, emphasizing strict adherence to contract terms.	NEC3 offers a more flexible, cooperative approach, with an emphasis on proactive management and negotiation to prevent disputes and terminations.	**FIDIC 1999**: Suits projects where strict adherence to defined processes and roles is necessary. **NEC3**: Better for projects requiring adaptability, collaboration, and prevention of disputes through ongoing management and negotiation.

Legend:
Similar Approach

The Table 3 compares similar approaches and differing approaches conducted during the termination processes and provisions in FIDIC 1999 and NEC3 contracts, focusing on termination by the contractor and employer. Both contracts require notices before termination, define grounds for termination, and outline the consequences following termination. However, FIDIC 1999 is more prescriptive and detailed, with specific grounds and a structured termination procedure involving the Engineer's role extensively. NEC3, on the other hand, is more flexible and collaborative, emphasizing early warnings and cooperation to resolve issues before they lead to termination. Financial adjustments post-termination also differs, with FIDIC relying on Engineer assessments, while NEC3 allows for more negotiated settlements.

CONCLUSION AND RECOMMENDATIONS

The review of contract termination under FIDIC 1999 and NEC3 standard forms emphasizes the balance between parties' rights and obligations. FIDIC 1999 offers a structured methodology, while NEC3 promotes a balanced approach, promoting early warning systems and cooperation. Both require careful consideration of termination provisions to mitigate risks. Effective contract termination in construction requires

understanding FIDIC 1999 and NEC3 contractual frameworks, open communication, and proactive management to minimize disputes and improve project outcomes.

The standard forms of contracts (SFoC) utilized within the industry vary significantly and are tailored to different types of projects. All parties involved in a construction project must be thoroughly educated and diligent in understanding which SFoC is most appropriate for their specific project needs. Furthermore, a comprehensive grasp of the causes, consequences, and the comparative analysis between FIDIC 1999 and NEC3 is essential. Parties must be well-versed in the relevant provisions and the solutions offered by the chosen SFoC to ensure informed decision-making and effective contract management.

The research has identified that the paper's limitation lies in its focus on the construction business, whereas the termination perspective is considered from both the contractor and employer viewpoints. Thus, all literature and approaches are confined only to the themes of Termination by Contractor and Termination by Employer.

REFERENCES

Aliaj, E., 2022. Termination of individual employment contract during an inappropriate time under Albanian legislation. *Revue Européenne Du Droit Social*, 56(3), 46-54.

Amoah, C. and Nkosazana, H., 2022. Effective management strategies for construction contract disputes. *International Journal of Building Pathology and Adaptation*, 41(6), 70-84.

Artan, D., 2012. Identification of the relations between dispute factors and dispute categories in construction projects. *International Journal of Law in the Built Environment*, 4(1), 45-59.

Asadi, R., Wilkinson, S., and Rotimi, J., 2023. Mixed-method approach to the evaluation of rework provisions within general contract conditions. *Construction Economics and Building*, 23(3/4).

Asadi, R., Wilkinson, S., and Rotimi, J. O. B., 2021. The common causes of rework in construction contracts: a diagnostic approach. *Journal of Engineering, Design and Technology*, 21(4), 1107-1133.

Ashworth, A., 2012. *Contractual Procedures in the Construction Industry*. 7th ed. Harlow: Pearson Education.

Ashworth, A. and Perera, S., 2018. *Cost Studies of Buildings*. 6th ed. Harlow: Pearson Education.

Bolton, S., Wedawatta, G., Wanigarathna, N., and Malalgoda, C., 2022. Late Payment to Subcontractors in the Construction Industry. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*.

Cardenas Barbosa, I., Dewulf, W., Vanelslander, T., Smet, C., and Beckers, J., 2017. The e-commerce parcel delivery market and the implications of home B2C deliveries vs pick-up points. *International Journal of Transport Economics*, 44, 235-256.

Cavanagh, J., 2016. *Construction Contracts: Law and Practice*. 2nd ed. London: Routledge.

Çela, A., 2015. Dismissal procedures in Albania: A comparative study. *Mediterranean Journal of Social Sciences*.

Clough, R.H. and Sears, G.A., 2018. *Construction Contracting: A Practical Guide to Company Management*. 8th ed. New Jersey: Wiley.

Cushman, R.F. and Carter, J.D., 2019. *Construction Law Handbook*. 2nd ed. New York: Aspen Publishers.

Dąbrowska, A., 2019. Analysis of the FIDIC arbitration clause in the light of international jurisprudence. *ASEJ Scientific Journal of Bielsko-Biala School of Finance and Law*, 23(1), 27-30.

Daradkeh, L., 2016. Solution by negotiation and determination by arbitration in Arab world construction disputes: Comparative study between FIDIC rules of 1987 and FIDIC rules of 1999. *Arab Law Quarterly*, 30(4), 395-409.

Dosumu, O., Idoro, G. I., and Onukwube, H. N., 2017. Causes of errors in construction contract documents in southwestern, Nigeria. *Journal of Construction Business and Management*, 1(2), 11-23.

Elliot, C. and Quinn, F., 2013. *Consideration, Contract Law*. 9th ed. UK: Pearson Education Limited

Fawzy, S., El-adaway, I., Perreau-Saussine, L., Wahab, M., and Hamed, T., 2018. Analyzing Termination for Convenience Provisions under Common Law FIDIC Using a Civil Law Perspective. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*.

Gagula, A. and Meškić, Z., 2020. Termination of the contract under FIDIC: The perspective of Bosnia and Herzegovina. *Revija Kopaonicke Skole Prirodnog Prava*, 2(2), 57-75.

Graça, B., and Au-Yong-Oliveira, M., 2024. *Methodology*. Springer Nature, Switzerland.

Gould, N., 2018. *Construction Law: Contracts and Dispute Management*. 3rd ed. London: Informa Law.

Gould, N. and Joyce, R., 2020. *Construction Law and Practice*. 4th ed. London: Sweet & Maxwell.

Haron, R. C. and Arazmi, A. L. H., 2020. Late payment issues of subcontractors in malaysian construction industry. *Planning Malaysia*, 18(11).

Heaphy, I., 2013. NEC versus FIDIC. *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law*, 166(1), 21-30.

Hughes, W.P. and Murdoch, J., 2015. *Construction Contracts: Law and Management*. 5th ed. London: Routledge.

Hyari, K. H., 2022. Payment procedures under FIDIC construction contract. *Proceedings of International Structural Engineering and Construction*, 9(1).

Jung, H., Kosmopoulou, G., Press, R., and Sicotte, R., 2021. Subcontracting and the incidence of change orders in procurement contracts. *Economic Inquiry*, 60(1), 247-264.

Kelley, G. S., 2012. Termination of the construction contract. *Construction Law*, 181-186.

Krippendorff, K., 2019. *Content analysis: An introduction to its methodology*. SAGE Publications, Inc.

Lau, C. H., Jayantha, W. M., Lam, P. T., and Javed, A., 2019. The challenges of adopting New Engineering Contract: A Hong Kong study. Engineering, *Construction and Architectural Management*, 26(10), 2389-2409.

Laxsana, S., Abiramy, S., and Fayasa, A., 2023. Measures to mitigate termination of construction contracts in Sri Lanka. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ramachandra, T. and Ranadewa, K.A.T.O. ed. *Proceedings of the 11th World Construction Symposium*, Sri Lanka 21-22 July 2023, 767-778.

Lee, H., and Choi, I., 2003. A study on the cost estimation in case of termination in the building construction contract. *Journal of the Korean Institute of Building Construction*, 3, 95-102.

Miller, D. P., 2014. Subcontracting and competitive bidding on incomplete procurement contracts. *The RAND Journal of Economics*, 45(4), 705-746.

Mitkus, S. and Averkienė, D., 2019. Legal significance of construction documents: Consequences of non-implementation of contractual regulations for the client and the contractor in Lithuania. *International Scientific Conference on Contemporary Issues in Business, Management, and economics Engineering'2019*, Lithuania 9–10 May 2019. Vilnius Gediminas Technical University, 671-678.

Odeh, A., and Battaineh, H., 2002. Causes of construction delay: Traditional contracts. *International Journal of Project Management*, 20, 67-73.

Othman, A., 2012. A study of the causes and effects of contractors' non-compliance with the health and safety regulations in the South African construction industry. *Architectural Engineering and Design Management*, 8, 180 - 191.

Parchamijalal, M., Moradi, S., and Shirazi, M. Z., 2021. Claim management office maturity model (CMOMM) in project-oriented organizations in the construction industry. *Engineering, Construction and Architectural Management*, 30(1), 74-104.

Rameezdeen, R. and Shiyamasuntharan, R., 2004. A comparative study of ICTAD 1989 and ICTAD 2002 standard conditions of contract for building and civil engineering works. *Built-Environment Sri Lanka*, 5(1), 12-17.

Riveros, C. S., Ruiz, A. L., Mesa, H., and Guevara, J., 2022. Critical factors influencing early contract termination in public design–build projects in developing and emerging economies. *Buildings*, 12(5), 614.

Rosli, N. M., Mustaffa, N. M., Ariffin, H.L.T., Ya'acob, I. A. M., Rahmat, M. and Leu, K.S. 2022. Crucial conditions of domestic subcontract in Malaysian construction industry. *E3S Web of Conferences*, 347.

Serpell, A., and Torres, I., 2023. Causes of contractual disputes in construction projects. *Proceedings of International Structural Engineering and Construction*.

Shen, W., Tang, W., Yu, W., Duffield, C., Hui, F. K. P., Wei, Y., and Fang, J., 2017. Causes of contractors' claims in international engineering-procurement-construction projects. *Journal of Civil Engineering and Management*, 23(6), 727-739.

Stannard, J., 2018. Delay in the Performance of Contractual Obligations.

Surahyo, A., 2018. Suspension and Termination of Construction. 205-214.

Tanriverdi, C., Atasoy, G., Dikmen, İ., and Birgönül, M. T., 2021. Causal mapping to explore emergence of construction disputes. *Journal of Civil Engineering and Management*, 27(5), 288-302.

Tembo-Silungwe, C. K. and Khatleli, N., 2017. A conceptual model for risk allocation in the construction industry. *American Journal of Applied Sciences*, 14(7), 690-700.

Terrell, D. and Surace, N., 2016. *Termination of Construction Contracts. Construction Contract Claims, Changes, and Dispute Resolution*: 3rd ed. ASCE Press.

Twyford, J., 2007. Risk allocation in construction contracts. *Design and Construction*, 204-218.

Willig, C. 2012. *APA Handbook of Research Methods in Psychology*. American Psychological Association.

Wilsoncroft, C., 2009. NEC3: Managing change. *ASME 2009 12th International Conference on Environmental Remediation and Radioactive Waste Management*, Liverpool 11-15 October, 2009. ASME, 25-30.

Yao, H., Chen, Y., Zhang, Y., and Du, B. X., 2021. Contractual and relational enforcement in the aftermath of contract violations: The role of contracts and trust. *International Journal of Managing Projects in Business*, 14(6), 1359-1382.

Yates, J., 2011. The Art of Negotiation in Construction Contract Disputes. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 3, 94-96.

FOREIGN DIRECT INVESTMENT: DETERMINANTS AND EFFECTS ON SRI LANKAN CONSTRUCTION

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FOREIGN DIRECT INVESTMENT: DETERMINANTS AND EFFECTS ON SRI LANKAN CONSTRUCTION INDUSTRY

ABSTRACT

Sri Lanka's construction industry faces significant challenges, including economic instability, political uncertainty, and infrastructure deficits. This research investigates the determinants and impacts of Foreign Direct Investment (FDI) within the sector, exploring how FDI can address these challenges. A qualitative approach was employed, involving 13 semi-structured interviews with industry professionals and officials from the Board of Investment (BOI) to explore the key factors influencing FDI inflows, such as economic growth, political stability, and infrastructure quality. The findings reveal that FDI positively contributes to technology transfer, enhanced productivity, and capital formation. However, concerns remain regarding wage disparities, environmental impacts, and the alignment of foreign investments with national interests. The study provides a detailed understanding of FDI's role in fostering sustainable growth in Sri Lanka's construction industry, offering valuable insights for policymakers and stakeholders.

Keywords: *Construction Industry; Foreign Direct Investment; Economy; Sri Lanka.*

INTRODUCTION

Globalization is the most prominent feature of the contemporary world, which creates inevitable and tremendous impacts on any country's economic development. According to Vaupot (2021), cross boarder investment in the form of foreign direct investment (FDI) was one of the key features of globalization especially since 1990. However, Pekarskiene and Susniene (2015) concede that FDI is a broad technique, which is considered a key driving force of globalization. FDI is a significant concept, which can be identified as an investment made by foreign investor with the basis of long-term economic relation and "interests between a foreign investor and the direct investment enterprise" (Kuliaviene & Sol-nyskiniene, 2014). FDI inflows are concentrated with various sectors of any country such as manufacturing sector, which consists of food and beverages, wood products, textile, electronic and electrical, paper products, printing, chemicals, petroleum, rubber, mineral products, metal products, agriculture sector and especially infrastructure construction and services sector (Konara, 2013). Among these sectors, construction industry can be identified as stimulus for economic advancement of any country. FDI can be identified as one of the best alternatives for capital formation to construction sector investment, which maximises the advantages of innovative technology, managerial competencies, market relations and trained workforce. In the case of Sri Lanka, it is required to attract FDIs into the construction sector and FDIs are highly encouraged (OSL, 2020).

Due to innovative global trends in construction industry, FDIs are encouraged with government policies especially in infrastructure projects such as expressways, power generation, water supply, roads and wastewater disposal (OSL, 2020). According to detailed statistical data of the Organization for Economic Co-operation and Development (OECD, 2022), global FDI has risen back in 2021 with 88% increment and 37% increment than pre-pandemic period. Even though global economic condition is being amplified by FDI, Sri Lanka has recently witnessed its worst economic crisis in history. Further, it is mentioned that the huge economic recession will cause to major issues, which relate to unemployment, material shortages and reduction of FDIs than any downturn (Edmund et al., 2018). Recent studies confirm that due to the pandemic and recent past of Sri Lanka, FDI has been reduced since 2019 (Nazeeruddin & Baig, 2022; Joseph, 2022). Moreover, during the stable economic situation in 2017 and 2018, Sri Lankan construction industry was mainly driven by FDIs than local government funds (Daily FT, 2018). Further to the authors, during that period, the annual output value of construction sector was USD 3 billion, without considering the Colombo Port City and the other mega projects. After the COVID-19 pandemic, Sri Lanka is going through the worst economic crisis due to decline of foreign reserves since August 2020 (Sulthana, 2022).

Due to this economic downfall of the country, many negative impacts had to be faced especially in construction sector and because of these consequences of the crisis such as currency depreciation, reduction of importing goods, frequent power failures, foreign exchange rate uncertainty and political instability, "Sri Lankan construction industry to contract by 4.6% growth in real terms in 2022" even though previous projection was 9.2% (LNW, 2022). In this context, Sri Lanka's construction industry is key to economic recovery, especially given the current domestic capital shortage. Foreign direct investments (FDI) are seen as a potential solution, but little research has explored the factors driving FDI in Sri Lanka's construction sector, particularly after the recent crisis.

While many studies have examined FDI globally, few focus on its specific impact on Sri Lanka's construction industry. Most research looks at broader sectors or macroeconomic effects, leaving a gap in understanding how FDI addresses the unique challenges faced by this industry in developing countries like Sri Lanka. The aim of this research is to Investigate the determinants and effects of FDI on Sri Lanka's Construction Industry. To fulfil the aim of the research, following objectives were established. 1) Identify the determinants of FDI for Sri Lankan Construction Industry. 2) Identify the impacts of FDI on Sri Lanka's Construction Industry. Data collection was conducted solely within the Sri Lankan context, involving professionals from the construction industry and subject matter experts in Sri Lanka. The findings foster a positive mindset among relevant authorities regarding FDI and to create an optimal environment for attracting inflows of foreign investments.

LITERATURE SYNTHESIS

Foreign Direct Investment (FDI) can be identified as a cross-border investment, which consists of at least 10% investment of the equity capital in the host country firm (OECD, 2008; Hashimoto & Wacker, 2012; Rahman & Semenovskiy, 2022). Further to the authors, in terms of origin, it is differentiated than the domestic investment, because FDI originates from another country and opposite to that domestic investment originates in the country itself. According to Melega et al. (2021), FDI acts as an internationalisation instrument, which allows to transfer technology and part of the capital from parent company to another country through opening of subsidiaries in another countries.

TYPES OF FOREIGN INVESTMENT

According to Saraci (2014), FDI can be categorized by considering two perspectives: that of the investor and that of the host country. According to investor's perspective, mainly there are four types of FDI can be identified (Saraci, 2014; "Different types of FDI", 2019; "Foreign Direct Investment", 2022). Horizontal FDI occurs when a business expands into a foreign country while maintaining its core activities. Secondly, vertical FDI involves a business entering a foreign market by relocating a part of its supply chain without altering its main business functions. Furthermore, Conglomerate FDI is characterized by business investing in a foreign country with entirely different products, thereby entering a new market. Finally, Platform FDI takes place when a business expands into a foreign country, with the output being exported to a third country.

From the perspective of host country, there are three types of FDI can be identified (Saraci, 2014). FDI Import Substitutes involve the production of goods that are typically imported but are manufactured in the host country. Additionally, FDI Rising Export relates to investments aimed at acquiring raw materials or intermediary goods. Lastly, FDI Initiated by Governments pertains to foreign investments encouraged by government policies designed to incentivize investment and reduce the balance of payments deficit. Regardless of the type, FDI is recognized as one of the most advantageous financing methods for both host and home countries (Saraci, 2014).

DETERMINANTS OF FOREIGN DIRECT INVESTMENT

Previous studies confirmed that several micro and macro level factors are affected to determine FDI flows into a particular country (Konara, 2013). According to Rahman and Semenovskiy (2022), several research have been conducted to identify determinants of FDIs concerning both country specific and company specific factors. Determinants of FDIs, irrespective of country or company are shown in Table 1.

Table 1: Determinants of FDI

Determinant	Sources
Size and growth of host country's economy	[1], [4], [8], [9], [11], [12], [15], [17], [18]
Trade openness	[1], [4], [8], [9], [10], [14], [15], [18], [20]
Political instability	[1], [6], [7], [9], [11], [12], [15], [19]
Human capital	[1], [3], [9], [11], [12], [19], [20]
Exchange rate	[1], [2], [6], [8], [11], [12], [13], [18]
Infrastructure, logistics performance	[1], [3], [6], [8], [9], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20]
Labour costs	[1], [6], [7], [11], [15], [18]
Host country gross domestic product	[2], [5], [14], [18], [20]
Host country annual inflation	[2], [8], [12], [13], [14]
Macroeconomic stability	[3], [9], [19]
Market access, size and potential	[3], [6], [9], [10], [11], [13], [15], [17], [18]
Human and natural resources	[3], [9], [12], [13], [19], [20]
Cost components	[3], [5], [9]
Telecommunication and ICT	[3], [8], [11], [16], [20]
Government incentive policies	[6], [9], [10], [19]
Advanced technology	[6], [11], [19]
Skill and knowledge	[8], [19], [20]
Socio economic factors	[13]
Geographical position	[17], [20]

These determinants of FDI directly related to the motivation, which is behind the decision to invest in foreign country (Meivitawanli, 2021).

IMPACT OF FOREIGN DIRECT INVESTMENT TO THE HOST COUNTRY

FDI plays a significant role in economic growth of a country by facilitating transfer of technology, management skills, human capital, different products and services from a home country to a host country (Bouchoucha et al., 2019). In addition, Rahman and Semenovskiy (2022) confirms that spillover effects of FDI consists of wide range of benefits to the host country with technology advancement and infrastructure development. According to Lipsey and Sjoholm (2005), there are several possible impacts of FDI on host country can be identified specially producing high quality outputs for lower prices or greater volumes than previous. In contrast, impact of FDI on the issues

related to the host country has been considered at both macro and micro levels (Li et al., 2018). An overview of the key impacts of FDIs are demonstrated in Table 2.

Table 2: Impacts of FDIs to the host country

Impacts	Source
Benefits	
Transfer advance product and process technologies	[1], [3], [4], [5], [7], [10], [12]
Transfer managerial knowledge and skills	[1], [3], [4], [5]
Improving the efficiency of existing operations	[1], [5]
Increase in productivity in the firm	[1], [2], [8], [9], [11]
Contribute to capital formation	[1], [3], [4], [5], [6], [8], [9], [10], [12]
Improving the skill level of human capital	[1], [7]
Increasing the employment rate	[1], [3], [4], [6], [10], [11]
Higher wages for employers	[1], [2], [3], [8], [11]
Effects on trade performance	[1], [3], [4]
Effects on host country's balance of payment account	[1], [3]

Increasing competition	[3], [7]
Integration into global economy	[7]
Firms' development and restructuring	[7]
Introduction of new industries	[1], [8]
Adverse Effects	
Foreign MNEs may have greater economic power than local competitors	[3]
Adverse Effects on Balance of Payments	[3]
Environmental Impact	[3], [12]
Major privatization	[3]
Difficulty of implementation economic policies	[7]
Sources: [1] Konara (2013), [2] Lipsey & Sjoholm (2005), [3] Kastrati (2013), [4] Ciobanu (2020), [5] Bouchoucha et al. (2019), [6] Sass et al. (2018), [7] Singh (2009), [8] Lipsey (2004), [9] Vahter & Masso (2006), [10] Johnson (2005), [11] Mkombe et al. (2020), [12] Rafique et al. (2020)	

However, most of the economies are benefited from FDI inflows over the period especially developing countries (Ayamba et al., 2020). As a conclusion, Literature findings provided an in-depth overview of Foreign Direct Investment (FDI), including its types, determinants, and impacts on host countries. The analysis highlights FDI's role as a crucial driver of economic growth, while also acknowledging the potential challenges it may pose, especially in developing countries. To validate these findings within the Sri Lankan context, expert interviews were employed in this research.

RESEARCH METHOD

This research consists of a background study, a comprehensive review of the literature, and data collection through semi-structured interviews, which benefited from both structured and unstructured approaches. In the literature survey, it could be identified some in depth details regarding FDI concept through published materials. But due to the limited details regarding Sri Lankan context, semi structured interviews conducted to fill the gap of the survey. In semi structured interviews, a high level of information is gathered. Further, in-depth information can be obtained with the interview's skills and adequate flexibility and easy observation of information can be identified as the main advantages of this approach.

The main purpose of the two separate guidelines was the necessity to gather different data from BOI officials including BOI facilities for FDI projects, strategies use by BOI to address the current situation on the performance of FDIs. Specifically, construction professionals were selected for their handson experience with FDI-funded projects, while BOI officials were included due to their regulatory role in facilitating FDI. Although only two BOI officials were interviewed, their inclusion was critical in understanding the policy perspective, while the majority of construction practitioners helped reflect the operational and industry level impacts of FDI on the ground. Data collection was limited to experts related to FDI projects and purposive sampling is applied as the most appropriate sampling method for the study. Purposive sampling was employed for this study as it is a non-probability sampling technique that allows researchers to deliberately select participants based on their knowledge, experience, and relevance to the research objectives. Content analysis was used as the data analysis technique because it is the most well-known method to carry out qualitative data analysis. It was performed manually to ensure accuracy, allowing the researchers to closely engage with the data and interpret it in the context of the research objectives.

RESPONDENT PROFILE

Semi structured interviews were conducted with eleven (11) industry professionals in Sri Lankan construction industry and two (2) BOI officials. Table 3 summarizes the brief description of thirteen interviewees in relation to their experience and relevant expertise related to FDI.

Table 3: Profile of the Interviewees

Code	Designation	Type of the organization	Experience	Key experience related to FDI
R1	Managing Director	Contractor	30 years	Extensive knowledge in FDI projects
R2	Chief Quantity Surveyor	Contractor	30 years	Involved in numerous FDI contracts
R3	Chief Quantity Surveyor	Consultant	30 years	Extensive knowledge in FDI projects
R4	Chief Quantity Surveyor	Consultant	35 years	Extensive knowledge in FDI projects
R5	Chief Quantity Surveyor	Contractor	35 years	Involved in numerous FDI contracts
R6	General Manager	Contractor	32 years	Involved in numerous FDI contracts
R7	Quantity Surveyor	Contractor	20 years	Involved in numerous FDI contracts
R8	CEO	Contractor	31 years	Involved in numerous FDI contracts
R9	Quantity Surveyor	Contractor	15 years	Participated in FDI feasibility studies
R10	Quantity Surveyor	Consultant	10 years	Participated in FDI feasibility studies
R11	Quantity Surveyor	Consultant	14 years	Involved in numerous FDI contracts
R12	Assistant Director	BOI	15 years	Policy development for FDI projects
R13	Assistant Director	BOI	30 years	Facilitated FDI projects' approvals

As per the above table, all experts were with a significant experience in Foreign direct investments and construction industry. This diverse expertise highlights the suitability of the respondents for providing valuable insights on FDI in the Sri Lankan construction industry.

COLLECTION, ANALYSIS AND FINDINGS

VALIDATION OF DETERMINATION OF FDI IN THE CONTEXT OF SRI LANKA.

The interviewees were requested to comment on the relevancy of the identified determinants of FDIs through the literature synthesis into Sri Lankan construction industry. Based on their opinion, factors were categorized as highly affecting (HA), affecting (A) and not affecting (NA). Accordingly, the identified determinants of FDIs in construction industry were validated by respondents with their experience related to the FDI projects. Table 4 demonstrates about their response towards each determinant identified through the literature.

Table 4: Responses of the interviewees on determinants of FDI

Determinants of foreign direct investments												
No	**Determinant**	**R 1**	**R2**	**R3**	**R 4**	**R 5**	**R 6**	**R7**	**R 8**	**R9**	**R1 0**	**R1 1**
1	Size and growth of host country's economy	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA
2	Trade openness	HA	HA	HA	A	A	A	A	A	A	A	A
3	Political instability	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA
4	Human capital	A	A	A	A	A	A	A	A	A	A	A
5	Institutional environment	A	A	A	A	A	A	A	A	A	A	A
6	Domestic stock market development	A	A	A	NA	A	A	A	NA	NA	A	A
7	Exchange rate	HA	A	HA	HA	HA	HA	HA	A	A	A	A
8	Infrastructure, logistics performance	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA
9	Labour costs	A	A	A	A	A	HA	A	HA	A	A	A
10	Exports to the host country	NA	NA	A	A	NA	NA	NA	NA	NA	NA	NA
11	Imports from the host country	NA	NA	A	A	NA	NA	NA	NA	NA	NA	NA
12	Host country gross domestic product	HA	HA	HA	HA	HA	A	HA	HA	A	HA	HA
13	Host country annual inflation	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA
14	Host country technological development	HA	A	HA	A	A	HA	A	A	A	A	A
15	Host country trade and exchange reforms	HA	HA	HA	HA	HA	HA	A	A	A	A	A
16	Host country competition reforms	A	A	A	A	A	A	A	NA	NA	A	A
17	Macroeconomic stability	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA
18	Financial structure and development	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA
19	Public governance	A	A	A	A	HA	A	A	A	A	A	A
20	Business environment	A	A	A	A	A	A	A	A	A	A	A
21	Market Access, Size and Potential	HA	HA	HA	A	HA	HA	A	HA	HA	HA	HA
22	Natural Resources	A	A	A	A	A	NA	A	A	NA	A	NA
23	Cost components	HA	HA	HA	A	HA	HA	HA	HA	HA	HA	HA
24	Telecommunication and ICT	HA	HA	HA	A	A	A	HA	A	A	A	A
25	Commodity price index	A	A	A	A	A	A	A	A	A	A	A
26	Risk factors	HA	A	HA	A	A	HA	HA	A	A	HA	A

Determinants of foreign direct investments												
No	**Determinant**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**
27	World stock market index	A	A	A	NA	NA	A	NA	A	NA	A	NA
28	Gross fixed capital formation	A	A	A	A	A	A	A	A	A	A	A
29	Population of host countries	A	NA	A	A	NA	NA	NA	A	A	NA	NA
30	Administrative bottlenecks	A	A	A	A	HA	A	A	A	HA	A	A
31	Entry restrictions	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA
32	Complementary factors of production	A	A	A	A	A	A	A	A	A	A	A
33	Restrictions of foreign trade	A	A	A	A	A	A	A	A	A	A	A
34	Change in trade shares	A	A	A	A	A	A	A	A	A	A	A
35	Post entry restrictions	A	A	A	A	A	A	A	A	A	A	A
36	Technology related regulations	A	A	A	A	A	A	A	A	A	A	A
37	High investment return	HA	HA	A	HA	HA	HA	HA	HA	HA	A	HA
38	Government incentive policies	A	A	A	A	A	A	A	A	A	A	A
39	Part of company's globalization strategy	A	HA	A	A	A	HA	A	A	A	A	A
40	Serving as an export platform	A	A	A	A	A	A	A	A	A	A	A
41	Regulatory efficiency	HA	HA	HA	HA	A	A	HA	HA	A	A	A
42	Global competitiveness	A	A	A	A	A	A	A	A	A	A	A
43	Skill & knowledge	A	A	A	HA	A	A	HA	HA	A	A	A
44	Legal integration	A	A	HA	A	A	HA	HA	HA	HA	A	A
45	Interest rates	A	A	A	A	A	A	NA	A	A	NA	NA
46	Entrepreneurial matters	A	A	A	A	A	A	A	A	A	A	A
47	Cultural factors	A	A	A	A	A	A	A	A	A	A	A
48	Government consumption expenditure	A	A	A	NA	NA	A	NA	NA	NA	NA	A
49	Tax polices	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA
50	Socio economic factors	A	A	A	A	A	A	A	A	A	A	A
51	Geographical position	HA	A	A	HA	A	A	A	A	HA	HA	HA
52	Transparency of financial policies	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA	HA
53	Improvement of the research institutions	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

All respondents agreed that size and growth of host country's economy, political instability, infrastructure, logistics performance, host country annual inflation, macroeconomic stability, financial structure and development, entry restrictions, tax policies and transparency of financial policies are highly affected to the FDI inflows.

As per R3, "if you look at any of the investors, they have draft list of their checklist. It is not simple and when they need to make an investment decision, they think about those factors in their checklist". Further

R2, R3 and R5 added that economic status of the country, political situation and infrastructure development are the main criteria in that checklist.

According to R3, "there is a good example in Venezuela. They were going as a good investing point for oil and gas. Many companies like British companies and American companies invested for the oil and gas. One government changed and what they deal with is expropriation. Expropriation means if there is a private business, they take that to the government either by compensation or even without compensation. The national policy of the government is foreigners can not involve in that business and these should be taken by the local government, in this case of national interest. So, something like expropriation is something coming from government. Therefore, government policies and political stability is important to make the investment decision".

In addition, R5 described that inflation is crucial for the investment decision mainly because it affects to the stability of the business environment. The R3 is elaborated that "in a gulf country like Dubai, United Arab Emirates, the inflation was something lesser than 5%. It is a good indication and for a long time any investor, who invest in that particular country can predict their business plans and their commercial planning very nicely because it is a stable environment". According to R1, project to project these determinants can be changed. The R1, R2 and R3 mentioned that when some entities investing in Sri Lanka, they bring their labour force also to the country and due to that they do not much consider about the human capital within the country. Further, as an ex-ample R3 explained that "in Mahaweli development project, which was mainly from UK, they did not bring in their labour force to Sri Lanka. But China brought their surplus labour resources as one of their strategies. So, they do not care much about the labour force or human capital of the host country".

Even though most of the respondents agreed that high investment return is the primary criteria, which is highly affected to the investment decision, R3 and R10 mentioned that some investors are coming not just because of high investment return. Although they gain low or medium return, they may have some other strategic objectives. As an example, sometimes investors want to keep the eyes on some other region. So, they came to a near country as investors. So, this factor is also affecting, but sometimes it may not be the full criteria". As per the respondents, more than half of them mentioned that the population of the country is not much affected to FDI inflows. But according to R1, R3, R4, R8 and R9 population and population growth are directly related to the construction demand. Further, R3 explained that "population is affected because through this product or service they are catering or serving somebody. So, in that purpose also the population is important. The other reason is the labour factor. So, that one is affecting".

Moreover, six respondents described that government consumption expenditure is not affecting to the FDIs because it usually says how much money the government spends on personal goods and services. But other five respondents explained that this factor indirectly affects to FDIs. For instance, if the government spends a significant amount for infrastructure projects, then it directly affects to FDIs, because it provides more favourable environment for foreign investors. However, all of the respondents agreed that improvement of the research institutions is not affecting to FDI inflows to Sri Lanka. Because R3 mentioned that "even today we have not seen that any of these Chinese companies come and looking for the research opportunities".

Further R12 and R13 were questioned about the incentives granted by BOI, which act as a determinant of FDI inflows to Sri Lanka. As per the view of R12, custom duty-free import facility is the major benefit provided by the BOI. Further R12 added that "most of time we provide corporate income tax for reduced rates or sometimes income tax exceptions for certain years. It depends on the project. Usually for Strategic Development Projects, we provide corporate income tax exemption for 5 to 10 years". Moreover, R13 described that BOI provides visa facilities for the foreign investors, top level management and the lower-level workers of the projects for a certain period. Further, as per R12 "there is an investor facilitation centre. In there, there is something called information desk, application submission desk and inter agency coordinating committee. So, the investor could get all information, finding local partners and solving any other issues very easily. And also, there is virtual platform to submit their applications for the projects and even for applying visa facilities". Moreover, R13 mentioned that "Once an investor signs up with BOI, the agreement is valid lifetime of the project. So, investment is guaranteed". The expert interviews confirmed that key factors such as economic stability, political conditions, infrastructure, and inflation significantly

impact FDI inflows into Sri Lanka's construction industry. Additionally, while incentives like tax exemptions and visa facilities offered by the BOI are beneficial, factors like government consumption expenditure and human capital are less consistently influential.

IMPACT OF FDI IN THE CONTEXT OF SRI LANKA

The professionals were requested to comment on the relevancy of the identified impacts of FDIs to the country through the literature synthesis. All of the respondents described transfer advance product and process technologies, transfer managerial knowledge and skills, efficiency of existing operations, productivity of the firm, contribution to capital formation, skill level of human capital, employment rate, effects on trade performance, effects on host country's balance of payment account, integration into global economy are the benefits for the host country. As per the previous question the impacts of FDIs in construction industry was identified through the literature synthesis were validated by respondents with their knowledge and experience related to FDI projects. Table 5 shows about their response towards each impact identified through the literature.

Table 5: Responses of the interviewees on impacts of FDI

Impacts of FDIs												
No	**Impact**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**
1	Transfer advance product and process technologies	X	X	X	X	X	X	X	X	X	X	X
2	Transfer managerial knowledge and skills	X	X	X	X	X	X	X	X	X	X	X
3	Efficiency of existing operations	X	X	X	X	X	X	X	X	X	X	X
4	Productivity of the firm	X	X	X	X	X	X	X	X	X	X	X
5	Contribution to capital formation	X	X	X	X	X	X	X	X	X	X	X
6	Skill level of human capital	X	X	X	X	X	X	X	X	X	X	X
7	Employment rate	X	X	X	X	X	X	X	X	X	X	X
8	Wages for employers	X	-	X	X	X	X	X	X	-	X	-
9	Effects on trade performance	X	X	X	X	X	X	X	X	X	X	X
10	Effects on host country's balance of payment account	X	X	X	X	X	X	X	X	X	X	X
11	Competition	X	X	X	X	X	X	X	X	X	X	X
12	Integration into global economy	X	X	X	X	X	X	X	X	X	X	X
13	Firms' development and restructuring	X	X	X	-	X	X	-	X	X	X	X
14	Introduction of new industries	X	X	X	X	X	X	X	X	X	X	X
15	Foreign MNEs may have greater economic power than local competitors	X	X	X	X	X	X	-	X	X	X	X
16	Environmental Impact	X	X	X	X	X	X	X	X	X	X	X
17	Major privatization	X	X	X	X	X	X	X	X	X	X	X
18	Difficulty of implementation economic policies	X	-	X	X	-	X	X	-	X	X	-

However, as per R1, even though productivity of the firm is increased by FDIs, the maximum advantage can be gained through proper managerial skills, supervisory and control by the firm. Otherwise, even though foreign investors contribute to the efficiency and productivity of local firmsthrough their technology and skills, it cannot be maintained by the local company. Further R3 explained that "generally skill level of human capital is positive impact of FDIs, but training and development process should be imposed upon the people to gain maximum advantage". The R3, R5, R7 and R8 described that FDI can have both positive and negative impacts on wages for employers. The R5 further elaborated that "when foreign companies invest in a country, they may create new job opportunities and increase the demand for skilled labour. This can lead to higher wages for employees with the necessary skills. Further, FDIs can generate spillover

effects, which occur when a foreign company invests in a country and other companies in the same industry or related industries also benefit". The R8 added that the foreign company may bring new technologies, management practices, and expertise that assist to increase productivity and efficiency. This can lead to higher wages as employees are able to produce more output in less time. However, according to R7, in some cases, foreign companies may take advantage of a large pool of low skilled workers and pay them lower wages than they would in their home country. This can lead to wage stagnation for these workers and slow overall wage growth. Further R10 highlighted that when foreign companies invest in a country, they may compete with local companies for market share, leading to job displacement. This can lead to lower wages for those who lose their jobs or who are forced to accept lower wages in order to stay employed.

According to the majority of respondents, firms can be developed and restructured through FDIs specially from strategic alliances and partnerships. As per R11, because of the innovative technologies, increased competition, strategic partnerships and joint ventures, local firms can be restructured. Further, R10 added that the necessity to entering into new markets through foreign investors also can be a reason for restructuring of firms. However, according to the respondents, environmental impact may be a major negative impact of FDIs. As per R7, major privatization can be considered as a negative impact of FDIs if it is not carried out in a transparent and accountable manner. According to R3, "sometimes governments may adopt policies to encourage or require the privatization of state-owned enterprises as a condition for attracting foreign investment. This can be particularly true in countries that are undergoing economic reforms or are seeking to reduce the size of the public sector". Further, R1 added that foreign investors may form joint ventures with state owned enterprises, with the eventual goal of acquiring full ownership and control. This can lead to the privatization of state-owned enterprises over time.

The R2, R5, R8 and R11 described that there cannot be any difficulties when implementing economic policies for foreign investors. But R3 explained that when a country attracts a significant amount of FDI, it may become more difficult for the government to implement certain economic policies that could negatively affect foreign investors. This can limit the policy space available to the government to pursue its development objectives. Further he elaborated that "sometimes the interests of foreign investors may conflict with the national interests of the host country. This can make it difficult for the government to implement policies that are in the best interests of its citizens, particularly if these policies negatively affect foreign investors". In addition, R4 highlighted that in some cases, the regulatory capacity of the host country may not be strong enough to effectively oversee and enforce the rules and regulations governing FDI. This can make it more difficult to ensure that FDI is contributing to sustainable development and not causing negative impacts on the environment or local communities. Further, R12 and R13 were questioned about the benefits gained to the Sri Lankan construction industry from FDIs. According to them, transfer innovative technology is the main benefit, which gain from FDIs. The R12 further added that "as an example we can say that lifting formwork system first came to Sri Lanka through FDI projects. And also, most of times for FDI projects they use high quality materials from oversees. So, we can ensure the quality of the product". The R13 further elaborated that "when government restrict importation of steel, they complain about the quality of steel in local market is not up to the standards".

As a conclusion, the identified impacts of FDIs on Sri Lanka, particularly in the construction industry, include benefits such as technology transfer, enhanced managerial skills, improved productivity, and increased capital formation. However, concerns were raised about potential negative impacts, such as wage disparities, environmental effects, and challenges in implementing economic policies that align with national interests.

CONCLUSION AND RECOMMENDATION

The study highlighted that determinants such as economic stability, political conditions, infrastructure, and inflation are critical for attracting FDIs into Sri Lanka's construction industry. While BOI incentives like tax exemptions and visa facilities are beneficial, factors such as human capital and government consumption expenditure show varying impacts. FDIs have positively influenced the industry by transferring technology, enhancing managerial skills, and boosting productivity, but concerns about wage disparities, environmental effects, and policy implementation challenges remain. To leverage FDIs effectively, Sri Lanka should improve political and economic stability, upgrade infrastructure, and offer

targeted incentives. Additionally, policies should address wage protection, environmental sustainability, and alignment with national development goals. Strategic alliances between local and foreign firms should be encouraged to foster industry growth and ensure long-term benefits.

REFERENCES

Addison, T., & Heshmati, A., 2003. The new global determi-nants of FDI flows to developing countries: The importance of ICT and democratization. United Nations Uni-versity, World Institute for Development Economics Research.

Ali, S., & Guo, W. 2005. Determinants of FDI in China. *In Global Business and Technology* (1)2.

Asongu, S., Akpan, U. S., & Isihak, S. R. 2018. Determinants of foreign direct investment in fast-growing economies: Evidence from the BRICS and MINT countries. *Financial Innovation*, 4(1).

Assunção, S., Forte, R., Aurora, A. A., Teixeira, A. A. C., & Teixeira, A. C. 2011. Determinants of FDI: A Literature Review

Bouchoucha, A., Bouchoucha, N., & Ali, W. 2019. The impact of FDI on economic growth in Tunisia: An estimate by the ARDL approach.

Canh, N. P., Binh, N. T., Thanh, S. D., & Schinckus, C. 2020. Determinants of foreign direct investment inflows: The role of economic policy uncertainty. *International Economics*, 161, 159–172.

Ciobanu, A. M. 2020. The Impact of FDI on Economic Growth in Case of Romania. *International Journal of Economics and Finance*, 12(12), 81.

Daily, F. 2018. Construction sector increasingly FDI driven: Rishad. Daily FT. https://www.ft.lk

Dellis, K., Sondermann, D., & Vansteenkiste, I. 2011. Working Paper Series Determinants of FDI inflows in advanced economies: Does the quality of economic structures matter?

Demirhan, E., & Masca, M. 2008. Determinants of foreign direct investment flows to developing countries: A cross-sectional analysis. *Prague Economic Papers*, 4, 356–369.

Edmund, B.-T., Yang, H., & Eric, A. 2018. A general overview of the impact of global financial crisis on construction industries. *International Conference on Construction and Real Estate Management* 2018, 28–38.

Gunathilaka, M. H. V. S. S., & Mustafa, A. M. M. 2019. Determinants of foreign direct investment of infrastructure industry in Sri Lanka (25).

Hashimoto, Y., Wacker, K. M., Angulo, E., Cady, J., Che, N., Davies, R., Grosskurth, P., Klasen, S., Matei, S., & Orthofer, A. 2012. The Role of Risk and Information for International Capital Flows: New Evidence from the SDDS; By Yuko Hashimoto and Konstantin M. Wacker; *IMF Working Paper* 12/242.

Ho, C. S. F., Husni, A., & Rashid, M. (n.d.). Macroeconomic and country specific determinants of FDI.

Jayasekara, S. D. 2014. Determinants of foreign direct investment in Sri Lanka. 2, 4–13.

Joseph, D. 2022. An overview of Sri Lankan economic crisis 2022 and how it affects India. *International Journal of Recent Advances in Multidisciplinary Topics*, 3(4), 58–59.

Kariuki, C. 2015. The Determinants of Foreign Direct Investment in the African Union. *Journal of Economics, Business and Management*, 3(3), 346–351.

Konara. 2013. Foreign Direct Investment in Sri Lanka: Determinants and Impact [Doctoral thesis]. University of York.

Kuliaviene, A., & Solnyskiniene, J. 2014a. The evaluation of the impact of foreign direct investment on lithuanian economy using lag-analysis. *Economics and Management*, 19(1).

Meivitawanli, B. 2021. Determinants of Foreign Direct Investment: Evidence from Provincial Level Data in Indonesia. *Journal of Asian Finance*, 8(5), 53–60.

Melega, A., Macovei, A. G., Grosu, V., & Ciubotariu, M. S. 2021. Context analysis of determinants in attracting FDI by emerging economies under the effects of Covid-19. *Proceedings of the 38th International Business In-formation Management Association (IBIMA)*, 3706–3715.

Melega. 2020. Finance and Management Studies Evolution of Foreign Direct Investment at the Level of BRICS Economies. *Journal of Economics*.

Mohammed. 2018. The impact of foreign direct investment on economic growth by construction sector in KRG-IRAQ.

Nunnenkamp, P. 2002. Determinants of FDI in developing countries: Has Globalization Changed the Rules of the Game.

Nazeeruddin, M., & Baig, M. J. 2022. Sri Lanka's Economic crisis- An Eye Opener. *International Journal of Multidisciplinary*, 7(4), 01–02.

OECD. 2022. FDI in Figures. https://www.oecd.org/investment/investment-policy/statistics

OECD. 2008. OECD Benchmark Definition of Foreign Direct Investment – Fourth edition-2008.

Opportunity Sri Lanka (OSL). (2020). Construction & engineering sector overview & investment opportunities. https://opportunitysrilanka.com

Pekarskiene, I., & Susniene, R. 2015. Features of foreign direct investment in the context of globalization. *Procedia - Social and Behavioral Sciences*, 213, 204–210.

Rahman, M. N., & Semenovskiy, I. D. 2022. Outward FDI: Theories and determinants. *Management and Econom-ics Research Journal,* 1(1), 1–6.

Saraçi, A. 2014. Origin of foreign direct investments. *Mediterranean Journal of Social Sciences*, 5(7), 48–53.

Sass, M., Gál, Z., & Juhász, B. 2018a. The impact of FDI on host countries: the analysis of selected service industries in the Visegrad countries. *Post-Communist Economies*, 30(5), 652–674.

Tocar, S. 2018. Determinants of Foreign Direct Investment: A Review. *Review of Economic and Business Studies*, 11(1), 165–196.

Vahter, P., & Masso, J. 2006. Home versus host country effects of FDI: Searching for New Evidence of Productiv-ity Spillovers.

Vaupot, Z. 2021. New institutional economics and FDI determinants.

PROBLEMATIC AREAS RELATED TO PRICE ESCALATION FOR REVISITING THE PRICE FLUCTUATION FORMULA

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PROBLEMATIC AREAS RELATED TO PRICE ESCALATION FOR REVISITING THE PRICE FLUCTUATION FORMULA

ABSTRACT

Price escalation is a critical risk factor in construction projects, characterized by its unpredictability and inevitability. This study examines the problematic areas of the CIDA price escalation formula within Sri Lanka's construction industry, identifying key discrepancies. The research, based on a quantitative approach and data collected from Civil Engineers, Project Managers, Quantity Surveyors, and CIDA personnel, highlights several critical findings. Rapid material price increases, absence of price control mechanisms, high inflation, and the impact of international raw material costs were identified as major contributors to price escalation. Additionally, issues such as the US dollar exchange rate, political instability, and delayed updates to price indices further complicate cost management. The study offers insights into improving the CIDA formula, suggesting more frequent updates and location-specific indices to enhance accuracy and ensure fair compensation for contractors. These findings provide valuable guidance for addressing price volatility challenges in Sri Lanka's construction sector.

Keywords: *CIDA Formula; Construction Industry; Price Escalation; Sri Lanka.*

INTRODUCTION

The construction development sector is critical to a country's economic prosperity. It encompasses engineering projects, new constructions, and renovations involving additions, modifications, maintenance, and/or repairs (Nivehithan, et al., 2017). Unlike other industries, construction is unique due to its varied job roles, skill sets, climatic conditions, and working environments (Gunarathne, et al., 2018). Given its significant role in Sri Lanka's economy, the sector's success directly impacts national development (Gunarathne, et al., 2018).

Effective project cost control is essential to maintaining construction budgets (Ali & Kamaruzzaman, 2010). Contractors aim to complete projects quickly to minimize costs, while clients seek timely completion for the intended use (Wijesekara, 2012). Cost overruns are often caused by inaccurate project assessments, leading to project failures (Peeters & Madauss, 2008). Additionally, rising price indices, driven primarily by inflation, reflect the increase of cost of construction inputs (Janardana, et al., 2021). Price fluctuations, therefore, pose a significant risk in Sri Lanka's construction industry (Abeynayake & Harshana, 2018).

The Construction Industry Development Authority (CIDA) price escalation formula aims to help mitigate unforeseen price increments in construction inputs in construction projects to a satisfactory degree (Hajjath & Rathnayake, 2019). However, the substantial increase in material prices during the period of 2021 to 2023 period in Sri Lanka has led to the abandonment or mutual termination of several projects. Given the complexities of accurately calculating actual price changes, the CIDA formula should closely reflect real price escalations while remaining user-friendly and applicable regularly.

Currently, rising costs are driven by various factors, including global oil prices, technological advancements, and inflation (Abeynayake & Harshana, 2018). The CIDA formula, based on the value of work executed during a specific period and the average escalation rate, offers a comparative analysis of actual price escalations. Any necessary revisions must be made to account for cost impacts in projects, especially given the highly competitive nature of Sri Lanka's construction industry. (Chandrasena, 2005). As such, the purpose of the present research is to assess the efficacy of the CIDA price escalation formula for capturing the actual trends in price change within the construction industry of Sri Lanka. It aims at finding out the problematic areas in the CIDA price escalation formula in Sri Lanka. Thus, the study identifies the antecedents of these differences as inflation rates, cross-boundary costs of raw materials, fluctuating foreign exchange rates, and economic downturns and seeks to offer guidelines for the formula's adjustment to better fit local market conditions and facilitate the performance of the cost increase management on construction projects.

LITERATURE REVIEW

COST OVERRUN IN CONSTRUCTION

The construction industry is widely recognized as a key driver of overall economic growth (Dolage & Wijesinghe, 2018). Accurate cost estimation during the early stages of the project is essential for decision-makers to effectively manage project expenses, employing technological or statistical methods (Herath, et al., 2018). Construction economics focuses on strategies that enable informed economic decisions, either by reducing costs or maximizing project benefits (Stasiak-Betlejewska & Potkány, 2015).

Consultants, contractors and suppliers must deliver realistic cost estimates and schedules during the project approval stage to demonstrate the project's economic viability and facilitate financial planning. Cost overruns can jeopardize the financial feasibility of a project and therefore price escalation has become an increasingly important factor in construction contract management. According to CIDA (2007), in Sri Lanka's construction industry, price escalation resulting from changes in the costs of inputs such as labour, materials, and machinery must be adjusted in the contractor's payments in accordance with the formula specified in the relevant contract clause to compensate the contractor's overruns explained above.

THE EVOLUTION OF PRICE ESCALATION PRACTICES IN SRI LANKA

CIDA, the regulatory authority for construction-related activities in Sri Lanka, has established a standard formula for adjusting contract prices due to price escalations. Price escalation is defined as the percentage difference between the initial base cost and the final completed cost (Dawood & Bates, 2000). Factors considered in price escalations include changes in the costs of materials, equipment, and labor, which may result from currency fluctuations, inflation, material shortages due to competing projects, or any other factor impacting overall costs (Zaki, 2020). In 1990, CIDA introduced a bulletin for Price and Cost Indices bulletin, using 1990 as the base year. This bulletin is used to calculate contract price escalations. Some clients and contractors in long-term construction projects have found the CIDA's Price Escalation (PA) technique, also known as the CIDA price escalation method, to be particularly useful. Additionally, for construction projects extending beyond three months, the CIDA price escalation methodology has been recommended (Jayalath & Wickramasinghe, 2020).

PRICE ESCALATION FORMULA

Contractors and clients in Sri Lanka use the price escalation formula to ensure fair contract prices, reflecting market conditions and maintaining cost fluctuations. This formula was developed for contracts valued at over Rs 10 million (Jayasinghe, et al., 2015). In Sri Lanka, CIDA is responsible for both the formula and the Price Index (CIDA, 2021). Currently, 61 price indices are available, including 55 for materials, 3 for labour, and 3 for plant and equipment dry hire rates. The rising input costs in construction and their impact on contractors have emphasized the need for a method to reclaim price escalations and this formula is intended to fulfil that requirement (Abeynayake & Harshana, 2018). However, the formula technique does not aim to calculate the exact amount of loss (Ramus, 1982).

$$F = \frac{0.966\,(V - Vna)}{100} \frac{\sum Px\,(Ixb - Ixc)}{Ixb} \qquad \textit{(Eq: 01)}$$

where, F = Price Escalation for the period, V = Value of work done for the period, Vna = Nonadjustable amount for the period, Px = Percentage for cost contribution of Input X, Ixb = Base index for input X, Ixc = Current Index for Input X.

CONTRACTOR-CLIENT DISPUTES OVER PRICE ESCALATION

Price changes are inevitable in any building or infrastructure project. Large-scale construction projects must continuously monitor input costs, including materials, labour, and equipment, as these can significantly deviate from the prices considered in obtaining initial contract value. Depending on contract terms, price changes may be recoverable. Fixed-price contracts lack escalation clauses, leading contractors to charge

higher markups to cover potential cost increases. Parties use standard and formula-based approaches to address price escalations in recoverable contracts.

The "price escalation" claims have been a persistent challenge for the construction sector and organizations since late 2021. Volatility must be considered, as it does not only drive price increases but also impacts resource allocation and selecting which projects to bid (Hajjath & Rathnayake, 2019). Contractors face significant difficulties due to clients' reluctance to cover price differences based on genuine market conditions, which affects both parties' financial health and the project's overall success.

Challenges include uniform distribution of input percentages, escalation calculations based on assessed valuation rather than cost changes, lack of standardized norms for calculating input percentages, disregard for market trends, and the dependence of Price Indices (Ixc and Ixb) on demographic factors. Accordingly, Table 01 illustrates a list of Problematic Areas of Price Escalation in Sri Lanka.

Table 1: Problematic Areas of Price Escalation in Sri Lanka

List of Problems	CIDA, 2021	Hajjath & Rathnayake, 2019	Janardana, et al., 2021	Karunaratne & Silva, 2021	Donato, et al., 2021	Silva, et al., 2008
No Price Control	√			√		
Impact of International Raw Material	√					
US Dollar Exchange Rate	√			√		√
Government Policy and restriction	√					√
COVID -19 Pandemic	√			√	√	
Material Price Increase Rapidly		√				
High Tax		√				√
Update the Bulletin Lately		√				
Accuracy of Indices is low		√	√			
Material Price Change in Different Location		√	√			
Some items not included in the list			√	√		
High Price Inflation					√	√
Government Support on Construction						√
Political Instability						√
Rapid Change in National Economy						√

The author identified 15 major problematic circumstances through a review of the literature. These categories include: lack of price control, the impact of international raw material costs, fluctuations in the US dollar exchange rate, government policies and restrictions, the COVID-19 pandemic, rapid increases in material prices, high taxation, delays in updating bulletins, low accuracy of indices, regional variations in material prices, the exclusion of certain items from lists, high inflation rates, insufficient government support for construction, political instability, and rapid changes in the national economy.

RESEARCH METHODOLOGY

The research used a quantitative research technique due to the resultant need for an in-depth investigation into the study. Based on the literature on the possible areas of problems concerning price escalation in the Construction Industry of Sri Lanka, a structured questionnaire survey was generated using Likert-scale questions. The questionnaire was administered to a purposive sample of 30 professionals including

Engineers of different forms of practice, Quantity Surveyors and Project Managers of construction organizations working in Sri Lanka, who were conveniently recruited from the Construction Industry Development Authority (CIDA). Accordingly, critically significant relative issues about the volatility of price structures of the construction industry in Sri Lanka have been identified by a Relative Importance Index (RII) analysis. Price escalation was also confined to using the CIDA escalation formula and real price data in the construction industry. A review of international literature sought to establish approaches to manage the risks of price inflations by analysing specific areas of concern in the construction process of Sri Lanka.

DATA ANALYSIS

Below Figure 1 illustrates problematic areas in the CIDA price escalation.

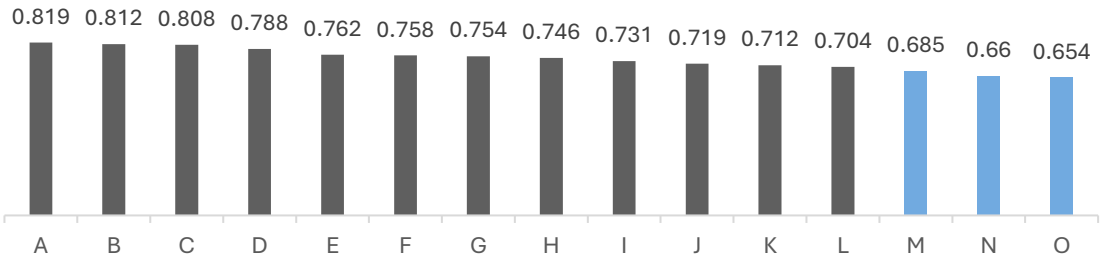

Figure 1 Data Findings for Problematic Areas in the CIDA Price Escalation

Table 2: RII Values of Problematic Areas in the CIDA Price Escalation

Problematic Areas	RII
A - Material Price Increase Rapidly	0.819
B – No Price Control	0.812
C - High Price Inflation	0.808
D - Impact of International Raw Material	0.788
E - US Dollar Exchange Rate	0.762
F - Rapid Change in the National Economy	0.758
G - Political Instability	0.754
H - Government Support on Construction	0.746
I - High Tax	0.731
J - Government Policy and restriction	0.719
K- COVID -19 Pandemic	0.712
L - Material Price Change in Different Locations	0.704
M - Accuracy of Indices is low	0.685
N - Update the Bulletin Lately	0.660
O - Some items not included in the list	0.654

Minor issues, with RII values below 0.700, include the low accuracy of indices, delays in issuing the CIDA bulletin, and the limited input percentage for certain construction materials. The study highlighted the need for CIDA to address the material shortage and rising fuel costs, which affect transportation expenses. A unique formula is also suggested for claiming imported goods impacted by the fluctuating dollar rate.

Contractors face financial challenges due to inadequate compensation for "price escalation," which is often omitted from tender documents, contrary to national tender standards. Even when included, the escalation calculation does not reflect actual market prices. The study underscores that outdated CIDA methodologies fail to represent actual market conditions accurately, leading to significant financial losses for contractors.

The research suggests contractors should follow proper claim and dispute procedures if discrepancies arise, referencing specific clauses within standard bidding documents (SBD). The Sri Lankan government has

taken steps to mitigate these issues by allowing compensation for price variations up to 20% of the contract value, even when the price escalation clause was not initially included. However, challenges remain, as the CIDA formula does not always reflect the real price variation for a given period, impacting contractor cash flow. A fair resolution would involve adjusting escalations monthly based on actual costs.

CONCLUSION AND RECOMMENDATION

Thus, the result obtained from this study emphasizes a rather substantial disparity between the CIDA price escalation formula and the real increase in prices in Sri Lanka construction industry. The main problems highlighted are the constant increase in material prices and the lack of credible measures for their regulation, high inflation rates, and instability of costs of the raw materials imported from other countries. This also underscores the effect of the exchange rate of the US dollar, political volatility, and bureaucratic restraints; all of which go a long way in making it even more challenging in cost control effort in construction projects. The calculation shows that although the CIDA formula can be used as a benchmark to address price surges, it lacks responsiveness to competitive market rates, therefore yielding poor returns to contractors.

The present research therefore brings out significant gaps in the old formula as it heavily relies on archaic indices, is ineffective in coping with high rates of economic turnover and does not factor in issues such as exchange rates fluctuations and global disruptions of supply chain. Peculiarly, the study calls for an improvement on the escalation formula to a more flexible formula that includes indices based on locations, price differences within regions, and frequent update on price bulletins. This would make it possible to determine fairly the actual pay to contractors so the above formula would be more in tune with the present market.

The novelty of this research lies in its focus on the accuracy of the CIDA formula during an unprecedented period of economic crisis and extreme price volatility. The study uses a Relative Importance Index (RII) to come up with a list of causes of cost overruns for which relative importance the projects affect most to be ranked high. Some of the recommendations made include coming up with different formulas for imported good and availing the price indices updates monthly all of which are practical measures that can improve the formula massively. Such findings are important in the ongoing efforts of fine tuning the cost management practices in construction industry in Sri Lanka as well as in formulating the policy changes and necessary reforms in future.

REFERENCES

Abeynayake, D. N, & Harshana, A. 2018. Calculating input percentages of ICTAD price fluctuation formula: Methods and issues. *Proceedings of annual technical sessions 2018 institute of quantity surveyors Sri Lanka*.

Ali, A., & Kamaruzzaman, S. 2010. Cost performance for building construction projects in Klang Valley. *Journal of Building Performance, 1*(1), 110-118.

Chandrasena, H. D. 2005. Application of the ICTAD formula for computation of price variation in construction contracts a consultant's point of view. *ICTAD auditorium*, 1-3.

CIDA. 2021. *Construction Industry Development Authority* . Sri Lanka: State Ministry of Rural Housing and Construction & Building Materials Industries Promotion.

Dawood, N., & Bates, W. 2000. A decision support system specification for out-turn cost and cost escalation in the heavy engineering industry. Engineering, *Construction and Architectural Management*, 330-346.

Dolage, D., & Wijesinghe, W. 2018. An investigation to problems faced by specialized small scale contractors in the construction industry. *ICSBE*.

Gunarathne, A., Zainudeen, N., & Perera, C. 2018. A review on integrating value engineering and sustainability in construction: Improving project value in sri lankan construction projects. *proceedings of annual technical sessions 2018, IQSSL.*

Hajjath, A., & Rathnayake, M. 2019. Appropriateness of CIDA price fluctuation formula for road construction in Sri Lanka. *Proceedings of the 8th World Construction Symposium,* 107-115.

Herath, J., Coomasaru, P., & Perera, B. 2018. An investigation of the effects of changes made during pre-contract stages of water supply projects. *Outsourcing Quantity Surveying Services in Construction Projects in Sri Lanka: Client/Consultant's Perspective.*

Janardana, J., Samaraweera, A., & Jayasena, H. 2021. Suitability of ICTAD formula and CIDA price indices to calculate the amount of price escalated in construction projects. *Proceedings of the 9th World Construction Symposium*, 505-515.

Jayalath, C., & Wickramasinghe, W. 2020. Limitation and hypothesis underlying the application of CIDA price fluctuation formula in Sri Lanka. *Proceesing of the 17th internatinal conference on business management, 17.*

Jayasinghe, S. A., Alahakoon, C., & Wijewardena, L. 2015. Sensitivity of the ICTAD Price Fluctuation formula procedure for the true material price fluctuations in construction industry. *Journal of Engineering and Technology of the Open University of Sri Lanka (JET-OUSL),* 3(1).

Nivehithan, T., B A K S, P., & Mallawaarachchi, H. 2017. A cost planning framework for the building construction. *CIDA JOURNAL, XV.*

Peeters, W., & Madauss, B. 2008. A proposed strategy against cost overruns in the space sector: The 5C approach. *Space Policy*, 80-89.

Ramus, J. 1982. Contract practice for Quantity surveyors. *Biddles Ltd.*

Silva, N. D., Rajakaruna, R., & Bandara , K. 2008. Challenges faced by the construction industry in Sri Lanka: Perspective of clients and contractors. *Building Resilience.*

Stasiak-Betlejewska, R., & Potkány, M. 2015. Construction costs analysis and its importance to the economy. *Procedia Economics and Finance*, 35 – 42.

Wijesekara, D. 2012. Cost effective and speedy construction for high-rise buildings in Sri Lanka by using aluminium panel system formworks. *ACEPS,* 239-244.

Zaki M. H. 2020. Example of price adjustment as of *FIDIC RED BOOK.*

THE ROLE OF CONTRACTOR PROJECT MANAGER IN ACHIEVING WORK-LIFE BALANCE (WLB) OF CONSTRUCTION SITE LABOURERS FOR A SUCCESSFUL PROJECT COMPLETION

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THE ROLE OF CONTRACTOR PROJECT MANAGER IN ACHIEVING WORK-LIFE BALANCE (WLB) OF CONSTRUCTION SITE LABOURERS FOR A SUCCESSFUL PROJECT COMPLETION

ABSTRACT

This study investigates how project managers can help construction site workers in Sri Lanka, where work-life balance is still a relatively new idea, achieve WLB. The PM is in charge of handling HR problems that the construction industry faces, especially labour dissatisfaction. The research investigates the relationship between the roles of PMs and workers' WLB via a survey of 100 construction labourers and PMs using questionnaires and interviews. Factors influencing WLB are identified through hypothesis testing using correlation, regression, and Repetitive Importance Index (RII) analysis. The report addresses industry, management, labour, and demographic aspects of Sri Lankan construction projects and makes recommendations for PMs looking to enhance WLB.

Keywords: *Construction Industry; Project Manager; Work-Life Balance*

INTRODUCTION

The construction industry encompasses organizations involved in designing, manufacturing, altering, rehabilitating, maintaining, managing facilities, and providing resources for construction (Fox *et al.*, 2008). Sri Lanka's construction industry experienced 12% growth in Q1 2016, contributing significantly to the nation's economic growth through expertise in building projects, highway construction, and infrastructure development (Marambage and Maduwansha, 2021). Investment decisions in private construction projects significantly influence developer profitability and financial stability (Sing *et al.*, 2015). In 2008-2009, 51.3% of the public sector's engineering construction work was contributed by the private sector for residential and non-residential building projects (Francis *et al.*, 2013). According to Moradi *et al*. (2020) The successful completion of construction projects relies on the private sector delivery method, and collaborative techniques like project partnering, integrated delivery, and alliances. PMs coordinate projects, ensuring smoothness in time, cost, and quality. However, there's a lack of expertise in project-based relationship management, which focuses on establishing and sustaining relationships with stakeholders (Meng and Boyd, 2017). Further, long-hour culture negatively impacts employee productivity, with internal rivalry and standardized hours hindering success. Manager's selflessness and devotion to the organization hinder these efforts (Moore, 2007).

People have diverse social needs, requiring various relationships and activities (Steverink and Lindenberg, 2006). Construction necessitates labour, and on-time attendance is crucial for project success. Absenteeism can lead to workflow disruption, decreased productivity, and revenue loss (Ahn *et al.*, 2014). Active workers in construction must meet social needs for overall well-being, with a hierarchy of needs, goals, and resources emphasizing universal needs, practical objectives, and resources (Steverink & Lindenberg, 2006). Discrimination, personal attributes, job features, self-actualization, self-esteem, and professional respect all impact job satisfaction. Also, addressing social challenges and promoting professional respect is crucial for job fulfilment (Ni *et al.*, 2022). Improving migrant worker's health is crucial for economic and social reasons; addressing emotional, physical, occupational, and other health difficulties and involving them in health plans can prevent long-term disease and skill loss (Onarheim *et al.*, 2021). The importance of study highlights a safe working environment in the construction industry, especially in high-risk environments, and the significance of maintaining stable social relationships (Kaluarachchi *et al.*, 2022). This study aims to identify the role of PMs in maintaining the WLB of construction site workers. This research only focuses on projects located in Colombo.

LITERATURE REVIEW

CONSTRUCTION INDUSTRY & WLB

- The Importance of Work-Life Balance to the construction Industry

WLB is crucial in the construction industry, as workers often experience negative health outcomes like stress, anxiety, and burnout. Weekend and irregular shift workers are more susceptible to emotional tiredness, stress, and psychosomatic health issues. Long workdays can lead to high suicide fatality rates, and overtime does not necessarily indicate concurrent fatigue in shift workers.	(Chan *et al.*, 2020)
Technology has enhanced life by providing longer, healthier lives and working flexibility, but it can blur the lines between work and family time, leading to stress and burnout. To manage these issues, promote WLB and schedule fun activities. Saying no to significant responsibilities outside work hours helps maintain a healthy WLB. WLB benefits companies and employees, increasing stock returns and reducing healthcare costs, but further research is needed to understand its interaction with work hours and safety.	(Pattu Meenakshi *et al.*, 2013)
WLB policies enhance employee productivity by promoting dedication, teamwork, and personal well-being. They reduce absenteeism, and turnover, and improve performance. Factors like motivation, skill development, communication, organizational culture, leadership, and individual qualities also impact productivity in the construction industry.	(Apraku *et al.*, 2020).

- Factors Affecting the Work-Life Balance of Construction Workers

Organizations should adopt WLB initiatives to enhance employee independence, manage work-family responsibilities, reduce stress, and improve the workplace environment by resolving work-family issues.	(Vyas *et al.*, 2017)
Culture, a collective mental programming, divides group members and evolves over generations. Management characteristics like leadership competence, project structures, and personality impact project success. Communication issues can arise from different languages, while values, norms, and stereotypical assumptions indirectly influence culture.	(Atsiaya and Wanyoike, 2017)

- Importance of Work-Life Balance to Successful Completion of Project

The construction industry, dominated by men, faces challenges in WLB due to its gendered culture and demanding work environment, hindering effective interventions in areas like work schedules and health initiatives.	(Bradley *et al.*, 2010)
The construction sector faces inflexibility, heavy workloads, unfavourable working conditions, limited skill development opportunities, a lack of senior management support, and high productivity expectations, leading to staff turnover and skill shortages. Both male and female workers struggle with work-life balance, which impacts their success and well-being in the industry.	(Panojan *et al.*, 2022).

Culture significantly impacts organizational performance, project management culture defines objectives and efficiency, and national culture influences performance objectives and manager management in construction projects.	(Liu *et al.*, 2020)
PMs can enhance WLB by offering flexible work hours, job sharing, part-time work, parental leave, telecommuting, childcare facilities, and health benefits like fitness programs and extended insurance.	(Lucy Wambui *et al.*, 2017)

THE ROLE OF CONSTRUCTION PROJECT MANAGERS IN WORK-LIFE BALANCE FOR SUCCESSFUL PROJECT COMPLETION

PM is responsible for planning, coordinating, and managing a construction project from start to finish. They ensure the project is functional, profitable, and completed on schedule, within budget, and to quality standards. PMs also oversee resources to ensure projects are implemented on time, within agreed budgets, and with desired functionality.	(Ali & Chileshe, 2009)
The PM's role in construction projects is unclear, with some focusing on preconstruction planning, administration, client management, communication, coordination, information flow, project management, manpower operations, and site logistics.	(Shibani and Sukumar, 2015)
The significance of comprehending a PM's abilities, choices, leadership, personalities, and roles. That study focuses on the requirement for a competency or competence development framework to assess prior performance and forecast results. According to the same research, project management, personality attributes, and leadership philosophies are equally important. Also stated the value of teamwork, trust, and relationship management in a project's success. Researchers can choose and manage PMs more effectively by being aware of these aspects.	(Meng and Boyd, 2017)
Interest is in PM's abilities in building projects, along with new competencies in leadership, communication, goal orientation, analytical thinking, flexibility, and adaptability, requiring further investigation.	(Moradi *et al.*, 2020b)
PMs are essential in projects, ensuring successful service engagements by providing value, understanding procedures, tools, and methodologies, and managing problems throughout the project life cycle.	(Ali and Chileshe, 2009)
Role stress, a significant aspect of job stress, involves difficulty in understanding and executing tasks, leading to role conflict, ambiguity, and overload. PMs often face significant stress due to their role in organizing, managing, and planning the project team. This stress can lead to job burnout, emotional exhaustion, cynicism, and reduced professional efficacy. Job performance refers to the PM's actions in meeting project goals and organizational requirements.	(Wu *et al.*, 2019)
A PM manages a construction project daily, maintaining team morale, discipline, and organization. They manage finances, analyze data, and practice self-discipline while defining and planning the project.	(Abdulsamad Ali and Chileshe, 2009)

PROJECT MANAGER'S PRACTICES TO IMPROVING WORK-LIFE BALANCE FOR SUCCESSFUL PROJECT COMPLETION

PMs are essential in the preconstruction, administration, and postconstruction phases of construction projects, overseeing HR, contractors, and subcontractors. Factors affecting Construction Labour Productivity (CLP) status vary by country, including hiring challenges, high employee turnover, absenteeism, and communication issues.	(Van Tam *et al.*, 2021).
PMs must understand techniques for evaluating equipment and labour productivity to manage construction resources effectively and ensure revenue. They must control labour, equipment, and cash flow for projects to meet revenue needs. The construction sector must address the lack of productivity standards and the industry's declining rate. The factors are: • Industry-related factors • Management-related factors • Labour-related factors	(Shehata and El-Gohary, 2011).

- Practices for WLB of construction employees:

The construction industry's long work hours negatively affect worker satisfaction and WLB, leading to higher burnout rates and negative spillover. Reducing work-family conflict through WLB programs may help safeguard employee well-being.	(Keith *et al.*, 2006).

- Practices for WLB of labour productivity:

The construction industry's workers rely on management, with factors like job nature, pay, working conditions, and society impacting productivity. To increase productivity, study positive and negative elements like project specificity, technological exploration, labour organization, wage trends, and skill development.	(Abdul Karim et al., 2012)
The research identifies four main categories of factors influencing workforce productivity: administration, location, design, and weather. These factors vary across countries and projects and can be categorized globally, maintaining their strength and indefensibility regardless of geographic and environmental locations. Further study is needed to understand their frequency and significance.	(Alaghbari *et al.*, 2019).
The construction productivity issue requires a thorough analysis of both positive and negative factors. Technological factors like design, material, location, organizational continuity, administrative factors like building techniques, equipment, labour, and social factors also impact site productivity. Labour characteristics, project work conditions, and unproductive activities also affect productivity. The Palestinian construction sector faces challenges with project scheduling and material delivery timetables. Tailored training initiatives can enhance efficiency.	(Enshassi *et al.*, 2007)

WLB is a concept that promotes collaboration between employers and employees to balance personal and professional responsibilities, increase output, control costs, and improve job satisfaction, with gender playing a significant role in its achievement.	(Tamunomiebi & Oyibo, 2020)
Work-family balance promotes minimal role conflict and good functioning at work and home, enhancing employee and organizational performance, reducing turnover intentions, and increasing job satisfaction. However, conflicts can negatively impact affective commitment and job satisfaction.	(Business & Research, 2014)
The construction sector, reliant on human labour, faces negative effects like low productivity and high absenteeism due to its long workdays, heavy workloads, and tight deadlines. To address this, stakeholders and policymakers must implement a WLB culture across the industry.	(Adah *et al.*, 2023)

METHODOLOGY

The research methodology outlines study objectives, findings, and human behaviour trends, using semi-structured interviews and structured surveys for qualitative and quantitative data collection.

RESEARCH APPROACH

The purpose of this study is to investigate the relationship between project management techniques and worker's attainment of WLB on construction sites. By combining both qualitative and quantitative information collection techniques, the objective is to significantly contribute to the effective implementation of the construction industry in Sri Lanka.

CONCEPTUAL FRAMEWORK

The dependent variable of this study is WLB for the successful completion of the project, and the independent variable is the PM's role in achieving the WLB of construction site labourers.

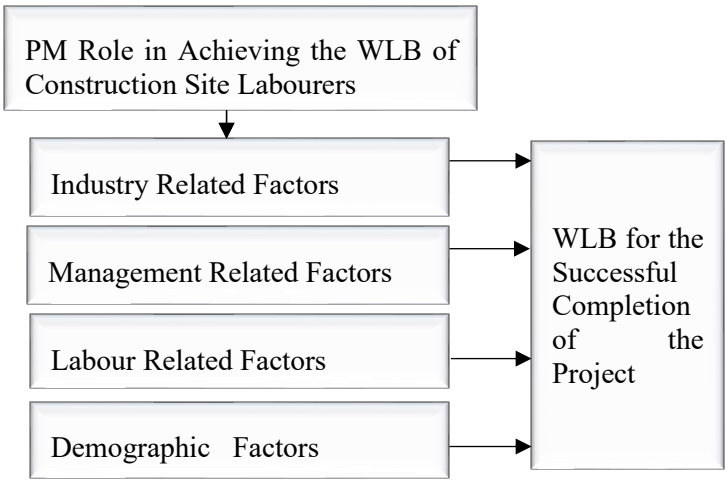

Figure 1: Conceptional Framework of Variables

DATA COLLECTION

The primary data for this research was gathered using simple random sampling, purposive sampling, and selective sampling methods, with PMs and construction site labourers in the Sri Lankan construction industry as respondents. The secondary data for this research was gathered using a comprehensive literature survey to identify the factors affecting the WLB of the construction industry.

DATA ANALYSIS

Data was obtained through two questionnaires and one semi-structured interview response to achieve the objectives. A total of 118 of the target population were collected for data collection, and 90 responses were obtained from both, with a response rate of 76.27%.

Table 1: Data Collection, Sample & Analyze Techniques

Data Collection	Population	Sample	Sampling Technique	Analyzing Technique
Literature Survey	Web Articles/ Journals		Secondary Data	
Detailed Questionnaire	PM	30	Selective Sampling	Correlation & Regression Analysis
	Labourers	50	Simple Random Sampling	RII Analysis
Semi-Structured Interview	PM	10	Purposive Sampling	Content Analysis

RESULTS

To identify the relationship of the project manager's role on the Work-Life Balance of construction site labours for a successful project completion. As a result, the gathered information was converted into a quantitative collection and examined using the statistical analysis program of the Statistical Package for the Social Sciences (SPSS). The collected quantitative data had a correlation and regression analysis because the objective was to determine the relationship between the role of the PM role and the WLB of construction site labourers for successful project completion. The presence, quality, and strength of relationships were investigated using correlation analysis. The statistically calculated significance value (p) was the key to determining the relationship.

- Testing of Relationship:

The study reveals a strong correlation between the PM role in worker's industry-related factors and the WLB of construction site labourers in the project's successful completion, with a significance level of less than 0.005, indicating a stronger relationship. The study found a significant correlation between management-related factors and the WLB of construction site labourers, indicating a strong relationship between the PM's role in managing these factors and the WLB for project success. The third independent variable, labour-related factors, has a significant correlation with the WLB of construction site labourers in successful project completion, indicating a strong connection between the WLB and the project's effective completion and the role of PM. The study reveals a significant relationship between the WLB of construction site labourers and the project's successful completion on demographic factors, with a correlation level of less than 0.005, indicating the crucial role of project management in managing demographic factors.

- Impact of the Project Manager's role in affecting the Work work-life balance of construction labourers and completing the project:

The first independent variable suggests that successful project compliance will result in a 32.7% increase in the PM's responsibility for the WLB of construction site labourers, particularly influenced by industry-related

factors. The second independent variable suggests that successful project compliance is correlated with a 7.7% decrease in the PM's contribution to the WLB of construction site labourers, influenced by management-related factors. The third independent variable suggests that successful project compliance will result in a 90.6% increase in the PM's impact on the WLB of the construction labourers, specifically affected by labour-related factors. The final independent variable suggests that, regarding successful project compliance, the PM's role in the WLB of the construction labourers, specifically the influence of demographic factors, should decline by 5.1%.

TO RECOMMEND PROJECT MANAGER'S PRACTICES TO IMPROVE THE WORK-LIFE BALANCE OF CONSTRUCTION SITE LABOURERS FOR A SUCCESSFUL PROJECT COMPLETION

- The role of PM is defined by the respondents:

In the construction industry, PMs are responsible for defining their duties and responsibilities, focusing on time, cost, and quality. However, only 20% of respondents identified HRM as a primary responsibility, highlighting the complexity of project roles in the industry. The WLB concept was not explicitly identified in interviews, with only a small percentage acknowledging its existence. Most PMs demonstrated some familiarity with the concept, with one manager actively integrating it into their managerial style. However, some PMs were unaware of the concept, with some having over 35 years of experience and others having just three years of experience. These differences in awareness levels highlight the diverse viewpoints within the construction management field regarding understanding and applying the WLB concept.

- Practices are following currently, to maintain the Work-Life Balance of construction site labourers:

Workload management is the main factor identified by the PMs to maintain the WLB of construction site labourers. All the respondent PMs specified that they all have work schedules, holiday schedules, and a good work environment without any work-related stress. According to the other half family side balance, only one PM said they organize well fair and functional activities for the labourers. Functional activities are organized once every 3 or 4 months. The construction industry is a stressful job, and people should have a chance to release their stress. Many PMs identified proper communication as very effective for WLB. Several of the PMs gave a chance to all labourers to discuss their issues with him. Most labourers had an issue with their salary, and they tried to get loans or other things from higher management. All PMs create a good physical work environment for the site labourers.

- Identifying issues to maintaining the Work-Life Balance for construction site labourers:

The PMs identified that they always maintain a gap with their labourers. Because of the specified level, the two professions shouldn't be at the same level. The main task in the industry was the PM should guide their labourers for specific asks. Respondents mainly said labourers leave is the most impactful case in the industry. The case was that labourers got their leave and didn't come again on the correct day. They should get more leave, and it is highly damaging for the duration of the project. Language matter was another, which was defined by the PMs. In the Colombo area, statistically, the majority of Tamil labourers are working. PM should get the additional effect of communicating that kind of labour. On the labourer's side, they should want more salary and benefits. In those cases, the PM had a big issue because the labour turnover rate was increasing in those kinds of cases. Construction is teamwork, and the PM should maintain the teamwork between all labourers and other employees on the project.

- Recommended Project Manager's practices for improving the WLB of construction site labourers:

The study reveals that there is limited awareness among PMs about WLB in the construction industry. Only 10% of respondents had a good understanding of WLB, indicating a lack of academic awareness. However, nearly 80% of PMs used WLB to resolve labour issues in various industries. The PMs recommended that each organization have a policy on maintaining WLB, and over 50% of respondents were responsible for it

themselves. PMs should handle labourers and resolve their issues, and policy awareness can be maintained on construction sites. PMs also suggested training and skill development programmers for both PMs and construction site labourers. However, construction site labourers want to train programmers to develop their behaviours and attitudes, as they have a responsibility to balance work and life. Over 80% of respondents should specify this point. To improve WLB, PM practices should be implemented, including effective scheduling, workload distribution, on-site amenities, safety precautions, open communication between workers and management, protective gear, weather-responsive work schedules, and modifying work schedules to consider Sri Lankan religious and cultural holidays. These strategies can significantly enhance the overall WLB of labourers on construction sites in Sri Lanka.

TO ASSESS THE MOST IMPACTFUL ASPECTS OF WORK-LIFE BALANCE ON LABOUR SATISFACTION FOR SUCCESSFUL PROJECT COMPLETION

Salary, compensation and benefits, and freedom in the workplace are the most impactful aspects of labour satisfaction among the KPIs. This data outcome helped determine what should be asked in the questionnaire when analysing the fourth objective. According to those responses, identify five of the most impactful aspects and rank them. Salary was at the top of the table. Because in the questionnaire specified, construction site workers weren't satisfied with their salaries. Most construction companies pay labourers on a day-rate basis. Labourers should attend more work to increase their salary. Number two of the above was obtained by the compensation and benefits. Labourers were also needed in that, as were overtime and additional salaries. Also, they were required to receive other beneficial things from organizations, such as new year benefits, Christmas, and others. In a semi-structured interview, identified labourers require more work from construction PMs to get more salary and overtime. But do more than workload and it hurt the WLB. The third rank hierarchy is specified as freedom in the workplace. Construction is a stressful industry, and lobbyists should be required to have workplace freedom to do their specialized tasks on the project.

Table 2: Analysis of the Most Impactful Factors for Labourers

Most Impactful Aspect	Response					No of Respondents	Total Weight	Frequency Index	Rank
	5	4	3	1	1				
Salary	46	2	3	0	0	51	247	0.8517	1
Compensation & Benefits	24	8	13	6	0	51	203	0.7000	2
Freedom in Personal Life	18	10	8	5	10	51	174	0.6000	4
Minimize Responsibilities	8	10	10	10	13	51	143	0.4931	5
Freedom in Workplace	17	13	8	9	4	51	183	0.6310	3

DISCUSSION

The construction industry, predominantly dominated by men, faces challenges in WLB due to its male-dominated nature. This study examines the relationship between the WLB of Sri Lankan construction site labourers and the roles of PMs. The research identified factors related to the industry, management, labour, and demographics as independent variables. The findings showed a strong positive correlation between the PM role and labour-related factors, indicating a significant impact on the project manager's ability to improve WLB. Organizations should adopt WLB initiatives to enhance employee independence, manage work-family responsibilities, and address work-family issues to reduce stress and improve the workplace environment. Techniques such as workload management, effective communication, and creating a positive work environment can help raise WLB. Work hours and support significantly impact WLB, affecting occupational health and safety. Prioritizing WLB and promoting belonging can improve health and safety management. The study provides PMs with valuable advice on raising worker satisfaction and achieving project objectives in the construction sector in Sri Lanka.

TO IDENTIFY THE FACTORS AFFECTING THE WORK-LIFE BALANCE OF CONSTRUCTION SITE LABOURERS FOR A SUCCESSFUL PROJECT COMPLETION

This was included as the first objective of the research study. From this objective, factors affecting construction workers' WLB were identified through secondary data analysis. After identifying the main factors affecting the WLB of construction site labourers in the industry, this was to prove findings and get a general idea of what factors should be highlighted in that context. According to the identified factors, questions were included in the semi-structured interview to get an idea of the experts in the current construction industry. Through the interviews, it was identified what the current practices of the industry were according to those factors and how effective those factors were in maintaining the WLB of construction workers.

TO IDENTIFY THE RELATIONSHIP OF THE PROJECT MANAGER'S ROLE ON THE WORK-LIFE BALANCE OF CONSTRUCTION SITE LABOURERS FOR A SUCCESSFUL PROJECT COMPLETION

This is the second objective of this study. To achieve this goal, a detailed questionnaire was distributed among construction PMs who were working on ongoing construction projects. SPSS software was used to analyse the collected data. An analysis of correlation was performed to determine the relationship between independent and dependent variables. Hypotheses were initially defined for this purpose. It was determined that a positive relationship exists only if the significance (p) value is less than 0.005. It was discovered that every independent variable has a positive relationship with the dependent variable. Based on the computed results, regression analysis was performed to determine the impact of the relationship. A positive or negative impact was determined based on the variance value of each relationship. The dependent variable increases when the variance indicates a positive one and the independent variable also increases. Variance increases when the independent variable is negative, while the dependent variable declines.

For this objective, an industry expert questionnaire was conducted. Data was collected from thirty construction PMs in the industry who are currently working on ongoing projects. The main outcomes that were obtained are: There must be two positive relationships identified according to the relationship between the PM's role and the WLB of construction site labourers. They were labour-related and industry-related factors according to the PM's role in maintaining the WLB of construction site labourers. Also, two negative relationships had been identified through this survey. The negative impacts were management-related and demographic factors of construction site labour according to the PM's role in the WLB.

TO RECOMMEND PROJECT MANAGER'S PRACTICES TO IMPROVE THE WORK-LIFE BALANCE OF CONSTRUCTION SITE LABOURERS FOR A SUCCESSFUL PROJECT COMPLETION

As the third objective of this research study, this objective gives recommended PM practices for improving the WLB of construction site labourers. Data for this objective was obtained through preliminary interviews. Preliminary interviews were conducted by 4 construction PMs in the industry who are currently working in the industry. This objective provides recommendations for construction PMs to improve their practices on the WLB concept to maintain it through construction site labourers. The practices are indicated through the independent variables. Such as industry-related, management-related, labour-related, and demographic factors. According to each factor, there must be five indicators. To fulfil this objective, I got answers from the experts on a practical basis in the industry. That's the reason why this preliminary interview was conducted through the industry PMs who are working at the current sites. The data were analysed using content analysis according to related current practices, issues, and recommendations given by the interviewers.

TO ASSESS THE MOST IMPACTFUL ASPECTS OF WORK-LIFE BALANCE ON LABOUR SATISFACTION FOR SUCCESSFUL PROJECT COMPLETION

This is the fourth and last objective of this study. To accomplish this task, labourers on construction sites who were employed by the construction industry at the time were given a comprehensive questionnaire. This questionnaire was made in Sinhala language because it was filled out by construction site labourers. Questionnaire data was collected from 51 construction site labourers in the industry. The RII method was used to analyse this primary data. This method ranks the most impactful factor for the labourers to maintain their current WLB positively. Ranks must be determined using a Likert scale filled out by construction industry workers. Through this questionnaire, the following factors were identified:

- The stress level of construction site labourers
- Types of stress were associated with construction industry labourers
- The involvement of PM in the WLB of construction site labourers
- The most impactful aspects of WLB for construction industry labourers

The first three factors were analysed through content analysis. The result of these factors was that a very large number of labourers had stress in their lives. According to the type of stress, most of the stress was related to the industry. Also, they were referring to working with higher management on construction projects and working with employees. Another considerable amount of stress in construction work is assigned to the labourer. The involvement of construction PM was of very rare value. It was described that PMs hadn't engaged with labourers to maintain construction site labourers WLB. The main direction of this objective was to identify the most impactful aspects for the construction site labourers in their WLB. According to the rank of the RII indicator, salary was their priority aspect in WLB. In addition to those other aspects:

- Compensation and Benefits
- Freedom in Personal Life
- Minimize Responsibilities
- Freedom in the workplace

RECOMMENDATION

The research study reveals that WLB is crucial for successful project completion in the Sri Lankan construction industry. Recommendations are made for construction PMs to improve WLB. These include implementing WLB policies tailored to the industry's specific needs, providing comprehensive training programmes for PMs, encouraging flexible work arrangements, integrating health and safety measures, and offering employee assistance programmes. Flexible work schedules should be encouraged to meet the varied requirements of construction site labourers, such as compressed workweeks, remote work, or staggered work hours. Health and safety measures should be integrated into WLB projects, ensuring that PMs prioritize safety procedures on construction sites. Employee assistance programmes should provide counselling, stress management resources, and mental health support to encourage overall well-being. The adoption of WLB practices can lead to enhanced employee satisfaction and retention, improved productivity and project success, a positive industry reputation, compliance with global standards, and a better understanding of cultural differences that affect Sri Lankan workplace dynamics. This alignment can increase the industry's global competitiveness and attract investment from companies that value morality and sustainability in their operations. Family and community well-being should also be considered when customising WLB policies and practices to local cultural expectations. By integrating WLB policies, providing thorough PM training, introducing employee assistance programmes, implementing flexible work arrangements, emphasising health and safety, and taking cultural nuances into account, the construction industry in Sri Lanka can become more sustainable and competitive.

CONCLUSION

The study on WLB practices in the construction industry in the Colombo region of Sri Lanka has limitations. Its focus on government and private projects may limit its applicability to other industries, potentially omitting a range of approaches and experiences. The study's methodological flaws include reliance on semi-structured interviews and questionnaires, which can introduce subjectivity and response bias. The temporal scope may also ignore seasonal variations or shifts in project dynamics over time. The study's findings may not fully explore the impact of organizational policies on WLB practices, and the absence of a longitudinal perspective may hinder understanding of how these practices evolve.

Future studies should compare government and private projects, examine various sectors of the construction industry, and broaden their geographical scope to gain a deeper understanding of the role PMs play in helping construction site labourers achieve WLB. A mixed-methods approach combining qualitative and quantitative methods can provide a comprehensive understanding of the subject. A more comprehensive socioeconomic perspective can be obtained by investigating stakeholders' viewpoints such as community representatives, labour unions, and the government. A more dynamic picture can be obtained by including a long-term aspect in the research design. Further research may examine intervention techniques and ethical issues.

REFERENCES

Abdul Karim, N., Hafizan Hassan, S., Nur Yunus, J., & Zain Hashim, M. (2012). Factors influence labour productivity and the impacts on the construction industry.

Abdulsamad Ali, M. M., & Chileshe, N. (2009). The influence of the project manager on the success of construction projects. *ICCEM-ICCPM Conference*.

Abdussalam Shibani, & Denish Sukumar. (2015). The role of the project manager in construction projects in India. *Chinese Business Review*, 14(6).

Adah, C. A., Aghimien, D. O., & Oshodi, O. (2023). Work-life balance in the construction industry: a bibliometric and narrative review. *Engineering, Construction and Architectural Management*.

Adams, W. C. (2015). Conducting semi-structured interviews. In *Handbook of Practical Program Evaluation: Fourth Edition* (pp. 492–505). Wiley Blackwell.

Adom, D., Hussein, E. K., & Kamil, E. (2018). Theoretical and conceptual framework: Mandatory ingredients of quality research. *ResearchGate*.

Ahn, S., Lee, S., & Steel, R. P. (2014). Construction workers' perceptions and attitudes toward social norms as predictors of their absence behaviour. *Journal of Construction Engineering and Management*, 140(5).

Alaghbari, W., Al-Sakkaf, A. A., & Sultan, B. (2019). Factors affecting construction labour productivity in Yemen. *International Journal of Construction Management*, 19(1), 79–91.

Apraku, K., Bondinuba, F., Eyiah, A., & Sadique, A. (2020). Construction workers' work-life balance: A tool for improving productivity in the construction industry. *Social Work and Social Welfare*, 2(1), 45–52.

Atsiaya, P. M., & Wanyoike, D. (2017). Assessment of factors influencing the work-life balance of project team members in the health sector construction projects in Nyandarua Central Sub-County, Kenya. *International Journal of Economics, Commerce and Management United Kingdom*, Issue 5.

Ayid, S., & Alshammari, R. (2019). Developing a comprehensive construction delay analysis technique.

Azman, N. S., Ramli, M. Z., Razman, R., Zawawi, M. H., Ismail, I. N., & Isa, M. R. (2019). Relative importance index (RII) in ranking of quality factors on industrialised building system (IBS) projects in Malaysia. *AIP Conference Proceedings*, 2129.

Bahna, S. L. (2009). Statistics for clinicians editor: Statistics for clinicians, 103 (4).

Bradley, L., Brown, K., Lingard, H., Townsend, K., & Bailey, C. (2010). Talking the talk and walking the walk: How managers can influence the quality of work-life balance in a construction project. *International Journal of Managing Projects in Business*, 3(4), 589–603.

Business, G., & Research, M. (2014). Work-life balance and employees' performance: The mediating role of affective commitment. *An International Journal*, 6(1).

Chan, A. P. C., Chiang, Y.-H., Wong, F. K.-W., Liang, S., & Abidoye, F. A. (2020). Work-life balance for construction manual workers. *Journal of Construction Engineering and Management*, 146(5).

Enshassi, A., Mohamed, S., Mustafa, Z. A., & Mayer, P. E. (2007). Factors affecting labour productivity in building projects in the Gaza Strip. *Journal of Civil Engineering and Management*, 13(4), 245–254.

Etikan, I. (2017). Sampling and sampling methods. *Biometrics & Biostatistics International Journal*, 5(6).

Fox, P. W., Skitmore, M., Hon, C. K. H., & Fong, P. (2008). The role of project managers in construction industry development.

Francis, V., Lingard, H., Prosser, A., & Turner, M. (2013). Work-family and construction: Public and private sector differences. *Journal of Management in Engineering*, 29(4), 392–399.

Golafshani, N. (2003). Understanding reliability and validity in qualitative research. *The Qualitative Report*, 8.

Görsch, C., Seppänen, O., Peltokorpi, A., & Lavikka, R. (2020). Construction workers' situational awareness – An overlooked perspective. *IGLC 28 - 28th Annual Conference of the International Group for Lean Construction 2020*, pp. 937–948.

Guest, D. E. (2002). Perspectives on the study of work-life balance. *Social Science Information*, 41(2), 255–279.

Kaluarachchi, Y., Nartallo, P., & Emuze, F. (2022). How the construction industry can improve the health and well-being of their workers in a post-COVID-19 era. *IOP Conference Series: Earth and Environmental Science*, 1101(3).

Keith, D., Senior, T., Fellow, R., Brown, K., Bradley, L., Lingard, H., & Bailey, C. (2006). How would employees "construct" a balance between work and non-work life? Work-life balance in the construction industry.

Lambert, S. J., & Haley-Lock, A. (2004). The organizational stratification of opportunities for work-life balance: Addressing issues of equality and social justice in the workplace. *Community, Work and Family*, 7(2), 179–195.

Liu, B., Xue, B., Meng, J., Chen, X., & Sun, T. (2020). How project management practices lead to infrastructure sustainable success: An empirical study based on goal-setting theory. *Engineering, Construction and Architectural Management*, 27(10), 2797–2833.

Liu, H., Motoda, H., & Yu, L. (2004). A selective sampling approach to active feature selection. *Artificial Intelligence*, 159(1–2), 49–74.

Lucy Wambui, M., Caroline Cherotich, B., Emily, T., & Dave, B. (2017). Effects of work-life balance on employees' performance in institutions of higher learning: A case study of Kabarak University. *Kabarak Journal of Research & Innovation*, 4(2), 60–79.

Malone, E. K., & Issa, R. R. A. (2013). Work-life balance and organizational commitment of women in the U.S. construction industry. *Journal of Professional Issues in Engineering Education and Practice*, 139(2), 87–98.

Marambage, H. M. B. P., & Maduwansha, N. A. N. J. (2021). Factors affecting the work-life balance of construction industries' site workers in Colombo District, Sri Lanka (with special reference to Acces Engineering plc). *International Journal of Arts and Commerce*, 10(6), 29–40.

Mazhar, S. A. (2021). Methods of data collection: A fundamental tool of research. *Journal of Integrated Community Health*, 10(01), 6–10.

Meng, X., & Boyd, P. (2017). The role of the project manager in relationship management. *International Journal of Project Management*, 35(5), 717–728.

Moore, F. (2007). Work-life balance: Contrasting managers and workers in an MNC. *Employee Relations*, 29(4), 385–399.

Moradi, S., Kähkönen, K., & Aaltonen, K. (2020). Project managers' competencies in collaborative construction projects. *Buildings*, 10(3).

Ni, G., Li, H., Jin, T., Hu, H., & Zhang, Z. (2022). Analysis of factors influencing the job satisfaction of new generation of construction workers in China: A study based on DEMATEL and ISM. *Buildings*, 12(5).

Om, E., & Giri, P. (2019). Study on the role of project manager in improving the project performance. *Technical Journal*, 1(1).

Onarheim, K. H., Phua, K. H., Babar, Z. R., Flouris, A. D., & Hargreaves, S. (2021). Health and social needs of migrant construction workers for big sporting events. *The BMJ*, 374.

THE IMPACT OF UNETHICAL PRACTICES OF QUANTITY SURVEYORS ON SUSTAINABLE DEVELOPMENT IN THE SRI LANKAN CONSTRUCTION INDUSTRY

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THE IMPACT OF UNETHICAL PRACTICES OF QUANTITY SURVEYORS ON SUSTAINABLE DEVELOPMENT IN THE SRI LANKAN CONSTRUCTION INDUSTRY

ABSTRACT

The construction industry is rapidly growing, especially in developing nations like Sri Lanka, where economic expansion has significantly driven the sector's importance. Within this context, Quantity Surveyors play a pivotal role in managing costs and ensuring project efficiency. However, unethical practices by Quantity Surveyors, such as corruption, negligence, and fraudulent behaviour, can have a detrimental impact on sustainability. This study explores the unethical practices prevalent among Sri Lankan Quantity Surveyors and their effects on the sustainability of the construction industry. Using in-depth qualitative interviews, the study identifies key unethical behaviours and categorizes their impact into organizational, professional, social, and environmental dimensions. The findings highlight the critical need for ethical management practices to achieve sustainability goals in the Sri Lankan construction industry.

Keywords: *Ethics; Quantity Surveyor; Sri Lanka; Sustainability; Unethical Practices.*

INTRODUCTION

The construction industry has become one of the fastest-growing sectors in the global economy (Stiles *et al.*, 2021). In Sri Lanka, the post-war period has seen significant expansion, with construction contributing heavily to the growth of Gross Domestic Product (GDP) (Somachandra *et al.*, 2024). The construction industry involves a wide range of stakeholders, both direct and indirect, whose contributions are essential for the success of projects within established time, cost, and quality parameters (Kamble and Sabanna, 2023). However, alongside its economic importance, the construction industry is often criticised for unethical practices, including corruption, environmental negligence, and insufficient regard for societal welfare (Shah & Alotaibi, 2018). Unethical behaviours by stakeholders, such as prioritizing personal gains, negligence, professional incompetence, and fraudulent practices, are commonplace and can occur during both the pre-construction and post-construction phases (Aigbavboa *et al.*, 2016).

Ethics, defined as moral principles or the morally valued behaviours of individuals, are integral to any profession. The codes of ethics laid out by professional bodies like the Royal Institution of Chartered Surveyors (RICS) and the Institute of Quantity Surveyors Sri Lanka (IQSSL) provide a foundation for ethical conduct (Senaratne & Sabesan, 2010). Furthermore, the modern construction industry increasingly focuses on the principles of sustainable development. The concept of sustainability is defined as the responsible use of available resources to meet current needs without compromising the ability of future generations to meet their own needs (Bañon Gomis *et al.*, 2011). Sustainable development encompasses three interrelated and mutually reinforcing pillars: economic growth, social development, and environmental protection (Salas-Zapata & Ortiz-Muñoz, 2019).

However, unethical practices by construction professionals can significantly undermine sustainability efforts, leading to the misuse of materials, energy, and other resources (Paul *et al.*, 2021). The environmental burdens associated with construction activities include noise pollution, greenhouse gas emissions, dust, land degradation, waste generation, and social issues like safety hazards and construction-related accidents (Purchase *et al.*, 2021). Therefore, the establishment of ethical management practices among key stakeholders is essential for achieving sustainability (Maseko, 2017).

Quantity Surveyors (QSs) play a central role in the construction industry, providing financial and cost management services that ensure the efficient use of resources (Noor *et al.*, 2020). Their responsibilities extend to giving cost management advice to owners and designers, ensuring that projects meet their financial targets while benefiting all parties (Olatunji *et al.*, 2017). Professional bodies such as the RICS, the Australian Institute of Quantity Surveyors (AIQS), and the IQSSL have developed codes of ethics that guide QSs in maintaining professional integrity (Royal Institute of Chartered Surveyors (RICS), 2023).

Despite these codes, QSs are not immune to unethical behaviour, with dishonest conduct, bribery, fraud, and negligence being commonly reported issues, which can negatively affect the sustainability of construction projects (Akinrata *et al.*, 2019).

In Sri Lanka, Quantity Surveying is a rapidly growing profession and a vital component of the construction industry (Senaratne & Sabesan, 2010). However, similar to other countries, Sri Lankan QSs are often implicated in unethical practices that compromise sustainable development. This study investigates how unethical practices by QSs in Sri Lanka impact sustainability in the construction industry. The objectives are as follows: investigate the importance of management of ethics in achieving sustainability, identify the unethical practices prevalent among QSs in Sri Lanka, and analyse the impact of these practices on sustainability in the construction industry in Sri Lanka.

LITERATURE REVIEW

IMPORTANCE OF MANAGEMENT OF ETHICS IN CONSTRUCTION

Management of ethical practices is a cornerstone of professionalism in any industry, particularly in construction. According to Fewings (2008), professional bodies such as the RICS, AIQS, Chartered Institute of Building (CIOB), Pacific Association of Quantity Surveyors (PAQS), and IQSSL have established codes of ethics to guide the conduct of professionals. These codes not only protect the reputation of the profession but also ensure that members act in ways that promote public trust. Maseko (2017) emphasized that ethical behaviour strengthens the construction industry's reputation and overall development.

Professionals in the construction industry must prioritize public interest over financial gains. Murdoch and Hughes (2002) pointed out that working exclusively for financial benefits may create conflicts of interest, but ethical conduct promotes long-term sustainability. Akinrata et al. (2019) highlighted the duality of construction ethics: while contractors often focus on profit, professionals from the client's side should adhere to ethical standards, exercising accountability and professional judgment.

Furthermore, Noor *et al.* (2020) argued that ethical behaviour across all professional roles within construction is crucial. This integrated framework enhances both accountability and responsibility, fostering higher ethical standards. Oke *et al.* (2017) noted that leadership plays a vital role in promoting ethical behaviour by setting examples for others to follow.

ETHICS AND PROFESSIONAL STANDARDS FOR QUANTITY SURVEYORS

The ethical conduct of QSs has a direct impact on the value and safety of the construction industry. Royal Institute of Chartered Surveyors (RICS) (2018) defined several key ethical principles for QSs, such as integrity, high standards of service, trust, respect, and accountability. Acting with integrity, for instance, involves honesty, transparency, and safeguarding client confidentiality. QSs are also expected to perform to high standards, providing informed advice and enabling clients to make well-considered decisions (Royal Institute of Chartered Surveyors (RICS), 2023).

Ethics also involve trust-building and respect for all stakeholders, irrespective of personal characteristics such as age, gender, race, or nationality (Senaratne and Sabesan, 2010). This is particularly crucial in maintaining a positive professional image. Additionally, QSs are accountable for their work, ensuring that any issues are addressed with care and skill.

Australian Institute of Quantity Surveyors (AIQS) (2018) further emphasised the importance of ethical compliance in maintaining professional integrity. AIQS (2018) outlined a procedure for managing complaints related to unethical practices. The organisation has the authority to impose penalties on members found guilty of unethical behaviour, ensuring a high standard of ethics within the quantity surveying profession.

RELATIONSHIP BETWEEN ETHICAL MANAGEMENT PRACTICES AND SUSTAINABILITY

The construction industry has significant impacts on the environment, economy, and society. Xu and Li (2012) asserted that construction professionals must consider a broader range of public interests beyond client satisfaction. Royal Institute of Chartered Surveyors (RICS) (2023) also emphasized the need to balance client objectives with public well-being, highlighting the ethical dimension of sustainable development.

Balasubramanian *et al.* (2022) stressed the importance of achieving corporate sustainability by integrating ethical behaviour among all construction stakeholders, including clients, contractors, consultants, architects, engineers, and quantity surveying professionals. This collaborative approach is critical for aligning sustainability goals with social, environmental, and economic outcomes.

Lindgreen and Swaen (2010) highlighted the concept of Corporate Social Responsibility (CSR) as a fundamental component of corporate sustainability, which is further supported by ethical practices. The author further highlighted CSR as an organization's responsibility for the societal and environmental impacts of its decisions and activities. In this context, ethical responsibility is a key driver of CSR, which in turn supports the broader goals of sustainability (Tai and Chuang, 2014).

UNETHICAL PRACTICES OF QUANTITY SURVEYORS AND THEIR IMPACT ON THE CONSTRUCTION INDUSTRY

Unethical practices by QSs can have far-reaching consequences on project performance. Research from Nigeria highlights various unethical behaviours, such as bid shopping, collusion, and fraudulent claims, which negatively impact project costs (Tijani *et al.*, 2017). These unethical practices are not confined to developing countries; Lee and Cullen (2018) identified similar issues, including negligence and corruption, across global construction markets.

Cartlidge (2023) documented unethical practices among QSs, including manipulation of bills of quantities (BOQs), delays in agreeing on final payments, and manipulation of change orders. Rashid *et al*. (2019) argued that such practices erode public trust and lead to inefficiencies such as cost overruns, delays, and reputational damage. These unethical behaviours often permeate multiple stages of construction projects, from planning and design to execution and maintenance.

Unethical practices not only increase project costs but also create uncertainty and risk within the industry. Shah and Alotaibi (2018) suggested that unethical conduct by QSs can undermine the quality of the final project outcome, thereby contributing to broader systemic issues such as project delays, inflated costs, and substandard work. The long-term implications of unethical behaviour include damage to the industry’s reputation and a reduction in public approval (Oke *et al.*, 2017).

METHODOLOGY

This study required gathering the opinions of industrial experts in order to successfully achieve research objectives. Within them, there was a need to identify unethical practices prevalent among QSs in Sri Lanka, and the impact of these practices on the construction industry's sustainability. According to Edwards and Brannelly (2017), the qualitative research approach is appropriate when there is a need to collect information from multiple individuals based on their experiences and perspectives. Since opinions of experts are needed to conduct this research, a qualitative research approach can be used.

Interviews are considered one of the best data collection methods because they reveal the depth of opinion of the interviewee (Punch, 2013). Therefore, the semi-structured interviews were conducted with ten (10) professionals to refine the findings from the literature and determine unethical practices prevalent among QSs in Sri Lanka, and the impact of these practices on the construction industry's sustainability. The profile of the subject matter experts who participated in the detailed interviews with Experts is summarized in Table 1. As stated by Hsieh et al. (2004), content analysis is widely used to analyse qualitative data in which meaningful findings can be derived from the content of data. Therefore, manual content analysis was used to analyse the data collected from expert interviews.

Table 1: Profiles of Experts

Interviewee Code	Designation	Years of Experiences
IE1	Quantity Surveyor	8+ years
IE2	Senior Quantity Surveyor	16+ years
IE3	Quantity Surveyor	8+ years
IE4	Quantity Surveyor	10+ years
IE5	Quantity Surveyor	11+ years
IE6	Quantity Surveyor	9+ years
IE7	Senior Quantity Surveyor	12+ years
IE8	Senior Quantity Surveyor	18+ years
IE9	Quantity Surveyor	8+ years
IE10	Quantity Surveyor	7+ years

FINDINGS & DISCUSSION

The findings of this study have revealed the QSs' unethical behaviour and its effect on sustainability in the Sri Lankan Construction industry, which can be analysed under four broad categories: Organizational, Professional, Social, and Environmental. These results highlight how systemic issues within these domains hinder the achievement of CSR and, consequently, industrial sustainability.

ORGANIZATIONAL

Toor and Ofori (2008) highlighted that construction professionals on the client's side often rely on their skills and judgment, operating with accountability to the client. On the contractor's side, however, they sometimes act in ways that prioritize profit over ethical considerations. This observation aligns with the findings from the interviews conducted in this study, which revealed that many Sri Lankan QSs follow a similar pattern. Their decision-making is influenced by company directives, leading them to apply their skills and judgment in ways that are shaped by organizational goals rather than ethical standards. The analysis of data reflects this trend; thus the identified categories help to further illustrate these dynamics.

- Company Culture

Company culture plays a pivotal role in shaping the ethical behaviour of QSs. Experts revealed that company-driven motivations often lead QSs to act dishonestly, particularly when pressured to inflate bills or misrepresent project costs to maximize profits. For instance, as IE10 stated, the top management encourages practices such as inflating bills by submitting higher-than-actual costs, which directly violates the RICS Code of Ethics that mandates integrity and transparency. This unethical behaviour suggests that the pursuit of profit often supersedes ethical conduct, reinforcing findings from Toor and Ofori (2008), who pointed out that professionals often prioritize company objectives over client accountability.

- Company Profit

A relentless focus on company profit emerged as a driving force behind unethical quantity surveying practices. IE5 and IE8 admitted that they engage in actions such as manipulating labour costs and subcontractor payments to boost company profits. This further indicates that financial goals overshadow ethical standards. The conflict between upholding professional ethics and maintaining company profitability results in QSs compromising on ethical duties, which aligns with literature that emphasizes profit-driven motives as a significant factor in unethical decision-making in construction (Murdoch and Hughes, 2002).

- Responsibility

Despite these unethical tendencies, the study found instances where QSs uphold their responsibilities, particularly in safeguarding confidential client information. IE2 emphasized that QSs avoid sharing sensitive project details, which demonstrates a degree of integrity. This suggests that while the organizational culture may encourage unethical behaviour in some aspects, there are boundaries within which QS professionals still strive to maintain their ethical responsibilities.

PROFESSIONAL

According to (Royal Institute of Chartered Surveyors (RICS), 2012), maintaining ethical behaviour within a profession not only enhances its value but also contributes to a safer and more trustworthy industry environment. This notion is supported by the findings from the interviews conducted in this study, where both ethical and unethical practices among Sri Lankan QSs were highlighted. Experts revealed a significant impact of these behaviours on the sustainability of the construction industry. The various categories identified in this analysis help to demonstrate the dual nature of quantity surveying practices and their broader influence on industry standards and sustainability.

- Behaviour

The interviews revealed widespread unethical behaviour among QSs, particularly in relation to the manipulation of project data for personal or organizational gain. This unethical behaviour not only tarnishes the reputation of QSs but also undermines trust in the industry. For example, IE1 discussed how QS selectively provide incomplete or inaccurate details to different stakeholders, further damaging professional integrity. This behaviour is consistent with literature that highlights a lack of transparency and honesty as critical challenges in maintaining ethical standards in the construction industry (Royal Institute of Chartered Surveyors (RICS), 2012).

- Freedom

While QS professionals possess the freedom to offer advice, the decision-making process is often controlled by higher management, limiting their ability to act independently. As IE2 noted, they can point out ethical concerns but are not empowered to make decisions. This lack of autonomy creates a conflict between personal ethical standards and organizational goals, limiting QSs' ability to uphold the highest standards of ethical conduct.

- Respect

Professional respect within the quantity surveying field is inconsistent. According to IE2, while some QSs treat colleagues with respect, regardless of background, others exhibit discriminatory behaviour, particularly between degree-holders and diploma-holders. This disrespect weakens professional collaboration and contradicts the ethical mandate of equality and fairness within the industry, as outlined in the RICS Code of Ethics.

1.1. *SOCIAL FACTORS*

Murdoch and Hughes (2002) emphasized that the core objective of any profession is to serve the public, with true professionals prioritizing public welfare over financial gain. While such principles are embedded in the ethical codes of many regulatory bodies, the interviews in this study revealed that Sri Lankan quantity QS seldom prioritize public benefits over financial considerations. This rare focus on public welfare by QSs suggests a misalignment with ethical guidelines. The analysis of these practices in the Sri Lankan construction industry, therefore, reflects how this imbalance affects overall industrial sustainability.

- Benefits

The findings indicate that QSs often prioritize client profits over public or social benefits. For instance, IE10 highlighted how QSs rarely consider social welfare in private sector projects, focusing instead on maximizing client profits. However, in government projects, there is some consideration for social benefits. This divergence between public and private projects highlights a critical area where QSs could enhance its contribution to societal well-being by balancing financial and social priorities.

- Neighbourhood

Neighbourhood considerations, such as minimizing disturbances from construction projects, are frequently neglected by QSs, particularly in project planning. IE8 revealed that little attention is paid to the impact of construction noise and activities on local residents, leading to complaints and project delays. This lack of consideration for neighbourhood welfare further emphasizes the need for QSs to adopt a more holistic, community-centred approach to their work, consistent with the goals of CSR.

ENVIRONMENTAL FACTORS

Lu and Yuan (2011) highlighted the significant influence the construction industry has on the environment, economy, and society. This study supports that perspective, as the interviews demonstrated the substantial environmental impact of construction activities in Sri Lanka. The analysis of quantity surveying practices, both ethical and unethical, underscores the importance of their role in shaping the industry's sustainability outcomes. These findings have been categorized to reveal how quantity surveying actions directly affect industrial sustainability in the Sri Lankan construction sector.

- Material Selection

The interviews revealed troubling practices regarding material selection, with QSs often prioritizing cost savings over environmental considerations. As IE6 noted, local and recyclable materials are frequently disregarded due to higher costs, with QS favouring cheaper, lower-quality foreign materials. This focus on short-term savings at the expense of long-term environmental sustainability is a clear violation of ethical standards, as it undermines efforts to promote sustainable construction practices.

- Wastage and Pollution

The issue of material wastage and pollution was also highlighted as a significant problem. IE8 admitted that QSs often fail to take responsibility for minimizing material wastage or mitigating environmental damage. For instance, improper management of leftover materials and the absence of reconciliation reports were common issues, indicating a lack of accountability and responsibility in addressing environmental concerns. This unethical behaviour directly impacts the sustainability of the construction industry by contributing to environmental degradation.

CONCLUSION & RECOMMENDATION

This study has revealed critical insights into the unethical practices prevalent among QSs in the Sri Lankan construction industry, and their limited understanding of sustainability concepts. The findings underscore a need for improved awareness and education on sustainability, as most construction professionals demonstrate minimal concern for the environmental and social impacts of their work.

It was observed that many Sri Lankan QSs, particularly from the contractor and consultant sides, prioritize company profits over broader societal and environmental benefits. Their unethical practices such as negligence, dishonesty, delayed payments, corruption, and manipulation of invoices highlight a systemic disregard for ethical behaviour. These practices not only undermine the integrity of the profession but also prevent the achievement of CSR and, ultimately, industrial sustainability.

Furthermore, the study identified that QSs in Sri Lanka have limited knowledge of the RICS Code of Ethics. Many are unaware of core ethical principles, such as acting with integrity, delivering the highest standard of service, and fostering trust within the industry. This knowledge gap calls for targeted interventions, including continuing professional development (CPD) events, seminars, and other educational platforms to ensure QS are well-informed about their ethical responsibilities and the long-term value of sustainability. Despite these challenges, some ethical practices were noted. QSs are responsible for maintaining confidentiality in competitive construction environments, and many display respect for peers regardless of age, race, or gender. However, tensions between degree-holding and diploma-holding QSs suggest that more efforts are needed to foster mutual respect and collaboration within the profession.

The study also highlighted the lack of attention QSs pay to societal and environmental concerns. Their focus remains largely on economic factors, with limited opportunities to address social benefits. Although QSs are mindful of neighbourhood impacts such as noise and property safety, broader social contributions are often overlooked. Initiatives like community outreach programs such as blood donation drives and fundraising efforts for underprivileged communities could help bridge this gap. In the environmental category, it was found that QSs often manipulate material invoices and fail to prioritize the use of recyclable, local, or durable materials due to cost concerns. Additionally, the lack of material reconciliation reports and failure to address subcontractor waste represent significant barriers to environmental sustainability. Addressing these issues through more accurate quantity take-offs and effective waste management practices will be crucial for advancing sustainability in the construction industry.

In conclusion, QSs in Sri Lanka place greater emphasis on the economic pillar of sustainability, while neglecting the social and environmental aspects. To drive the industry toward a more sustainable future, it is essential to enhance QSs' ethical awareness and foster a culture that balances company profitability with social and environmental responsibility. Future research could explore how to achieve sustainability in the Sri Lankan construction industry through ethical quantity surveying practices while ensuring economic viability alongside social and environmental benefits.

REFERENCES

Aigbavboa, C., Oke, A. and Tyali, S. (2016), "Unethical practices in the South African construction industry", *5th Construction Management Conference*, pp. 15–22.

Akinrata, E.B., Ogunsemi, D.R. and Akinradewo, O.F. (2019), "Outcomes of unethical practices by quantity surveyors in Nigerian construction industry", *International Journal of Applied Research in Social Sciences*, Vol. 1 No. 3, pp. 84–94.

Australian Institute of Quantity Surveyors (AIQS). (2018), *Code of Conduct. Complaints Policy*.

Balasubramanian, S., Shukla, V., Islam, N. and Manghat, S. (2022), "Construction Industry 4.0 and Sustainability: An Enabling Framework", *IEEE Transactions on Engineering Management*, pp. 1–19, doi: 10.1109/TEM.2021.3110427.

Bañon Gomis, A.J., Guillén Parra, M., Hoffman, W.M. and McNulty, R.E. (2011), "Rethinking the concept of sustainability", *Business and Society Review*, Vol. 116 No. 2, pp. 171–191.

Cartlidge, D. (2023), "Ethics and the quantity surveyor", *New Aspects of Quantity Surveying Practice*, pp. 142–181.

Edwards, R. and Brannelly, T. (2017), "Approaches to democratising qualitative research methods", *Qualitative Research*, SAGE Publications Ltd, Vol. 17 No. 3, pp. 271–277, doi: 10.1177/1468794117706869.

Fewings, P. (2008), *Ethics for the Built Environment*, Routledge.

Hsieh, T.Y., Lu, S.T. and Wu, C.H. (2004), "Statistical analysis of causes for change orders in metropolitan public works", *International Journal of Project Management*, Vol. 22 No. 7, pp. 679–686.

Kamble, G.N. and Sabanna, T. (2023), "Role of Construction Industry in Economic Development: Issues and Challenges", *International Journal of Advanced Research in Science, Communication and Technology*, pp. 297–300, doi: 10.48175/IJARSCT-13044.

Lee, C.C.T. and Cullen, D. (2018), "An empirical comparison of ethical perceptions among the consultant's Quantity Surveyor and contractor's Quantity Surveyor in the UK Construction Industry", *Proceedings of the Construction, Building and Real Estate Research Conference*.

Lindgreen, A. and Swaen, V. (2010), "Corporate social responsibility", *International Journal of Management Reviews*, Vol. 12 No. 1, pp. 1–7.

Lu, W. and Yuan, H. (2011), "A framework for understanding waste management studies in construction", *Waste Management*, Vol. 31 No. 6, pp. 1252–1260, doi: 10.1016/j.wasman.2011.01.018.

Maseko, C.M. (2017), "Literature on theory and practice on unethical practices in the construction of projects: A case of an emerging economy", *Risk Governance and Control: Financial Markets and Institutions*, Vol. 7 No. 4, pp. 214–224.

Murdoch, J. and Hughes, W. (2002), *Construction Contracts: Law and Management*, Routledge.

Noor, S.N.A.M., Tobi, S.U.M. and Salim, K.R. (2020), "Competencies of Quantity Surveyors in Construction Industry: Document Reviews from Different Quantity Surveyor Professional Bodies", *IOP Conference Series: Materials Science and Engineering*, Vol. 864 No. 1, p. 012098, doi: 10.1088/1757-899X/864/1/012098.

Oke, A.E., Aghimien, D.O. and Aigbavboa, C.O. (2017), "Effect of code of ethics on quantity surveying practices in Ondo State, Nigeria", *Proceedings of the 3rd Nigerian Institute of Quantity Surveying Research Conference, Abuja, Nigeria*, pp. 144–155.

Olatunji, S.O., Olawumi, T.O. and Aje, I.O. (2017), "Rethinking Partnering among Quantity-Surveying Firms in Nigeria", *Journal of Construction Engineering and Management*, Vol. 143 No. 11, doi: 10.1061/(ASCE)CO.1943-7862.0001394.

Paul, C.A., Aghimien, D.O., Ibrahim, A.D. and Ibrahim, Y.M. (2021), "Measures for curbing unethical practices among construction industry professionals: Quantity surveyors' perspective", *Construction Economics and Building*, Vol. 21 No. 2, pp. 1–17.

Punch, K.F. (2013), *Introduction to Social Research: Quantitative and Qualitative Approaches*, SAGE Publications Ltd.

Purchase, C.K., Al Zulayq, D.M., O'Brien, B.T., Kowalewski, M.J., Berenjian, A., Tarighaleslami, A.H. and Seifan, M. (2021), "Circular Economy of Construction and Demolition Waste: A Literature Review on Lessons, Challenges, and Benefits", *Materials*, Vol. 15 No. 1, p. 76, doi: 10.3390/ma15010076.

Rashid, I.A., Hamid, A.R.A., Zainudin, A.M. and Hatem, Z.M. (2019), "Unethical behaviour among professional in the Malaysian construction industry", *Proceeding of Civil Engineering UTM*, Vol. 4 No. 1, pp. 126–132.

Royal Institute of Chartered Surveyors (RICS). (2012), *Professional Ethics*.

Royal Institute of Chartered Surveyors (RICS). (2023), "Quantity surveying: Your guide to becoming a quantity surveyor".

Royal Institute of Chartered Surveyors (RICS). (2018), *RICS QS and Construction Pathway Guide August 2018*.

Salas-Zapata, W.A. and Ortiz-Muñoz, S.M. (2019), "Analysis of meanings of the concept of sustainability", *Sustainable Development*, Vol. 27 No. 1, pp. 153–161.

Senaratne, S. and Sabesan, S. (2010), "Managing knowledge as quantity surveyors: An exploratory case study in Sri Lanka", *Built-Environment Sri Lanka*, Vol. 8 No. 2.

Shah, R.K. and Alotaibi, M. (2018), "A study of unethical practices in the construction industry and potential preventive measures", *Journal of Advanced College of Engineering and Management*, Vol. 3, pp. 55–77.

Somachandra, V., Sylva, K., Bandara, C. and Dissanayake, R. (2024), "Corporate Social Entrepreneurship (CSE) Model for the Construction Industry of Sri Lanka", *Green and Low-Carbon Economy*, doi: 10.47852/bonviewGLCE42022122.

Stiles, S., Golightly, D. and Ryan, B. (2021), "Impact of COVID-19 on health and safety in the construction sector", *Human Factors and Ergonomics in Manufacturing & Service Industries*, Vol. 31 No. 4, pp. 425–437, doi: 10.1002/hfm.20882.

Tai, F.M. and Chuang, S.H. (2014), "Corporate social responsibility", *Ibusiness*, Vol. 6 No. 3, p. 117.

Tijani, A.A., Adeoye, A. and Alaka, N.S. (2017), "Effects of corporate social responsibility on banks financial performance in Nigeria: A study of United Bank of Africa", *International Journal of Business, Economics and Management*, Vol. 4 No. 6, pp. 136–147.

Toor, S.U.R. and Ofori, G. (2008), "Leadership versus management: How they are different, and why", *Leadership and Management in Engineering*, Vol. 8 No. 2, pp. 61–71.

EXPLORING BENEFITS AND CHALLENGES OF TRENCHLESS TECHNOLOGY FOR UNDERGROUND UTILITY INSTALLATIONS IN SRI LANKA

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EXPLORING BENEFITS AND CHALLENGES OF TRENCHLESS TECHNOLOGY FOR UNDERGROUND UTILITY INSTALLATIONS IN SRI LANKA

ABSTRACT

Underground pipe laying and utility installations have been practiced for centuries. However, modern advanced methods are often lacking in the Sri Lankan construction industry, which faces challenges due to outdated technology and a shortage of skilled labour. This study investigates the benefits and challenges of available trenchless methods for underground pipe laying in Sri Lanka. A qualitative approach was adopted, utilising 15 semi-structured interviews with professionals experienced in utility installations, pipe laying, and road projects. The data were analysed using manual content analysis and revealed key economic, environmental, social, and technological benefits and challenges associated with trenchless methods. Overall, some notable benefits found in these installations include reduced social impacts, and shorter construction times. However, challenges such as high initial investment costs, noise pollution and vibrations issues were identified as a result of this study. The findings offer valuable insights for both academia and industry professionals, supporting the adoption of trenchless technologies within the Sri Lankan context.

Keywords: *Benefits; Challenges; Trenchless; Underground Utility Installations.*

INTRODUCTION

The Underground Utility Infrastructure (UUI) system is, in fact, a key component of urban infrastructure (Ariaratnam & Proszek, 2006). Its effectiveness will become a key indicator for cities' success as the demand for utility services continues to rise with growing populations and increasing urbanization (Hojjat *et al.*, 2018). It has been identified that various underground utilities are available for services such as gas, electricity, telecommunications, and street lighting. Moreover, additional services like non-potable water networks, pneumatic waste collection, and combined heat and power pipelines are expected to become more prevalent as urban areas expand in the future (Hunt *et al*., 2011).

In the past, the only solution for replacing and renewing underground utilities was the open-cut excavation of buried trenches (Kaushal *et al.*, 2020). However, frequent road improvements and excavations often lead to incremental damage to existing underground utilities and increase the risk of utility strikes, both of which carry significant economic, indirect, and social costs (Makana *et al*., 2016). As a result, there has been a growing shift towards incorporating sustainable principles into infrastructure development (Yigitcanlar & Dur, 2010). Several alternative utility placement techniques are now available, including Multi-Utility Tunnels (MUTs) and trenchless technologies such as pipe jacking, micro-tunnelling, auger boring, Horizontal Directional Drilling (HDD), guided drilling, pipe bursting, and pipe ramming (Hojjat *et al.*, 2018)

In the Sri Lankan context, it is common for roads to be fully constructed with asphalt pavement, only to be excavated later by service providers and contractors for utility pipe laying (Zeghal & Mohamed, 2019). According to the same authors, poor reinstatement practices are a primary cause of road safety, performance, and utility issues. This problem is prevalent across almost every province in Sri Lanka, with a lack of integration and communication being highlighted as a key factor behind this malpractice (Wijekoon, 2011). Additionally, there is a high risk of unintentionally damaging existing subsurface utilities during excavation, leading to significant financial losses and project delays or termination (Behzadan & Kamat, 2009). The National Research Council (2013) notes that underground infrastructure poses challenges for road engineers due to limited and inaccessible information on available subsurface space.

Moreover, considering social and environmental factors, reinstatement approaches negatively impact communities, businesses near construction sites, commuters, and surrounding areas due to road bottlenecks, traffic delays, noise, and pollution (Jung & Sinha, 2007). The authors emphasised that poor reinstatement practices for utility openings, such as potable water and storm drainage in highways, result in the loss of

original quality, unsafe conditions, and incomplete pavement restoration, leading to the gradual degradation of the entire roadway. To address these issues, alternative utility placement methods such as trenchless methods are needed. Although some studies have been conducted in the Sri Lankan context regarding utility pipeline installations and models (Fan, 2015; Jayakody *et al*., 2024; Ranasingha & Wattage, 2024), there is a significant lack of exploration into the specific benefits and challenges associated with trenchless methods in this particular setting. Therefore, this study aims to investigate the benefits and challenges of using trenchless utility placement methods for underground pipe laying in the Sri Lankan context, in comparison to traditional open trench methods.

LITERATURE REVIEW

AVAILABLE UTILITY PLACEMENT METHODS

Utility services are a crucial part of the entire transport network, which includes roads, railways, waterways, as well as pipelines, wires, and cables for the transport of people, goods, and public services (Canto-Perello *et al.*, 2009). Until the early 1980s, these pipes were typically installed by excavating labor-intensive trenches. In fact, open trenching techniques became the traditional method for the installation, inspection, repair, and maintenance of underground services (Ariaratnam, 2011). The following section will briefly discuss the utility placement methods available globally.

- **Traditional open cut method**

Since there were no alternative options available over a century ago, open cut technique was likely considered economically viable for installing underground potable water and wastewater networks (Monfared, 2018). The open-cut method remains the most widely used conventional approach for constructing, replacing, and repairing underground infrastructure services, with utility systems installed directly into open trenches during the process (Hunt *et al.,* 2014). However, dewatering is necessary for the open-cut technique when the groundwater table is above the subgrade (Onsarigo & Adamtey, 2020). Figure 1 illustrates a schematic cross-sectional view of the open-cut construction method.

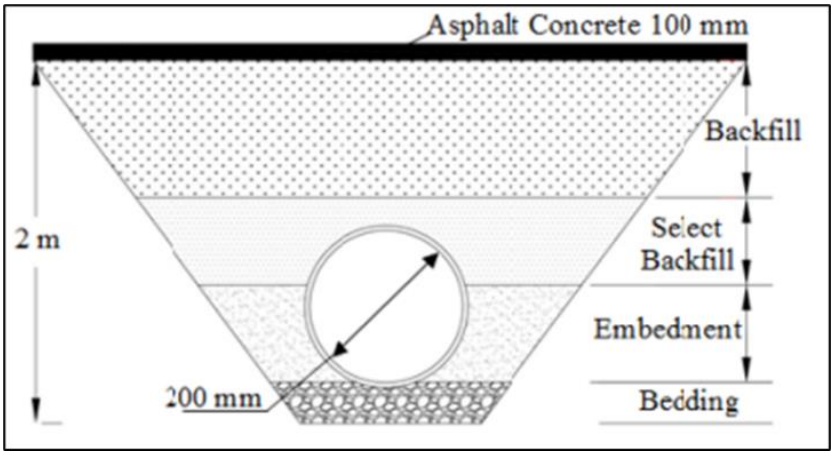

Figure 1: Schematic cross section view of open cut construction method

Source: (Tsung et al., 2016)

- **Trenchless Technologies for Placing Underground Utilities**

The significance of adopting sustainable development techniques, such as trenchless technology, is not fully recognised by project owners, as there remains a strong public preference for traditional open-cut methods in underground construction (Monfared, 2018). Trenchless technology employs efficient and convenient methods, utilising modern equipment compared to traditional approaches (Huang *et al.*, 2023). However, with the 'trenchless evolution,' it has become possible to repair and install underground services in previously challenging locations, such as under rivers and major highways (Ariaratnam, 2011). Hojjat *et al.* (2017) noted that decisions are still primarily based on direct costs, with little consideration for the long-

term economic, social, and environmental impacts. According to Najafi (2004), trenchless technology is divided into two categories: trenchless construction and trenchless renewal techniques. When considering trenchless renewal methods, these can be used to improve the service conditions of the pipe as well as extend its design life (Cossio *et al.,* 2012). On the other hand, trenchless construction includes all methods of new pipeline placement and laying pipelines without using open trenches (Ariaratnam, 2011). Moreover, Najafi (2005) outlined various utility installation methods practiced globally, which are summarised in Figure 2.

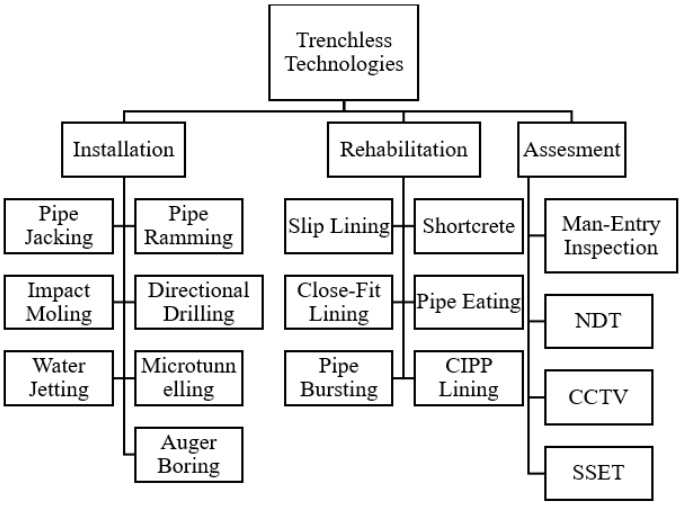

Figure 2: Types of Trenchless Technologies

Source: (Najafi, 2005)

BENEFITS OF TRENCHLESS METHODS FOR PLACING UNDERGROUND UTILITIES

In comparison to conventional open-cut construction techniques, Horizontal Directional Drilling (HDD) offers numerous benefits, with one obvious advantage being that it is trenchless (Cohen & Ariaratnam, 2017). According to the same authors, HDD has a small construction footprint, making it ideal for installations in urban areas. Micro tunnelling, is another trenchless method, significantly reduces the amount of material that needs to be excavated and stored compared to the open-cut method (Jusoh *et al.,* 2017). Aside from pit excavation, pipe boring requires minimal excavation (Jung & Sinha, 2007). This reduces the need for extensive road surface rebuilding after construction, minimising costs (Myers *et al*., 1999). Moreover, the Auger Boring method allows for shorter construction times and requires a smaller work area (Wu *et al.,* 2018). The augers can be retracted to the face, and items can be removed. Typically, it supports diameters between 8 and 84 inches and lengths between 100 and 400 feet (Iseley & Behbahani, 2016).

THE CHALLENGES OF TRENCHLESS METHODS FOR PLACING UNDERGROUND UTILITIES

Although HDD offers numerous advantages for utility installations, several studies have identified disadvantages and challenges associated with HDD systems (Norizam *et al.,* 2017; Woodroffe & Ariaratnam, 2009). Cohen and Ariaratnam (2017) argued that one of the most significant issues with HDD is the potential for consequences arising from improper specifications, which poses a problem for owners and their representatives. Regarding the micro tunneling method, the development of tunnels is fraught with uncertainty due to insufficient geological data, and micro tunneling machines are notably expensive, with only a few contractors possessing significant expertise with the technology (Chung *et al.,* 2004). Additionally, Jung and Sinha (2007) noted that while higher equipment costs are a major challenge for micro tunneling, the unit price can be competitive compared to other projects. Goduto and Atalah (2013) highlighted that auger boring may not be ideal when precise line and grade are critical. Moreover, auger boring requires a substantial investment due to the need for various casing diameters, cutting heads, and

augers, resulting in higher costs. The setup and bore pit excavation can be more expensive due to the forces needed to drive the cutting head, casing, and auger, compared to other trenchless methods (Atalah & Onsarigo, 2017).

RESEARCH METHODOLOGY

According to Creswell (2003), researchers commonly use three approaches: qualitative, quantitative, and mixed methods. This study is designed to investigate the benefits and challenges associated with trenchless utility placement methods for underground pipe laying within the Sri Lankan context. The research question is: 'What are the benefits and challenges of trenchless utility placement methods for underground pipe laying construction in Sri Lanka?' Creswell (2008) suggests that 'what' type questions are typically addressed with a quantitative approach. However, to fulfil the objectives of identifying the benefits and challenges of trenchless methods in Sri Lanka, a qualitative approach was deemed more suitable for capturing professional expertise, opinions, practices, and experiential knowledge.

Kothari (2004) defines an interview as a method of data collection involving "expounding verbal stimuli and answering orally." Semi-structured interviews, as noted by Dearnley (2005), do not strictly follow a predefined set of questions but allow for the exploration of additional insights from respondents. Semi-structured interviews were chosen as the most appropriate data collection technique for this study because they enable the interviewer to ask both structured and unstructured questions (Hillebrand & Berg, 2000). A total of 15 semi-structured interviews were conducted with professionals from the National Water Supply Board (NWSB) and the Road Development Authority (RDA) of Sri Lanka, based on their extensive experience in the construction industry and knowledge of utility placement methods, Table 1 presents the profile of interviewees.

Table 1: Profile of Interviewees

Interviewee Code	Discipline	Organisation	Experience	Key Expertise areas
E1	Chartered Civil Engineer	NWSDB	40 years	Potable water and sewerage
E2	MEP Engineer	NWSDB	35 Years	Telephone cables/ potable water
E3	Civil Engineer	NWSDB	20 Years	Potable water and sewerage
E4	Civil Engineer	NWSDB	22 Years	Potable water and sewerage
E5	Civil Engineer	NWSDB	17 Years	Potable water and sewerage
E6	Civil Engineer	NWSDB	22 Years	Telephone cables/ potable water
E7	Civil Engineer	NWSDB	22 Years	Potable water and sewerage
E8	Charted Engineer	NWSDB	35 Years	Potable water and sewerage
E9	Civil Engineer	NWSDB	17 Years	Potable water and sewerage
E10	Quantity Surveyor	NWSDB	18 Years	Telephone cables/ potable water
E11	Quantity Surveyor	NWSDB	20 Years	Potable water
E12	Quantity Surveyor	RDA	10 Years	Potable water
E13	Quantity surveyor	RDA	15 Years	Potable water
E14	Engineer	RDA	30 Years	Sewerage pipeline installations
E15	Engineer	RDA	15 Years	Sewerage pipeline installations

Content analysis is considered a suitable method for both qualitative and mixed-method approaches (Langos, 2014). Therefore, to analyse the gathered data and to facilitate the discussion, conclusions, and recommendations, manual content analysis was employed.

DATA ANALYSIS AND DISCUSSION

BENEFITS OF USING TRENCHLESS METHODS (HORIZONTAL DIRECTIONAL DRILLING, MICRO TUNNELLING, AUGER BORING) IN SRI LANKAN CONTEXT

The HDD, Micro tunnelling, and Auger Boring methods were discussed during the data collection. It was found that these trenchless underground pipe laying methods used globally but rarely used in Sri Lanka. Some respondents acknowledged the potential advantages of implementing trenchless methods under appropriate conditions and locations in Sri Lanka.

For example, E09 noted that trenchless methods for urban pipe laying projects could minimise damage to road pavements, reduce traffic disruption, and lessen the need for resident evacuation, handling of excavated materials, and heavy ground machinery. Conversely, E01 mentioned that despite several advantages, a HDD project in Kandy failed due to unsuitable machinery. E01 also pointed out that, while trenchless methods offer benefits like traffic reduction and pavement protection, the high initial costs for skilled labour and advanced machinery can outweigh these advantages.

Regarding the Auger Boring method, E08 and E09 highlighted its benefits for providing household water connections. E09 explained, "*Most roads have a single-side water pipeline for drinking water. When a household on the opposite side requires a connection, the pavement must be damaged, and pipes laid under the road. Trenchless surface boring methods can provide these connections without damaging the road surface or disrupting traffic".* E15 emphasised that all trenchless methods are newer, advanced techniques offering more environmental, cost, and reliability benefits compared to the traditional open-cut method used in Sri Lankan pipe laying projects. E13 added that trenchless methods could be efficiently employed in coastal and north, north-central urban areas due to the even terrain and extensive road networks. E13 also noted that trenchless methods could be used in uneven terrains, such as Kandy, Ratnapura, and Kegalle, with proper supervision to ensure environmental stability and minimise potential landslides and earth slips.

Compared to findings in the literature, all interviews agreed that a shorter construction period is highly applicable to the Sri Lankan context. Minimizing road reinstatement costs is also seen as particularly relevant, as this is a major issue for utility installations in Sri Lanka. Additionally, reduced social impacts were identified through the interviews as a significant benefit specific to the Sri Lankan context. Moreover, Table 2 provides the benefits of trenchless methods in the Sri Lankan context across different aspect.

CHALLENGES OF USING TRENCHLESS METHODS (HORIZONTAL DIRECTIONAL DRILLING, MICRO TUNNELLING, AUGER BORING) IN SRI LANKAN CONTEXT

In addition to the benefits of trenchless methods, respondents also highlighted several challenges in implementing these techniques within the Sri Lankan construction industry. E03 pointed out that the high cost of machinery and initial investment are major barriers to adopting trenchless pipe laying methods. The lack of experience and stable funding has further limited the use of alternative pipe laying methods in Sri Lanka. E06 mentioned that contractors are accustomed to the open-cut method, and a significant challenge in implementing trenchless methods is the inadequate support from contractors. Regarding the major challenges, E10 emphasised that several trenchless projects have been unsuccessful due to a lack of understanding of terrain and ecosystem changes. E07 added that investigating soil profiles, gradients, and potential rock blasting or soil caves is essential to minimise unexpected challenges when using trenchless methods. E01 discussed how high initial costs and the need for heavy, sophisticated machinery pose significant challenges in Sri Lankan projects. Although methods like auger boring could be beneficial from a social perspective, financial constraints often restrict their use.

Drawing on the literature and findings from this study, Table 2 provides the benefits and challenges of trenchless methods in the Sri Lankan context across different aspects. Overall, the interviews pointed out that the lack of geological data, high cost of machinery, and limited technological expertise, as found in the literature, are significant challenges in adopting these trenchless technologies in the Sri Lankan context. Additionally, the interviewees highlighted the higher costs for skilled labour and machinery operation, as well as safety and risk concerns, as particularly relevant issues within Sri Lanka.

Table 2: Benefits & Challenges of Trenchless Methods in Economic, Environmental, Social and Technological Aspects

Aspect	Benefits	Challenges
Economical	▪ Less operating and maintenance expenses. ▪ Minimal open excavation cost. ▪ Shorter construction time ▪ Cost savings on future development and upgrades ▪ Reducing reinstatement costs for roads.	▪ High initial investment cost ▪ Higher costs for machines and equipment ▪ Higher costs for machine operators and skilled labours.
Environmental	▪ Less influence and damage on the project area and the surface. ▪ Small construction footprint. ▪ Minimizing roads and pavement damage. ▪ Less noise and air pollution ▪ Reducing the need of invasive excavations	▪ Effects from larger machinery and equipment ▪ Noise pollutions and vibrations ▪ Damage to other utilities ▪ Space required to develop the underground access points
Social	▪ Minimal disruption to traffic movements and business activities. ▪ Less disruption to people living and workings. ▪ Reducing risks. ▪ Less social impacts ▪ Less disturbance to road users	▪ Issues of compatibility and safety
Technological	▪ The ability of installation new and rehabilitate existing underground assets. ▪ Minimizing the personal exposure ▪ Shorter construction time ▪ Achieving Well organized underground space planning	▪ Less proper specifications ▪ Lack of geological data ▪ Lack of accurate as built drawings ▪ Limited high competent and experienced local contractors and operators ▪ Unforeseen impediments or soil changes ▪ Coordination issues ▪ Issues regarding selecting the proper machineries for related projects ▪ Unexpected potential risks ▪ Selecting incorrect Installation Technique

CONCLUSIONS AND RECOMMENDATIONS

This study was designed to investigate the benefits and challenges associated with trenchless utility placement methods for underground pipe laying construction within the Sri Lankan context. The study revealed that methods such as HDD, Auger Boring, and Multi-Utility Tunnels have been developed to address the challenges associated with traditional open-cut pipe laying methods. However, it was found that, from the colonial period to modern urban road construction, the open-cut or trenching method remains prevalent in Sri Lankan pipe laying and utility installation projects, rather than trenchless methods. The literature review discussed the benefits and challenges of trenchless methods in detail. Data analysis and discussion considered these methods in terms of economics, social impact, environmental concerns, and technological aspects. This study contributes to the knowledge base for both academia and industry by identifying the benefits and challenges of trenchless utility placement methods—including HDD, micro-

tunnelling, auger boring, and utility tunnelling specifically for Sri Lanka. It provides insights to relevant stakeholders on how to utilize these methods for improved underground utility installations. Recommendations for industry practitioners and authorities include increasing the use of advanced trenchless utility installation methods in suitable locations, providing proper training for these advanced construction techniques, and establishing new practices and standards for project funding, timing, and execution using advanced technologies.

REFERENCES

Ariaratnam, 2011. Sustainable development through innovative underground infrastructure construction practices. Arizona State University, AZ USA.

Ariaratnam, S., and Proszek, J., 2006. Legal consequences of damages to underground facilities by horizontal directional drilling. Journal of Professional Issues In Engineering Education & Practice 132, 342–355.

Atalah, A., and Onsarigo, L., 2017. Horizontal auger boring projects. ASCE Manuals and Reports on Engineering Practice, 2017 (106).

Behzadan, A. H., and Kamat, V. R., 2009. Interactive augmented reality visualization for improved damage prevention and maintenance of underground infrastructure. Building a Sustainable Future - Proceedings of the 2009 Construction Research Congress.

Cabahug, R. R., Arquita, M. B., Marie, S., De, E., Torre, L., Valledor, M. S., Mae, S., and Olivares, D., 2018. Factors Influencing the Delay of Road Construction Projects in Northern Mindanao, Philippines. Mindanao Journal of Science and Technology, 16(1).

Campbell, J., Solomon, G., Fawver, G., Lorello, R., Mathis, D., and Quiroga, C., 2009. Streamlining and Integrating Right-of-way and Utility Processes with Planning, Environmental, and Design Processes in Australia and Canada. Aashto, FHWA-PL-09(June).

Canto-Perello, J., Curiel-Esparza, J., and Calvo, V., 2009. Analysing utility tunnels and highway networks coordination dilemma. Tunnelling and Underground Space Technology, 24(2).

Chung, T. H., Abraham, D. M., and Gokhale, S. B., 2004. Decision Support System for Microtunneling Applications. Journal of Construction Engineering and Management, 130(6).

Cohen, A., and Ariaratnam, S. T., 2017. Developing a Successful Specification for Horizontal Directional Drilling. Pipelines 2017: Planning and Design - Proceedings of Sessions of the Pipelines 2017 Conference.

Cossio, M. L. T., Giesen, L. F., Araya, G., Pérez-Cotapos, M. L. S., Vergara, R. L., Manca, M., Tohme, R. A., Holmberg, S. D., Bressmann, T., Lirio, D. R., and Román, J. S., 2012. Trenchless Technology Piping: Installation and Inspection. Uma ética para quantos. 33(2).

Creswell, J. W., 2003. Research design Qualitative quantitative and mixed methods approaches. Research Design Qualitative Quantitative and Mixed Methods Approaches.

Creswell, J. W., 2008. Educational research: Planning, conducting, and evaluating quantitative and qualitative research (3rd ed.). Upper Saddle River, NJ: Pearson Education, Inc.

Dearnley, C., 2005. A reflection on the use of semi-structured interviews. Nurse researcher. 13(1).

Fan, M., 2015. Sri Lanka's water supply and sanitation sector: Achievements and a way forward. In ADB South Asia Working Paper Series (35).

Goduto, V., and Atalah, A., 2013. The Design and Construction Cost of a Water Line underneath I-75 in Bowling Green, OH. North American Society for Trenchless Technology (NASTT). 3. Sacramento, California: Construction Management Faculty Publications.

Hillebrand, J. D., and Berg, B. L., 2000. Qualitative Research Methods for the Social Sciences. Teaching Sociology, 28(1).

Hojjati, A., Jefferson, I., Metje, N., and Rogers, C. D. F., 2017. Embedding sustainability criteria into pre-appraisal of underground utility for future cities. Proceedings of the Institution of Civil Engineers: Urban Design and Planning, 170(6).

Hojjati, A., Jefferson, I., Metje, N., and Rogers, C. D. F., 2018. Sustainability assessment for urban underground utility infrastructure projects. Proceedings of the Institution of Civil Engineers: Engineering Sustainability, 171(2).

Huang, Y., Zhong, H., Liu, X., Dong, B., Wang, B., and Dong, Q., 2023. incorporating Trenchless Technology Research. Researchgate.Net, 134.

Hunt, D. V. L., Nash, D., and Rogers, C. D. F., 2014. Sustainable utility placement via Multi-Utility Tunnels. Tunnelling and Underground Space Technology, 39.

Hunt, D. V. L., Jefferson, I., and Rogers, C. D. F., 2011. Assessing the sustainability of underground space usage - A toolkit for testing possible Urban Futures. Journal of Mountain Science, 8(2).

Iseley, T., and Behbahani, S. S., 2016. Lessons Learnt from Horizontal Auger Boring School. Pipelines 2016: Out of Sight, Out of Mind, Not Out of Risk - Proceedings of the Pipelines 2016 Conference.

Jayakody, J. A. N. N., Nasvi, M. C. M., Robert, D. J., Navaratnarajah, S. K., Kurukulasuriya, L. C., Giustozzi, F., Gunasekara, C., and Setunge, S., 2024. Development of a Cross-Asset Model for the Maintenance of Road and Water Pipe Assets using AHP Method. Civil Engineering Journal (Iran), 10(2).

Jung, Y. J., and Sinha, S. K., 2007. Evaluation of Trenchless Technology Methods for Municipal Infrastructure System. Journal of Infrastructure Systems, 13(2).

Jusoh, S. N., Asnida, A. R., Aminaton, M., and Kassim, F., 2017. Tunnel and Microtunnel For Future Smart and Sustainable Infrastructure Solution. IPTEK Journal of Proceedings Series, 3(6).

Kaushal, V., Najafi, M., and Serajiantehrani, R., 2020. Environmental Impacts of Conventional Open-Cut Pipeline Installation and Trenchless Technology Methods: State-of-the-Art Review. Journal of Pipeline Systems Engineering and Practice, 11(2).

Kothari, C. R., 2004. Research Methodologies, Methods and Techniques. In Methods and Technique. 5(2).

Makana, L., Metje, N., Jefferson, I., and Rogers, C., 2016. What Do Utility Strikes Really Cost? University of Birmingham. School of Civil Engineering, Birmingham, UK.

Monfared, M. N., 2018. Comparison of Trenchless Technologies and Open Cut Methods in New Residential Land Development. University of Alberta, Department of Civil and Environmental Engineering.

Myers, M. B., Stickrod, T. W., Abraham, D. M., and Iseley, T., 1999. Microtunnelling Technology for Conduit Construction. Practice Periodical on Structural Design and Construction, 4(2), 56-63.

Najafi, 2005. Trenchless technology. McGraw-Hill, New York.

Najafi, M., and Kim, K. O., 2004. Life-cycle-cost comparison of trenchless and conventional open-cut pipeline construction projects. Proceedings of the ASCE Pipeline Division Specialty Congress - Pipeline Engineering and Construction.

Norizam, M. S., Nuzul Azam, H., Helmi Zulhaidi, S., Abdul Aziz, A., and Nadzrol Fadzilah, A., 2017. Literature review of the benefits and obstacles of horizontal directional drilling. IOP Conference Series: Materials Science and Engineering, 271(1).

Onsarigo, L., and Adamtey, S., 2020. Feasibility of state transportation agencies acquiring trenchless technologies: A comparison of open cut and horizontal auger boring. Tunnelling and Underground Space Technology, 95.

Ranasingha, C. M., and Wattage, P., 2024. Rainwater Harvesting (RWH) Systems: Is the Conservation of Water in Colombo Urban Areas Worth It? Conservation, 4(1).

Tsung, N., Zheng, M., Najafi, M., and Mehraban, S., 2016. A Comparative Study of Soil Pressure and Deformation of Pipes Installed by the Open-Cut Method and Trenchless Technology. Pipelines 2016: Out of Sight, Out of Mind, Not Out of Risk - Proceedings of the Pipelines 2016 Conference.

Wijekoon, S., 2011. Study on the factors influence performance of road construction Industry. 8.

Woodroffe, N. J., and Ariaratnam, S. T., 2009. Contractor Perspective on Factors for Evaluating Installation Options for Small-Diameter Utilities. Journal of Construction Engineering and Management, 135(2).

Wu, L., Wen, G., Wang, Y., Huang, L., and Zhou, J., 2018. Enhanced automated guidance system for horizontal auger boring based on image processing. Sensors (Switzerland), 18(2).

Yigitcanlar, T., and Dur, F., 2010. Developing a sustainability assessment model: The sustainable infrastructure, Land-use, environment and transport model. Sustainability, 2(1).

Zeghal, M., and Mohamed, E. H., 2019. Reinstatement of utility cuts: an innovative solution to an old problem. nnovations in Urban Infrastructure, pp. 165-177.

CHALLENGES AND MITIGATION STRATEGIES OF ERP SYSTEM POST IMPLEMENTATION IN THE SRI LANKAN CONSTRUCTION INDUSTRY

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CHALLENGES AND MITIGATION STRATEGIES OF ERP SYSTEM POST-IMPLEMENTATION IN THE SRI LANKAN CONSTRUCTION INDUSTRY

ABSTRACT

Enterprise Resource Planning (ERP) systems have been increasingly adopted in the Sri Lankan Construction Industry to address challenges related to project management. When implemented in construction projects, ERP systems can offer significant benefits. However, their post-implementation challenges require mitigation. Hence, this study investigates strategies to overcome post-implementation issues in infrastructure projects. A single case study of a construction company involving infrastructure projects with an ERP system was used to collect qualitative data. Currently, the ERP system is used to perform different tasks and duties. The post-implementation challenges identified are system complexities, internet issues, lengthy approval procedures, lack of knowledge among the staff, and incompatibility of the system with practical situations. Some proposed strategies are simplification, training programs and system customisation. Accordingly, the potential of the ERP systems can be optimised with enhanced project outcomes.

Keywords: *Construction Industry, ERP system, infrastructure projects, mitigating strategies, post-implementation problems, Sri Lanka,*

INTRODUCTION

The construction industry has been experiencing significant transformation due to the involvement of foreign companies (Kurukulasooriya & Gunatilake, 2023). Local companies struggle with project delays, unorganised management practices, inefficient resource allocation and delayed payments (Samaraweera *et al.*, 2019). These have failed to meet the project's key requirements: time, quality and cost. As a result, foreign companies have entered the industry with high competition, which has led many local companies to change their strategy to align with the market behaviour (Lakshman, Kumarasinghe and Weerasinghe, 2023). This has led to a growing interest in adopting more advanced management systems, particularly ERP systems.

ERP systems allow the integration of various business processes into a platform that enables real-time data sharing and improved decision-making (Karsak & Ozogul, 2009). In construction, the ERP system allows for streamlining the operations through project management (Hewavitharana, Hewavitharana, *et al.*, 2019), resource allocation (Abhijeet, Patil and Attar, 2013) And financial planning. However, implementing the ERP system in the Sri Lankan Construction Industry has specific challenges. Due to the complex nature of the industry, the adoption of the system can be a critical task (Hewavitharana et al., 2019). Moreover, the unfamiliarity of the system within the Sri Lankan construction sector further increases the challenges and leads to post-implementation issues that reduce the potential of the system (Jayamaha *et al.*, 2024). According to Aboabdo et al. (2019), the ERP systems have the potential to increase efficiency and competitiveness.

In the construction industry, infrastructure projects are particularly complex due to the involvement of various stakeholders, the requirement for proper coordination of resources and processes and the large geographical dispersion (Wu *et al.*, 2018). Hence, implementing an ERP system can benefit these projects. Currently, some construction companies in Sri Lanka are in the post-implementation stage of ERP systems (Jayamaha *et al.*, 2024). However, their practical use is doubtful. Therefore, it is necessary to understand and address the post-implementation challenges of ERP to ensure successful and practical use of ERP. Accordingly, this research aims to investigate the strategies that can be employed to overcome post-implementation issues, particularly in infrastructure projects. Further, the objectives of the study were to (1) identify the benefits of ERP systems, (2) investigate the specific post-implementation challenges that arise when ERP systems are deployed in Sri Lankan infrastructure projects, and (3) develop strategies that can effectively mitigate these challenges.

LITERATURE REVIEW

The ERP systems are software platforms that are designed to streamline various business processes across an organisation (Aryani *et al.*, 2021). The system was initially developed to manage manufacturing processes and later enhanced to manage a wide range of functions (Davenport & Brooks, 2004; Magnusson & Nilsson, 2017). The primary objective of an ERP system is to facilitate real-time information sharing and decision-making through centralising the data in a shared database (Nugraha et al., 2023).The integration of the system allows for efficient and effective resource management, leading to an enhanced project outcome.

BENEFITS OF THE ERP SYSTEM

There has been an increasing need for improved efficiency, transparency and control over project activities, which has resulted in the adoption of ERP systems (Jayamaha *et al.*, 2024). ERP systems can optimise the performance of a project due to its ability to provide real-time project data (Menezes & Guevara, 2010). This optimisation includes resource allocation, progress tracking, and financial management. The real-time visibility enables project managers to make informed decisions, reduce the likelihood of errors, and respond more quickly to potential issues (Spathis & Constantinides, 2003).

ERP systems can contribute to improved communication and collaboration (Elmonem et al., 2016) among different departments and stakeholders within a construction company. The system centralises the information in a single database eliminates the need for redundant data entry and reduces the risk of inconsistencies in project documentation (Kaufman & Erica 2024). This streamlines the workforce and enhances accountability and transparency. Additionally, ERP systems can also support strategic decision-making by providing details regarding project performance and profitability (Wijaya *et al.*, 2023). Further, construction companies can identify trends, optimise resource allocation and improve project outcomes. (Nugraha *et al.*, 2023; Ouiddad *et al.*, 2021). Therefore, an ERP system is valuable in a competitive market, where delivering projects on time and within budget is critical.

ERP SYSTEM IMPLEMENTATION IN SRI LANKAN CONSTRUCTION INDUSTRY

Implementing an ERP system requires a significant change within the organization (Mahar *et al.*, 2020), often leading to new challenges due to its impact on organisational behaviour (Mahmood *et al.*, 2020) According to (Kiriwandeniya *et al.*, 2013) most Sri Lankan organisations that adopt ERP systems have failed to experience the actual benefits due to poor post-implementation practices. Despite these challenges, the use of ERP systems in Sri Lanka is growing, particularly among large and medium-scale organisations. Jayamaha et al. (2024)stated that ERP systems can be adapted for cost management of building construction projects in Sri Lanka, and they can provide a competitive edge. However, ERP implementations often face difficulties due to limited resources, lack of computer literacy, language barriers, and cultural issues, which can lead to failure (Jayamaha *et al.*, 2024).

CHALLENGES OF ERP IMPLEMENTATION

(Mahmood *et al.*, 2020) identified the areas affecting ERP system implementation, including top management approach, change management, training and development, communication and system integration. Since the construction industry is unique and complex compared to other industries, there will be a gap between the standardised ERP system procedures and the non-standardised construction process. (Hewavitharana & Perera 2019). ERP implementation challenges happen due to the complexity of construction projects, which often involve a wide range of activities, stakeholders, and regulatory requirements (Chung *et al.*, 2009; Prasetya *et al.*, 2023). This complexity makes standardising and integrating processes into a single ERP system difficult. Construction projects generally depend on high flexibility (Walker & Shen, 2002). Therefore, it can be constrained by the rigid structures of many ERP systems.

Another significant challenge is construction professionals' lack of familiarity with ERP systems, where many construction industry participants are more familiar with traditional management practices and resist adopting new technologies (Musthafa & Marikar, 2020). This resistance can be increased by the ERP

systems' perceived complexity and the time and effort required to learn how to use them effectively (Hewavitharana & Perera, 2019). In developing countries like Sri Lanka, these challenges are further increased due to the limited access to training and support resources (Hewavitharana, Hewavitharana, *et al.*, 2019). The high cost of ERP system software and the need for specialised hardware and maintenance can cause companies difficulty finding investments for the project (Hewavitharana, Nanayakkara, *et al.*, 2019), mainly when the return on the investments is uncertain. Accordingly, ERP implementation has many challenges, as identified by several research studies. However, after initial implementation, construction companies may face several post-implementation challenges, especially in infrastructure projects requiring strategies for mitigating those challenges.

RESEARCH METHODOLOGY

The qualitative method is effective in exploring complex issues within a specific context (Creswell, 2009). This approach allows a deeper understanding of the post-implementation challenges associated with ERP systems in Sri Lankan infrastructure projects. Further, it was difficult to find a large sample in the Sri Lankan construction industry to collect data related to ERP post-implementation in infrastructure projects. Therefore, this study employed a qualitative approach. Accordingly, a case study strategy was used to examine a single construction company already implementing an ERP system across multiple infrastructure project sites. This strategy is particularly suited to this research as it enables the investigation of the real-life context (Algozzine & Algozzine 2016). Data was collected using semi-structured interviews with key personnel from the company's head office and three infrastructure project site offices. Manual content analysis was employed to identify patterns, themes, and key insights from the qualitative data collected. (Anastasiei & Georgescu 2020).Analysing the obtained data helps uncover the underlying challenges and effective strategies related to ERP system implementation in the construction industry. The interviewees were selected based on the purposive sampling method, including a diverse group of professionals from the head office and project sites of a leading construction company (Case) in Sri Lanka. This group comprises project managers, quantity surveyors, engineers, and IT personnel having at least one year of experience with the ERP system, as shown in Table 1.

Table 1: Criteria of Selected Interviewees

Office	Interviewee Code	Interviews Position	Total Experience	Experience with ERP
Head Office	HO-PM	Planning Manager	40 Years	03 Years
	HO-PD	Project Director	20 Years	03 Years
	HO-ITM	IT Manager	05 years	03 Years
	HO-QS1	Quantity Surveyor	10 Years	03 Years
	HO-QS2	Quantity Surveyor	10 Years	03 Years
	HO-QS3	Quantity Surveyor	08 Years	03 Years
Project A	PA-CM	Construction Manager	06 Years	03 Years
	PA-QS	Quantity Surveyor	04 Years	02 Years
	PA-AQS	Assistance Quantity Surveyor	02 Years	02 Years
	PA-SK	Storekeeper	10 Years	03 years
	PA-Eng.	Engineer	08 Years	02 years
Project B	PB-PM	Project Manager	17 Years	03 Years
	PB-QS	Quantity Surveyor	12 Yeas	03 Years

	PB-AQS	Assistance Quantity Surveyor	04 Years	02 Years
	PB-SK	Storekeeper/Logistic Officer	3.5 Years	03 Years
	PB-Eng.	Engineer	05 Years	01 Year
Project C	PC-PM	Project Manager	13 Years	03 Years
	PC-QS	Quantity Surveyor	08 Years	03 Years
	PC-AQS	Assistance Quantity Surveyor	02 Years	02Years
	PC-SK	Storekeeper	05 Years	02 Years
	PC-Eng.	Engineer	07 Years	02 Years

RESEARCH FINDINGS

BENEFITS OF ERP SYSTEM IMPLEMENTATION

The case study interviews provided various insights regarding how the ERP system is utilized within their daily operations and the benefits the system has provided. According to the responses, the system has significantly streamlined its processes. However, the benefits experienced by each user differ from each other. These questionnaires were divided into four major groups in accordance with the different roles the respondents were playing in the given construction project. Whereas the Project Managers would oversee the overall lifecycle of the project, manage resources, budgets, and progress through the ERP system, it would be the Quantity Surveyors and Engineers who work on cost management, data accuracy, and the assurance that the technical standards set are met. The ERP IT Manager has to ensure that the ERP system is up and running securely for smooth collaboration within the organization. On the other hand, the Storekeeper will ensure material inventory through the observation of stock levels for orderly and efficient reconciliation. Each group will use the ERP system according to their responsibilities and the needs of a particular project. Table 2 provides the details of these benefits experienced by various users.

Table 2: Key Benefits of ERP System According to Different User Groups

User Group	**Key Uses/Benefits highlighted**
Project Managers	Material, labour and machinery planning
	Budget control through authorised access
	Monitoring all progress via a dashboard
	Predicting project cost and income and checking historical events
	Monitoring daily progress and issues efficiently
	Daily stock balance monitoring and Invoice tracking
	Up-to-date project status
Quantity Surveyors/ Engineers	Long-term data security
	Early Problem identification and faster approvals
	Accessible communication with other stakeholders and less reliance on hard copies
	Easy project monitoring and cost comparison
	Simplified reconciliation report preparation
	High accuracy with data and the possibility to check at specific levels.
	Easy work analysis and planning
IT Manager	Efficient system operation and administration
	Ensures Data security

	Effective collaboration within the organisation
Storekeeper	Easier material Reconciliation
	Better control over the stock levels
	Easy retrieval of previous data
	Ability to track, monitor and record inventories in multiple areas

The findings of this study highlight the most important advantages of ERP systems by various user groups, each closely linked to their specific functions regarding the case, as a way to organize workflows and facilitate collaboration to enhance overall efficiency. Among others, project managers experienced significant advantages at the level of resource planning and allocation. One of the respondents then elaborated, "The system gives us access to authorized budget control, hence enabling us to monitor financials in real-time and have tight control over project costs." Another project manager spoke about how the system helps track at a historical level: "It's invaluable for checking past activities and monitoring current progress, hence making it easier to identify trends and stay on schedule." Quite a number commented on the issue of tracking stock balances and efficiently processing invoices as a big plus because it can guarantee better material management and reduce any delay in the procurement process.

Quantity surveyors possess other sets of benefits, more directly related to cost management and construction processes. As one surveyor described, "The ERP system provides data security long-term, and it's very important for early problem identification to avoid escalation of problems." This was also observed to enhance efficiency, particularly by reducing approval times, while another respondent added, "Faster approvals mean less time wasted waiting around and a smoother project flow overall." Another key benefit highlighted was that the stakeholders were able to communicate better, with one surveyor continuing, "The system makes communication to all parties easier, reduces our hard copies dependence, and everybody keeps themselves updated regarding changes in the process." They also valued the functionality related to monitoring projects and comparing costs more accurately, which thus enhanced budgetary oversight and allowed further planning.

Probably the most useful benefits for IT managers are the assurance of the efficiency and data security provided by the ERP system. As one respondent attested, "The system allows us to manage operations with ease and ensures that critical sensitive project data are secured, which is important in preventing any breaches of information." This group also discussed the ERP system as one that enables effective interdepartmental collaboration, thus enabling teams to work much stronger together and boosting overall organizational efficiency.

Storekeepers also liked the system for tracking and monitoring inventory that was scattered over several locations. The comments of one storekeeper were, "It's a lot easier to track, monitor, and record inventories, even if materials are spread across different sites, which gives us much better control over stock levels." Accurate tracking helped reduce the risk of stock shortages or overstocking, improving material flow and supporting the construction timeline.

POST-IMPLEMENTATION CHALLENGES OF ERP SYSTEM

Despite the identified benefits, the interviews revealed specific challenges in implementing the ERP system in infrastructure projects. Table 3 shows all the challenges identified in the interviews.

Table 3: Post Implementation Challenges of ERP System in Sri Lankan Infrastructure Projects

Challenges	Project Managers	Quantity Surveyors	Engineers	IT Personnel	Storekeepers
Excessive system entry requirements	✓			✓	✓
Frequent internet and network disruptions	✓	✓	✓	✓	✓
Confusion from system updates and performance issues	✓	✓	✓	✓	✓
Staff absence or lack of system knowledge causing delays	✓	✓	✓		✓
Inefficient data and document management	✓	✓	✓	✓	
Involvement of several steps and long approval processes causing project delays	✓	✓	✓		✓
Inadequate security and lack of long-term data backup		✓		✓	
Over-reliance on IT personnel for error correction		✓		✓	✓
Incompatibility of the system structure with the practical situation of each process		✓	✓		✓
Poor collaboration and communication with stakeholders	✓	✓		✓	
Difficulty in identifying and planning for site needs	✓	✓	✓		

According to the outcomes of the interviews, similar challenges were identified by the different user groups. Internet and network disruptions and confusion from system updates were discussed as the significant challenges in the post-implementation of ERP systems. Another major challenge was the absence of relevant staff, which caused disruptions and delays. PB-PM explained, “If a key person is unavailable, the system goes down and sometimes deep searching is required to give approvals". PA-PM warned, "From a single click, many data can be damaged". PB-PM added, “Delay by one person will affect the total process. Events cannot be edited without permission of previous editors”.

PC-PM, PB-QS, PA-SK and PB-Eng highlighted the involvement of several steps in the system processes that take too much time. PA-QS, PB-QS, and PA-Eng mentioned that if an error occurs, corrections can only be conducted by the IT manager, who does not have any practical knowledge of site works.

Further, the head office staff of the selected case disclosed problems associated with the ERP system: taking more time to train staff, resulting in slow project implementation [HO-PM], network problems and software updating problems [HO-PD], difficulties in making instant decisions [HO-PD], lack of training and lack of education in ICT [HO-ITM], mismatch of practical situation and Systems requirements [HO-PM, HO-QS1], not having proper data collecting methods in sites [HO-PM, HO- QS2], inability to change approved records [HO-PD], reports derived from the system are difficult to compare [HO- QSs].

MITIGATION STRATEGIES OF POST-IMPLEMENTATION CHALLENGES

As it were, the findings presented that there were various challenges faced by the staff in manipulating the ERP system on account of unfamiliarity and perceived complexity of the system. In this regard, interviewees proposed strategies to enhance usability. One easy method put forward was to simplify processes. According to the project managers, reducing steps for common tasks would guarantee ease of performance. The staff also insisted on developing training programs, claiming that constant practical training would enable the users at every level to grasp and apply the system better. Another approach is system customization: to this point, the respondents especially pointed out the need to adjust the ERP system to the specific demands of the construction projects. Mobility was another point touched upon where

staff recommended that the system needed to be made available on portable devices for real-time data input on-site. Other recommendations further called for a better integration with the current report formats, a periodic cross-checking procedure for the assurance of the accuracy of data, and a call to ensure that the administration is competent with both knowledge in ICT and construction. These plans have ranged from the simplification of the system to its adaptability to construction projects. These are provided in Table 4.

Table 4: Mitigation Strategies for Post-Implementation Challenges

Strategy	**Description**
Simplification of Processes	Reduce the number of steps required for common/everyday tasks and streamline approval processes [PA-CM, PB-PM, PC-PM, HO-PD].
Enhanced Training Programs	Provide comprehensive, ongoing training for all levels of staff, focusing on practical application [Site Staff].
Improved System Customization	Customise the ERP system to better align with the specific needs and conditions of construction projects and the users [PC-PM, Site QSs].
Mobility	Incorporate the system into portable devices for ease of use [Site Staff]
Better Integration with Existing Formats	Feeding more familiar and relevant formats for reports derived through the system [HO-QSs]
Cross Checking Methods	Average checking and cross-checking from time to time, Labour machinery plant cross-checking with actual site progress and checking with alternatives. [PA-PM, PB-PM, HO-QSs]
Competent administration	System Administrators should be competent in ICT and Construction. [HO-PM, HO-PD]

The major challenges faced by the staff while using the ERP system were related to its unfamiliarity. Therefore, the strategies revolve around increasing the usability of the ERP system for the staff.

CONCLUSION

This research explored the benefits, challenges, and mitigation strategies for post-implementation challenges of ERP systems in Sri Lankan infrastructure projects. Due to the unique nature of the construction project and the complexities in infrastructure projects, the system needs to be customised according to the project's requirements. According to the outcomes of the interviews, the ERP system provides benefits such as streamlined processes, enhanced data security, improved communication, and efficient resource management. Post-implementation challenges like system complexity, internet disruptions, staff knowledge gaps, and lengthy approval processes impact these benefits. However, the interviewees provided mitigation strategies that can address the identified issues. These strategies include process simplification, enhanced training programs, customised system improvements, and the introduction of mobile capabilities. The suggested strategies ensure that the competency of administrators is enhanced, and better system integration is provided. Accordingly, with the mitigation of the post-implementation strategies, the potential of the ERP system can be used for enhanced project outcomes.

This study has highlighted various avenues that could be taken in doing further research. First, there is the long-term influence of ERP system integration concerning the aspect of project efficiency and cost-effectiveness within the construction sector. One can thus be done in a longitudinal study of how ERP systems affect the outcome of the projects over extended time frames, focusing on gains in productivity, cost savings, and overall quality of the project. Another area of interest could be comparing the ERP system adoption between different sectors of infrastructure development in Sri Lanka; for instance, comparing the construction industry with transportation or utilities to come up with sector-specific challenges and benefits.

Other interesting areas of future research may include assessing the effectiveness of different mitigation strategies that have been advanced. For example, specific investigations could research what actual impact simplification of processes, mobilization, and increased training would have on the adoption and user satisfaction of the ERP systems. Another promising direction of research may be the investigation of how emerging technologies, such as AI and machine learning, could be embedded in ERP systems to automate decisions and further rationalize their operations. The contribution is academic, hence toward the literature on ERP systems in construction and infrastructure projects, which is a rarely touched area. It provides empirical evidence from the Sri Lankan context, reflecting specific benefits and challenges from the region's infrastructure sector. This study underlines the importance of tailoring ERP systems to fit the needs of the project in question and contextual factors, hence contributing to an extended understanding of how ERP systems can be adapted to different project environments.

REFERENCES

Abd Elmonem, M.A., Nasr, E.S. and Geith, M.H. (2016), "Benefits and challenges of cloud ERP systems – A systematic literature review", *Future Computing and Informatics Journal*, Future University in Egypt, Vol. 1 No. 1–2, pp. 1–9.

Abhijeet, M., Patil, Z. and Attar, A.C. (2013), "Optimizing construction resources using ERP".

Aboabdo, S., Aldhoiena, A. and Al-Amrib, H. (2019), "Implementing enterprise resource planning ERP system in a large construction company in KSA", *Procedia Computer Science*, Vol. 164, Elsevier B.V., pp. 463–470.

Algozzine, R. and Algozzine, B. (2016), *Doing Case Study Research: A Practical Guide for Beginning Researchers*, Teachers College Press.

Anastasia, I.D. and Georgescu, M.R. (2020), "Automated vs manual content analysis – A retrospective look", *Scientific Annals of Economics and Business*, Alexandru Ioan Cuza University of Iasi, Vol. 67, pp. 57–67.

Aryani, I., Akmal Tanjung, R. and Rahmadyah, N. (2021), "Analysis of the role of ERP systems in business process integrity", *Jurnal EMBA Review*, No. 2, p. 1.

Chung, B., Skibniewski, M.J. and Kwak, Y.H. (2009), "Developing ERP systems success model for the construction industry", *Journal of Construction Engineering and Management*, Vol. 135 No. 3, pp. 207–216.

Creswell, J.W. (2009), *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*, Sage.

Davenport, T.H. and Brooks, J.D. (2004), "Enterprise systems and the supply chain", *Journal of Enterprise Information Management*, Vol. 17 No. 1, pp. 8–19.

Hewavitharana, F.S.T. and Perera, A.A.D.A.J. (2019), "Gap analysis between ERP procedures and construction procedures".

Hewavitharana, T., Hewavitharana, F.S.T. and Perera, A.A.D.A.J. (2019), *Adaptability of the Enterprise Resource Planning System for the Construction Industry*.

Hewavitharana, T., Nanayakkara, S., Perera, A. and Perera, J. (2019), "Impact of enterprise resource planning (ERP) systems to the construction industry", Vol. 7 No. 2.

Jayamaha, B.H.V.H., Perera, B.A.K.S., Gimhani, K.D.M. and Rodrigo, M.N.N. (2024), "Adaptability of enterprise resource planning (ERP) systems for cost management of building construction projects in Sri Lanka", *Construction Innovation*, Vol. 24 No. 5, pp. 1255–1279.

Karsak, E.E. and Özogul, C.O. (2009), "An integrated decision-making approach for ERP system selection", *Expert Systems with Applications*, Vol. 36 No. 1, pp. 660–667.

Kaufman, M. and Erica, W. (2024), "Enterprise resource planning systems as a tool for standardisation, centralisation, and control: Insights from the qualitative accounting literature", Vol. 50.

Kiriwandeniya, I., Ruwan, V.U.A., Samarasinghe, S.S.U., Samarakoon, S.M.P.A., Kahandawarachchi, C. and Thelijjagoda, S. (2013), "Post-implementation framework for ERP systems with special reference to Sri Lanka", *2013 8th International Conference on Computer Science & Education*, IEEE, pp. 508–513.

Kurukulasooriya, I.N. and Gunatilake, S. (2023), "Why foreign consultants? Insights from the Sri Lankan construction industry", *2023 Moratuwa Engineering Research Conference (MERCon)*, IEEE, pp. 304–309.

Lakshman, D., Kumarasinghe, J. and Weerasinghe, R. (2023), "Internationalization of SMEs in a developing economy: Empirical evidence from SMEs in the Western Province, Sri Lanka", *Global Business Review*.

Magnusson, J. and Nilsson, A. (2017), "Enterprise systems and supply chains", *Lecture Notes in Logistics*, Springer Science and Business Media B.V., pp. 13–23.

Mahar, F., Ali, S.I., Jumani, A.K. and Khan, M.O. (2020), "ERP system implementation: Planning, management, and administrative issues", *Indian Journal of Science and Technology*, Indian Society for Education and Environment, Vol. 13 No. 1, pp. 106–122.

Mahmood, F., Khan, A.Z. and Bokhari, R.H. (2020), "ERP issues and challenges: A research synthesis", *Kybernetes*, Emerald Group Holdings Ltd., 20 February.

Menezes, P. and Gonzalez Ladron de Guevara, F. (2010), "Maximización de los beneficios de los sistemas ERP", *JISTEM Journal of Information Systems and Technology Management*, TECSI, Vol. 7 No. 1, pp. 5–32.

Musthafa, M.M. and Marikar, F. (2020), *Challenges and Benefits of ERP System and Non-ERP System Integration in a Developing Country*.

Nugraha, D.W., Ismail, H., Wardhana, A., Wijaksana, T.I. and Yunani, A. (2023), "A systematic literature review: Implementation of ERP systems in logistics companies supply chain management in developed and developing countries", *SPIE-Intl Soc Optical Eng*, p. 62.

Ouiddad, A., Okar, C., Chroqui, R. and Beqqali Hassani, I. (2021), "Assessing the impact of enterprise resource planning on decision-making quality", *Kybernetes*, Vol. 50 No. 5, pp. 1144–1162.

Prasetya, A., Isa Anshori, M. and Andriani, N. (2023), "Opportunities and challenges of enterprise resource planning (ERP) in construction companies in Indonesia: A systematic literature review", *Jurnal Ilmiah Manajemen Kesatuan*, Vol. 11.

Samaraweera, P.D.P., Perera, B.A.K.S. and Dewagoda, K.G. (2019), "Management of payment delays in government-funded construction projects in Sri Lanka", *World Construction Symposium*, Ceylon Institute of Builders, pp. 411–421.

Spathis, C. and Constantinides, S. (2003), "The usefulness of ERP systems for effective management", *Industrial Management and Data Systems*, Emerald Group Publishing Ltd., Vol. 103 No. 8–9, pp. 677–685.

Wijaya, S.F., Wiratama, J. and Kuswanto, V. (2023), "An evaluation of integrating ERP system to develop a strategy business", *2023 International Conference on Information Management and Technology (ICIMTech)*, IEEE, pp. 1–6.

Wu, C., Chen, D. and Huang, S. (2018), "Complexity of construction mega infrastructure project", *Complexity*, Vol. 2018 No. 1.

STATUS OF OFFSITE CONSTRUCTION IN SRI LANKA

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STATUS OF OFFSITE CONSTRUCTION IN SRI LANKA

ABSTRACT

A viable solution that aligns with the primary catalysts for change and offers a potential for disruption in the building industry is the use of offsite construction (OSC). Research on OSC identified various types documented in literature; however, none provided a convergence of them with practical usage of OSC that aligns with contemporary technological improvements in the global construction sector. Hence, this study explores the status of OSC, specific to Sri Lanka, focusing on its adoption and current applications. A survey was conducted among professionals from the construction industry, including engineers and quantity surveyors, to gather insights into the use of OSC methods. This research follows a mixed-method approach using purposive sampling with five (5) criteria. The data was analysed using manual content analysis and mathematical tools such as frequency. The research identifies volumetric pre-assembly, OSC buildings, particularly relocatable container-based systems, after component types OSC buildings as the most widely used OSC technique. Moreover, despite the potential benefits, the adoption of modular construction remains limited due to high costs, regulatory barriers, and lack of awareness. The study concludes that OSC has significant potential to improve efficiency and reduce costs, but further efforts are needed to enhance industry knowledge, awareness, and policy support for broader adoption in Sri Lanka.

Keywords: *Offsite Construction; Relocatable Modular Building; Sri Lanka; Volumetric Offsite*

INTRODUCTION

The construction sector plays a vital role in stimulating economic development in several nations. Despite seeing significant expansion from 2014 to 2018 in comparison to other sectors as industrial and services, the industry was adversely affected by the COVID-19 pandemic in 2020, resulting in a deceleration (Alhusban et al., 2022). As seen by the current performance of the real estate market, the industry is currently experiencing a period of recovery. Considering the substantial savings rates resulting from decreased demand in the last two years, investing in real estate has become a compelling choice for funds, particularly in light of the increasing inflation in the European Union. The pandemic has catalysed deliberations and reassessments of architecture, notably in the realm of residential buildings (Sánchez-Garrido et al., 2023). Consequently, the requirements and criteria for construction, especially in the field of housing, have become increasingly stringent in order to fulfil the needs of contemporary society (Dallasega et al., 2018) whereas technology is swiftly revolutionising the building industry, with one of the most cutting-edge suggestions being the adoption of technological solutions to mechanise construction operations and enhance the supply chain. An effective approach that aligns with the main factors that drive change, technology and offers a chance for disrupting the building industry is the implementation of offsite construction (Broadhead and Daniel, 2023).

The field of offsite construction (OSC) has attracted significant scholarly interest, including various subjects outside economic analysis such as cost reduction, decreased labour costs, and expedited project schedules (Sadabad, 2023; Wuni and Shen, 2019). Based on the findings of Almashaqbeh and El-Rayes (2021), the implementation of modularisation in building projects is anticipated to result in a reduction of construction costs by 10%-25%. According to Bao et al. (2022), the cost-benefit analysis is largely influenced by economies of scale, which are a key characteristic of factory production and have a significant impact on reducing costs in OSC. Managed manufacturing settings, process simplification, and reducing weather-related delays lead to reduced labour costs and enhanced efficiency, which in turn provide economic benefits (Jang et al., 2022). As shown by Pan et al. (2012), the incorporation of improved quality control in offshore construction results in a noticeable decrease in faults and rework, leading to a significant reduction in total project costs. Moreover, the activities conducted in industrial settings result in the acquisition of materials in large quantities, reduction of material waste through efficient use in a controlled environment, and efficient operations (Sokhangoo, Nik-Bakht and Han, 2018), eventually promoting financial economic efficiency (Pervez et al., 2021).

Developed nations account for approximately 85% of the peer-reviewed research on OSC (Tapia et al., 2023). It is projected that the worldwide offsite sector would generate $130.4 billion in 2020 and reach $235 billion by 2030. This number positions OSC at 1.3% in terms of market share. Globally, the rate of adoption differs by geographical area. In the United Kingdom, Australia, and the United States, the market share of prefabrication as a component of housing is quite similar, accounting for less than 5%. In contrast, Sweden, Japan, and the Netherlands have a far higher market share of 84%, 15%, and 20% respectively (Broadhead and Daniel, 2023). Furthermore, global researchers indicate that the lack of accessible cost data and information on OSC has resulted in negative public perception, insufficient awareness, and uncertainty regarding costs, despite its significant advantages (Sutrisna et al., 2019).

Despite the extensively studied advantages of the OSC, especially in least developed nations, the adoption of OSC is comparatively slower than in industrialised countries (Jayawardana et al., 2023c). The OSC market in Sri Lanka encounters obstacles including insufficient awareness, supply chain issues, cultural perceptions, and the absence of effective business process models (Goulding et al., 2015). However, it is essential to advocate for these construction methods in Sri Lanka to tackle emerging challenges such as a declining workforce, stringent time limitations, the necessity to adhere to environmental regulations, and the demand for enhanced quality (Jayawardana et al., 2023a). This heightened adoption of OSC offers considerable potential to improve the long-term sustainability of the Sri Lankan construction sector. Hence, this paper aims to explore the status of OSC in the Sri Lankan context by investigating the gap between theoretical typologies of OSC and their practical usage. This study further expects to strengthen the existing knowledge of OSC and converge it with the practical usage of OSC in Sri Lanka to make a way forward to promote OSC in Sri Lanka.

LITERATURE REVIEW

OFFSITE CONSTRUCTION

Hosseini et al. (2018) define OSC approach as the systematic fabrication and pre-assembly of different building components, modules, and parts before they are transported and installed at physical construction sites. Furthermore, Smith and Quale (2017) have elaborated on this concept, defining it as the deliberate process of planning, designing, fabricating, and assembling building components in a separate location from their final installation site. Its objective is to expedite the rapid and effective building of permanent structures (Hairstans and Smith, 2018; Quale and Smith, 2019; Smith and Quale, 2017). By contrast, conventional construction involves the assembly of structures on-site, usually using cast in-situ reinforced concrete (RC) and follows a sequential on-site construction procedure (Assaad et al., 2023).

TYPOLOGY OF OFFSITE CONSTRUCTION

Most of the OSC classifications in the literature possess the influence of the literature by Gibb (2001). Also, many other literature sources provide various bases for levels of OSC classification highlighting the value of the work (Sutrisna et al., 2019), the nature of the work (Hairstans and Smith, 2018), the material used (Pan & Sidwell, 2011), the level of pre-design (Quale and Smith, 2019), the value addition before onsite installation and the location of the work (Hairstans and Smith, 2018).

In the realm of OSC, there exists a myriad of taxonomies and terminology, both in the construction industry and academia, which often engenders a perplexing overlap and lack of clarity for users and researchers (Ginigaddara et al., 2022). While various attempts have been made to revise OSC classifications, some by introducing the "hybrid" OSC type and others by redefining 2D and 3D OSC categories, the underlying rationale for such categorisations often remains ambiguous (Ginigaddara et al., 2022). However, many authors identify the types of OSC with respect to the level of prefabrication in construction (Ginigaddara et al., 2022; Jin et al., 2020; Kamali & Hewage, 2016).

i) Non- Volumetric Offsite Construction Types

- Components

Since the first reference to "component manufacture and sub-assembly", components have been considered in many classifications as the simplest OSC type. Many components used in construction are actually sub-assemblies (e.g., door furniture or light fittings) (Yu et al., 2023). This category includes all small-scale sub-assemblies that would never be considered for on-site assembly in any country. Consequently, components can be regarded as the fundamental typology of OSC, characterised by a minimal proportion of offsite manufacture and a maximal proportion of onsite assembly and installation (Ginigaddara et al., 2019). They are prevalent in numerous buildings, regardless of whether they are erected traditionally or offsite. While previous classifications acknowledge the volume-based differentiation of OSC types, they do not account for the structural-based differentiation of non-volumetric elements (Ginigaddara et al., 2022). Hence, the authors suggest that reconfiguration of components, encompassing both structural and non-structural building elements is vital. Hence, this will include pre-manufactured fittings, fixtures, columns, beams, stairs, trusses, façades, and building services that involve site-intensive construction (Nguyen et al., 2018).

- Non-volumetric Pre-assembly

These items are assembled in a factory, or at least prior to being placed in their final position such as panelised systems. Panelised systems are normally structural framing pieces or several sub-assemblies that are built at an off-site location before being transported to the site and erected on a permanent basis (Darwish et al., 2020). Examples include wall panels, structural sections and pipework assemblies. However, there are several other terms referring to panels, all of which provide a similarity to components (Ginigaddara et al., 2019).

ii) Volumetric Offsite Construction Types

- Volumetric Pre-assembly

These items are also assembled in a factory. They differ from non-volumetric in that they enclose usable space and are usually installed on site within an assembled building services risers and modular lift shafts. In some literature, they are identified as hybrid systems, otherwise known as pods. It consists of fully manufactured or prefabricated building facilities, which are factory built and with all finishes complete. In hybrid systems, all furnishings and finishes are completed and transported from the factory to be placed on site (Lu, 2009). It is to be noted that pods are to be installed onsite within or onto an independent structural frame.

- Modular Units

These items are similar to volumetric units, but in this case the units themselves form the building, as well as enclosing usable space or module is the whole building itself. On completion, these modules are then transported to the site for permanent installation on a preestablished foundation (Boyd et al., 2013). Examples may include out-of-town retail outlets, office blocks and motels as well as concrete multi-story modular units used for residential blocks. Given the high prefabrication rate and large volume of modular units, the modular construction exhibits large challenges to the offsite manufacturing, logistic, onsite assembly, operation, and demolition processes in terms of technical and managerial aspects (Jin et al., 2020).

However, Complete Buildings are another typology of OSC which involves a significant number of offsite skills and an extremely minimal number of onsite skills due to the overall completion of the building within a factory facility (Ginigaddara et al., 2019). Furthermore, in modular buildings, there are two categories identified by Sandamini and Waidyasekara (2022). They are namely relocatable and non-relocatable modular buildings. Relocatable modular buildings are expected to be relocated when requirements arise as name implies. Hence, they are widely adopted in construction industry. In particular, non-relocatable modular buildings have lifespan with varying range of 30-60 years, and they are built upon permanent foundation structures. Their services are similar to conventional buildings structures as well (Mapston and Westbrook, 2010; Sandamini and Waidyasekara, 2022; Smith, 2014).

- Flat Packs

Remarkably, less authors have considered flat pack production, despite its presence in the industry for almost a decade (Ginigaddara et al., 2022). They are known as foldable volumetric buildings. These buildings comprise of primarily the roofing system (comprising the roof plate, roof frame, and corner fittings), the flooring system (containing the base plate, floor frame, and corner fittings), corner columns, wallboard, and additional components (Zhang et al., 2024).

In general, offsite techniques adoption is influenced by the type of project and the construction application (Brissi et al., 2021). Table 1 depicts the summary of OSC types and their applications. Some of the major applications of offsite have been in the areas of public/social housing, private housing, offices, hospitals/health, retail, schools, educational centres, student accommodation, factories/ warehousing, hospitality, restaurants/fast food, supermarkets, administration (Pan & Sidwell, 2011). Most used systems in different countries are framing systems, volumetric modular buildings, cladding systems, bath/toilet/ kitchen pods, building services, structural insulated panels, panelised roofing systems, foundation systems, precast load bearing wall panel, load bearing wall panel, load bearing block panel, form work, precast frame, precast floor and hollow core slab, steel frame (Arif et al., 2012).

However, the major focus of environmental performance analysis in the OSC field is still at the sub-assembly level (Hu et al., 2021). This is mainly because sub-assembly construction method can, to some extent, take the superiority of precast construction and maintain building aesthetic values (Jin et al., 2020). Besides, in comparison to a building constructed at a lower prefabrication rate, volumetric construction in OSC requires additional coordination and planning work due to its difficulties in logistics and building design process (Navaratnam et al., 2019). The high initial cost also impedes the application of volumetric construction in OSC because the modules for volumetric construction are built in a more integrated manner with higher completeness (Mao et al., 2015). As a result, the applications and studies on OSC with higher prefabrication rates are rare. However, given the importance of modular construction with due consideration of site, labour, and time restrictions, it is urgent to decode the environmental complexity embedded in buildings with higher prefabrication rates.

Table 1: Summary of Types of Offsite Construction

Type	Definition
Component and sub-assembly	Most items are made in a factory and onsite installation is done
Non- volumetric pre-assembly	These are offsite manufactured units with pre-assembled components not intending to enclose spaces
Volumetric pre-assembly	These are pre-assembled building subunits not intending to form a whole building (e.g.: toilet pods)
Modular Buildings	These are offsite pre-assembled whole volumetric buildings where fabric and structure are completed at offsite

Nevertheless, there happens to be often usage of onsite and offsite combination in each type of OSC in value terms of a construction project (Lawson et al., 2014). Recent research by Ginigaddara et al. (2022) claims that a determining factor for categorising OSC products is the product complexity and the value percentage of the product out of the total project value. Hence, it requires a thorough examination on categorisation. Figure 1 demonstrates the process of classifying the buildings into their relevant OSC types.

However, because to their extensive diversity and prevalence, the likelihood of components possessing a greater total value % than other OSC types is remarkably elevated. Jaillon and Poon (2009) assessed 11 prefabricated pieces often utilised in Hong Kong, comprising five components and the remainder consisting of panels or volumetric elements. Hence, Ginigaddara et al. (2022) ascertain that the next stages in OSC construction classification omit components in the process. Consequently, if a building possesses only one OSC type (panels, pods, modules, a whole building, or a foldable structure) in addition to components, it is classified under the pertinent OSC type. In a building with multiple OSC types, the OSC type with the

highest percentage value is prioritised. In instances where a building exhibit identical OSC percentages for two OSC kinds in monetary terms, the OSC type characterised by more complexity is deemed the pertinent OSC type. The intricacy of OSC kinds can be determined by the characteristics of the items and the production procedures utilized. For instance, in contrast to a panelised project, pods can exhibit significantly greater manufacturing complexity. The decision-making process takes into account the primary utilisation of a particular OSC type.

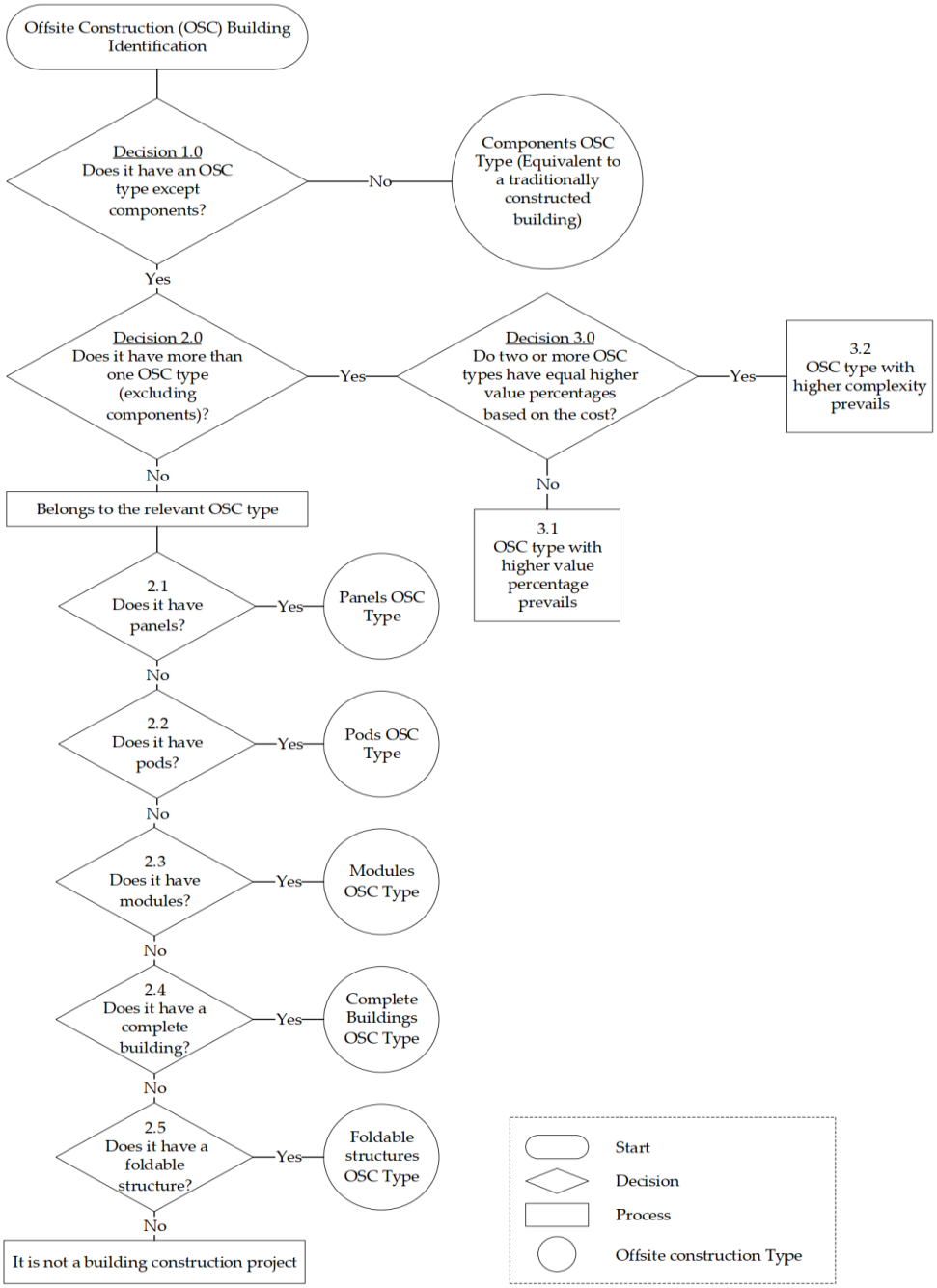

Figure 1: Process of OSC Building Classification

Source: Ginigaddara et al. (2022)

OFFSITE CONSTRUCTION IN GLOBAL CONTEXT

Increasing the utilisation of OSC with respect to several OSC types has been developing recently. Modular construction in the United Kingdom has made a substantial contribution to meeting the demand for housing in all types of ownership, resulting in more homes being built each year. This complements traditional construction methods and expands the number of users and options for development (Nazir et al., 2021). Further, Canada, along with other countries, is using modular construction for residential buildings as a solution to address homelessness rates. This approach has been particularly implemented in Vancouver, the capital city of Canada, where in 2017, there were 3,605 homeless individuals in the Metro Vancouver area (Nazir et al., 2021).

Among OSC, modular building is increasingly being seen as a significant method for improving productivity in Singapore where minimum of 15 projects have implemented the Prefabricated Prefinished Volumetric Construction (PPVC) method (Xu et al., 2020). Importantly, adoption rate of modular construction is high due to its enhanced sustainability performance such as reduction of Green House Gases (GHGs) emissions by 3% (Garusinghe et al., 2023; Xu et al., 2020).

OFFSITE CONSTRUCTION IN LOCAL CONTEXT

In Sri Lanka, the adoption of OSC is somewhat in younger stages. According to Jayasinghe et al. (2023), only certain suppliers have made their path to OSC in Sri Lanka using panelised systems and modular systems. One of the leaders in OSC in Sri Lanka manufactures precast wall panels with technology from ELEMATIC Finland. This precast wall panel technology has demonstrated an 80% reduction in labor, a 40% decrease in weight, a speed five times greater than traditional blockwork, and no expenses associated with plastering (Jayawardana et al., 2023a). In terms of panelised OSC, a local prefabrication solution provider supplies light wall panels composed of fly ash and rig foam as secondary material components. The incorporation of byproduct (fly ash) and waste material (rig foam) has potentially diminished the environmental impact of these wall panels. Additionally, it promotes circularity by integrating waste materials into the prefabrication process (Jayawardana et al., 2023a).

However, there is lack of knowledge on usage of modular construction in Sri Lankan context (Uthpala and Ramachandra, 2015). In particular, their usage is limited to relocatable modular buildings as identified previously, more specifically to container based (Sandamini and Waidyasekara, 2022). Nevertheless, modular building demonstrates a significant 36% decrease in labour expenses, a 16% decrease in embodied energy, and decrease of 32% in construction costs in comparison to traditional construction methods. This was identified by a survey conducted by Munmulla et al. (2023) with respect to Sri Lankan context. Hence, the utilisation of modular concepts enables the construction of economical buildings, which can be highly cost-efficient when the appropriate materials are selected ultimately to providing insufficient middle-income level housing needs as identified in Urban Development Authority in Sri Lanka.

RESEARCH METHODOLOGY

This research intends to analyse the status of OSC in the Sri Lankan context. Hence, this required obtaining data for status of OSC through a survey carried out among industry practitioners and company stakeholders who are specialised in providing OSC services in Sri Lanka. However, the sample stated in Table 2 may not represent the entire population of OSC applications in Sri Lanka. Due to the factual and contextual nature of the research, a mixed-method approach was adopted with the use of structured interviews (Battista and Torre, 2023). Further, this quantitative data helps to generalise across the population based on measurable outcomes.

In particular, purposive sampling has been adopted because it improves methodological rigour and trustworthiness in the research by aligning with the research methodology, aims, and objectives, enhancing credibility, transferability, dependability, and confirmability (Campbell et al., 2020). This method in the sense, allows the researcher to select participants based on their relevance to the research topic (Andrade, 2021) which is OSC in Sri Lanka. This sample represents possible existing and influential groups driving the OSC industry in Sri Lanka and it closely follows the population. Majorly, twenty (20) stakeholders from several construction companies were reached through the survey.

Quantitative data was manually analysed using mathematical tools such as frequencies and etc, by considering the quantitative and qualitative variables and qualitative data was analysed through content analysis as it is a method for identifying the prevalence of concepts within an argument (Kleinheksel et al., 2020).

RESEARCH FINDINGS

PROFILE OF THE SURVEY RESPONDENTS

Since offsite application is still a novel area for Sri Lankan context, there were twenty (20) respondents. In particular, there were different practitioners within the same organisation who had access to projects' data which they have involved earlier. Table 2 summarises profiles of the interview respondents who have working experience in the research context.

Table 2: Summary of Survey Respondents

Code	Profession	Designation	Compulsory Requirements (At least 2 criteria)			Additional Requirements (At least 1 criteria)		Accessibility
			C1	C2	C3	C4	C5	
R1	Engineer	Marketing Engineer	√	√	√	√	√	√
R2	Engineer	Planning Engineer	√	√		√		√
R3	Quantity Surveyor	Procurement Manager	√	√		√		√
R4	Engineer	Senior Project Executor	√	√		√	√	√
R5	Marketing Executive	Portfolio Manager	√	√	√			√
R6	Quantity Surveyor	Tender Manager	√	√	√	√	√	√
R7	Marketing Executive	Marketing Manager	√	√	√			√
R8	Engineer	Project Controller	√	√	√	√	√	√
R9	Quantity Surveyor	Commercial Manager	√	√	√	√	√	√
R10	Marketing Executive	Marketing Manager	√	√				√
R11	Quantity Surveyor	Procurement Director	√	√		√	√	√
R12	Quantity Surveyor	Managing Director	√	√		√		√
R13	Engineer	QAQC Engineer	√	√	√	√		√
R14	Engineer	Project Leader/MEP	√	√			√	√
R15	Engineer	Project Leader/Structural	√	√	√	√	√	√
R16	Quantity Surveyor	Quantity Surveyor Associate	√	√	√	√	√	√
R17	Engineer	Planning Engineer	√	√		√	√	√
R18	Quantity Surveyor	Post Contract Director	√	√	√	√		√
R19	Marketing Executive	Marketing Manager	√	√	√		√	√
R20	Quantity Surveyor	Project Controller	√	√		√	√	√
Criteria	C1- Holding a B.Sc. degree related to construction industry or any other related industry C2- Having at least 2 years' experience in business operations or construction industry C3- Working in a particular company for at least 8 months C4- Holding knowledge in offsite construction C5- Having in knowledge and interest in the sustainability concept							

FINDINGS OF THE SURVEY

As per the survey, one hundred ten (110) different offsite applications were identified in Sri Lankan context. The identified sources include offsite industry practitioners (20). The details of those offsite applications are summarised in Table 3.

Table 3: Summary of Offsite Applications in Sri Lanka

Building Type	**No**	**Non-Volumetric Components**		**Non-Volumetric Pre-assembly Buildings**		**Volumetric Pre-assembly Buildings**	**Flat Pack Buildings**	**Modular Buildings**	
		Strctrl	Non Strctrl	Lbwp	Dsawp	Wbr	Wbr	Wbr	Wbnr
Residential	45	-	25	2	-	8	5	3	2
Office	64	8	36	-	-	12	3	4	1
Commercial	94	10	40	-	4	36	2	2	-
Educational	41	7	30	1	-	2	1	-	-
Hospital	28	8	15	-	-	5	-	-	-
Religious	17	-	15	-	-	-	2	-	-
Administrative	44	9	34	1	-	-	-	-	-
Industrial	41	20	15	1	-	3	2	-	-
Total	374	62	210	5	4	66	15	9	3
Note: Dsawp- Decorative and sound absorption panels; Lbwp- Load bearing wall panels; Non-Strctrl- Non Structural; Strctrl- Structural; Wbr- Whole building relocatable; Wbnr- Whole building non relocatable									

As observed in Table 3, the OSC components comprised buildings are the widely applicable OSC type with two hundred seventy-two (272) applications. In particular, the highest frequency can be justified as, in general, almost all building components are sub assembled prior at factory conditions before the installation on site. As identified in literature review, components/sub-assemblies can be identified as aluminium doors, windows, fixtures and fittings etc. The next highest OSC building type is the volumetric pre-assembly buildings with sixty-six (66) applications in Sri Lanka. The third most applied type is the flat pack buildings (15) while the least applied type is the non-volumetric pre-assembly building. Even though there is a higher usage of volumetric pre-assembly buildings, most of respondents stated that they are based on 'steel cargo containers'.

The survey respondents further stated that the volumetric prefabrication can differ based on its mobility. Amongst, the whole building relocatable type of OSC is the most common than the other types of orientations in Sri Lanka with ninety (90) applications. In terms of volumetric pre-assembly building, approximately sixty-six (66) applications of whole building relocatable types are available in Sri Lanka which is higher than the volumetric type- modular buildings. The reason laying behind this was asserted by the respondents that since volumetric pre-assembly buildings can be erected easily since the pre-assembly itself is the building which is in smaller scale. However, in volumetric type- modular buildings, there should be several modules which constitute the whole building. In flat pack buildings also, there are only 15 number of whole building relocatable types in local context. However, considering non volumetric pre-assembly buildings, there can be seen higher application of load bearing structures which is followed by decorative and acoustic absorption structures which was identified by respondents. It was argued by the respondents that the lesser number of usages of non-volumetric pre-assembly types is due to 'lack of technology' prevailed in Sri Lanka. This can be interpreted that it is essential to ensure stability of the panel system. Also, it was further revealed that one of leading non-volumetric pre-assembly supplier utilises the overseas' technology to construct them.

When considering modular building as a type of OSC, there is a less number (12) of applications. However, the figure is slightly higher than non-volumetric pre-assembly types. The reason is due to a whole building can be constructed in less time with usage of 2-10 container boxes and it is comparatively easy to install them on a site. However, there is a smaller number (3) of non-relocatable modular buildings in Sri Lanka compared to its relocatable types. According to the interview respondents, due to the higher complexity

involved in modular PPVC non relocatable types, the application is still at the lower rates in Sri Lanka. Therefore, it was evident that there is a lack of awareness and lack of applications of modular non relocatable type construction in Sri Lanka.

In terms of building types, commercial buildings are having more exposure to offsite application in local context among others where those are constructed using volumetric pre-assembly building units in Sri Lanka. Most of them are relocatable types where they are used mostly used for hotels, showrooms, restaurants and cafes according to the interview respondents. They further were in the opinion that aesthetic appearance specially incorporating cargo containers is the newest trend of hospitality and restaurant culture. Interestingly, religious places and educational buildings are now incorporating OSC in local context.

However, the informal discussions among the respondents indicated that there is still lack of consideration and awareness of environmental sustainability of offsite applications in terms of modular building types. Due to the low adaptability rate of modular construction, the stakeholders have only concerned on economical sustainability because cost aspects are needed at initial phases of modular construction. Nevertheless, the survey further showed that there is a still gap in due consideration on environmental feasibility on modular construction despite its lower usage rate. However, the survey further indicated that the other types of OSC apart from modular construction are wide because of awareness of less impact on environment from those types such as less pollution from using steel container conversions.

CONCLUSIONS

The research sought to establish typologies of OSC that reflect the present integration of modern technologies in the construction sector in Sri Lanka, hence diminishing reliance on traditional onsite capabilities. It was revealed that three hundred seventy-four (374) building applications were identified with respect to OSC in Sri Lanka. Among them, this survey found that non-volumetric components buildings are the most common OSC building types in Sri Lanka because almost every building consists of components which are manufactured offsite. Furthermore, volumetric pre-assembly relocatable buildings are the next common sub type of OSC identified under volumetric type. Therefore, it depicted that due to the less time and cost taken for installation of container conversion boxes, they are widely adapted to offsite market. Furthermore, it was observed that non volumetric preassembly buildings are having a smaller number of applications because there are less buildings which have higher coverage of 2D preassembly components of structures. Hence, it is evident that proper analysis of classification of OSC should be conducted in order to investigate the status of OSC in Sri Lanka.

Furthermore, modular construction in particular, is still in its infancy in Sri Lanka, according to the preliminary survey. A lack of knowledge, hefty beginning costs, and regulatory restrictions are some of the challenges that the sector must contend with. On that note, it was observed that modular non relocatable buildings are least adapted where modular PPVC construction is nowhere to be seen. Nevertheless, OSC is gaining popularity despite the difficulties that it presents because of the potential benefits it offers in terms of time and money savings in local context.

The findings of this study further indicate that OSC has progressed throughout the years from the original categories to further progressions such as components with structural and non-structural constituents, noise and sound absorption panelised structure etc. The study emphasises the utilisation of sophisticated technology by industry professionals to achieve the definitive objectives of offsite produced structures. Consequently, the present findings contribute to an expanding corpus of literature on typologies of OSC in Sri Lanka, which is a crucial element of industrialisation in developing countries.

However, there are limitations of the usage of primary sources of literature and omittance of new developments in OSC field. Hence, it is further recommended that this study should be considered as a foundational study for assessing the status of OSC in Sri Lanka with collaboration of industry professionals in a way that the new studies would incorporate latest development in OSC field and wide coverage of OSC building applications in Sri Lanka.

REFERENCES

Alhusban, A.A., Alhusban, S.A., Alhusban, M.A., 2022. How the COVID 19 pandemic would change the future of architectural design. Journal of Engineering, Design and Technology 20, 339–357.

Almashaqbeh, M., El-Rayes, K., 2021. Optimizing the modularization of floor plans in modular construction projects. Journal of Building Engineering 39, 102316.

Andrade, C., 2021. The Inconvenient Truth About Convenience and Purposive Samples. Indian J Psychol Med 43, 86–88.

Arif, M., Bendi, D., Sawhney, A., Iyer, K.C., 2012. State of offsite construction in India-Drivers and barriers. In: Journal of Physics: Conference Series. Institute of Physics Publishing.

Assaad, R., El-adaway, I.H., Hastak, M., LaScola Needy, K., 2023. Opportunities and Challenges of Offsite Construction. In: Lecture Notes in Civil Engineering. Springer Science and Business Media Deutschland GmbH, pp. 555–568.

Bao, Z., Laovisutthichai, V., Tan, T., Wang, Q., Lu, W., 2022. Design for manufacture and assembly (DfMA) enablers for offsite interior design and construction. Building Research & Information 50, 325–338.

Battista, A., Torre, D., 2023. Mixed methods research designs. Med Teach 45, 585–587.

Boyd, N., Khalfan, M.M.A., Maqsood, T., 2013. Off-Site Construction of Apartment Buildings. Journal of Architectural Engineering 19, 51–57.

Broadhead, J.P., Daniel, E.I., 2023. Exploring Offsite Construction for the Construction Sector: A Literature Review.

Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., Walker, K., 2020. Purposive sampling: complex or simple? Research case examples. Journal of Research in Nursing 25, 652–661.

Dallasega, P., Rauch, E., Linder, C., 2018. Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review. Comput Ind 99, 205–225.

Darwish, M., Mohsen, O., Mohamed, Y., Al-Hussein, M., 2020. Integrated Simulation and Lean Approach for Production Line Improvement in a Prefabricated Panelized Homebuilding Facility. pp. 661–672.

Garusinghe, G.D.A.U., Perera, B.A.K.S., Weerapperuma, U.S., 2023. Integrating Circular Economy Principles in Modular Construction to Enhance Sustainability. Sustainability 15, 11730.

Gibb, A.G.F., 2001. Standardization and pre-assembly- distinguishing myth from reality using case study research. Construction Management and Economics 19, 307–315.

Ginigaddara, B., Perera, S., Feng, Y., Rahnamayiezekavat, P., 2019. Typologies of offsite construction. In: World Construction Symposium. Ceylon Institute of Builders, pp. 567–577.

Ginigaddara, B., Perera, S., Feng, Y., Rahnamayiezekavat, P., 2022. Development of an offsite construction typology: A delphi study. Buildings 12.

Goulding, J.S., Pour Rahimian, F., Arif, M., Sharp, M.D., 2015. New offsite production and business models in construction: priorities for the future research agenda. Architectural Engineering and Design Management 11, 163–184.

Gusmao Brissi, S., Debs, L., Elwakil, E., 2021. A Review on the Factors Affecting the Use of Offsite Construction in Multifamily Housing in the United States. Buildings 11.

Hairstans, R., Smith, R.E., 2018. Offsite HUB (Scotland): establishing a collaborative regional framework for knowledge exchange in the UK. Architectural Engineering and Design Management 14, 60–77.

Hosseini, M.R., Martek, I., Zavadskas, E.K., Aibinu, A.A., Arashpour, M., Chileshe, N., 2018. Critical evaluation of off-site construction research: A Scientometric analysis. Autom Constr.

Hu, X., Chong, H.Y., 2021. Environmental sustainability of off-site manufacturing: a literature review. Engineering, Construction and Architectural Management.

Jaillon, L., Poon, C.S., 2009. The evolution of prefabricated residential building systems in Hong Kong: A review of the public and the private sector. Autom Constr 18, 239–248.

Jang, H., Ahn, Y., Roh, S., 2022. Comparison of the Embodied Carbon Emissions and Direct Construction Costs for Modular and Conventional Residential Buildings in South Korea. Buildings 12.

Jayawardana, J., Jayasinghe, J.A.S.C., Sandanayake, M., Kulatunga, A.K., Zhang, G., 2023. Prefabricated Construction in Sri Lanka: A Proposed Adoption Strategy and a Pilot Case Study from Sustainability Perspective. Engineer: Journal of the Institution of Engineers, Sri Lanka 56, 71–80.

Jayawardana, J., Kulatunga, A.K., Jayasinghe, J.A.S.C., Sandanayake, M., Zhang, G., 2023. Environmental Sustainability of Off-Site Construction in Developed and Developing Regions: A Systematic Review. Journal of Architectural Engineering 29.

Jin, R., Hong, J., Zuo, J., 2020. Environmental performance of off-site constructed facilities: A critical review. Energy Build.

Kamali, M., Hewage, K., 2016. Life cycle performance of modular buildings: A critical review. Renewable and Sustainable Energy Reviews.

Kamali, M., Hewage, K., 2017. Development of performance criteria for sustainability evaluation of modular versus conventional construction methods. J Clean Prod 142, 3592–3606.

Kleinheksel, A.J., Rockich-Winston, N., Tawfik, H., Wyatt, T.R., 2020. Demystifying Content Analysis. Am J Pharm Educ 84, 7113.

Lawson, M., Ogden, R., Goodier, C., 2014. Design in Modular Construction. CRC Press.

Lu, N., 2009. Investigation of the designers' and general contractors' perceptions of off site construction techniques in the United States construction industry: Building a sustainable future. In: 2009 Construction Research Congress.

Mao, C., Shen, Q., Pan, W., Ye, K., 2015. Major Barriers to Off-Site Construction: The Developer's Perspective in China. Journal of Management in Engineering 31.

Mapston, M., Westbrook, C., 2010. Prefabricated building units and modern methods of construction (MMC). In: Materials for Energy Efficiency and Thermal Comfort in Buildings. Elsevier, pp. 427–454.

Munmulla, T., Hidallana-Gamage, H.D., Navaratnam, S., Ponnampalam, T., Zhang, G., Jayasinghe, T., 2023. Suitability of Modular Technology for House Construction in Sri Lanka: A Survey and a Case Study. Buildings 13, 2592.

Navaratnam, S., Ngo, T., Gunawardena, T., Henderson, D., 2019. Performance Review of Prefabricated Building Systems and Future Research in Australia. Buildings 9, 38.

Nazir, F.A., Edwards, D.J., Shelbourn, M., Martek, I., Thwala, W.D.D., El-Gohary, H., 2021. Comparison of modular and traditional UK housing construction: a bibliometric analysis. Journal of Engineering, Design and Technology 19, 164–186.

Nguyen, Q.C., Perera, S., Xiaohua, J., 2018. THE STATUS OF OFFSITE CONSTRUCTION IN VIETNAM. In: 42nd AUBEA Conference 2018: Educating Building Professionals for the Future in the Globalised World.

Pan, W., Alistair, ;, Gibb, G.F., Dainty, A.R.J., Asce, M., 2012. Strategies for Integrating the Use of Off-Site Production Technologies in House Building.

Pan, W., Sidwell, R., 2011. Demystifying the cost barriers to offsite construction in the UK. Construction Management and Economics 29, 1081–1099.

Pervez, H., Ali, Y., Petrillo, A., 2021. A quantitative assessment of greenhouse gas (GHG) emissions from conventional and modular construction: A case of developing country. J Clean Prod 294.

Quale, J., Smith, R., 2019. Offsite Architecture: Constructing the Future.

Sadabad, M.M., 2023. Offsite Construction in the UK: Economic and Environmental Benefits. pp. 343–349.

Sánchez-Garrido, A.J., Navarro, I.J., García, J., Yepes, V., 2023. A systematic literature review on modern methods of construction in building: An integrated approach using machine learning. Journal of Building Engineering 73, 106725.

Sandamini, K.Y., Waidyasekara, K.G.A.S., 2022. Container-based relocatable modular buildings for construction site offices in Sri Lanka: Contractors' perspective. In: Proceedings of 10th World Construction Symposium 2022. Building Economics and Management Research Unit (BEMRU), University of Moratuwa, pp. 236–248.

Smith, R.E., 2014. An Authoritative Source of Innovative Solutions for the Built Environment Off-Site and Modular Construction Explained.

Smith, R.E., Quale, J.D., 2017. Offsite architecture: Constructing the future. Taylor & Francis.

Sokhangoo, L.R., Nik-Bakht, M., Han, S., n.d. Optimal Space Layout Generation for Modular Off-site Construction for Whole Life Cycle Costs-Gaps and Requirements.

Sutrisna, M., Cooper-Cooke, B., Goulding, J., Ezcan, V., 2019. Investigating the cost of offsite construction housing in Western Australia. International Journal of Housing Markets and Analysis 12, 5–24.

Tapia, D., González, M., Vera, S., Aguilar, C., 2023. A Novel Offsite Construction Method for Social Housing in Emerging Economies for Low Cost and Reduced Environmental Impact. Sustainability (Switzerland) 15.

Uthpala, H.M.M., Ramachandra, T., 2015. STUDY ON MODERN METHODS OF CONSTRUCTIONS USED IN SRI LANKA.

Wuni, I.Y., Shen, G.Q.P., 2019. Holistic review and conceptual framework for the drivers of offsite construction: A total interpretive structural modelling approach. Buildings.

Xu, Z., Zayed, T., Niu, Y., 2020. Comparative analysis of modular construction practices in mainland China, Hong Kong and Singapore. J Clean Prod 245, 118861.

Yu, L., Wang, Y., Li, D., 2023. Calculating and Analyzing Carbon Emission Factors of Prefabricated Components. Sustainability 15, 8706.

Zhang, A., Zheng, L., Mei, Y., Zhang, J., Chen, S., Wang, X., Ma, H., Yu, R., 2024. Simulation Analysis of the Structure of an Integrated Modular House by Flat Pack Based on the Elastic–Plastic Contact Theory and Experimental Study of Its Corner Fitting Joint. Buildings 14, 635.

A REVIEW OF INDUSTRY 4.0 VS INDUSTRY 5.0: CONSIDERATION OF SUSTAINABILITY ENHANCEMENT IN CONSTRUCTION

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A REVIEW OF INDUSTRY 4.0 VS INDUSTRY 5.0: CONSIDERATION OF SUSTAINABILITY ENHANCEMENT IN CONSTRUCTION

ABSTRACT

The rapid advancement of digital technologies brought by Industry 4.0 alone cannot meet the requirements of achieving sustainability. Thus, Industry 5.0 emerged to ensure that technological advancements are compatible with human well-being and sustainability. Although studies have explored the sustainability aspects of Industry 4.0 and 5.0 separately, there is a lack of research comparing their contributions to sustainability, particularly in construction. This study addresses that gap through a comprehensive literature review and manual content analysis. Findings highlight that while Industry 4.0 emphasises environmental and economic aspects, Industry 5.0 adopts a more holistic approach, prioritising social sustainability through human-machine collaboration. This study highlights the need for future industrial revolutions to further enhance sustainability in construction, offering a balanced, integrated model.

Keywords: *Industry 5.0; Industry 4.0; Sustainability; Construction Industry*.

INTRODUCTION

As the digital revolution pushes every aspect of life forward at an ever-increasing pace, the era of change is measured not in years, but in days or hours (Kozlovska *et al*., 2021). Concurrently, the concept of Industry 4.0 originated in Germany in 2011 (Bahrin *et al*., 2016). Primarily it was viewed as a technology-driven revolution to increase productivity and efficiency (Xu *et al*., 2021). Also, it is contended as a contemporary movement that represents the idea of integrating people, things, and information in cyber-physical settings to create intelligent environments in factories (Marinelli, 2023). Moreover, the author declares Industry 4.0 as a technology-based concept woven around Cyber-Physical Systems (CPS), Artificial Intelligence (AI), the Internet of Things (IoT), Big Data, cloud computing, and robots. However, Longo *et al.* (2020) revealed that Industry 4.0 lacks and requires revision in several aspects, notably the human factor, sustainability, and responsibility, thereby emphasising the necessity for future revolutions.

The European Commission (EC) (2021) formally called for the Fifth Industrial Revolution called Industry 5.0 in 2021 (Xu *et al*., 2021). Industry 5.0 is a value-driven initiative that accelerates technological transformation for a specific goal, in contrast to the technology-driven revolution in Industry 4.0 (Mahiri *et al*., 2023). Unlike Industry 4.0, this is expected to increase customer satisfaction along with production efficiency (Nahavandi, 2019). Besides, Industry 5.0 with the collaborative work paradigm of human-robot collaboration (HRC) at its center, aspires to reintroduce the human aspect into the production system (Jamil *et al*., 2024; Marinelli, 2023). In fact, Industry 5.0 fundamentally differs from Industry 4.0 with the use of 'cobots' where robots are expected to work in collaboration with human operators (Nahavandi, 2019). Further, Mahiri *et al*. (2023) observed that Industry 5.0 has evolved into a balanced technological combination of AI and Machine Learning (ML), taking into account the human dimension. This means using data and AI to make production more flexible by using technology that adapts to workers, not the other way around, and leveraging technology for sustainability and circularity (Breque *et al*., 2021).

While assessing the relevance of sustainability in Industry 4.0, Satyro *et al*. (2022) highlighted that production line quality improvement and an increase in global competitiveness as key benefits. Some authors argue that the technologies in Industry 4.0 positively and significantly affect sustainability performance (Ghobakhloo *et al*., 2021). However, according to Breque *et al*. (2021), the original principles of sustainability and social fairness are under-focused in Industry 4.0. Moreover, it has created the problem of unemployment and potential social impacts (Satyro *et al*., 2022). Hence the authors emphasise the necessity to prioritise those aspects and avoid focusing solely on technology. In contrast, the next paradigm Industry 5.0 can be identified as an indication of addressing infrastructural resilience, environmental, and employee concerns in industrial settings, focusing on human-centric technology development and environmental goals (Turner *et al*., 2022). Indeed, human-centricity, sustainability, and resilience are

interpreted as the three core elements of Industry 5.0 (Breque *et al*., 2021; Ivanov, 2023). This is also supported by Xu *et al*. (2021) as three interrelated core values of Industry 5.0.

While both Industry 4.0 and Industry 5.0 have contributed to advancing sustainability in the construction sector (Franco *et al*., 2022; Yitmen *et al*., 2023), it is essential to compare their sustainability contributions to uncover opportunities for further improvements through future industrial revolutions. This comparison is particularly important to assess whether the current trajectory is appropriate. Moreover, the construction sector continues to face significant sustainability challenges, such as resource depletion and waste generation (Wang & Guo, 2022), underscoring the need for a deeper understanding of how these industrial revolutions differ in their sustainability impacts. Such a comparison is essential to guide the industry toward more effective and sustainable practices and to identify the key sustainability issues that need to be addressed in future industrial revolutions. Considering the theoretical need, previous studies have linked Industry 4.0 with sustainability (Balasubramanian *et al*., 2021; Satyro *et al*., 2022), and Industry 5.0 with sustainability (Breque *et al*., 2021; Ivanov, 2023). However, there are limited studies comparing the sustainability contributions of Industry 4.0 and Industry 5.0 side by side. Therefore, considering this practical need and theoretical gap, this study aims to investigate the contribution of Industry 4.0 Vs Industry 5.0 towards sustainability enhancement in construction. Its objectives are to identify the key elements of Industry 4.0 and its contribution towards the enhancement of construction sustainability, to identify the key elements of Industry 5.0 and its contribution towards the enhancement of construction sustainability, to compare Industry 4.0 and Industry 5.0 towards the enhancement of construction sustainability and to identify future directions.

LITERATURE REVIEW

CONCEPT OF INDUSTRY 4.0

The goal of Industry 4.0 was declared as increasing productivity and achieving mass production using innovative technology (Demir *et al*., 2019). Smart manufacturing is the primary concept in Industry 4.0, which aims to enhance productivity through the integration of advanced technologies (Poláková *et al*., 2023). Compared to the manufacturing industry, the construction industry faces many challenges in increasing productivity due to its complex nature, high level of uncertainties, and unique, time-bound projects (Wang & Guo, 2022). Currently, the construction industry is going through a smart transformation encouraged by contemporary technologies of Industry 4.0 (Kozlovska *et al*., 2021). For example, Building Information Modelling (BIM) is considered as the central technology for digitizing the construction manufacturing environment (Heijden, 2023). More to the point, the term Construction 4.0 emerged to reflect the interest in using AI and ML in the construction industry (Kozlovska *et al*., 2021). From a narrow point of view, Construction 4.0 is defined as a technological advancement that improves the time, cost, and quality aspects of construction projects (Franco *et al*., 2022). It comprises technologies such as Virtual Reality (VR), Augmented Reality (AR), IoT, BIM, prefabrication, and off-site construction (Heijden, 2023). The broad perspective of Construction 4.0 addresses economic, environmental, and social aspects (Wang & Guo, 2022). It admits that the automation process in the construction industry must be associated with legal, cultural, and organisational changes to achieve its full potential (Sherratt *et al*., 2020). Further, it explores how technological advancements affect the built environment, emphasising how crucial it is to maintain resilience and sustainability over the long run (Schönbeck *et al*., 2021). In fact, it argues that technological development alone cannot meet the requirements of achieving sustainability in the construction sector (Franco *et al*., 2022).

CONCEPT OF INDUSTRY 5.0

In 2020, EC initially discussed the concept of Industry 5.0 as a revolution that should be based on promoting socially and environmentally relevant values instead of the four industrial revolutions built around general-purpose technologies (Leng *et al*., 2022). However, the concept of Industry 5.0 was formally declared in 2021 (Xu *et al*., 2021). Breque *et al*. (2021) define Industry 5.0 as a concept where production respects the planetary boundaries and places industry workers' well-being at the center of the production process. Industry 5.0 is deeply inspired by the Society 5.0 concept and shares a common ground of focusing on

technology integration, a human-centric approach, cross-sector collaboration, and a shared vision of leveraging technology for a better future (Ghobakhloo *et al*., 2023). Leng *et al*. (2022), state that Industry 5.0 aims to address the mismatch between manufacturing and social needs, by focusing on human-centricity, and sustainability, compared to past industrial revolutions that prioritised economic aspects of sustainability. Industry 5.0 focuses on technology and human collaboration to share strengths and corresponding weaknesses, rather than replacing people with technology (Nahavandi, 2019). By focusing on human-centric, sustainable, and resilient concepts, Industry 5.0 is headed to bring significant improvements to the construction industry (Ikudayisi *et al*., 2023). Considering the impact the construction industry has on the economy, environment, and society, it is now in a position to embrace the broader concept of Industry 5.0 (Heijden, 2023). However, the concept of "Construction 5.0" has not yet been widely accepted by researchers as the future revolution of the construction industry (Yitmen *et al*., 2023). Further, the authors justify it by the lack of research to ensure efficient and safe interactions between humans and robots in construction environments and the use of interactive robots in construction which is currently at the experimental level. The construction 5.0 paradigm should focus on human-centric applications, be consistent with the needs of the construction industry, and align with Industry 5.0 principles (Marinelli, 2023). It can be ensured that technological advances in construction are consistent with human well-being and sustainability goals, by prioritising human interests and needs as the basis of the construction process (Yitmen *et al*., 2023). Nevertheless, it should be noted that the lack of necessary technical skills, lack of data for effective decision-making for stakeholders, and security issues for human-machine collaboration (HMC) have been identified as significant challenges associated with the adoption of Industry 5.0 in the construction industry (Ikudayisi *et al*., 2023).

SOCIAL SUSTAINABILITY

Since the economic crisis in 2008, the world has seen a partly negative shift in social progress, indicating that current economic models and practices do not guarantee long-term societal and human well-being (Missimer & Mesquita, 2022). While there are different interpretations of social sustainability, according to Eizenberg and Jabareen (2017), social sustainability refers to confronting risk while addressing social concerns, using four interrelated concepts: equity, safety, eco-prosumption, and urban forms. Moreover, some studies propose human well-being, equity, democratic government, and democratic civil society, as four universal principles covering social sustainability (Boström, 2012): Considering the relationship between Industry 4.0 and social sustainability, it is argued that Industry 4.0 technologies enhance employee health, safety, and satisfaction by automating repetitive tasks but also pose challenges such as reduced employment, electronic waste, information security risks, and potential quality issues (Bai *et al*., 2020). In contrast, Industry 5.0 highlights human-centered, resilient, and sustainable design, emphasising sustainability and human well-being as a subset of Society 5.0 (Mourtzis *et al*., 2022).

RESEARCH METHOD

A well-conducted literature review strengthens knowledge advancement and theory development by integrating insights from multiple empirical studies (Snyder, 2019). Standalone literature reviews provide researchers with the opportunity to critically engage with existing studies, facilitating the identification of gaps in the literature and highlighting potential directions for future research (Kraus *et al*., 2022). Further, a narrative literature review, on its part, refers to a comprehensive narrative synthesis of previously published information (Juntunen & Lehenkari, 2021). Accordingly, this study is a narrative literature review, which was conducted by reviewing the existing literature on the contribution of Industry 4.0 and Industry 5.0 towards the enhancement of the sustainability approach in the construction industry. The existing studies were searched in three databases: (i) Google Scholar, (ii) Web of Science, and (iii) Scopus by filtering through the key terms of “Industry 4.0”, or “Industry 5.0” and “construction sustainability”. When selecting the articles, only the journal articles and conference papers published within the past ten years were considered. Figure 1 presents the process adopted in conducting the literature review.

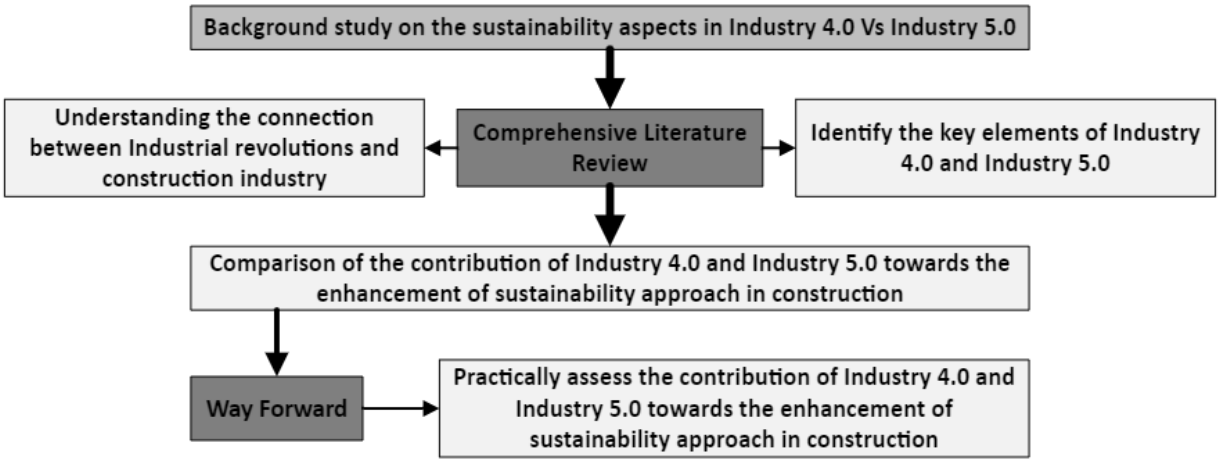

Figure 1: Research Process

As illustrated in Figure 1, a background study was conducted, followed by a comprehensive literature review on the concepts of Industry 4, Industry 5.0 and their key elements with their contribution towards sustainability. Subsequently, a comparison was carried out considering the sustainability contributions of Industry 4.0 and Industry 5.0 to the construction industry. Data analysis was conducted using manual content analysis, which is chosen for its sensitivity to content and ability to analyse diverse open datasets, ensuring accurate conclusions are drawn from the text (Kyngäs *et al.,* 2020). It is a widely used method for interpreting textual data, particularly when statistical analysis is not feasible (Bengtsson, 2016). Hence content analysis with manual coding was employed by further categorising the data under themes and sub-themes to analyse the literature findings.

FINDINGS

This section encompasses a critical review of the literature about the key elements of Industry 4.0 and Industry 5.0, and their contribution towards construction sustainability. Moreover, it compares the contribution of Industry 4.0 and Industry 5.0 towards the enhancement of sustainability in the construction industry, while predicting potential future directions for sustainability advancements.

KEY ELEMENTS OF INDUSTRY 4.0 AND THEIR CONTRIBUTIONS TOWARDS SUSTAINABILITY

Industry 4.0 is mainly associated with automation and information technologies such as physical-digital interface technologies that include AR, VR, and IoT, and digital-physical process technologies that transfer digital information into physical execution such as 3D printing and robotics (Schönbeck *et al*., 2021) Moreover, it supports network technologies including Cloud Computing that allow for the storage of large amounts of data that can be shared by enabling data-driven production (Zizic *et al*., 2022). Given that these technologies form the foundation of Industry 4.0, they can be regarded as key elements of Industry 4.0 (Zizic *et al*., 2022). Table 1 provides a summary of key elements in Industry 4.0, identified by different authors.

Table 1: Key Elements (Technologies) of Industry 4.0 and their Contributions to Construction Sustainability

Industry 4.0 Elements (Technologies)	Authors (in code)	Contributions towards Sustainability
IoT	[A], [B], [C], [D], [E], [F], [G], [I]	• Promoting clean energy and material resources • Reducing waste through value-creating activities • Reducing the operational costs of different production processes
Big Data Analytics	[A], [B], [C], [D], [E], [G], [H], [I]	
Cloud Computing	[A], [B], [C], [D], [E], [F], [G], [H], [I]	
Automation using Robotics	[A], [B], [C], [D], [E], [G], [I]	
3D Printing (Additive Manufacturing)	[A], [B], [C], [D], [G]	

Industry 4.0 Elements (Technologies)	Authors (in code)	Contributions towards Sustainability
VR and AR	[A], [B], [D], [F], [G], [I]	• Improving customer experience • Enhancing employee working conditions
CPS	[A], [F], [H]	
AI	[A], [D], [F], [G], [H]	
Blockchain	[A], [D], [H], [I]	
BIM	[A], [D], [G]	
Machine Learning	[A], [D]	
A:(Balasubramanian *et al*., 2021), B:(Bahrin *et al*., 2016), C:(Groumpos, 2021), D:(Heijden, 2023), E:(Lu, 2017), F:(Zizic *et al*., 2022), G:(Schönbeck *et al*., 2021), H:(Atif, 2023), I:(Marinelli, 2023)		

Jamil *et al*. (2024) argue that Industry 4.0, must nonetheless prioritise the technologies that improve global sustainability. According to Sartal *et al*. (2020), Industry 4.0 technologies contribute to addressing the economic, environmental, and social dimensions of sustainable manufacturing at the value chain and factory levels. For example, from the environmental dimension of sustainable production, Industry 4.0 contributes by promoting clean energy and material resources and reducing waste through value-creating activities (Franco *et al*., 2022). From economic dimensions, the underlying digital technologies of Industry 4.0, such as the Industrial IoT, and CPS, contribute by reducing the operational costs of different production processes (Xu *et al*., 2021). In the social dimension, it contributes by improving customer experience, employee working conditions, and creating new job opportunities (Sartal *et al*., 2020). Moreover, new technologies permit organisations to minimise labour shortages, reduce manual work, and allocate human resources to higher value-adding capacities (Sherratt *et al*., 2020). Nevertheless, the application of new technologies impacts people at work and in everyday life, requiring, openness to learning, and flexibility to adapt new working conditions (Sartal *et al*., 2020). Hence, effective management of the role of human resources is declared as one of the basic challenges encountered within the context of digitalization in Industry 4.0, which influenced the dawn of the fifth industrial revolution (Nahavandi, 2019).

KEY ELEMENTS OF INDUSTRY 5.0 AND THEIR CONTRIBUTIONS TOWARDS SUSTAINABILITY

European Commission declares human-centricity, sustainability, and resilience, as three key elements of Industry 5.0 (Breque *et al*., 2021). While most researchers describe these as "key elements" (Atif, 2023; Poláková *et al*., 2023), some refer to them as core values (Xu *et al*., 2021), key drivers (Zizic *et al*., 2022), major pillars (Ivanov, 2023), and core principles (Ghobakhloo *et al*., 2021). In agreement with the majority, this study identifies them as the 'key elements of Industry 5.0'. Table 2 illustrates the summary of literature findings on the 3 key elements of Industry 5.0. Firstly, focusing on the human-centricity element, human involvement has always been crucial in industrial revolutions (Papetti *et al*., 2020). Unlike Industry 4.0's focus on automation, Industry 5.0 prioritises human needs and interests, viewing workers as investments rather than costs (Mahiri *et al*., 2023; Xu *et al*., 2021). HMC in Industry 5.0 integrates human creativity with automated systems, enhancing efficiency (Poláková *et al*., 2023). Mourtzis *et al.* (2023) term this integration "humachine," combining human and machine attributes while maintaining their uniqueness.

Table 2: Key Elements of Industry 5.0 and their Contributions to Construction Sustainability

Key Elements	Authors (in code)	Contributions towards Sustainability
Human-centricity	**[A], [B], [C], [D], [E], [F], [G], [H], [I], [J], [K], [L]**	• Resource efficiency • Utilisation of renewable and non-polluting resources • Reduction of greenhouse gas emissions • Fostering an adaptable, environmentally
Better adaptation of technology to human needs	[A], [B], [C], [E], [F], [G], [H], [I], [J], [L]	
Empower workers using digitalization	[A], [B], [C], [D], [E], [F], [G], [H], [I], [J], [L]	
Human-machine symbiosis	[C], [D], [E], [G], [H], [I], [J]	
Main domains of ergonomics (physical, cognitive and organisational)	[A], [C], [D], [I], [L]	

Key Elements	Authors (in code)	Contributions towards Sustainability
Sustainability	**[A], [B], [C], [D], [E], [F], [G], [H], [I], [J], [K], [L]**	conscious industrial landscape • Minimising energy consumption • Prevent natural resource depletion and degradation
Efficient usage of energy	[C], [E], [F], [G], [I], [J], [L]	
Sustainable supply chain networks	[A], [E], [I], [J]	
Develop circular processes for better resource efficiency	[B], [F], [J], [L]	
Ethical use of technology	[C], [G]	
Increased productivity, speed, quality, and savings using environmentally responsible methods	[D], [H], [I]	
Resilience	**[A], [B], [C], [D], [E], [F], [G], [H], [I], [J], [K], [L]**	
Implementation of risk plans and prevention techniques	[A], [C], [D], [E], [F], [I], [J], [L]	
Supply chain resilience	[C], [D], [E], [G], [I], [J]	
Resilience in the context of technology	[C], [D], [E], [J]	
Resilience planning	[B], [G], [H], [J]	
Information integration across industrial segments	[B], [C]	
A:(Atif, 2023), B:(Xu *et al*., 2021), C:(Zizic *et al*., 2022), D:(Yitmen *et al*., 2023), E:(Ivanov, 2023), F:(Breque *et al*., 2021), G:(Barata & Kayser, 2023), H:(Poláková *et al*., 2023), I:(Leng *et al*., 2022), J:(Ikudayisi *et al*., 2023), K:(Ghobakhloo *et al*., 2021), L:(Mahiri *et al*., 2023)		

As per Table 2, it is confirmed that the elements of Industry 5.0, human-centricity, sustainability, and resilience are well-established among the research and academic community. Unlike Industry 4.0's focus on automation, Industry 5.0 prioritises human needs and interests, viewing workers as investments rather than costs (Mahiri *et al*., 2023; Xu *et al*., 2021). HMC in Industry 5.0 integrates human creativity with automated systems, enhancing efficiency (Poláková *et al*., 2023). While embracing a human-centric approach, Industry 5.0 demands a more comprehensive approach emphasising resource efficiency, renewable and non-polluting resource utilisation, and greenhouse gas emission reduction (Ikudayisi *et al*., 2023). It focuses on developing robust industrial production to withstand disruptions and support critical infrastructure during crises under the resilience element (Breque *et al*., 2021). It highlights human dependence and the ability to manage disruptions, which was underemphasised in Industry 4.0 (Zizic *et al*., 2022). Unexpected events like the Covid-19 outbreak demonstrate vulnerabilities in global production require adaptable production capacity, resilient strategic value chains, and flexible business processes (Breque *et al*., 2021). Aligning producers' capabilities with market orientation promotes resilience making it a core element of Industry 5.0 due to the systematic risks of highly integrated systems (Xu *et al*., 2021).

Industry 5.0 utilises activities to reduce and prevent waste throughout the supply chain network by encouraging manufacturers to balance economic, social, and environmental aspects to thrive in competitive markets (Atif, 2023). Despite the fact that studies on sustainability have gained attention in the last two decades, the concept of Industry 5.0 demands a more comprehensive approach where sustainability focuses on resource efficiency, the utilisation of renewable and non-polluting resources, and the reduction of greenhouse gas emissions (Ikudayisi *et al*., 2023). Moreover, Breque *et al*. (2021) claim that sustainability refers to minimising energy consumption and greenhouse gas emissions to prevent natural resource depletion and degradation and to fulfil the needs of current generations without compromising the needs of future generations. Industry 5.0 ensures industrial system stability, natural resource preservation, social well-being, and environmental balance, fostering an adaptable, environmentally conscious industrial landscape (Yitmen *et al*., 2023). Undoubtedly, this revolution significantly contributes to construction sustainability by integrating people, processes, technology, and information, focusing on sustainability, resilience, and human-centric values (Ikudayisi *et al*., 2023).

COMPARISON TOWARDS THE ENHANCEMENT OF SUSTAINABILITY APPROACH IN INDUSTRY 4.0 VS INDUSTRY 5.0

Implementing Industry 4.0 would aid in the creation of a truly sustainable supply chain, with environmental benefits such as reduced waste and energy consumption, economic benefits such as cost-effectiveness and resource utilisation, and social benefits such as improved employee learning and human-machine interaction (Marinelli, 2023). The new technologies: IoT and CPS, will have an impact on products, economy, the work environment, and organisational skills, resulting in a profound shift in supply chains (Jamil *et al*., 2024). According to Balasubramanian *et al*. (2021), although Industry 4.0 technologies, including BIM, CPS, 3D printing, and BC, have shown a positive impact on economic and environmental sustainability, it is still lacking in terms of social sustainability. However, as Ghobakhloo *et al*. (2021) report that the productivity of Industry 4.0 is accelerating the degradation and depletion of natural resources and contributing to the ongoing crisis of overconsumption and rebound effects. Furthermore, Satyro *et al*. (2022) emphasise that the social dimension of sustainability in Industry 4.0, which has created unemployment, should focus on preventing the increase of social inequalities. Manufacturing digitalization can have significant social consequences such as creating unemployment among low-skilled workers and raising data security and privacy (Ghobakhloo *et al*., 2021). In contrast, Industry 5.0 focuses on human well-being emphasising social sustainability, which is under-focused in Industry 4.0 (Ikudayisi *et al*., 2023). Overall, Industry 5.0 highly contributes to the enhancement of sustainability in construction highlighting HMC, and technology integration while balancing the three pillars of sustainability (Yitmen *et al*., 2023).

FUTURE DIRECTIONS TOWARDS SUSTAINABILITY ENHANCEMENTS IN CONSTRUCTION

Building on the insights from both Industry 4.0 and Industry 5.0, future sustainability enhancements in construction should adopt a holistic approach that integrates technology, human-centered design, and environmental responsibility. While Industry 4.0 technologies have driven significant improvements in efficiency, waste reduction, and resource utilisation, there is a growing need to address social sustainability challenges, particularly in the areas of employment and equitable resource distribution (Marinelli, 2023). Industry 5.0 presents a promising direction for addressing these gaps, emphasising human-centricity, resilience, and sustainability as core elements. Hence, future advancements in construction sustainability will likely focus on human-machine collaboration, integrating human creativity and decision-making with automated processes to enhance both efficiency and worker well-being (Poláková *et al*., 2023). This shift will require rethinking workforce development, ensuring that employees are empowered through digitalisation and can adapt to evolving technological landscapes while preventing the negative social impacts of automation, such as job displacement (Yitmen *et al*., 2023). Additionally, future sustainability strategies must continue to prioritise resource efficiency, renewable energy adoption, and the reduction of greenhouse gas emissions. Further, the circular economy principles, such as waste minimisation, and resource reuse, will become increasingly vital in achieving long-term sustainability goals in the construction (Atif, 2023).

CONCLUSIONS AND RECOMMENDATIONS

This study investigated the contribution of Industry 4.0 Vs Industry 5.0 towards the enhancement of sustainability in the construction industry through a comprehensive literature review. Findings revealed that while Industry 4.0 has brought substantial technological advancements, it falls short in addressing the human and social aspects of sustainability. Although Industry 4.0 positively impacts environmental and economic sustainability through efficiency improvements and resource optimisation, its neglect of social sustainability, particularly in terms of worker well-being and job security, is a significant drawback. In contrast, Industry 5.0 presents a more balanced and human-centric approach, prioritising collaboration between humans and machines and incorporating resilience, and social welfare into its core values. Finally, the study concludes that Industry 5.0's explicit focus on sustainability and its emphasis on human well-being position it as the more appropriate framework for driving long-term, sustainable development in construction. Therefore, transitioning towards Industry 5.0 practices in the sector is essential to meet the broader sustainability goals. This study serves the theory by providing a comparative analysis of Industry 4.0 and Industry 5.0 sustainability enhancements. For the industry, this research underscores the importance

of transitioning to Industry 5.0, which is a more human-centred and sustainable model. Practitioners can leverage Industry 5.0 to enhance workplace safety, improve worker satisfaction, and achieve long-term environmental and social benefits. For society, Industry 5.0's focus on social sustainability offers a pathway to more equitable and human-friendly industrial development. Accordingly, future research can be directed to assessing the long-term sustainability impacts of Industry 5.0, particularly in addressing social inequalities and resource efficiency within the construction sector.

This study has several limitations, primarily due to its reliance on a literature review, which may overlook recent research or unpublished studies, resulting in an incomplete understanding that may not fully capture advancements in the field. Furthermore, the selection of search parameters and literature articles can influence the findings, limiting the generalisability of the results. However, despite these limitations, this study can be used as a benchmark for future in-depth research studies in the area.

REFERENCES

Atif, S., 2023. Analysing the Alignment between Circular Economy and Industry 4.0 nexus with Industry 5.0 Era: An Integrative Systematic Literature Review. Sustainable Development, 1–21.

Bahrin, M. A. K., Othman, M. F., Azli, N. H. N. and Talib, M. F., 2016. Industry 4.0: a Review on Industrial Automation and Robotics. Journal Technology (Sciences & Engineering), 78, 137–143.

Bai, C., Dallasega, P., Orzes, G. and Sarkis, J., 2020. Industry 4.0 Technologies Assessment: A Sustainability Perspective. International Journal of Production Economics, 229.

Balasubramanian, S., Shukla, V., Islam, N. and Manghat, S., 2021. Construction Industry 4.0 and Sustainability: An Enabling Framework. IEEE Transactions on Engineering Management.

Barata, J. and Kayser, I., 2023. Industry 5.0 – Past, Present, and Near Future. Procedia Computer Science, 219, 778–788.

Bengtsson, M., 2016. How to Plan and Perform a Qualitative Study Using Content Analysis. Nursing Plus Open, 2, 8–14.

Boström, M., 2012. A Missing Pillar? Challenges in Theorizing and Practicing Social Sustainability: Introduction to the Special Issue. Sustainability: Science, Practice and Policy, 8 (1), 3–14.

Breque, M., Nul, L. De and Petridis, A., 2021. Industry 5.0 towards a sustainable, human-centric and resilient European industry.

Demir, K. A., Döven, G. and Sezen, B., 2019. Industry 5.0 and Human-Robot Co-working. In: Procedia Computer Science. Elsevier B.V., 688–695.

Eizenberg, E. and Jabareen, Y., 2017. Social Sustainability: A New Conceptual Framework. Sustainability (Switzerland), 9 (1).

Franco, J. de A. B., Domingues, A. M., Africano, N. de A., Deus, R. M. and Battistelle, R. A. G., 2022. Sustainability in the Civil Construction Sector Supported by Industry 4.0 Technologies: Challenges and Opportunities. Infrastructures, 7 (3).

Ghobakhloo, M., Fathi, M., Iranmanesh, M., Maroufkhani, P. and Morales, M. E., 2021. Industry 4.0 ten years on: a Bibliometric and Systematic Review of Concepts, Sustainability Value Drivers, and Success Determinants. Journal of Cleaner Production, 302.

Ghobakhloo, M., Iranmanesh, M., Tseng, M.-L., Grybauskas, A., Stefanini, A. and Amran, A., 2023. Behind the Definition of Industry 5.0: A Systematic Review of Technologies, Principles, Components, and Values. Journal of Industrial and Production Engineering.

Groumpos, P. P., 2021. A Critical Historical and Scientific Overview of all Industrial Revolutions. In: IFAC PapersOnLine. Elsevier B.V., 464–471.

Heijden, J., 2023. Construction 4.0 in a narrow and broad sense: a systematic and comprehensive literature review. Building and Environment, 244.

Ikudayisi, A. E., Chan, A. P. C., Darko, A. and Adedeji, Y. M. D., 2023. Integrated practices in the architecture, engineering, and construction industry: current scope and pathway towards industry 5.0. Journal of Building Engineering, 73.

Ivanov, D., 2023. The industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives. International Journal of Production Research, 61 (5), 1683–1695.

Jamil, Md. A., Mustofa, R., Hossain, N. U. I., Rahman, S. M. A. and Chowdhury, S., 2024. A structural equation modeling framework for exploring the industry 5.0 and sustainable supply chain determinants. Supply Chain Analytics, 6, 100060.

Juntunen, M. and Lehenkari, M., 2021. A narrative literature review process for an academic business research thesis. Studies in Higher Education, 46 (2), 330–342.

Kozlovska, M., Klosova, D. and Strukova, Z., 2021. Impact of industry 4.0 platform on the formation of construction 4.0 concept: a literature review. Sustainability (Switzerland), 13 (5), 1–15.

Kraus, S., Breier, M., Lim, W. M., Dabić, M., Kumar, S., Kanbach, D., Mukherjee, D., Corvello, V., Piñeiro-Chousa, J., Liguori, E., Palacios-Marqués, D., Schiavone, F., Ferraris, A., Fernandes, C. and Ferreira, J. J., 2022. Literature reviews as independent studies: guidelines for academic practice. Review of Managerial Science, 16 (8), 2577–2595.

Kyngäs, H., Mikkonen, K. and Kääriäinen, M., 2022. The Application of Content Analysis in Nursing Science Research.

Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., Wuest, T., Mourtzis, D. and Wang, L., 2022. Industry 5.0: prospect and retrospect. Journal of Manufacturing Systems, 65, 279–295.

Longo, F., Padovano, A. and Umbrello, S., 2020. Value-oriented and ethical technology engineering in industry 5.0: a human-centric perspective for the design of the factory of the future. Applied Sciences, 10 (12), 1–25.

Lu, Y., 2017. Industry 4.0: a survey on technologies, applications and open research issues. Journal of Industrial Information Integration.

Mahiri, F., Najoua, A., Souda, S. Ben and Amini, N., 2023. From industry 4.0 to industry 5.0: the transition to human centricity and collaborative hybrid intelligence. Journal of Hunan University Natural Sciences, 50 (4).

Marinelli, M., 2023. From industry 4.0 to construction 5.0: exploring the path towards human–robot collaboration in construction. Systems, 11 (3).

Missimer, M. and Mesquita, P. L., 2022. Social Sustainability in Business Organizations: A Research Agenda. Sustainability (Switzerland), 14 (5).

Mourtzis, D., Angelopoulos, J. and Panopoulos, N., 2022. A literature review of the challenges and opportunities of the transition from industry 4.0 to society 5.0. Energies, 15 (17).

Mourtzis, D., Angelopoulos, J. and Panopoulos, N., 2023. The future of the human–machine interface (HMI) in society 5.0. Future Internet, 15 (5).

Nahavandi, S., 2019. Industry 5.0- a human-centric solution. Sustainability, 11 (16).

Papetti, A., Gregori, F., Pandolfi, M., Peruzzini, M. and Germani, M., 2020. A method to improve workers' well-being toward human-centered connected factories. Journal of Computational Design and Engineering, 7 (5), 630–643.

Poláková, M., Suleimanová, J. H., Madzík, P., Copuš, L., Molnárová, I. and Polednová, J., 2023. Soft skills and their importance in the labour market under the conditions of Industry 5.0. Heliyon, 9 (8).

Sartal, A., Bellas, R., Mejías, A. M. and García-Collado, A., 2020. The sustainable manufacturing concept, evolution and opportunities within Industry 4.0: A literature review. Advances in Mechanical Engineering, 12 (5).

Satyro, W. C., de Almeida, C. M. V. B., Pinto, M. J. A., Contador, J. C., Giannetti, B. F., de Lima, A. F. and Fragomeni, M. A., 2022. Industry 4.0 implementation: the relevance of sustainability and the potential social impact in a developing country. Journal of Cleaner Production, 337.

Schönbeck, P., Löfsjögård, M. and Ansell, A., 2021. Collaboration and knowledge exchange possibilities between industry and construction 4.0 research. In: Procedia Computer Science. Elsevier B.V., 129–137.

Sherratt, F., Dowsett, R. and Sherratt, S., 2020. Construction 4.0 and its potential impact on people working in the construction industry. Proceedings of Institution of Civil Engineers: Management, Procurement and Law, 173 (4), 145–152.

Snyder, H., 2019. Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333–339.

Turner, C., Oyekan, J., Garn, W., Duggan, C. and Abdou, K., 2022. Industry 5.0 and the circular economy: utilizing LCA with intelligent products. Sustainability, 14 (22).

Wang, K. and Guo, F., 2022. Towards sustainable development through the perspective of construction 4.0: systematic literature review and bibliometric analysis. Buildings, 12 (10).

Xu, X., Lu, Y., Vogel-Heuser, B. and Wang, L., 2021. Industry 4.0 and Industry 5.0—inception, conception and perception. Journal of Manufacturing Systems, 61, 530–535.

Yitmen, I., Almusaed, A. and Alizadehsalehi, S., 2023. Investigating the causal relationships among enablers of the construction 5.0 paradigm: integration of operator 5.0 and society 5.0 with human-centricity, sustainability, and resilience. Sustainability (Switzerland), 15 (11).

Zizic, M. C., Mladineo, M., Gjeldum, N. and Celent, L., 2022. From Industry 4.0 towards Industry 5.0: a review and analysis of paradigm shift for the people, organization and technology. Energies, 15 (14).

APPLICATION OF TiO_2-BASED PHOTOCATALYTIC COATING TECHNOLOGY FOR AIR POLLUTION MITIGATION: A LITERATURE REVIEW

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APPLICATION OF TIO2-BASED PHOTOCATALYTIC COATING TECHNOLOGY FOR AIR POLLUTION MITIGATION: A LITERATURE REVIEW

ABSTRACT

The critical issue of increasing air pollution is highly in need of innovative pollution mitigation strategies. In response, Titanium dioxide (TiO_2)-based photocatalytic coatings (PCC) can be regarded as an emerging solution for this issue. Hence, this study investigates the adaptability of TiO_2-based PCC for air pollution mitigation. The research aims to investigate the literature sources, such as books, reports, theses, journals, magazines, and conference proceedings to explore the use of TiO_2-based PCC technology to mitigate air pollution. The literature review focused on air pollution issues and the working principles of TiO_2-based photocatalysis and explored the benefits of PCC for mitigating air pollution. It was revealed that the air purification and self-cleaning ability are the crucial benefits of TiO_2-based PCC for the air pollution mitigation. Therefore, this study fills a crucial research gap in the theory by enhancing existing knowledge on TiO_2-based PCC while there is a dearth of literature on the major benefits of TiO_2-based PCC and further, it offers perspective to personnel such as policymakers, industry stakeholders, and urban planners finally contributing to a cleaner and more sustainable urban environment.

Keywords: *Adaptability; Benefits; Photocatalytic Coatings; Strategies; TiO_2.*

INTRODUCTION

The primary focal point of global risk perceptions in the coming decade centres around climate and environmental risks (Falk and Hagsten, 2023). Remarkably, these are the risks for which the global community is perceived to have the least level of preparedness (Tol, 2023). Climate change is intricately linked to the increase of air pollution, as ever-rising temperatures and changing weather patterns can increase the formation of air pollutants and aggravate the environmental and health effects associated with air quality deterioration (Fiore et al., 2015). Haase et al. (2014) highlighted that reduced quality of air will have a direct influence on human health and will also have an impact on ecosystems, which could potentially contribute to a feedback loop impacting the climate.

One of the prime causes of pollution of air, particularly in emerging nations, stems from the phenomenon of swift urban expansion (Munsif et al., 2021). With the rise of globalisation, this urbanisation process has led to a considerable surge in the urban population (Mikayilov et al., 2017). According to United Nations data, the urban population, which was at 1.76 billion in 1976, is now projected to reach 4.6 billion by 2030 (Dadon, 2019). Shahbaz et al. (2016) stated that more than half of the world's population now lives in urban areas and utilizes more than 50% of the world's total energy. Authors further explained while substantial energy consumption is essential for urban populations, unchecked, uncontrolled and excessive usage can result in harm to the environment.

It is generally accepted that air pollution has multiple negative influences on human health and is a major problem for the global population (Franchini & Mannucci, 2012). Manisalidis et al. (2020) stated that numerous pollutants significantly contribute to human diseases, with Particulate Matter (PM), consisting of variably sized but very fine particles, entering the respiratory system through inhalation. This could lead to respiratory and cardiovascular illnesses, as well as disruptions in the reproductive and central nervous systems, and an increased risk of cancer (Manisalidis et al., 2020). Moreover, Darkin (2014) explains that the well-being of a population is significantly influenced by the air's quality, and diseases stemming from pollution have implications for an individual's life satisfaction. Further, the author described that air pollution acts as a stressor, diminishing the overall quality of life, imposing economic burdens through healthcare expenses, and absenteeism from work and educational institutions.

Numerous recent technologies have emerged for cleansing the air in urban environments on a global scale (Gulia et al., 2020). These innovations include the deployment of smog towers, air purifiers, and water

sprinklers. Nevertheless, these technologies are not favoured worldwide due to their downsides, including their expensive installation and limited effectiveness (Singla et al., 2021). As a result, there has been extensive research into the utilisation of photocatalysis for the oxidation of pollutants across various environmental mediums, including air, water, and soil (Kaur et al., 2023). The process of air purification using heterogeneous photocatalysis involves several stages. Initially, when exposed to Ultraviolet (UV) light, the photoactive Titanium Dioxide (TiO_2) on the material's surface becomes activated (Andriyanti et al., 2020). Following this activation, pollutants undergo oxidation, facilitated by the presence of the photocatalyst, and subsequently, they are deposited onto the material's surface (Boonen et al., 2017). Ultimately the authors explain that these pollutants can be eliminated from the surface through natural processes such as rain or by cleaning and rinsing with water. Among the different oxidation methods, TiO_2 -based photocatalysis has been identified as the most beneficial due to its superior efficiency, ease of use on various surfaces, lower operational expenses, and environmentally friendly nature without harm to ecosystems and living organisms (Thind et al., 2018). Hence, in recent times, the scientific community has been actively investigating the potential use of photocatalysis to mitigate urban air pollution (Kim et al., 2018). The author further explains that various surfaces within urban areas around the world, including buildings, roads, and monuments, are coated with various photocatalytic substances. These applications have been associated with a notable decrease in the levels of air pollutants.

Countries around the world have been utilising photocatalytic coatings in construction to mitigate air pollution (Richter & Caillol, 2011). In Belgium, photocatalytic coated concrete has been employed to increase the degradation of pollutants such as Nitrogen Oxides (NO_x) and Volatile Organic Compounds (VOCs), particularly in highly polluted areas such as urban environments and road tunnels (Boonen & Beeldens, 2014). Similarly, in cities such as Tokyo and Osaka, local governments have been assessing the process of photocatalytic materials for their air purifying qualities on a larger scale to address pollution by contaminants such as NO_x (Maggos et al., 2007). As per the views of Bisinella et al. (2021), it revealed that the use of photocatalytic coatings (PCCs) on concrete and asphalt can have positive environmental effects by reducing levels of NO_x, Photochemical Ozone Formation, Acidification, and Terrestrial Eutrophication. This makes PCCs one of the most intelligent technologies that can be implemented in the construction industry to combat air pollution.

While various studies attempted on investigating chemical conductivity (Wang et al., 2015), efficacy (Zhang et al., 2017), and applications (Dell'Edera et al., 2021) of TiO_2 -based PCCs, there is still a gap existing on the investigation of its overall adaptability specifically focusing on major benefits. Hence, this study aims to explore the adaptability of TiO_2-based PCCs for air pollution mitigation by investigating the technology prevailing in PCCs and its benefits. Therefore, this study was conducted to investigate the potential of assessing the adaptability of TiO_2 -based PCCs in rigorous way in future research. The paper is structured with background study, the research methodology, research findings and finally, conclusions of the study.

RESEARCH METHODOLOGY

Research methodology is a systematic strategy to elucidating the research topic, encompassing processes, rationale, and the identification of pertinent methods and approaches for each research issue (Swarooprani, 2022). Moreover, literature review offers an extensive summary of literature pertaining to a specific issue, theory, or methodology, integrating previous research to enhance the knowledge base (Paul and Criado, 2020). In this study, the primary focus is to assess the adaptability of TiO_2-based PCC as an air pollution mitigation method which is a novel concept in sustainability (Leary and Westwood, 2011). It was performed by conducting a literature review following an investigation of the technology and major benefits of TiO_2-based PCC using the existing literature. Hence, the literature was rigorously assessed to consolidate the findings it was performed by consulting books, papers, theses, journals, magazines, and conference proceedings to ascertain the technology of TiO_2-based PCC and its benefits. Utilising the search engines 'Scopus', 'Google Scholar', 'Emerald', and 'Science Direct', keywords such as 'TiO_2', TiO_2-based Photocatalytic' and 'Benefits of TiO_2-based PCC' were employed to compile a thorough literature synthesis.

Furthermore, content analysis is Content analysis is a research tool used to determine the presence of certain words or concepts within texts, making inferences about messages, writers, audiences, and cultural contexts

(Kleinheksel et al., 2020). Therefore, the analysis of the collected data from the literature study was conducted using content analysis with synthesising the literature to group of related literature in developing new theories of TiO_2-based PCC benefits and technology.

RESEARCH FINDINGS

AIR POLLUTION

Air pollutants are detrimental compounds present in the atmosphere that have adverse effects on living creatures, alter the climate, and are released into the air by both human activities and natural processes (Saxena and Sonwani, 2019). Baral et al. (2018) have identified PMs, Sulphur oxides (SOx), NO_x, carbon monoxide (CO), ground-level ozone (O3), and lead (Pb) as the primary air pollutants which cause air pollution. The rising urban population has led to a global concern for human health due to the escalating levels of air pollution (Hsieh et al., 2022).

AIR POLLUTION MITIGATION METHODS

In the endeavour to address the pervasive issue of air pollution, a multifaceted approach is more suitable (Manisalidis et al., 2020). A comprehensive overview of various air pollution mitigation methods has been synthesised in Table 1. These methods comprise controlling sources of pollution, harnessing economic incentives, encouraging individual actions, implementing transportation strategies, leveraging advanced technologies, and refining monitoring and measurement techniques. Hooper and Kaufman (2018) have highlighted that it is important to deploy a strategy that involves not only regulatory and technological interventions but also active engagement at the individual and community levels to effectively mitigate air pollution and foster a cleaner and healthier environment.

Table 1: Air Pollution Mitigation Methods

Air Pollution Mitigation Method	References
Controlling sources of pollution	Levin (1992), Holman (1999), Seskin et al. (1983)
Economic incentives	Lakhani (1982), Blackman and Harrington (2018), Harrington et al. (1994)
Individual actions	Sofia et al. (2020), Rajagopalan et al. (2020), Sierra Vargas and Teran (2012)
Transportation strategies	Ambarwati et al. (2016), Gwilliam et al. (2004), Colvile et al. (2001)
Advanced technologies	Zhao et al. (2020), Yunus et al. (2012), Mukhopadhyay and Pandit (2014)
Monitoring and measurement	Snyder et al. (2013), Kelly et al. (2012), Kim et al. (2016)

INTRODUCTION TO TiO_2-BASED PHOTOCATALYSIS

Photocatalytic mechanisms harness energy from direct sunlight or UV sources to transform gaseous contaminants into benign components (Sakthivel et al., 2018). Photocatalysis is recognised as a promising approach to tackling existing environmental and climate issues by removing harmful greenhouse gases from the atmosphere. TiO_2 is considered the most effective option for converting both mineral and organic compounds, thereby supporting efforts to combat climate change (Bersch et al., 2023). The author further asserts that TiO_2 has been extensively studied for its self-cleaning properties and is recognised as a very efficient material in lowering pollution gases such as SOx, VOCs, and NO_x.

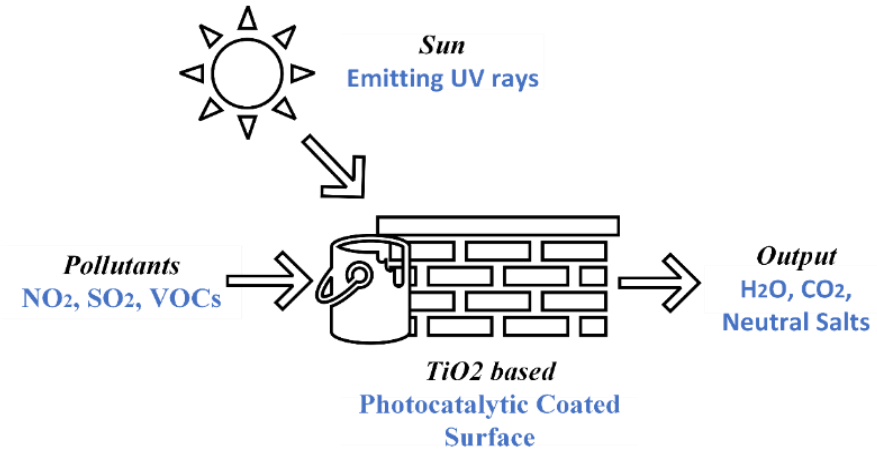

Figure1: Photocatalysis Process of TiO_2-Based PCCs

Figure 1 depicts the photocatalysis process of TiO_2-based PCCs where in the presence of natural sunlight, pollutants such as NO2, SO2 and VOCs are degraded to neutral outputs such as Hydrogen Dioxide (H2O), Carbon Dioxide (CO2) and salts. TiO_2 semiconductor chemically acts as a catalyst for this reaction (Kerketta et al., 2022).

TiO_2 as a Photocatalytic Material

TiO_2 is extensively employed as a photocatalyst due to its exceptional attributes (Juárez-Cortazar et al., 2022), such as its low cost, chemical stability, high efficiency in catalysing light-induced reactions, ability to facilitate the oxidation of various indoor air pollutants at room temperature, complete degradation of a wide range of pollutants, and the absence of the need for chemical additives.(Hager et al., 1999).

According to Hiroi (2022), TiO_2 is present in three different mineral forms: Anatase, Rutile, and Brookite. Titanium Dioxide is a multifunctional substance with diverse uses in items such as paint pigments, sunscreen moisturisers, electrochemical electrodes, capacitors, solar cells, and even as a food colouring additive and in toothpaste (Sakthivel et al., 2018).

Major Benefits of TiO_2-Based PCCs

Photocatalytic coatings, made with nano-grade titanium dioxide, not only provide environmental benefits such as pollution reduction but also benefit the paint and coatings industry by reducing the need for frequent cleaning and maintenance (Knowles, 2006). Including these benefits, many other benefits are discussed in the literature and are briefed below.

- Air purification

Many advanced technologies such as biological methodologies (Velmozhina et al., 2023), plasma-chemical systems (Vershinin et al., 2021) and advanced oxidation processes (Wang et al., 2007) have recently been developed for quick and inexpensive removal of VOCs from the air. Photocatalytic oxidation is a safe and beneficial process that can be used in construction technology to break down impurities using solar light completely (Boyjoo et al., 2017). It is being applied for both indoor and outdoor air purification (Faure et al., 2013). Moreover, PCC is mostly recommended for sites with high levels of air pollution such as highly trafficked streets, road tunnels, and urban environments (Boonen et al., 2017). The authors elaborate on the introduction of TiO_2 as the outermost layer of concrete pavement in Belgium Giampiccolo et al. (2021) highlight that PCC could effectively reduce VOC concentrations which can cause health problems such as sick-building syndrome and contribute to purifying air.

- Self-cleaning ability

The continuous development of façade systems is resulting in the incorporation of advanced technology in envelope components, such as the integration of solar active systems in the form of heat accumulation or

photovoltaic modules for electricity generation (Miglioli et al., 2023). The author further explains that building facade cleaning is frequently delayed due to the considerable and ongoing expenditures involved. As a result of this delay, architectural structures become soiled in urban contexts. However, as dirt builds on the facade, the effort and resources required for cleaning, such as water, detergents, operational expenses, and time, increase regularly (Andaloro et al., 2016). The dirt quickly accumulates on these surfaces in urban or industrial contexts, raising concerns about both longevity and look. As a result, keeping facade materials generally clean is critical to preserving the long-term operation of these building features (Rigone, 2011). Installing Building Maintenance Units (BMUs) provides cost-effective maintenance access to envelope surfaces, reducing long-term maintenance costs over the life of a building. However, BMUs may not be possible or cost-effective for buildings with complex geometry, such as existing or new constructions. In such cases, self-cleaning coatings are helpful, since they simplify cleaning procedures due to their chemical and physical capabilities on treated surfaces (Diamanti et al., 2013; Watanabe et al., 1999). A study conducted by Guo et al. (2015)shows that after 20 years of use under Hong Kong weather conditions, a unique transparent photocatalytic coating put to architectural mortar effectively eliminates NO_x and displays self-cleaning characteristics, with minimal harm seen. Therefore, with the integration of these self-cleaning TiO_2-based PCCs in building facades and exteriors, significant savings can be made in terms of maintenance (Grebenişan et al., 2019).

- Antimicrobial effect

Bacterial contamination has emerged as a significant issue, leading to several conditions in various domains such as food storage, medical implants, hospital settings, biosensors, and public health events (Ferraris and Spriano, 2016). There is a growing recognition of the importance of human health and diseases, as well as the methods we use to prevent germs from jeopardising the safety and well-being of persons (Regan et al., 2012). Conventional methods of cleaning using wiping are not efficient in the long run, cannot be standardised, and require a significant amount of time and staff. Furthermore, the utilisation of aggressive chemicals is accompanied by other issues (Kühn et al., 2003). Antibacterial agents are often employed in hospitals and other public spaces. Various types of biocides, whether organic or metallic, have been utilised to prevent the growth of mould. However, these biocides are only effective for a limited period and can also provide a toxicity risk (Chen et al., 2009). Certain antimicrobial drugs possess significant irritant and detrimental properties, prompting current research efforts to focus on developing novel, cost-effective biocidal substances that are safe for use (Endrino et al., 2011). The imperative to create cost-effective and highly efficient antibacterial techniques has arisen due to the escalating societal concern over the detrimental impact of pathogenic germs. Moreover, surfaces serve as repositories of germs that have the potential to facilitate the transmission of microbial diseases (Machida et al., 2005). There is a pressing requirement to create self-sterilizing surfaces to manage the transmission of this illness. Photocatalytic surface coatings are highly effective in disinfecting microorganisms on frequently handled surfaces, including business touch screens, mobile phones, ceramics, and walls (Ademola Bode-Aluko et al., 2021). Kumaravel et al. (2021) describe that nontoxic metal oxides such as TiO_2 are one of the best photocatalysts for commercial antimicrobial coatings due to their versatile enabling qualities and properties.

- Protection from UV radiation

Currently, transparent coatings that absorb or block UV radiation (Blanchard & Blanchet, 2011; Zhou & Wu, 2009) have two primary uses: as a protective layer for wooden surfaces to shield them from UV rays, and as a barrier coating applied to polymer-based products or devices to slow down the deterioration of the polymer or the internal components enclosed within the polymer-based device. Afzal et al. (2021) state that transparent UV-blocking TiO_2 coatings are in the early stages of development, unlike photocatalytic and self-cleaning coatings which are already established. However, there is a growing industrial interest in these coatings due to the increasing demand for durable materials that maintain their aesthetic appearance. UV-blocking coatings are typically made from dispersions of UV-absorbing nanocrystals without the need for additional heating, due to the low thermal resistance of wood and most polymers (Faure et al., 2013).

- Chemical stability

TiO_2 has garnered global interest owing to its distinctive physicochemical characteristics, particularly its excellent chemical stability. These qualities have positioned TiO_2 as the most extensively researched material for photocatalysis (Haider et al., 2017; Hashimoto et al., 2005). Multiple research publications

have examined the stability of TiO_2 and have determined that the quality of the TiO_2 coating is crucial for ensuring the long-term durability of its photocatalytic self-cleaning characteristics (Liu et al., 2010).

Various modification strategies can enhance the durability of TiO_2 PCCs by expanding their photo-response to visible light, hence improving their photocatalytic activity (Kim et al., 2005). The durability of thin TiO_2-based coatings has also been studied, and it has been found that after high-temperature treatment, the photocatalytic coating on ceramic tiles and glass is typically stable and permanent (da Silva et al., 2018).

- Energy-sustainability

In recent years, studies have extensively examined the energy sustainability aspects of TiO_2-based PCCs. One significant feature lies in their ability to facilitate energy savings through their self-cleaning properties (Powell et al., 2016). By utilizing photocatalysis to degrade organic pollutants and prevent surface fouling, these coatings contribute to the reduction in cleaning and maintenance requirements for infrastructures (Andaloro et al., 2017), thereby conserving energy typically expended in traditional cleaning processes.

Furthermore, the integration of TiO_2-based PCCs in building materials holds promise for energy-efficient architectures. The coatings' capacity to break down organic contaminants in the air contributes to the mitigation of urban air pollution, subsequently enhancing indoor air quality (Binas et al., 2017; Ching et al., 2004). This aspect not only promotes a healthier living environment but also reduces the energy demand for air purification systems within buildings.

The method of cooling buildings by using the TiO_2 photocatalyst is used in the industry. He and Hoyano (2008) described that water is continually sprinkled over the surfaces of structures coated with TiO_2 using this method, as seen in Figure 2. Because of the coated TiO_2, the surface becomes very hydrophilic when exposed to sunlight, reducing the quantity of water required to form a water film. With a minimal amount of water supply, a very thin water coating of around 0.1 mm thickness may cover the whole structure. The structure is cooled not by water, but by the latent heat flow that occurs when water evaporates. On a clear day in the middle of summer, the temperature decrease was determined to be 15 degrees Celsius on window glass and 40-50 degrees Celsius on black roof-tile surfaces (Hashimoto et al., 2005). This novel application of photocatalytic building materials has the potential to significantly reduce the amount of electricity used for air conditioning (Chen & Poon, 2009) making it an energy-sustainable technology in the form of a coating.

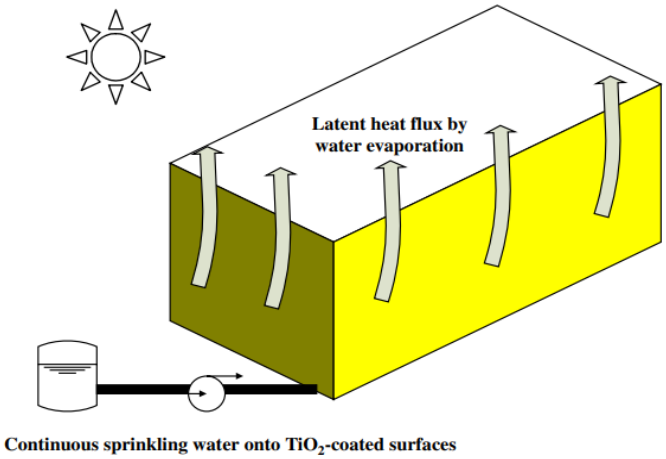

Figure 2: Energy Saving System Using PCC and Stored Water

- Preserve aesthetics

In the case of building facades, aside from environmental concerns, aesthetic concerns are also integrated into the intentions of using TiO_2 since, when exposed to urban pollution, the coated surfaces may be soil due to the deposition of air particles (Diamanti et al., 2008). According to the views of Munafò et al. (2015), TiO_2-based PCC's self-cleaning feature can be extremely useful while high degrees of wettability benefit the final elimination of contaminants. Thus, the photoinduced super hydrophilicity process undertaken by TiO_2 favours self-cleaning ability, which is similarly dependent on the creation of excited electrons and holes by UV irradiation.

CONCLUSION

This study has ventured broadly into the identification of the viability of TiO_2-based PCC as a novel method of controlling air pollution using literature analysis. The results emphasise the benefits of TiO_2 based PCCs for their capability to purify the air, self-cleaning nature, antimicrobial property, UV filter, chemical inertness, and energy efficiency. These make the TiO_2 based PCCs efficient technology to implement on air pollution problem. However, there may be challenges on the successful application of TiO_2-based PCCs depending on several factors including the nature of the coating material, environmental conditions and pollutants of interest. Nevertheless, this research encompasses limitations on scope of literature review, focusing only on benefits of TiO_2-based PCCs. Therefore, more studies are required to improve the efficiency of the TiO_2-based PCCs and investigate their sustainability addressing it on context specific basis, as well as their efficiency in practical use. Therefore, the application of TiO_2-based photocatalytic coatings provide a viable route in enhancing the air quality and towards the development of a healthier atmosphere in a global perspective. With this technology, the world will be on a step closer towards effectively counteracting the impacts of air pollution as well as to advance in the development of sustainable urban infrastructure.

REFERENCES

Ademola Bode-Aluko, C., Pereao, O., Kyaw, H.H., Al-Naamani, L., Al-Abri, M.Z., Tay Zar Myint, M., Rossouw, A., Fatoba, O., Petrik, L., Dobretsov, S., 2021. Photocatalytic and antifouling properties of electrospun TiO2 polyacrylonitrile composite nanofibers under visible light. Materials Science and Engineering: B 264, 114913.

Afzal, A., Habib, A., Ulhasan, I., Shahid, M., Rehman, A., 2021. Antireflective Self-Cleaning TiO2 Coatings for Solar Energy Harvesting Applications. Front Mater 8.

Ambarwati, L., Verhaeghe, R., van Arem, B., Pel, A.J., 2016. The influence of integrated space–transport development strategies on air pollution in urban areas. Transp Res D Transp Environ 44, 134–146.

Andaloro, A., Mazzucchelli, E.S., Lucchini, A., Pedeferri, M.P., 2017. Photocatalytic self-cleaning coatings for building facade maintenance. Performance analysis through a case-study application. Journal of Facade Design and Engineering 4, 115–129.

Andaloro, Annalisa, Sergio, E., Politecnico, M., Milano, D., Lucchini, Angelo, Di Milano, P., Andaloro, A, Mazzucchelli, E.S., Lucchini, A, Pedeferri, M.P., 2016. Photocatalytic self-cleaning coatings for building façade maintenance. Article in Journal of Facade Design and Engineering 4, 115–129.

Andriyanti, W., Nurfiana, F., Sari, A.N., Kundari, N.A., Aziz, I., 2020. Synthesis TiO 2 -Ag thin film by DC Sputtering method for dye degradation. J Phys Conf Ser 1436, 012008.

Baral, A., Sen, S., Roesler, J.R., 2018. Use phase assessment of photocatalytic cool pavements. J Clean Prod 190, 722–728.

Bersch, J., Flores-Colen, I., Masuero, A., Dal Molin, D., 2023. Photocatalytic TiO2-Based Coatings for Mortars on Facades: A Review of Efficiency, Durability, and Sustainability. Buildings.

Binas, V., Venieri, D., Kotzias, D., Kiriakidis, G., 2017. Modified TiO 2 based photocatalysts for improved air and health quality. Journal of Materiomics 3, 3–16.

Bisinella, V., Dahl, L., Jensen, H., Mikkelsen, T.N., Christensen, T.H., 2021. Environmental Profile of NOx Reduction by a Photocatalytic Surface Coating and a Vehicle Catalytic Converter. J Environ Prot (Irvine, Calif) 12, 590–623.

Blackman, A., Harrington, W., 2018. The use of economic incentives in developing countries: Lessons from international experience with industrial air pollution. The Theory and Practice of Command and Control in Environmental Policy 199–238.

Blanchard, V., Blanchet, P., 2011. Color stability for wood products during use: Effects of inorganic nanoparticles. Bioresources 6, 1219–1229.

Boonen, E., Beeldens, A., 2014. Recent Photocatalytic Applications for Air Purification in Belgium. Coatings 4, 553–573.

Boonen, E., Beeldens, A., Dirkx, I., Bams, V., 2017. Durability of Cementitious Photocatalytic Building Materials. Catal Today 287, 196–202.

Boyjoo, Y., Sun, H., Liu, J., Pareek, V.K., Wang, S., 2017. A review on photocatalysis for air treatment: From catalyst development to reactor design. Chemical Engineering Journal 310, 537–559.

Chen, F., Yang, X., Wu, Q., 2009. Antifungal capability of TiO2 coated film on moist wood. Build Environ 44, 1088–1093.

Chen, J., Poon, C., 2009. Photocatalytic construction and building materials: From fundamentals to applications. Build Environ 44, 1899–1906.

Ching, W.H., Leung, M., Leung, D.Y.C., 2004. Solar photocatalytic degradation of gaseous formaldehyde by sol–gel TiO2 thin film for enhancement of indoor air quality. Solar Energy 77, 129–135.

Colvile, R.N., Hutchinson, E.J., Mindell, J.S., Warren, R.F., 2001. The transport sector as a source of air pollution. Atmos Environ 35, 1537–1565.

da Silva, A.L., Dondi, M., Raimondo, M., Hotza, D., 2018. Photocatalytic ceramic tiles: Challenges and technological solutions. J Eur Ceram Soc 38, 1002–1017.

Dadon, I., 2019. Planning the Second Generation of Smart Cities: Technology to handle the pressures of urbanization. IEEE Electrification Magazine 7, 6–15.

Darçın, M., 2014. Association between air quality and quality of life. Environmental Science and Pollution Research 21, 1954–1959.

Dell'Edera, M., Lo Porto, C., De Pasquale, I., Petronella, F., Curri, M.L., Agostiano, A., Comparelli, R., 2021. Photocatalytic TiO2-based coatings for environmental applications. Catal Today 380, 62–83.

de_Richter, R., Caillol, S., 2011. Fighting global warming: The potential of photocatalysis against CO2, CH4, N2O, CFCs, tropospheric O3, BC and other major contributors to climate change. Journal of Photochemistry and Photobiology C: Photochemistry Reviews 12, 1–19.

Diamanti, M.V., Ormellese, M., Pedeferri, M.P., 2008. Characterization of photocatalytic and superhydrophilic properties of mortars containing titanium dioxide. Cem Concr Res 38, 1349–1353.

Diamanti, M. V., Del Curto, B., Ormellese, M., Pedeferri, M.P., 2013. Photocatalytic and self-cleaning activity of colored mortars containing TiO2. Constr Build Mater 46, 167–174.

Endrino, J.L., Prasad, R., Basavaraju, D., Rao, K.N., Mosquera, A., Naveen, C.S., Phani, A.R., 2011. Antimicrobial properties of nanostructured TiO2 plus Fe additive thin films synthesized by a cost-effective sol–gel process. Nanoscience and Nanotechnology Letters 3, 629–636.

Falk, M., Hagsten, E., 2023. Threat Perception and Adaptive Capacity of Natural World Heritage Site Management. Environ Manage 71, 285–303.

Faure, B., Salazar-Alvarez, G., Ahniyaz, A., Villaluenga, I., Berriozabal, G., De Miguel, Y.R., Bergström, L., 2013. Dispersion and surface functionalization of oxide nanoparticles for transparent photocatalytic and UV-protecting coatings and sunscreens. Sci Technol Adv Mater 14, 023001.

Ferraris, S., Spriano, S., 2016. Antibacterial titanium surfaces for medical implants. Materials Science and Engineering C.

Fiore, A.M., Naik, V., Leibensperger, E.M., 2015. Air quality and climate connections. J Air Waste Manage Assoc.

Franchini, M., Mannucci, P.M., 2012. Air pollution and cardiovascular disease. Thromb Res.

Giampiccolo, A., Tobaldi, D.M., Jones, E., Labrincha, J.A., Kurchania, R., Ansell, M.P., Ball, R.J., 2021. UV / visible sol gel W–TiO2 photocatalytic coatings for interior building surfaces. Build Environ 205, 108203.

Grebenişan, E., Szilagyi, H., Hegyi, A., Mircea, C., Baeră, C., 2019. Opportunities regarding the potential use of the self-cleaning concept within urban contemporary architecture in Romania. MATEC Web of Conferences 289, 05003.

Gulia, S., Tiwari, R., Mendiratta, S., Kaur, S., Goyal, S.K., Kumar, R., 2020. Review of scientific technology-based solutions for vehicular pollution control. Clean Technol Environ Policy 22, 1955–1966.

Guo, M.-Z., Maury-Ramirez, A., Poon, C.S., 2015. Photocatalytic activities of titanium dioxide incorporated architectural mortars: Effects of weathering and activation light. Build Environ 94, 395–402.

Gwilliam, K.M., Kojima, M., Johnson, T., 2004. Reducing air pollution from urban transport. World Bank Washington, DC.

Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., Gomez-Baggethun, E., Gren, Å., Hamstead, Z., Hansen, R., Kabisch, N., Kremer, P., Langemeyer, J., Rall, E.L., McPhearson, T., Pauleit, S., Qureshi, S., Schwarz, N., Voigt, A., Wurster, D., Elmqvist, T., 2014. A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. Ambio.

Hager, S., Bauer, R., Kudielka, G., 1999. Photocatalytic oxidation of gaseous chlorinated organics over titanium dioxide.

Haider, A.J., AL– Anbari, R.H., Kadhim, G.R., Salame, C.T., 2017. Exploring potential Environmental applications of TiO2 Nanoparticles. Energy Procedia 119, 332–345.

Harrington, W., Walls, M.A., McConnell, V.D., 1994. Using economic incentives to reduce auto pollution. Issues Sci Technol 11, 26–32.

Hashimoto, K., Irie, H., Fujishima, A., 2005. TiO2 Photocatalysis: A Historical Overview and Future Prospects. Jpn J Appl Phys 44, 8269.

He, J., Hoyano, A., 2008. A numerical simulation method for analyzing the thermal improvement effect of super-hydrophilic photocatalyst-coated building surfaces with water film on the urban/built environment. Energy Build 40, 968–978.

Hiroi, Z., 2022. Inorganic Structural Chemistry of Titanium Dioxide Polymorphs. Inorg Chem 61, 8393–8401.

Holman, C., 1999. Sources of air pollution. In: Air Pollution and Health. Elsevier, pp. 115–148.

Hooper, L., Kaufman, J., 2018. Ambient Air Pollution and Clinical Implications for Susceptible Populations. Ann Am Thorac Soc 15, S64–S68.

Hsieh, H.-P., Wu, S., Ko, C.-C., Shei, C., Yao, Z.-T., Chen, Y.-W., 2022. Forecasting Fine-Grained Air Quality for Locations without Monitoring Stations Based on a Hybrid Predictor with Spatial-Temporal Attention Based Network. Applied Sciences 12, 4268.

Juárez-Cortazar, D.E., Torres-Torres, J.G., Hernandez-Ramirez, A., Arévalo-Pérez, J.C., Cervantes-Uribe, A., Godavarthi, S., de los Monteros, A.E.E., Silahua-Pavón, A.A., Cordero-Garcia, A., 2022. Doping of TiO2 Using Metal Waste (Door Key) to Improve Its Photocatalytic Efficiency in the Mineralization of an Emerging Contaminant in an Aqueous Environment. Water (Basel) 14, 1389.

Kaur, M., Noonia, A., Dogra, A., Singh Thind, P., 2023. Optimising the parameters affecting degradation of Cypermethrin in an aqueous solution using TiO2/H2O2 mediated UV photocatalysis: RSM-BBD, kinetics, isotherms and reusability. Int J Environ Anal Chem 103, 1153–1167.

Kelly, F.J., Fuller, G.W., Walton, H.A., Fussell, J.C., 2012. Monitoring air pollution: Use of early warning systems for public health. Respirology 17, 7–19.

Kerketta, U., Tesler, A., Schmuki, P., 2022. Single-Atom Co-Catalysts Employed in Titanium Dioxide Photocatalysis. Catalysts 12, 1223.

Kim, G.-S., Son, Y.-S., Lee, J.-H., Kim, I.-W., Kim, J.-C., Oh, J.-T., Kim, H., 2016. Air pollution monitoring and control system for subway stations using environmental sensors. J Sens 2016.

Kim, T.K., Lee, M.N., Lee, S.H., Park, Y.C., Jung, C.K., Boo, J.-H., 2005. Development of surface coating technology of TiO2 powder and improvement of photocatalytic activity by surface modification. Thin Solid Films 475, 171–177.

Kim, Y.K., Hong, S.J., Kim, H.B., Lee, S.W., 2018. Evaluation of in-situ NOx removal efficiency of photocatalytic concrete in expressways. KSCE Journal of Civil Engineering 22, 2274–2280.

Kleinheksel, A.J., Rockich-Winston, N., Tawfik, H., Wyatt, T.R., 2020. Demystifying Content Analysis. Am J Pharm Educ 84, 7113.

Knowles, T., 2006. The new toolbox: Nanotechnology in paints and coatings. European Coatings Journal.

Kühn, K.P., Chaberny, I.F., Massholder, K., Stickler, M., Benz, V.W., Sonntag, H.G., Erdinger, L., 2003. Disinfection of surfaces by photocatalytic oxidation with titanium dioxide and UVA light. Chemosphere 53, 71–77.

Kumaravel, V., Nair, K., Mathew, S., Bartlett, J., Kennedy, J., Manning, H., Whelan, B., Leyland, N., Pillai, S., 2021. Antimicrobial TiO2 nanocomposite coatings for surfaces, dental and orthopaedic implants. Chemical Engineering Journal 416, 129071.

Lakhani, H., 1982. Air pollution control by economic incentives in the US: Policy, problems, and progress. Environ Manage 6, 9–20.

Leary, R., Westwood, A., 2011. Carbonaceous nanomaterials for the enhancement of TiO2 photocatalysis. Carbon N Y 49, 741–772.

Levin, H., 1992. Controlling sources of indoor air pollution. In: Chemical, Microbiological, Health and Comfort Aspects of Indoor Air Quality—State of the Art in SBS. Springer, pp. 321–341.

Liu, T., Zhang, F., Xue, C., Li, L., Yin, Y., 2010. Structure stability and corrosion resistance of nano-TiO2 coatings on aluminum in seawater by a vacuum dip-coating method. Surf Coat Technol 205, 2335–2339.

Machida, M., Norimoto, K., Kimura, T., 2005. Antibacterial activity of photocatalytic titanium dioxide thin films with photodeposited silver on the surface of sanitary ware. Journal of the American Ceramic Society 88, 95–100.

Maggos, Th., Bartzis, J.G., Liakou, M., Gobin, C., 2007. Photocatalytic degradation of NOx gases using TiO2-containing paint: A real scale study. J Hazard Mater 146, 668–673.

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., Bezirtzoglou, E., 2020. Environmental and Health Impacts of Air Pollution: A Review. Front Public Health.

Miglioli, A., Aste, N., Del Pero, C., Leonforte, F., 2023. Photovoltaic-thermal solar-assisted heat pump systems for building applications: Integration and design methods. Energy and Built Environment 4, 39–56.

Mikayilov, J., Shukurov, V., Mukhtarov, S., Yusifov, S., 2017. Does urbanization boost pollution from transport? Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis.

Mukhopadhyay, A., Pandit, V., 2014. Control of industrial air pollution through sustainable development. Environ Dev Sustain 16, 35–48.

Munafò, P., Goffredo, G.B., Quagliarini, E., 2015. TiO2-based nanocoatings for preserving architectural stone surfaces: An overview. Constr Build Mater.

Munsif, R., Zubair, M., Aziz, A., Nadeem Zafar, M., 2021. Industrial Air Emission Pollution: Potential Sources and Sustainable Mitigation. In: Environmental Emissions. IntechOpen.

Paul, J., Criado, A.R., 2020. The art of writing literature review: What do we know and what do we need to know? International Business Review 29, 101717.

Powell, M.J., Quesada-Cabrera, R., Taylor, A., Teixeira, D., Papakonstantinou, I., Palgrave, R.G., Sankar, G., Parkin, I.P., 2016. Intelligent Multifunctional VO2/SiO2 /TiO2 Coatings for Self-Cleaning, Energy-Saving Window Panels. Chemistry of Materials 28, 1369–1376.

Rajagopalan, S., Brauer, M., Bhatnagar, A., Bhatt, D.L., Brook, J.R., Huang, W., Münzel, T., Newby, D., Siegel, J., Brook, R.D., 2020. Personal-level protective actions against particulate matter air pollution exposure: a scientific statement from the American Heart Association. Circulation 142, e411–e431.

Regan, F., Chapman, J., Sullivan, T., 2012. Nanoparticles in Anti-Microbial Materials Use and Characterisation.

Sakthivel, R., Arun Kitcha, T., Student, B.E., Aravindh, S., 2018. Experimental Study of Photocatalytic Concrete using Titanium Dioxide. IJIRST-International Journal for Innovative Research in Science & Technology| 4.

Saxena, P., Sonwani, S., 2019. Criteria Air Pollutants and their Impact on Environmental Health. Springer.

Seskin, E.P., Anderson Jr, R.J., Reid, R.O., 1983. An empirical analysis of economic strategies for controlling air pollution. J Environ Econ Manage 10, 112–124.

Shahbaz, M., Loganathan, N., Muzaffar, A.T., Ahmed, K., Ali Jabran, M., 2016. How urbanization affects CO2 emissions in Malaysia? The application of STIRPAT model. Renewable and Sustainable Energy Reviews 57, 83–93.

Sierra Vargas, M.P., Teran, L.M., 2012. Air pollution: Impact and prevention. Respirology 17, 1031–1038.

Singla, N., Singla, S., Thind, P.S., Singh, S., Chohan, J.S., Kumar, R., Sharma, S., Chattopadhyaya, S., Dwivedi, S.P., Saxena, A., Issakhov, A., Khalilpoor, N., 2021. Assessing the Applicability of Photocatalytic-Concrete Blocks in Reducing the Concentration of Ambient NO2of Chandigarh, India, Using Box-Behnken Response Surface Design Technique: A Holistic Sustainable Development Approach. J Chem 2021.

Snyder, E.G., Watkins, T.H., Solomon, P.A., Thoma, E.D., Williams, R.W., Hagler, G.S.W., Shelow, D., Hindin, D.A., Kilaru, V.J., Preuss, P.W., 2013. The changing paradigm of air pollution monitoring. Environ Sci Technol 47, 11369–11377.

Sofia, D., Gioiella, F., Lotrecchiano, N., Giuliano, A., 2020. Mitigation strategies for reducing air pollution. Environmental Science and Pollution Research.

Swarooprani, K., 2022. An Study of Research Methodology. Int J Sci Res Sci Eng Technol 537–543.

Thind, P.S., Kumari, D., John, S., 2018. TiO2/H2O2 mediated UV photocatalysis of Chlorpyrifos: Optimization of process parameters using response surface methodology. J Environ Chem Eng 6, 3602–3609.

Tol, R., 2023. Climate economics: economic analysis of climate, climate change and climate policy. Edward Elgar Publishing.

Velmozhina, K., Shinkevich, P., Zhazhkov, V., Politaeva, N., Korablev, V., Vladimirov, I., Morales, T.C., 2023. Production of Biohydrogen from Microalgae Biomass after Wastewater Treatment and Air Purification from CO2. Processes 11, 2978.

Vershinin, N.N., Balikhin, I.L., Berestenko, V.I., Efimov, O.N., Kabachkov, E.N., Kurkin, E.N., 2021. Synthesis and Properties of a Carbon Monoxide Oxidation Catalyst Based on Plasma-Chemical Titanium Carbonitride, Titanium Dioxide, and Palladium. High Energy Chemistry 55, 75–79.

Wang, S., Ang, H.M., Tade, M.O., 2007. Volatile organic compounds in indoor environment and photocatalytic oxidation: State of the art. Environ Int 33, 694–705.

Wang, Y., Zheng, Y.-Z., Lu, S., Tao, X., Che, Y., Chen, J.-F., 2015. Visible-Light-Responsive TiO 2 -Coated ZnO:I Nanorod Array Films with Enhanced Photoelectrochemical and Photocatalytic Performance. ACS Appl Mater Interfaces 7, 6093–6101.

Watanabe, T., Nakajima, A., Wang, R., Minabe, M., Koizumi, S., Fujishima, A., Hashimoto, K., 1999. Photocatalytic activity and photoinduced hydrophilicity of titanium dioxide coated glass.

Yunus, I.S., Harwin, Kurniawan, A., Adityawarman, D., Indarto, A., 2012. Nanotechnologies in water and air pollution treatment. Environmental Technology Reviews 1, 136–148.

Zhang, Y., Fan, W., Du, H.Q., Zhao, Y.W., 2017. Study on photocatalytic performance of TiO 2 and Fe 3+ /TiO 2 coatings. Surface Engineering 33, 849–856.

Zhao, Y.-L., Tang, J., Huang, H.-P., Wang, Z., Chen, T.-L., Chiang, C.-W., Chiang, P.-C., 2020. Development of iot technologies for air pollution prevention and improvement. Aerosol Air Qual Res 20, 2874–2888.

Zhou, S., Wu, L., 2009. Development of Nanotechnology-Based Organic Coatings. Compos Interfaces 16, 281–292.

COMPENSATION MECHANISMS FOR THE CONSTRUCTION LABOUR ACCIDENTS IN BUILDING CONSTRUCTION IN SRI LANKA

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COMPENSATION MECHANISMS FOR THE CONSTRUCTION LABOUR ACCIDENTS IN BUILDING CONSTRUCTION IN SRI LANKA

ABSTRACT

The construction industry in Sri Lanka is experiencing frequent accidents and associated costs due to the abundance of human resources involved. This research investigates the current compensation mechanisms for construction labour accidents in building construction is adequately cover construction labor accidents in building projects in Sri Lanka. The study used a qualitative research method with an inductive approach and interpretivism philosophy. Data was collected through semi-structured interviews with seven labourers and supervisors. The data analysis was done by using the thematic analyzing method. The main accidents include collision of plant and equipment, earth collapse, slip and fall, and falls from height. The Workmen's Compensation (Amendment) Act No. 10 of 2022 is the statutory framework governing compensation for labour-related accidents where they only focused about the monthly wage of the labour and the injury. Compensation mechanisms used in Sri Lanka include third-party payments and full insurance payments, with compensation amounts varying based on labour age and insurance type where it is not a compulsory requirement.

Keywords: *Compensation Mechanism; Construction Industry; Cost of Accidents; Labour Accidents; Middle Rise Building.*

INTRODUCTION

The construction industry has become very complex with light construction, heavy construction, and industrial construction (Safa *et al.* 2015). Owing to that, construction industry is a high accident-based industry constitutionally (Zhou *et al.,* 2015). In the construction industry, it can be identified a variety of accidents, such as height-related accidents, fire accidents, slip and falls, etc (Nadhim *et al*. 2016). Those can be ensued to both professionals and the labours of the sites (Gunduz and Ahsan,2018). Mental problems, physical problems, mistakes, carelessness, lack of training, and lack of experience are some of the examples of the causes of the accidents (Bohle, *et al.,* 2010). Accidents can be categorized as recognizable and unrecognizable, and the impact of the accidents is either quantifiable or unquantifiable (Hamid, *et al.,* 2008). As well as some accidents are affected the long-term, short-term injuries, also some are affected by death (Asanka and Ranasinghe, 2015). Despite these categorizations, there is a considerable cost related to the occupational injuries in the construction industry such as "direct cost" and the "indirect cost" (Jallon, *et al.*, 2011). Visible costs are direct costs; similarly, medical costs, hospital fees and invisible costs are indirect costs such as wage expenses, material damage, administrator's time and production losses (Hosseinian and Torghabeh, 2012). Most construction projects have a compensation mechanism to treat the victim labourers. Specifically, large projects and large companies have their compensation mechanism to treat the victims' labourers. insurance payments, incentive payoffs, and company own payments are some of the instances (Feng,2015).

The accidents can highly influence labour, which may cause death or long-term injuries for them (Edirisinghe *et al*., 2014). For that reason, the cost of the accident is a considerable point. Hence, there should be a proper compensation mechanism for labour accidents in the building construction industry. Due to that, this research aimed to investigate whether the current compensation mechanism is sufficient to compensate for the construction labour accidents in building construction in Sri Lanka. To achieve that aim, there were three key objectives of the research to identify the types of cost of occupational injuries relating to labour accidents in building construction projects, identify the existing compensation mechanism for occupational injuries in Sri Lanka and evaluate the sufficiency of the current compensation mechanism for the labour accident in building construction industry in Sri Lanka.

LITERATURE REVIEW

THE COST RELATED TO THE CONSTRUCTION ACCIDENTS

The costs associated with workplace accidents are often depicted as a "drifting iceberg" (Hoła *et al*., 2016). Its visible section, which is above the water's surface, represents the costs that may be estimated (Hoła *et al*., 2016). The iceberg's considerably larger and unseen portion lies beneath the water's surface, symbolizing costs that are difficult to estimate and sometimes go undiscovered (Hoła et al. 2016). According to the study of Umar and Egbu, (2018) the cost of construction accidents depends on the two main pillars namely the number of workers and the project amount. According to the nature of the accidents at the site, it can be happened to unexpected costs such as the sick time payments, the replacement cost, the cost of the disability to the victims also the time and the cost of giving the correct action (Osei-Asibey *et al.,* 2021). The accidents and the cost of those accidents can be categorized as mainly two categories as direct cost and indirect cost. Those costs depend on the nature of the accidents and the various circumstances. Kanchana, Sivaprakash and Joseph, (2015) and Umar and Egbu, (2018), reflect the direct cost as the cost spends on injuries. According to Rahman *et al.*, (2024), the direct costs are the hospital fees, police fees, fire, and emergency transport fees, mental and health payments, nursing home fees. Furthermore, Karanikas, (2015) also introduced the direct cost as one category of the accident- related cost in the building construction industry like medical hospital fees, etc.

According to the study by Umar and Egbu, (2018) the other category has been identified as indirect cost and the cleaning cost, replacement of the labour cost time, etc. Loss of productivity since the accident of the victims, the cost of administering the replacement cost, loss of work time cost, tools, and the equipment damage cost is the indirect cost according to Waehrer *et al.,* (2007). Karanikas, (2015) illustrates the indirect cost related to the accidents in the building construction industry like loss of productivity, replacement cost, etc. The quality-of-life cost is one of the categories from three categories which are under the Waehrer *et al.*, (2007) study. The value of suffering from the pain in victims' families is under the quality-of-life cost. Feng, (2015); Cressler and Moore, (2016) reflected the two categorizations as primary cost and secondary cost. Happened a death or injury of the employee caused loss of the productivity, loss of the time, loss of the wages and they are under the primary cost and the secondary costs are including the payments for hospitals and the medical services nursing payments, etc. Hence there is a fair mechanism in the construction industry for both parties such as the contractor/client and the victims to identify the cost of such an accident for payments. That mechanism can be called the compensation mechanism (Feng, 2015).

COMPENSATION MECHANISM OF BUILDING CONSTRUCTION

According to the report of the International Labour Organization (2016), the Workman compensation ordinance of 1934 is the legislation that is only for employment injuries in Sri Lanka. According to this Act, labourers can file a case in the court of law against the employer if the employer does not pay compensation to the person who has sustained injuries. The employer can pay the compensation by himself or through the insurance which is maintained by him. In the Sri Lankan context, the compensation mechanism is totally based on the monthly wages and the maximum amount for death, or a sick is Rs. 2,000,000 according to the workmen's compensation (amendment) Act No:10, 2022 which describes the compensation payable amounts according to the monthly wages as below Table 1. In accordance with the given table 1, under the Workmen's Compensation Act, laborers are entitled to compensation for work-related accidents or illnesses based on the monthly wage and the nature of the accidents. Under this mechanism it is not considered any other parameter.

Table 1: Amount of Compensation Payable (Source: Workmen's compensation (amendment) Act no.10 of 2022)

Monthly wages of the workman injured (Rs.)	**Death of workman (**Rs.)	**Permanent disablement of workman (**Rs.)	**Half monthly compensation for temporary disablement of workman (**Rs.)
0 - 10,000	1,140,000	1,200,000	5,000
10,001 - 12,500	1,180,000	1,240,000	5,625
12,501 - 15,000	1,220,000	1,280,000	6,875
15,001 - 17,500	1,260,000	1,320,000	8,125
17,501 - 20,000	1,300,000	1,360,000	9,375
20,001 - 22,500	1,340,000	1,400,000	10,625
22,501 - 25,000	1,380,000	1,440,000	11,875
25,001 - 27,500	1,420,000	1,480,000	13,125
27,501 - 30,000	1,460,000	1,520,000	14,375
30,001 - 35,000	1,510,000	1,570,000	16,250
35,001 - 40,000	1,560,000	1,630,000	18,750
40,001 - 45,000	1,610,000	1,680,000	21,250
45,001 - 50,000	1,660,000	1,730,000	23,750
50,001 - 55,000	1,710,000	1,780,000	26,250
55,001 - 60,000	1,760,000	1,830,000	28,750
60,001 - 70,000	1,820,000	1,890,000	32,500
70,001 - 80,000	1,880,000	1,960,000	37,500
80,001 - 90,000	1,940,000	2,000,000	42,500
90,001 - 100,000	2,000,000	2,000,000	47,500
100,000 - and above	2,000,000	2,000,000	47,500

METHODOLOGY

This study employs a qualitative approach grounded in interpretivism and an inductive reasoning model. A quantitative approach is unsuitable for this research because it relies on structured, closed-ended questions, limiting the ability to capture nuanced, in-depth responses (Gunter, 2013). To explore the complexities of workmen's compensation mechanisms, open-ended questions in semi-structured interviews are necessary to gather rich, context-specific insights from participants. An inductive approach is suitable because, although there is extensive literature on accidents, existing literature may not fully capture the unique local context, cultural factors, and specific challenges within Sri Lanka's workmen's compensation system. This approach allows for themes and insights to emerge directly from Sri Lankan participants' perspectives, making the findings more applicable and relevant to the local setting. The research aimed to address three key objectives: to identify the types of costs associated with occupational injuries in middle-rise building construction, to investigate existing compensation mechanisms, and to evaluate the sufficiency of these mechanisms. To achieve these objectives, data was collected through semi-structured interviews with seven labourers who had sustained injuries and one stakeholder, who is an insurance company representative. The sampling technique used for this study is purposive sampling, which enabled the selection of participants with specific knowledge and experience regarding workmen's compensation in Sri Lanka. This method ensured that the data collected was highly relevant and context-specific, as it drew insights directly from individuals who were directly affected by the compensation mechanisms. Thematic analysis was employed to extract patterns and recurring themes from the qualitative data. Each interview was transcribed and coded manually using open coding techniques, with categories emerging around types of accidents, compensation, and perceived adequacy of insurance coverage.

DATA ANALYSIS AND FINDINGS

Thematic analysis revealed several key insights. Accidents reported by participants were primarily categorized into five types: fire accidents, slip and falls, plant and equipment accidents, falls from height, and earth collapses. The analysis of the participants' job roles indicates that the majority of accidents were

directly related to the specific tasks associated with their respective occupations. Most labours involved in the incidents had less than 10 years of industrial experience, with only one respondent reporting 15 years of experience in the field.

The dataset reveals a range of workplace accidents involving skilled and unskilled labours across various construction activities. One incident involved an electrician who encountered a fire accident due to a gas leakage at the worksite. Additionally, two unskilled labours were involved in separate incidents: one sustained injury from an equipment-related accident involving a JCB bucket while working near the machine, and the other experienced an earth collapse caused by unstable soil conditions. A carpenter also reported an accident categorized under plant and equipment incidents, which he mentioned as *it occurred while operating a wood-cutting machine during wood panel fabrication*. Furthermore, the dataset includes three masons, one of whom was injured by falling from a height, while the other two were involved in slip and fall incidents. Specifically, the accidents included a fall from a staircase, a fall from a ladder, and a fall from scaffolding.

Based on the type of accidents reported, the participants experienced varying degrees of injury, ranging from short-term to long-term injuries, and in one case, death. The worker involved in the fire accident sustained severe, long-term injuries, resulting in total blindness and extensive body damage. Similarly, the labour who experienced the earth collapse suffered a spinal injury, rendering him unable to walk, which is also classified as a long-term injury. Among the accidents involving falls from heights and slip and falls, two workers were paralyzed, categorizing these incidents as long-term injuries, while another tragically resulted in death. The carpenter, who lost his fingers while operating a wood-cutting machine, also sustained long-term injuries. Conversely, an unskilled labour who damaged his leg in a separate incident sustained a short-term injury.

An analysis of the injuries reveals both direct and indirect losses suffered by the workers. Direct damages include loss of eyesight, severe burns, spinal injuries, paralysis, loss of fingers, and death. Indirect losses encompass the inability to work, loss of monthly income, wages, and career opportunities. In some cases, the injured workers received compensation, while in others, no compensation was provided. Compensation mechanisms, as identified through interviews, included insurance payments and company-provided funds. The worker who suffered severe burns and blindness received an insurance payment of 300,150 LKR and an additional 25,000 LKR from the company. Among the slip and fall and fall-from-height cases, two workers received insurance payments and additional compensation: one received 352,000 LKR in insurance and 30,000 LKR from the company, while another received 225,000 LKR in insurance and 50,000 LKR in additional funds. A worker who fell from a ladder received only the insurance payment for death, amounting to 565,000 LKR. The carpenter who lost his fingers received an insurance payment of 100,000 LKR, while the labour with spinal damage received 300,000 LKR through insurance. However, the labour who sustained leg injuries did not receive any compensation, as he was categorized as casual labour.

Interviews with labours were supplemented by discussions with stakeholders, including insurance company representatives, to gain insights into the current compensation mechanisms for labours in Sri Lanka. During discussions with an insurance officer, it was highlighted that it is mandatory for all employees at a worksite to be insured. Typically, the insurance coverage is valid for one year, and contractors are required to renew it annually, regardless of the contract duration. For example, if the project lasts only six months, the contractor must still ensure that workers are insured for the entire year. Failure to do so results in the forfeiture of insurance compensation in the event of an accident during the construction period. Additionally, the insurance premium is influenced by the age of the worker, with higher premiums applied to older employees. Generally, the annual insurance payment starts at 150 LKR and can go up to a maximum of 700 LKR for third-party insurance options, which are commonly used by contractors for their employees. However, some companies opt for full insurance coverage for their workers, a decision that largely depends on the size and financial capacity of the contracting company.

According to the accident, there are three categories to pay the victims the insurance companies such as;

- ADB-Accident Death Benefit
- TPD-Total Permanent Disability
- PDB-Partial Disability Benefit

ADB, TPD, and PDB are the accidents covered and the ADP is the payment for the death due to accidents and the TPD is the payment for the permanent disability due to an accident. If damage is happened to the two parts of the body due to the accidents, the payment is done under the TPD. As well as if the damage is happened to the one part of the body, due to the accidents, the payments are done under the PDB. The payment amount is the same for any accidents in the third-party option. According to that, the accident payment amount is 100,000 LKR.

Among those accidents, the fatal accident had happened in 2020 and others were happened in 2021. According to the workmen compensation amendment 2005 act no 10, the amount of compensation for fatal accident is 550,000LKR yet the actual payment which was made for the fatal accident was 565,000LKR. The dead labour is a mason and the salary is 50,000LKR per month. Electrician, carpenter, another mason and one unskilled labours' compensation amount were not enough according to their salary. Among the gathered data set unskilled labours are the owners of the lowest monthly wages, yet their monthly payment is still over to 20,000LKR. Then they should receive the maximum amount (550,000LKR) for death and permanent disabilities. As well as one labour had not received the payment since he was a casual labour at the moment of accident. These details are summarized as follows Table 2.

Table 2: Summary of the compensation received for respondents.

Worker Type	Accident Type	Monthly Salary (LKR)	Compensation Amount (LKR)	Max Compensation per Law (LKR)	Comments
Mason (Fatality)	Fall from height (2020)	50,000	565,000	550,000	Compensation exceeded maximum allowed amount.
Electrician	Fire accident (2021)	50,000	Not disclosed	550,000	Compensation insufficient based on salary.
Carpenter	Plant & equipment (2021)	45,000	Not disclosed	550,000	Compensation insufficient based on salary.
Mason (2nd)	Slip and fall (2021)	50,000	Not disclosed	550,000	Compensation insufficient based on salary.
Unskilled Labour	Earth collapse (2021)	20,000	Not disclosed	550,000	Eligible for maximum compensation but did not receive full amount.
Casual Labour	Leg injury (2021)	<20,000	None	None	Did not receive compensation due to casual status.

According to the Workmen Compensation Act No. 10 of 2022, compensation amounts have been increased based on workers' wages. However, at the time of receiving compensation, the real value of these amounts may be diminished due to inflation, which has risen significantly in the current economic climate. As a result, injured workers may not receive the full benefits intended by the compensation. In line with the suggestions made by labours, it would be advantageous to establish a statistical formula that accounts for inflation. This would ensure that victims receive adequate and fair compensation, reflective of the actual economic conditions at the time of payout.

CONCLUSION AND RECOMMENDATIONS

The construction industry in Sri Lanka is characterized by a high risk of occupational accidents, resulting in both long-term and short-term injuries for labourers and professionals. This study aimed to explore the types of costs associated with occupational injuries, evaluate existing compensation mechanisms, and assess their adequacy for workers involved in middle-rise building projects. Through the analysis, it was found that the most common form of compensation is third-party insurance, which provides a maximum coverage of 100,000 LKR, regardless of the severity of the injury. However, some companies opt for full insurance, which offers significantly higher compensation of up to 50,000,000 LKR. Despite the existence of these mechanisms, the research indicates that the current compensation structure is often insufficient to

fully address the long-term financial and medical needs of injured workers, especially when inflation is taken into account. This aligns with existing literature, which suggests that current compensation frameworks often fail to provide long-term financial security (Feng, 2015). The study concludes that while compensation mechanisms are in place, they do not adequately support workers over the long term, particularly in cases of permanent disability or death. Therefore, the adequacy of compensation remains a key issue that needs to be addressed in the construction industry in Sri Lanka. This study contributes to the industry and society by highlighting the need for a fair and balanced compensation mechanism that addresses the perspectives of both employers and employees.

The current compensation amounts are inadequate to support injured workers and their families over the long term, especially given the financial burdens resulting from ongoing medical needs and loss of income. Casual labourers are particularly disadvantaged, often receiving no compensation for occupational injuries, and there is no mechanism to calculate compensation based on actual wages. To address these issues, this study recommends developing a compensation model that adjusts for inflation, ensuring that payouts reflect the real economic conditions when they are received. Such a model would provide fairer and more adequate financial support to injured workers, allowing them to better manage the lasting impacts of their injuries.

REFERENCE

Asanka, W.A. and Ranasinghe, M., 2015. Study on the Impact of Accidents on Construction Projects. In *6th International Conference on Structural Engineering and Construction Management*. 4, 58-67.

Bohle, P., Pitts, C., and Quinlan, M., 2010. Time to Call It Quits? The Safety and Health of older Workers. *International journal of health services, 40*(1), 23-41.

Cressler, T. E., & Moore, J. R., 2016. Tracking Safety Performance in Construction: A Focused Approach to the Measurement of Fatal and Non-Fatal Injuries, 2003–2012. *Safety science, 88*, 44-53.

Edirisinghe, R., Lingard, H., Bliss, N. and Wakefield, R., 2014, June. Would the Time Delay of Safety Data Mat-Ter? Real-Time Active Safety System (RASS) for construction industry. In *CIB W099 International Conference on Achieving Sustainable Construction Health and Safety*, Lund 2-3 June 2014. Lund, Sweden: Lund University, Sweden Ingvar Kamprad Design Centre, 532-542.

Feng, Y., 2015. Mathematical models for determining the minimum level of voluntary safety investments for building projects. *Journal of Construction Engineering and Management, 141*(7), 04015015.

Gunduz, M., and Ahsan, B., 2018. Construction safety factors assessment through frequency adjusted importance index. *International Journal of Industrial Ergonomics,* 64, 155-162.

Gunter, B., 2013. *The Quantitative Research Process* 2nd ed. London: Routledge.

Hamid, A.R.A., Majid, M.Z. and Singh, B., 2008. Causes of Accidents at Construction Sites. *Malaysian journal of civil engineering, 20*(2). 242-259.

Hoła, A., Hoła, B., Sawicki, M., and Szóstak, M. (2016). Analysis of Selected Factors that Generate the Costs of Accidents at Work Using the Polish Construction Industry as An Example. In *MATEC Web of Conferences,* 86, 07005.

Hosseinian, S.S. and Torghabeh, Z.J., 2012. Major Theories of Construction Accident Causation Models: A Literature Review. *International Journal of Advances in Engineering & Technology, 4*(2), 53.

Jallon, R., Imbeau, D. and de Marcellis-Warin, N., 2011. Development of an Indirect-Cost Calculation Model Suitable for Workplace Use. *Journal of safety research, 42*(3), 149-164.

Kanchana, S., Sivaprakash, P., and Joseph, S. 2015. Studies on Labour Safety in Construction Sites. *The Scientific World Journal, 2015*(1), 590810.

Karanikas, N. 2015. An Introduction of Accidents' Classification Based on their Outcome Control. *Safety science, 72*, 182-189.

Nadhim, E.A., Hon, C., Xia, B., Stewart, I. and Fang, D., 2016. Falls from Height in the Construction Industry: A Critical Review of the Scientific Literature. *International journal of environmental research and public health, 13*(7), 638.

Osei-Asibey, D., Ayarkwa, J., Acheampong, A., Adinyira, E., and Amoah, P. 2021. Impacts of Accidents and Hazards on the Ghanaian Construction Industry. *International Journal of Construction Management, 23*(4), 708-717.

Rahman, F.S., Harvey, L.A., Agho, K.E., Avsar, G. and Tannous, W.K., 2024. Economic Costs of Responders for Responding to Residential Fire Incidents in New South Wales, *Australia. Fire Safety Journal, 146*, p.104176.

Safa, M., Sabet, A., MacGillivray, S., Davidson, M., Kaczmarczyk, K., Gibson, G.E., Rayside, D. and Haas, C., 2015. Classification of Construction Projects, *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, 9(6), 721-729.

Umar, T., and Egbu, C. (2018). Causes of Construction Accidents in Oman. *Middle East Journal of Management, 5*(1), 21-33.

Waehrer, G. M., Dong, X. S., Miller, T., Haile, E., and Men, Y. (2007). Costs of Occupational Injuries in Construction in the United States. *Accident Analysis & Prevention, 39*(6), 1258-1266.

Zhou, Z., Goh, Y.M. and Li, Q., 2015. Overview and Analysis of Safety Management Studies in the Construction Industry. *Safety science*, 72, 337-350.

EVALUATING THE FEASIBILITY OF EXPANDING THE USE OF LOCALLY SOURCED TIMBER AS A FLOORING MATERIAL IN SRI LANKA

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EVALUATING THE FEASIBILITY OF EXPANDING THE USE OF LOCALLY SOURCED TIMBER AS A FLOORING MATERIAL IN SRI LANKA

ABSTRACT

This paper evaluates the feasibility of using locally sourced timber as a sustainable flooring material in the Sri Lankan construction industry. Through a comprehensive literature review, this research assesses the environmental, economic, and durability aspects of timber compared to imported materials. The findings demonstrate that local timber species can be a viable alternative to imports, potentially reducing import dependency and enhancing resilience against economic disruptions. Recommendations are provided for species selection criteria and methods for overcoming common limitations, such as susceptibility to decay and moisture, in an attempt to explore a wider spectrum of locally sourced timber species. The review also explores innovative technologies that promote wider adoption of local timber flooring.

Keywords: *Construction Industry, Timber Flooring, Sri Lanka, Economic Crisis, Sustainability*

INTRODUCTION

Sri Lanka's construction industry has traditionally relied heavily on imported materials, which has made it vulnerable to economic instability (Weerakoon, 2023). The flooring material, also considered as one such input, depends heavily on imports (Import and Export control department, 2020). The COVID-19 pandemic exacerbated the economic crisis, resulting in severe shortages of essential construction materials such as tiles and cement. Import restrictions and currency depreciation further worsened these shortages, disrupting supply chains and inflating construction costs (UNDP, 2022;). Given the current economic climate, there is an urgent need to explore alternative materials that can be sourced locally, reducing dependency on imports and contributing to the industry's sustainability.

Timber, a renewable resource, presents a viable alternative to imported flooring materials. It offers significant environmental benefits, such as carbon sequestration and lower embodied energy compared to widely used other materials like concrete and ceramic tiles (Asif *et al*., 2007). Furthermore, utilizing local timber can promote economic self-sufficiency by reducing reliance on foreign supplies, making the construction sector more resilient to economic shocks. Despite these potential advantages, the use of local timber for flooring applications remains underexplored in Sri Lanka. The industry predominantly relies on a limited selection of timber species, and comprehensive research on the suitability of various local species for flooring applications is lacking.

The research problem addressed in this study is the absence of a structured framework for selecting and using locally sourced timber for flooring in Sri Lanka. While the country boasts a rich variety of timber species, there has been little effort to systematically assess their suitability for flooring, particularly in terms of durability, affordability, and environmental performance. Additionally, most studies on timber usage have focused on structural applications rather than interior flooring, which presents unique challenges such as moisture resistance, pest infestation, and aesthetic considerations (Dietsch *et al*., 2015; Hashim *et al*., 2016).

This study aims to identify suitable locally sourced timber species for flooring in Sri Lanka and to explore new techniques for timber flooring applications. By reviewing the literature on timber selection criteria and limitations, this paper seeks to identify timber species that meet the performance standards of the construction industry while contributing to environmental sustainability. Furthermore, the study will examine innovative treatment techniques and technologies to address challenges like warping, termite attacks, and high humidity, which are commonly associated with timber flooring (Arancon, 2009; Zhan *et al*., 2024).

The objectives of this research are as follows:

- To investigate and compare timber with alternative flooring materials based on sustainability parameters.
- To evaluate the key properties of timber that determine its suitability for flooring applications, to facilitate the exploration of wider spectrum of locally sourced timber for flooring
- To identify the limitations associated with timber usage in flooring and explore techniques to overcome these limitations, thereby promoting wider adoption of locally sourced timber in the construction industry.

Through these objectives, this study aims to contribute to efforts to reduce Sri Lanka's dependence on imported materials while enhancing the resilience and sustainability of its construction industry. By developing a comprehensive framework for timber selection, the research seeks to pave the way for the increased use of local timber in flooring applications, ultimately supporting the country's economic recovery and sustainable development goals.

RESEARCH METHODOLOGY

Research methodology provides a structured approach for conducting research, ensuring the reliability and validity of findings. This research was conducted through a comprehensive literature review to systematically analyze existing scholarly articles, books, and other relevant resources on timber selection properties, limitations in timber use, sustainability aspects, and innovative techniques in timber flooring. By examining the current state of knowledge, the study aims to develop a framework that guides the selection and use of timber in flooring applications, promoting sustainability and minimizing limitations. (Wickramaratne, *et al*., 2020; Cuadrado *et al*., 2015).

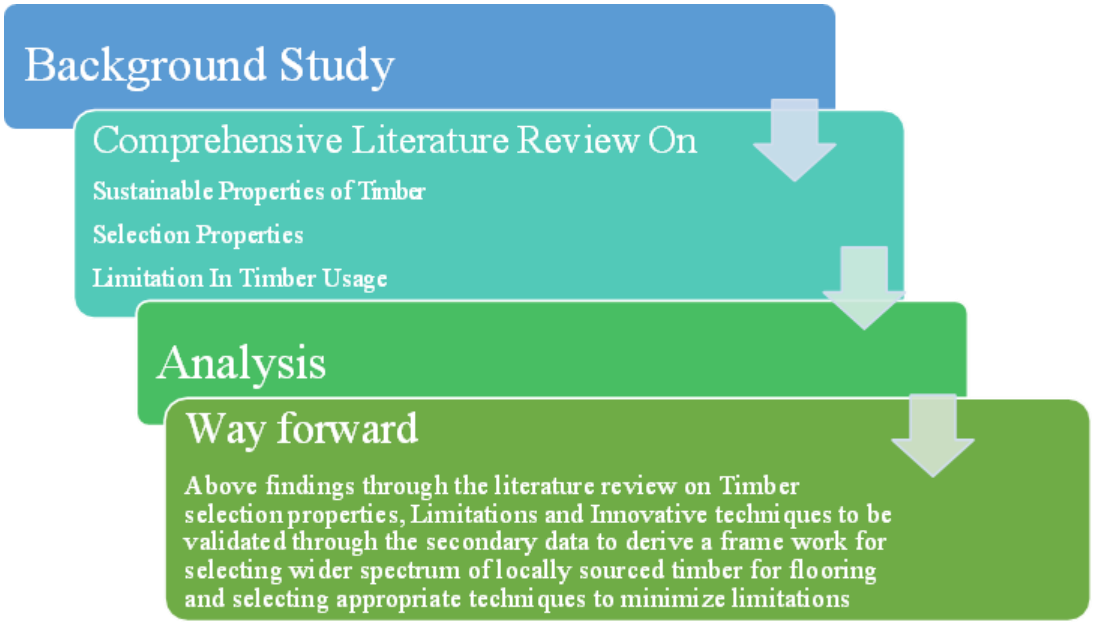

Figure 1: Research Process

RESULTS AND DISCUSSION

PERFORMANCE OF SRI LANKAN CONSTRUCTION INDUSTRY AMID THE ECONOMIC CRISIS

The economic crisis in Sri Lanka led to soaring prices, shortages, and increased debt (George *et al*., 2022; Bhowmick, 2022; Tripathi *et al*., 2022). Fiscal recklessness, reliance on tourism, and a trade deficit contributed to the crisis (George *et al*., 2022). The construction industry faced challenges due to strained government finances, currency depreciation, and import shortages (Bhowmick, 2022; Tripathi *et al*., 2022).

The crisis highlights the dangers of unsustainable economic policies and the need for resilience and adaptation in the construction industry (George *et al*., 2022; Tripathi *et al*., 2022).

The COVID-19 pandemic severely impacted Sri Lanka's construction sector, leading to disruptions, challenges, and a reliance on imported materials. The sector's heavy reliance on imported raw materials made it vulnerable to supply chain disruptions and currency fluctuations, worsening the crisis (Pathirana, 2020; Weerakoon *et al*., 2023). Despite these challenges, opportunities emerged for using locally available resources to reduce dependency on imports and promote sustainable development within the sector (Dabare *et al*., 2023). The interconnected challenges highlight the need for comprehensive strategies to navigate the economic crisis and rebuild the construction sector's resilience amid ongoing uncertainties.

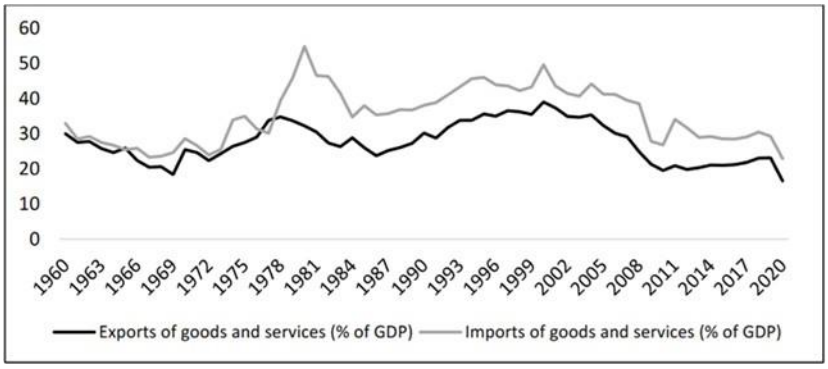

Figure 2: GDP Rates

EVALUATING THE SHORTAGE OF FLOORING MATERIALS DURING THE ECONOMIC DOWNTURN

The economic downturn in Sri Lanka resulted in a significant shortage of flooring materials, particularly tiles and cement, due to import restrictions and currency depreciation (Pathirana, 2020). To address the foreign exchange crisis, restrictions were placed on non-essential imports, including tiles (The Morning, 2021). This limitation on ceramic tile imports had a direct impact on the construction sector (Kamalakkannan *et al*., 2019). The country's dependence on imports for flooring materials worsened the situation, with the annual demand for tiles reaching approximately 30 million square meters in 2019 (ADA Derana, 2023). Additionally, disruptions in the import of raw materials, compounded by currency depreciation, led to a halt in cement production, further intensifying the shortage of flooring materials (Perera *et al*., 2020).

In response to this challenge, Sri Lanka’s abundant natural resources, particularly timber, have emerged as a potential alternative to imported materials. Timber offers sustainability benefits, such as a lower carbon footprint, while also helping to reduce construction costs (Dayaratne, 2010; Dabare *et al*., 2023; Mpakati-Gama, 2012; Gong *et al*., 2023).

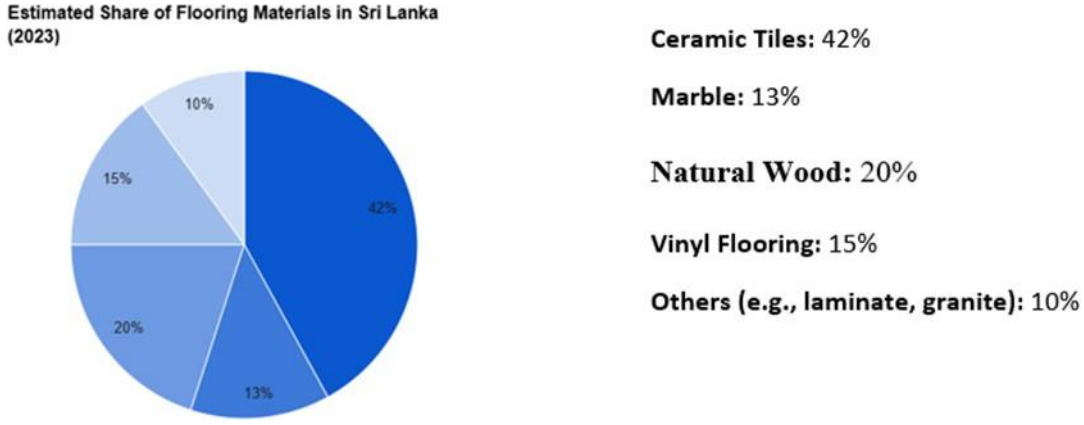

Figure 3: Usage of Flooring Materials

THE ADVENT OF SUSTAINABLE PRACTICES INTO THE CONSTRUCTION SECTOR

The concept of sustainability has gained significant momentum due to increasing concerns about environmental, social, and economic challenges (Martins *et al*., 2019). Sustainability is crucial for addressing pressing issues like climate change and resource scarcity (Cooper *et al*., 2008; Brennan & Cotgrave, 2014). The construction industry plays a vital role in advancing sustainable development goals (Myers, 2005). However, the adoption of sustainable practices within the sector remains inconsistent (National Statistics UK, 2011).

The United Nations' Sustainable Development Goals (SDGs) highlight the importance of sustainability in construction (Carlsen & Bruggemann, 2022). Building materials are central to achieving these goals (Bösch, 2021). Sustainable materials, which mitigate environmental damage and are either reusable or recyclable, are essential for environmentally responsible construction (Sheth, 2016).

Incorporating sustainability into material selection requires a multidimensional approach (Ogunkah & Yang, 2012). The choice of building materials significantly influences the overall performance of a structure (Gluch & Baumann, 2004; Zhou *et al*., 2010). While technological innovations can improve a building's environmental and health attributes, they can also impact its carbon footprint (Zhang *et al*., 2020). These innovations provide designers with more options and encourage the adoption of green building practices (Jahan & Edwards, 2013). "Green building materials," known for their environmentally friendly features, form a subset of sustainable materials (Fithian, Cody & Sheets, Andrea, 2010). To be classified as 'green' or 'eco,' these materials must comply with sustainable production standards and use raw materials that do not harm the environment (Tazmeen & Mir, 2024). Such materials enhance environmental safety and preserve ecosystems. Sustainable building materials aim to achieve maximum functionality with minimal environmental impact, aligning with natural ecosystem processes and reducing dependence on other resources (Ji, 2016). Their adoption is key to advancing a service-based economy that meets both current and future needs (Eze *et al*., 2022).

TIMBER AS A SUSTAINABLE BUILDING MATERIAL IN THE CONSTRUCTION INDUSTRY

The section highlights timber as a sustainable building material due to its regenerative ability, recyclability, and low embodied energy (Reinprecht, 2016). Its use in construction promotes environmental stewardship and enhances resource efficiency (Tanthanawiwat *et al*., 2024). One of the key advantages of timber is its ability to absorb carbon dioxide, making it an environmentally friendly option (European Environment Agency, 2019; Kua *et al*., 2019). Additionally, timber's physical and mechanical properties, such as its lightweight nature and strength, make it a reliable and efficient material for construction (Kolb, 2008; Bartlett *et al*., 2019). The growing adoption of timber in construction further supports recycling efforts and strengthens sustainability initiatives (Iovane *et al*., 2023).

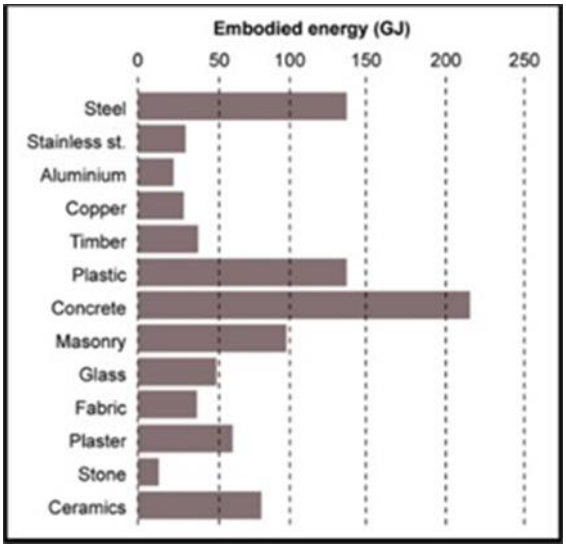

Figure 4: Embodied Energy Comparison

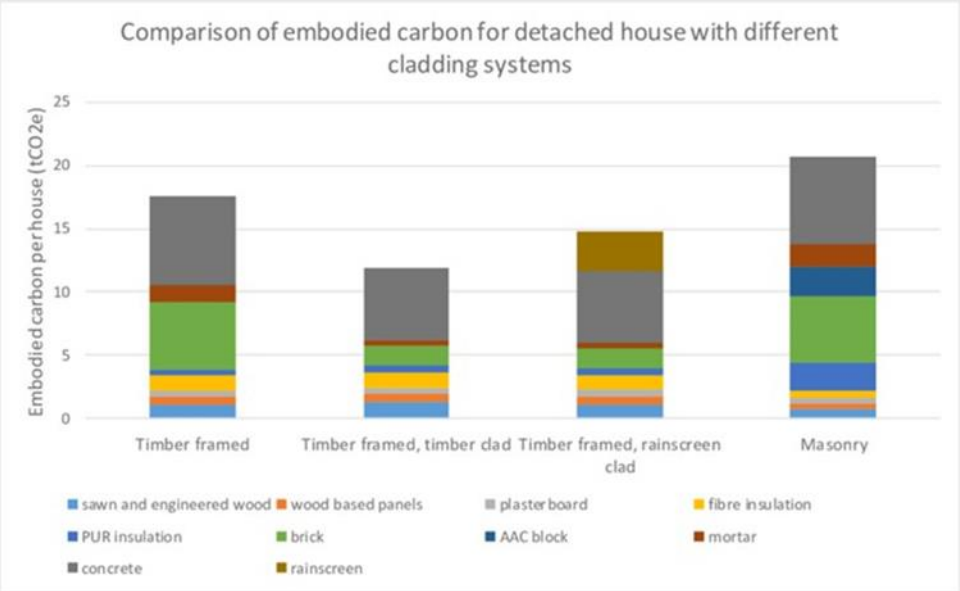

Figure 5: Embodied Carbon Comparison

TIMBER AS A FLOORING MATERIAL IN CONSTRUCTION

The demand for primary construction materials has risen significantly over recent decades due to industrialization and global economic growth. As affluence and the world population continue to increase, this demand is expected to grow even further (Smil, 2013). Timber, one of the oldest construction materials used by humans, has been an essential building material throughout history. However, with the advent of concrete and steel, its use in construction gradually declined (Asiz, 2023). Despite this, a resurgence in timber use occurred in the late 20th century, driven by the discovery of massive timber elements that have reignited interest in timber as a sustainable material, adaptable to local needs (Tchanturia & Dalakishvili, 2023).

Timber is increasingly being used for flooring due to its versatility and sustainability. With around 6,000 different types of wood available globally, factors such as affordability, moisture content, and weight-to-strength ratio are critical when selecting wood for flooring (Cavalli *et al*., 2016b). The performance of timber flooring also depends on its finishing system, which must be chosen based on environmental factors like temperature, humidity, and traffic intensity (Gungor *et al*., 2009).

In Sri Lanka, timber remains a vital resource for construction, particularly for flooring. Home gardens, which have expanded to cover over 1.2 million hectares, contain more than 400 wood species, contributing significantly to the country’s timber supply (Lands & Forestry, 1995; Pathirana, 2022). The Construction Industry Development Authority has recommended 22 of the 120 locally available timber species for flooring applications, highlighting the ongoing importance of timber in Sri Lanka's construction sector (Construction Industry Development Authority, 2024).

CHARACTERISTICS FOR SELECTING TIMBER FOR FLOORING PURPOSES

Timber, a natural material sourced from trees, has been a cornerstone of human construction for centuries. Its versatility, strength, and aesthetic appeal have made it a popular choice for construction, furniture, and a variety of other applications. However, the performance of timber in these applications is heavily influenced by a complex interplay of its physical and mechanical properties.

One of the key factors in determining timber's suitability for different applications is its ability to withstand various forces. Tensile strength, flexural strength, shear strength, and compressive strength are crucial properties that affect timber's performance. For example, high tensile strength is essential for beams and columns, while high flexural strength is critical for beams and joists (Katzengruber *et al*., 2006; Morin-Bernard *et al*., 2020).

The density and weight of timber are also closely related and have a significant impact on its performance. Denser timbers offer superior strength, durability, and sound insulation, but they can be more challenging to work with and may require specialized handling equipment. The increased weight of these timbers also affects their suitability for certain applications, such as flooring, where heavier timbers provide better sound insulation but may require additional support (Jayalath *et al*., 2021; Dinwoodie, 1975).

Maintaining an appropriate moisture content (between 6-12%) is essential to prevent defects like warping, cracking, and decay. Moisture content is influenced by environmental factors such as humidity and temperature, making proper drying and storage critical for ensuring the stability and longevity of timber (Dietsch *et al*., 2015; Lima *et al*., 2022).

The arrangement of wood fibers, known as the grain structure, significantly affects the properties of timber. Straight-grained timber typically exhibits greater strength and stability compared to those with irregular grain patterns. The texture of timber, determined by the fiber arrangement and the presence of features like knots and sapwood, also influences its appearance and workability (Morin-Bernard *et al*., 2020; Katzengruber *et al*., 2006).

Durability, including resistance to decay, insect attack, and other forms of degradation, is another crucial factor when selecting timber for flooring. Different timber species vary in their durability and resistance to threats like moisture and pests. These factors, along with proper treatment and exposure conditions, play a significant role in determining the lifespan of timber (Jayalath *et al*., 2021; Lima *et al*., 2022).

By understanding these complex properties, designers, builders, and craftsmen can select and use timber effectively in a wide range of applications, ensuring the longevity, performance, and aesthetic value of their projects.

Table 1: III Selection Criteria of Characteristics of Timber

Selection Criteria	**Authors**							
	A	B	C	D	E	F	G	H
Tensile strength	✓	✓					✓	
Flexural strength		✓					✓	
Shear strength	✓	✓						
Compressive strength	✓							✓
Density and weight	✓			✓				
Moisture content					✓	✓		
Grain structure	✓	✓						
Durability (resistance to decay, insect attack)			✓			✓		
[A]Katzengruber *et al*., 2006 [B] Morin-Bernard *et al*., 2020 [C] Jayalath *et al*., 2021 [D] Dinwoodie, 1975. [E] Dietsch *et al*., 2015 [F] Lima *et al*., 2022 [G]Bednarek *et al*., 2009 [H] Brandner, R., 2018.								

LIMITATIONS OF TIMBER AS A FLOORING MATERIAL

The illegal timber trade, accounting for nearly half of the global timber trade (Basu, A. & Basu, J.P., 2023; Zhang & Chen, 2021), is a significant driver of deforestation (Food and Agriculture Organization of the United Nations, 2020). This deforestation has far-reaching consequences for biodiversity and climate stability.

While regulations have been implemented to combat illegal timber trade (Stokely *et al*., 2022; Lawson & MacFaul, 2010;), the demand for timber, particularly exotic hardwoods, continues to fuel unsustainable practices. The construction industry, a major consumer of timber products, plays a crucial role in driving this demand.

Timber defects, such as knots, shakes, and wanes, can significantly impact the performance of wood-based products (Wdowiak, 2017). These defects can weaken structural integrity, reduce durability, and affect the overall appearance of timber. To mitigate these issues, boron-based wood preservatives can be used to prevent stains and molds.

However, identifying timber defects solely based on color or tonal information is not sufficient (Conners *et al*., 1992; Weidenhiller & Denzler, 2014). Advanced techniques and technologies are required for accurate detection.

High humidity levels in tropical regions can significantly impact timber flooring. The fluctuating moisture content can cause warping, swelling, or shrinking, leading to dimensional instability and potential damage. Additionally, termites and mold are common problems in tropical climates. These organisms can cause structural damage and affect the appearance of timber flooring. (Webb & Van-Aardt,1959; Ewart & Cookson, 2014)

To ensure the longevity and beauty of timber flooring in tropical environments, regular maintenance is essential. This includes sweeping, mopping, and applying protective finishes to prevent damage from moisture, pests, and wear and tear. Regular inspections can help identify and address any issues early on.

While timber flooring can be more expensive than some alternative materials, investing in sustainable sources and proper maintenance can provide long-term benefits. By choosing sustainably sourced timber and implementing appropriate care practices, you can contribute to environmental conservation and enjoy a durable, aesthetically pleasing flooring option (Liang & Bergman, 2020; Manalo *et al*., 2010).

To address the challenges associated with timber flooring in tropical climates, it is essential to prioritize sustainable sourcing, proper selection, effective maintenance, and consider alternative materials. Supporting certified sustainable timber and avoiding illegal trade helps protect forests and reduces environmental harm. Choosing timber species that are well-suited to tropical conditions and resistant to pests minimizes damage. Regular cleaning, inspections, and treatments are crucial for preventing defects and prolonging the lifespan of timber flooring. In certain situations, exploring engineered timber products or alternative materials can be a viable option to reduce reliance on natural timber. By implementing these strategies, the construction industry can contribute to a more sustainable and resilient built environment. (Ajuziogu *et al*., 2020).

Table 2: Limitations

Limitations	**Authors**													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Illegal timber trade and deforestation	√	√	√				√	√						
Timber defects (knots, shakes, wanes)				√					√					
Difficulty in identifying timber defects based on color or tonal information					√	√								
Susceptibility to damage from high humidity, termites, and mold in tropical climates									√	√	√			
Higher cost compared to some alternative materials												√	√	
Potential for dimensional instability (warping, swelling, shrinking)														√
[A] Basu, A. and Basu, J.P., 2023; [B] Zhang and Chen, 2021; [C] Food and Agriculture Organization of the United Nations, 2020 [D] Wdowiak, A., 2017 [E] Conners *et al*., 1983 [F] Weidenhiller and Denzler, 2014 [G] Stokely *et al*., 2022; [H] Lawson and MacFaul, 2010 [I] Caldeira, 2004; [J] Webb and Van-Aardt, 1959; [K] Ewart and Cookson, 2014; [L] Liang and Bergman, 2020; [M] Manalo *et al*., 2010 [N] Ajuziogu *et al*., 2020														

CONCLUSION AND WAY FORWARD

This study explored the parameters in increasing the use of locally sourced timber as a sustainable flooring material in Sri Lanka's construction industry. Amidst the economic crisis, the need to reduce dependency on imported materials has become more evident, with the construction sector facing critical shortages in flooring materials due to restrictions and currency depreciation. Through a comprehensive literature review,

this research highlights the benefits of utilizing local timber species, including their lower embodied carbon, ability to support local economies, and potential to enhance the sustainability of the construction sector.

Furthermore, it also explored the key parameters in identifying wider spectrum of timber species for flooring. The findings suggest that a structured approach to timber selection, considering factors like tensile strength, durability, and moisture content, can enable the construction industry to expand its use of timber.

However, the study also identified several limitations that need to be addressed for the widespread adoption of timber flooring. The susceptibility of timber to moisture, pests such as termites, and potential warping in tropical climates poses significant challenges. These limitations, coupled with the higher initial cost of timber compared to some synthetic materials, require careful consideration in promoting timber as a flooring solution. Innovative treatments, such as boron-based preservatives and engineered timber products, present viable options to mitigate these challenges.

WAY FORWARD

To ensure the successful adoption of timber as a mainstream flooring material in Sri Lanka, several steps are recommended. First, continued research is needed to empirically validate the findings of this study, particularly through primary data collection that assesses the performance of local timber species under actual conditions. Second, the introduction of policies promoting sustainable timber sourcing and local manufacturing can encourage the industry to transition towards greater timber use.

Additionally, incorporating advanced treatment technologies and exploring circular economy principles, such as the reuse and recycling of timber products, can further mitigate the limitations associated with timber. Education and training within the construction sector, focusing on sustainable timber usage and best practices for maintenance, will also be crucial in promoting the benefits of timber flooring while addressing potential drawbacks.

In conclusion, while challenges remain, the use of locally sourced timber presents a promising pathway toward sustainability and resilience within Sri Lanka's construction industry. By addressing the key limitations identified in this study and building on the findings through future research and technological innovation, the construction sector can significantly reduce its reliance on imported materials and contribute to a more sustainable economic model.

REFERENCES

Abeysundara, U.G., Babel, S. and Piantanakulchai, M., 2009. A matrix for selecting sustainable floor coverings for buildings in Sri Lanka. *Journal of Cleaner Production*, 17, .231–238.

Arancon, R.N., (2009. *The Situation and Prospects for The Utilization of Coconut Wood In Asia And The Pacific*.

Ajuziogu, G.C., Amujiri, A.N., Njoku, E.U., Ozokolie, C.B. and Ojua, E.O., 2020. Determination of swelling and dimensional stability of some nigerian timber species. *Annual Research & Review in Biology*, 35(1), 24-29.

Asif, M., Muneer, T. and Kelley, R., 2007. Life cycle assessment: A case study of a dwelling home in Scotland. *Building and Environment*, 42, 1391–1394.

Basu, A. and Basu, J.P., 2023. Impact of forest governance and enforcement on deforestation and forest degradation at the district level: A study in West Bengal State, India. *Regional Sustainability*, 4(4), 441-452.

Bednarek, Z., Griškevičius, M. and Šaučiuvėnas, G., 2009. Tensile, compressive and flexural strength reduction of timber in fire. *Statybinės konstrukcijos ir technologijos*, 1(3), 148-156.

Bhowmick, S., 2022. Understanding the economic issues in Sri Lanka's current debacle. In Bhowmick, S., ed. *Understanding the economic issues in Sri Lanka's current debacle*. New Delhi, India: ORF, Observer Research Foundation.

Brandner, R., 2018. Cross laminated timber (CLT) in compression perpendicular to plane: Testing, properties, design and recommendations for harmonizing design provisions for structural timber products. *Engineering Structures*, 171, 944-960.

Caldeira, F., Nunes, L. and Botelho, C., 2004. Boron in wood preservation: problems, challenges and proposed solutions-An overview on recent research.

Conners, R.W., Mcmillin, C.W., Lin, K. and Vasquez-Espinosa, R.E., 1983. Identifying and locating surface defects in wood: Part of an automated lumber processing system. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, (6), 573-583.

Cuadrado, J., Zubizarreta, M., Pelaz, B. and Marcos, I., 2015. Methodology to assess the environmental sustainability of timber structures. *Construction and Building Materials*, 86, 149-158.

Dayaratne, R., 2010. Reinventing Traditional Technologies for Sustainability: Contemporary Earth Architecture of Sri Lanka. *Journal of Green Building*, 5.

Dietsch, P., Franke, S., Franke, B., Gamper, A. and Winter, S., 2015. Methods to determine wood moisture content and their applicability in monitoring concepts. *Journal of Civil Structural Health Monitoring*, 5, 115-127.

Dinwoodie, J.M., 1975. Timber—a review of the structure-mechanical property relationship. *Journal of Microscopy*, 104(1), 3-32

Ewart, D. and Cookson, L.J., 2014. Termites and timber. In *Deterioration and Protection of Sustainable Biomaterials*. American Chemical Society, 159-181.

George, A.H., George, A.S. and Baskar, T., 2022. Sri Lanka's economic crisis: A brief overview. *Partners Universal International Research Journal*, 1(2), 9-19.

Gu, H., Liang, S. and Bergman, R., 2020. Comparison of building construction and life-cycle cost for a high-rise mass timber building with its concrete alternative. *Forest Products Journal*, 70(4), 482-492.

Hashim, U.R., Hashim, S.Z.M. and Muda, A.K., 2016. Performance evaluation of multivariate texture descriptor for classification of timber defect. Optik, 12715, 6071–6080.

Imports and Exports Control Department, 2020 Gazette [online] Available from: https://www.customs.gov.lk/wp-content/uploads/2021/06/31.icl200630.pdf [Accessed 25 May 2024].

Jayalath, A., Navaratnam, S., Gunawardena, T., Mendis, P. and Aye, L., 2021. Airborne and impact sound performance of modern lightweight timber buildings in the Australian construction industry. *Case Studies in Construction Materials*, 15, 00632.

Katzengruber, R., Jeitler, G., Brandner, R. and Schickhofer, G., 2006. Tensile proof loading to assure qualityof finger-jointed structural timber. In *Proceedings of WCTE (CD-ROM), 9th World Conference on Timber Engineering*. 6-10.

Lawson, S. and MacFaul, L., 2010. *Illegal logging and related trade: Indicators of the Global Response*. London: The Royal Institute of International Affairs.

Manalo, A., Aravinthan, T., Karunasena, W. and Ticoalu, A., 2010. A review of alternative materials for replacing existing timber sleepers. *Composite Structures*, 92(3), 603-611.

Mekouar, M.A., 2018. Food and agriculture organization of the United Nations (FAO). *Yearbook of International Environmental Law,* 29, 448-468.

Morin-Bernard, A., Blanchet, P., Dagenais, C. and Achim, A., 2020. Use of northern hardwoods in glued-laminated timber: A study of bondline shear strength and resistance to moisture. *European Journal of Wood and Wood Products*, 78, 891-903.

Scotland, N. and Ludwig, S., 2002. Deforestation, the timber trade and illegal logging. In *EC Workshop on Forest Law, Enforcement, Governance and Trade*, Brussels.

Stokely, T.D., Kormann, U.G., Verschuyl, J., Kroll, A.J., Frey, D.W., Harris, S.H., Mainwaring, D., Maguire, D., Hatten, J.A., Rivers, J.W. and Fitzgerald, S., 2022. Experimental evaluation of herbicide use on biodiversity, ecosystem services and timber production trade-offs in forest plantations. *Journal of Applied Ecology*, 59(1), 52- 66.

Stürzenbecher, R., Hofstetter, K., Katzengruber, R. and Bogensperger, T., 2006. Mechanical Characterization of Strand Based Engineered Wood Products by Means of Multiscale Modelling. In *Proceedings of the International PhD Workshop on" Wood as a Building Material"*. Norwegian University of Science and Technology, 10-11.

Tripathi, S., Sharma, K. and Pandya, R., 2022. A study of the economic crisis and its impacts with special reference to Sri Lanka. *Towards Excellence*, 14(4), 218-231.

UNDP, 2022. The Sovereign Debt Crisis in Sri Lanka: Causes, Policy Response and Prospects. [online] Available at: https://www.undp.org/publications/sovereign-debt-crisis-sri-lanka-causes-policy-response and-prospects [Accessed 27 May 2024].

Wdowiak, A., 2017. Defects in structural timber. *Structure and Environment*, 9(2), 112-122.

Weerakoon, T., Wimalasena, S. and Zvirgzdins, J., 2023. Identifying Potential Household Waste as Secondary Raw Materials in The Construction Industry: A Case Study of Sri Lanka. 11, 172–198.

Webb, T.L. and Van-Aardt, J.H.P., 1959. Deterioration of materials under tropical conditions. *Ekistics*, 7(41), 260-266.

Weidenhiller, A. and Denzler, J.K., 2014. On the suitability of colour and texture analysis for detecting the presence of bark on a log. *Computers and Electronics in Agriculture*, 106, 42-48.

Wickramaratne, K.S.L. and Kulatunga, A.K., 2020. Building life cycle assessment to evaluate environment sustainability of residential buildings in Sri Lanka. *Engineer: Journal of the Institution of Engineers, Sri Lanka*, 53(4), 01.

Zhan, W., Yang, Z., Xu, H., Xue, S., Lin, J. and Guan, X., 2024. Exploring the potential of StyleGAN for modeling high-quality and diverse digital wood textures: Towards advancements in the wood industry. *Industrial Crops and Products*, 209, 117880.

Zhang, Q., Cheng, B., Diao, G., Tao, C. and Wang, C., 2023. Does China's natural forest logging ban affect the stability of the timber import trade network. *Forest Policy and Economics*, 152, 102974.

Zhang, Y., Li, Y., and Li, G. 2020. The impact of technological innovation on carbon emissions: Evidence from Chinese cities. *Frontiers in Ecology and Evolution*, 8, 596.

EFFECT OF GREEN BUILDING ARCHITECTURE ON THE HEALTH AND SAFETY OF THE EMPLOYEES IN THE CONSTRUCTION INDUSTRY: A LITERATURE REVIEW

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EFFECT OF GREEN BUILDING ARCHITECTURE ON THE HEALTH AND SAFETY OF THE EMPLOYEES IN THE CONSTRUCTION INDUSTRY: A LITERATURE REVIEW

ABSTRACT

The construction industry is adopting green building architecture to promote sustainability and environmental responsibility. Green building architecture, which emphasizes non-toxic materials, improved air quality, and efficient site management, can reduce workers' exposure to harmful substances and unsafe working conditions. Yet, there is a noticeable gap in applying green building architectural designs to improve the well-being of construction employees and overall site safety. Therefore, this study aims to comprehend the applicability of green building architecture in improving the Health and Safety of Employees in the Construction Industry. Accordingly, a comprehensive literature review was conducted on existing studies. The content analysis method was under qualitative method. The findings demonstrate that green building architecture can positively affect workers' health and safety.

Keywords: *Construction, Employees, Green Building Architecture, Health and Safety.*

INTRODUCTION

Green building, also known as sustainable or environmentally friendly construction, represents a pivotal approach in modern architecture and urban planning, focusing on minimizing environmental impact and maximizing resource efficiency throughout a building's life cycle. This includes considerations from initial design through construction, operation, maintenance, renovation, and eventual decommissioning (Laeeq, 2017). The transformation towards green architecture is complex, often hindered by the use of inappropriate materials and insufficient design processes (Aldeek, 2020).

The United Nations Environment Program (UNEP) has recognized the need for this shift by launching the Sustainable Buildings and Climate Initiative (SBCI), addressing the pressing environmental and social challenges posed by traditional construction methods (Waniko, 2001). Despite this progress, safety remains a critical concern within the green construction industry. While the sector has seen substantial global growth, the safety of structures and personnel continues to be a significant challenge (Berniak-Woźny & Rataj, 2023). Accidents on construction sites are prevalent, and they impact both developed and developing countries alike, including Sri Lanka. Addressing these issues through technological advancements and innovative methods is crucial for the safe advancement of green construction practices (Abbas *et al*., 2017).

Furthermore, construction sites involve both skilled and unskilled labourers who are vulnerable to accidents and health risks (Kanchana *et al*., 2015). Despite existing safety laws, accidents persist, and management practices often fall short in safeguarding worker health. The United States Council on Energy and Environmental Design (LEED) provides guidelines to improve safety and health outcomes in green buildings. Analyzing data from both green and conventional construction projects helps in understanding the differences in reported incidents and their impact on structural safety and health (Rajendran *et al*., 2009).

A study published in the American Journal of Public Health highlights the impact of green buildings on worker health, showing benefits such as reduced stress, lower absenteeism, and fewer days lost due to respiratory issues and other health problems (Uğur & Leblebici, 2018). Despite these advantages, research by Mr. Hwang and the Korean Society of Civil Engineers indicates that green building projects may have a higher accident rate compared to conventional construction projects. Issues such as exposure to hazardous substances and respiratory impairments are critical concerns in green building construction (Hwang *et al*., 2018).

In conjunction with the construction industry's transformation to green building architecture, there is a pressing need for comprehensively investigating the impact on health and safety procedures. There is a noticeable gap in applying green building architectural designs to improve the well-being of construction employees and overall site safety in Sri Lanka. Therefore, this study aims to bridge these gaps by identifying the applicability of green building architecture in improving the health and safety of employees in the construction industry. The objectives set to achieve this aim were: Identify the relationship between green building architecture and health and safety practices in the construction industry and identify the relationship between green building architecture on the health and safety of the employees in the construction industry.

LITERATURE REVIEW

GREEN BUILDING ARCHITECTURE AND ITS IMPACT ON HEALTH AND SAFETY

Green building architecture, also known as sustainable architecture, focuses on minimizing harmful effects on human health and the environment through resource-efficient processes during a building's life cycle (Laeeq, 2017).

- Architect Ken Yeang: Green Architecture should provide the present needs taking into consideration the right of coming generations to supply their needs too.
- Architect William Reed: Green buildings are just designed in a way that focuses on the environmental factors, also he thinks that an important principle in designing a Green building is to reduce its effect on the environment besides decreasing the construction costs.
- Architect Stanley Abercrombie: There is an effective relationship between the building and the site, as an old nations planned cities taking into consideration the south elevations – studying the sun movement – throughout the day and year (different seasons).

The Sri Lankan construction industry is gradually aligning with the global trend of green building architecture. Although the government has made strides in promoting sustainable building practices, several obstacles, including financial, regulatory, social, industrial, and knowledge/skills barriers, hinder its widespread adoption (Karunasena, 2016). Key issues, such as environmental pollution, depletion of natural resources, and the energy crisis, emphasize the need for green building solutions to preserve resources for future generations. Despite some progress, challenges in implementation remain (Liyanage *et al*., 2020). Sri Lanka has introduced several policies, like the National Environment Act (1980) and the National Climate Change Policy (2011), to indirectly guide green construction efforts. The Green Building Council of Sri Lanka (GBCSL) leads efforts to advance sustainable buildings in the country (Thalpage & Karunasena, 2016).

SPECIFIC HEALTH AND SAFETY BENEFITS IN THE SRI LANKAN CONSTRUCTION INDUSTRY

In the green construction industry, safety at project sites is essential, especially in developing countries where safety is often addressed reactively after accidents. In Sri Lanka, one in six accidents and 25 out of 40 construction site fatalities occur due to carelessness or negligence, reflecting inadequate safety measures (Priyadarshani, Karunasena, & Jayasuriya, 2013). The health and safety benefits in Sri Lanka's construction sector include reduced accident rates, improved work environments, better regulatory compliance, cost savings, enhanced reputations, and risk mitigation. By focusing on these areas, the industry can enhance safety and contribute to a sustainable, secure work environment (Cross, Shelley, & Mayer, 2017; Priyadarshani & Karunasena, 2013).

Table 1: Health and Safety Benefits in the Sri Lankan Construction Industry

Reduced Accident rates	Implementing effective safety measures can lead to a reduction in accident rates, thereby minimizing injuries and fatalities among construction workers (Cross *et al*., 2017)
Improved work environmental	Prioritizing health and safety regulations not only protects workers but also ensures construction companies comply with legal requirements, avoiding penalties and legal issues.
Enhanced Compliance	Adhering to health and safety regulations not only protects workers but also ensures that construction companies comply with legal requirements, avoiding penalties and legal issues.
Cost Saving	Investing in construction safety measures can generate result in long-term cost savings by reducing medical expenses, compensation claims, and project delays caused by accidents
Increased Reputation	Prioritizing health and safety can enhance the reputation of construction companies, attracting skilled workers and clients who value safety standards
Risk Mitigation	Implementing safety protocols helps in identifying and mitigating potential risks, ensuring a safer work environment for all involved in construction activities

GREEN BUILDING RELATED TO HEALTH AND SAFETY OUTCOMES

During the construction period, green building practices can have a direct impact on health and safety outcomes for employees. Also, there are some ways in which green building initiatives can enhance health and safety during construction. (Sedaghati *et al*.,2019).

Table 2: Green Building Related to Health and Safety Outcomes

Reduced exposure to hazardous materials	Green Building materials are often selected for their low toxicity levels, reducing the risk of exposure to hazardous chemicals and materials during construction. This can help protect the health of construction employees
Enhanced safety protocols	Green Building Architecture Projects often prioritize safety protocols and procedures to minimize risks during construction. It can include proper handling and disposal of materials, as well as implementing safety measures to prevent accidents on the construction site.
Use of sustainable green construction methods	Green Building Projects Often incorporate sustainable green construction methods that prioritize worker safety. Include the use of ergonomic tools, safe construction practices, and efficient workflows to reduce the risk of injuries and accidents during construction.

SRI LANKAN CURRENT SITUATION OF GREEN BUILDING ARCHITECTURE

The current situation of green building architecture in Sri Lanka is evolving, with a growing interest in adopting sustainable practices and green technologies in the construction industry. The country has seen an increase in the construction of green buildings that are certified by green building assessment schemes such as BREEAM, LEED, Green Star, Green Mark, And GREENSL. Furthermore, the Green Building Council of Sri Lanka (GBSL) plays a significant role in promoting green building practices and certifying green buildings in the country. The government of Sri Lanka has also developed a national program called “Haritha Lanka” to Promote sustainable development Goals. While there are initial cost implications

associated with constructing green buildings, such as the example of the MAS Thurulie factory in Thulhiriya, which had a 30% higher construction cost compared to conventional buildings, the long-term benefits in terms of economic, environmental, and social dimensions make green building development worthwhile. Overall, green building architecture in Sri Lanka is gaining momentum, with more buildings obtaining green certification and incorporating sustainable green design and construction practices to create environmentally friendly and energy efficient structures. (Ekanayaka *et al*.,2021).

LEEDS IN GREEN BUILDING CONSTRUCTION INDUSTRY

The LEED (Leadership in Energy and Environmental Design) certification system is influential in promoting sustainable practices in green building construction. It provides a comprehensive framework for designing, constructing, and operating resource-efficient green buildings with minimized environmental impact (Uğur & Leblebici, 2018).

Key aspects of LEED in green construction include its cost-effectiveness, as integrating environmental and cost strategies early can keep design and construction costs competitive while reducing long-term operational costs. Among over 30 global green assessment systems, LEED, a point-based system, stands out by awarding points for meeting criteria in sustainability excellence, with certification levels ranging from Certified to Platinum. Each level reflects a building's sustainability performance. LEED versions such as v3 and v4 expand the certification's applicability across various sectors. Benefits of LEED-certified buildings include lower energy costs, improved indoor environmental quality, and enhanced occupant health and productivity, reinforcing environmental sustainability (Uğur & Leblebici, 2018).

Figure 1: LEED Certification

GREEN TRANSFORMATION AND SUSTAINABLE TRANSFORMATION PROCESS IN URBAN AND ARCHITECTURAL PROJECTS

Literature highlights that the green and sustainable transformation in Jordanian cities is challenged by rapid urbanization, suboptimal design processes, and unsuitable building materials. In underdeveloped contexts, there's a need for affordable, sustainable solutions that integrate innovative techniques to reduce building costs, manage waste, and employ renewable energy. Sustainable parametric potentiality (SPP) is proposed to optimize sustainable architecture by streamlining processes, using cost-effective materials, and promoting energy-efficient designs. This approach advocates for green urban spaces, interior redesign, and appropriate material use to foster sustainable transformation in urban and architectural projects, addressing environmental concerns, improving energy efficiency, and creating healthier living environments (Aldeek, 2020).

GREEN BUILDING ARCHITECTURAL DESIGNS INFLUENCE THE WELL-BEING OF CONSTRUCTION EMPLOYEES AND OVERALL SITE SAFETY

The Influence of green building architecture designs on the well-being of construction employees and overall site safety is a crucial aspect of sustainable construction practices. Green buildings are designed to enhance occupant health and comfort while minimizing negative impacts on the environment (Cross, Shelley, & Mayer,2017).

Green Building priority factors such as indoor air quality checks, natural lighting, and thermal comfort, can contribute to a healthier and more comfortable work environment for construction workers. Improved indoor environmental quality has been linked to higher productivity, reduced absenteeism, and better overall well-being. Furthermore, Safety considerations in green Building designs often incorporate features that enhance safety for construction workers, such as efficient lighting systems, non-toxic materials, and ergonomic workspaces. These design elements can help reduce accidents and injuries on construction sites. Also, Green buildings typically use materials that are environmentally friendly and have low volatile organic compound (VOC) emissions. This can help minimize exposure to harmful chemicals for construction workers, promoting better health and well-being. Green building projects often involve innovative techniques and technologies that prioritize worker safety and well-being. For example, the use of prefabrication and modular construction methods can streamline processes and reduce risks for construction workers. Green building architectural designs play a significant role in promoting the well-being of construction employees and enhancing overall site safety. By prioritizing factors such as indoor environmental quality, safety considerations, reduced exposure to hazardous materials, biophilic design, and innovative construction techniques, green building can create healthier and safer work environments for construction workers (Cross, Shelley, & Mayer,2017).

METHODOLOGY

This study was initiated with an outlook on green architecture and its relationship with the health and safety of the Employees in the Construction Industry. This was cemented by a survey of past literature leading to identify a relationship between green architecture and its relationship with the health and safety of the Employees. Journal articles, conference proceedings, newspaper articles, and reports relating to green architecture and health and safety concerns were gathered and scrutinized to perform the literature review. The content analysis method was used to analyse the collected data from the literature review. The Content Analysis method has a straightforward criterion for categorizing data to improve the contextual significance (Kyngäs, 2020).

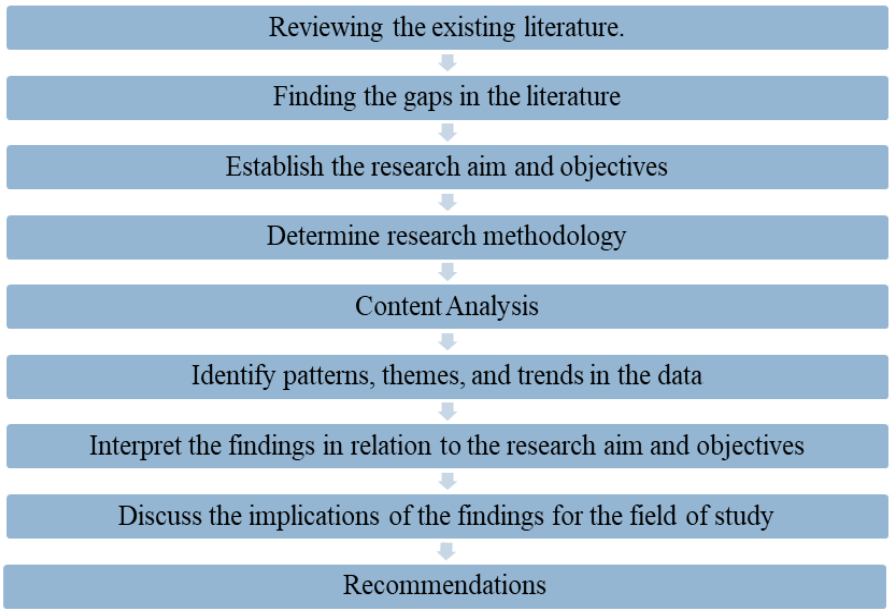

Figure 2: Research Process

FINDINGS

This research shown inconclusive evidence regarding the impact of green building design on construction worker safety and health. While some positive effects have been identified, more research is needed to fully understand the overall implications. The presence of green design and construction features does not necessarily guarantee improved safety performance for construction workers, highlighting the need for a more comprehensive approach to sustainability that includes worker well-being.

RELATIONSHIP BETWEEN GREEN BUILDING DESIGN PRINCIPLES AND HEALTH AND SAFETY PRACTICES IN THE CONSTRUCTION INDUSTRY

The relationship between green building design principles and health and safety practices in the construction industry is crucial for promoting sustainable and safe construction practices. Compliance with green building legislation requirements has been found lacking among contractors on construction sites. While there is awareness of the National Building Regulations and Standards Act, there remains a significant gap in the knowledge and application of green building practices (Windapo & Goulding, 2015). Stakeholder attitudes toward green building practices vary; senior management tends to show a more positive outlook, especially when these practices align with legislative requirements, particularly in health and safety. However, site operatives often display a passive attitude, following instructions without a deep understanding or intrinsic motivation to adopt green practices (Windapo & Goulding, 2015).

Perceived benefits of green building practices differ across organizational levels. Management personnel recognize enhanced public image as a primary advantage of green building practices on construction sites. In contrast, while site operatives appreciate the environmental benefits, they do not see direct personal advantages from implementing these practices (Windapo & Goulding, 2015). Awareness and education are critical areas for improvement, as respondents noted the need for better education on green building practices, particularly as they relate to health and safety. Many respondents viewed green practices as optional and noted that compliance is often enforced only when directly related to health and safety requirements (Windapo & Goulding, 2015). Furthermore, legislation and economic factors heavily influence attitudes toward green building practices, with contractors prioritizing compliance with health and safety legislation that directly impacts their organization, often overlooking broader green building principles.

This relationship between green building design principles and health and safety practices in the construction industry is complex and multifaceted. Green building design principles aim to create sustainable, environmentally friendly structures through the use of efficient materials, technologies, and strategies. While these approaches offer advantages like reduced operating costs and enhanced occupant well-being, they can also introduce new safety risks for construction workers. Research indicates that some green design elements and strategies associated with certifications like LEED may expose construction workers to unfamiliar tasks and hazardous environments due to new materials, technologies, and innovative techniques, which can lead to increased safety risks during construction and maintenance operations. To address these challenges, the concept of prevention through design (PtD) has been proposed, aiming to eliminate construction hazards proactively in green jobs. PtD involves integrating safety considerations early in the design process to modify permanent features of a facility and reduce construction hazards upstream. By incorporating PtD strategies into green designs, the social sustainability dimension, including occupational health and safety, can be enhanced. Despite the potential of PtD, barriers such as liability concerns, contractual methods, and a lack of safety knowledge among professionals hinder its widespread adoption in the construction industry. Overcoming these obstacles and promoting ethical considerations could support the successful implementation of PtD in sustainable design and construction projects (Karakhan and Gambatese, 2017).

Table 3: Green Building Design Principles and Health and Safety Practices in the Construction Industry

Main Focus	Authors
Definition of green building architecture, challenges due to lack of clear definition.	Laeeq (2017) Zuo and Zhao (2014)
Financial, regulatory, and knowledge barriers to adopting green building practices in Sri Lanka.	Karunasena (2016)
Green building practices reduce accident rates, improve work environments, ensure compliance, and enhance reputations.	Priyadarshani *et al*., (2013)
Sustainable construction methods and materials reduce worker exposure to hazardous substances, improving safety.	Sedaghati and Hosseynzadeh Kashi (2019)
LEED certification promotes resource-efficient designs, lowers environmental impact, and improves energy consumption and health.	Uğur and Leblebici (2018)
Integrating sustainable practices in underdeveloped urban areas can promote healthier living and address environmental issues.	Aldeek (2020)
Green building designs improve indoor air quality, lighting, and use non-toxic materials, enhancing well-being and safety.	Cross *et al*., (2017)

IDENTIFY THE RELATIONSHIP BETWEEN GREEN BUILDING ARCHITECTURE ON THE HEALTH AND SAFETY OF THE EMPLOYEES IN THE CONSTRUCTION INDUSTRY

In order to meet the goal of assessing the impact of green building architecture designs on the health and safety of construction workers, and safety of the construction site worthy factors that needs to be analysed (Cross *et al*.,2017). Wellbeing is thought to be more comprehensive than comfort (often the focus of environmental designers), which is used to refer to a neutral and durable, yet basic relaxed or pleasant state (Clements *et al*.,2019).First, the indoor environment quality including air quality, natural lighting and thermal comfort affects the quality of work and productivity of the workers besides reducing the rate of absenteeism. The effects of utilizing good and energy efficient lighting systems could be used in construction sites, to avoid increased cases of accidents. Also, the low VOC and nontoxic materials will reduce the emission of hazardous chemicals that may affect the health of the workers (Smith M. *et al*.,2013). Innovatively created workspace environments in green structures offer numerous ways that prevent risks and cases of accidents. Advanced construction practices such as pre-construction, and modulation strategies impact the construction processes in reducing number of workers exposed to risky conditions. Besides, use of biophilic design principles which brings part of nature to the workers improves their psychological and physiological health. Wellbeing in the workplace continues to gain in popularity due to increasing recognition of its importance for employees and organizations (De Simone, 2014). Workplace wellbeing experiences are contingent upon the multi-sensory experiences (through to the common five senses as well as additional sensory modalities, such as thermoception, proprioception, etc.) provided by one's workplace building (De Simone, 2014). In fact, the WELL Building Standard, which was founded in 2014, explicitly highlights these considerations in their rating system by incorporating an array of environmental designs factors impacting sensory experiences. some researchers have concluded that green buildings enhance health, however, there have also been mixed or inconsistent results as well (Newsham *et al*.,2013). Found occupants reported higher overall health, measured by visual and physical discomfort symptoms, mood, and sleep quality in green buildings compared to conventional buildings (Steemers *et al*.,2010). Furthermore, discovered a strong correlation between occupant satisfaction and physical wellbeing in green buildings. In a study on occupation stress and workplace design, connection to nature (the presence of natural elements) in green buildings contributed to reductions in stress (Hui *et al*.,2018).

Finally, archiving and contrasting the health status and safety performance of Integrated Green building and conventional sites will establish the correlation between green design principles and employee's health and safety on site (Cross *et al*.,2017). Furthermore, reduced exposure to hazardous materials, enhance safety protocols, III. Use of Sustainable Green Construction Methods are some ways in which green building initiatives can enhance health and safety during construction (Sedaghati and Hosseynzadeh Kashi, 2019). Further green buildings aim to minimize waste during construction and operation. They include recycling

programs and use materials that are easily recyclable or biodegradable (Tokbaevich *et al*, 2024) which can affect to health and safety of the construction employees.

In order to meet the goal of assessing the impact of green building architecture designs on the health and safety of construction workers, and safety of the construction site worthy factors that needs to be analysed (Cross *et al*.,2017). Wellbeing is thought to be more comprehensive than comfort (often the focus of environmental designers), which is used to refer to a neutral and durable, yet basic relaxed or pleasant state (Clements *et al*.,2019).

Table 4: Green Building Architecture on the Health and Safety of the Employees in the Construction Industry

Selection Criteria	**Authors**							
	A	B	C	D	E	F	G	H
Improve worker health, productivity, and reduce absenteeism.	√			√				
Pre-construction and modulation strategies reduce the number of workers exposed to risky conditions, enhancing safety	√							
Workers' psychological and physiological health by integrating natural elements into the work environment	√	√	√				√	
Non-toxic materials reduce the emission of hazardous chemicals, improving worker health.						√		
Green construction methods reduce exposure to hazardous materials and improve safety protocols on construction sites.				√	√			
Green building methods aim to minimize waste, incorporating recycling programs and using recyclable/biodegradable materials				√				√
Contingent upon the multi-sensory experiences		√						
[A-Cross *et al*., (2017), B- De Simone (2014), C- Hui *et al*., (2018), D- Newsham *et al*., (2013), E- Sedaghati and Hosseynzadeh Kashi (2019), F- Smith M. *et al*., (2013), G- Steemers *et al*., (2010), H- Tokbaevich *et al*., (2024)]								

CONCLUSION

Green building architecture is taking over the construction industry to make sure the sector becomes sustainable and causes minimum detrimental effects on the environment. While most advantages of such buildings relate to environmental advantages, the present study has identified considerable health and safety benefits that green building architecture can offer to the construction employees. By the use of non-toxic materials, improved air quality, and efficient lighting systems, the greening of buildings tends to afford workers healthier places to work and their occupants with reduced exposures to toxic agents, improved productivity, and reduced absenteeism. Research also indicates that well-designed green buildings also improve the worker safety by using low-VOC materials, biophilic design, and other innovative construction practices that are safer, such as pre-fabrication and modular construction, which reduce the number of workers exposed to dangerous conditions on site.

In addition, LEED certification and other green standards also facilitate compliance with sustainability practices to maintain improvements in indoor environmental quality and reduce the rate of accidents due to improved design in the workplace and construction methods. Indeed, this has established that incorporation of the concept of green building at the construction site not only helps the environment but also health, safety, and productivity of the working staff. While these advantages are apparently clear, challenges persist in fully embedding health and safety into green building practices. Most times, green building regulations are poorly complied with, and while the benefits may seem a bit apparent to senior management, workers

on-site may not fully understand or appreciate the personal health and safety advantages of green design principles. In addition, new materials and technologies associated with green buildings have introduced new risks to workers if they are not properly trained in their use. For this reason, awareness, education, and compliance with green building practices should be considerably encouraged in order to safeguard the health and safety of construction employees. The incorporation of strategies like "Prevention through Design" could further help in reaching a total avoidance of safety risks by addressing the potential for hazards during the design phase. In the end, the findings of this literature review provide evidence that green building architecture, if implemented appropriately, would ensure an integrated approach toward both environmental improvement and the health and safety of the employees in the construction industry, so as to guarantee a more sustainable and safer future for the building construction industry.

REFERENCES

Abbas, M., Farhan S., Faqir Muhammad A., Muhammad A., Tabussam T., Muhammad Shakeel B., Adnan I., Shahzad H., and Hafiz Ansar R. 2017. "Natural Polyphenols: An Overview." International Journal of Food Properties. Taylor and Francis Inc.[online],V12

Aldeek, Zaid A.O. 2020. "Green Architecture and Sustainability in the Complex Transformation of the Built Urban Environment in Jordan." International Journal of Design and Nature and Ecodynamics v.15(1)

Berniak-Woźny, Justyna, and Małgorzata R. 2023. "Towards Green and Sustainable Healthcare: A Literature Review and Research Agenda for Green Leadership in the Healthcare Sector." International Journal of Environmental Research and Public Health.[online] V.14

Clements-Croome, D., Turner, B. and Pallaris, K. 2019 'Flourishing workplaces: a multisensory approach to design and POE', *Intelligent Buildings International*, 11(3–4), pp. 131–144.

Cross, Jennifer E., Tara O.Conner S., and Adam P. M. 2017. "Putting the Green into Corrections: Improving Energy Conservation, Building Function, Safety, and Occupant Well-Being in an American Correctional Facility." Energy Research and Social Science v.32(October)

De Simone, S. 2014. Conceptualizing Wellbeing in the Workplace. *International Journal of Business and Social Science*, [online] 5(12). Available at: https://ijbssnet.com/journals/vol_5_no_12_november_2014/14.pdf.

Fagan, A. 2015. Defending corporate social responsibility: Myanmar and the lesser evil. The International Journal of Human Rights, 19(6), pp.867–882.

Heerwagen, J. "Green Buildings, Organizational Success and Occupant Productivity." Building Research & Information, vol. 28, no. 5-6, Sept. 2000, pp. 353–367.

Hui, F. and Aye, L. 2018. Occupational Stress and Workplace Design. *Buildings*, [online] 8(10), p.133.

Hwang, Bon G., Ming S., and Siong Leng P. 2018. "Safety in Green Building Construction Projects in Singapore: Performance, Critical Issues, and Improvement Solutions." KSCE Journal of Civil Engineering v.22 (2)DOI: 447–58.

Kanchana, S., P. Sivaprakash, and Sebastian J. 2015. "Studies on Labour Safety in Construction Sites." Scientific World Journal 2015. V.13.

Kyngäs, H. 2020. Inductive content analysis. In H. Kyngas, K. Mikkonen, & M. Kaariainen (Eds.), The application of content analysis in nursing science research (pp. 13–21).

Lingard, H. and Turner, M., 2023. *Work, Health and Wellbeing in the Construction Industry*. Taylor & Francis.

Manuele, F.A., 2008. Prevention through design addressing occupational risks in the design and redesign processes. *Professional Safety*, *53*(10). Rajendran, S., Gambatese, J. A., & Behm, M. G. 2009. Impact of green building design and construction on worker safety and health. Journal of construction engineering and management.

Newsham, G. R. *et al.* 2013 'Do 'green' buildings have better indoor environments? New evidence', *Building Research & Information*, 41(4), pp. 415–434.

Rajendran, S., John A G., and Michael G B. 2009. "Impact of Green Building Design and Construction on Worker Safety and Health." v.02 (2).

Sedaghati, R., and Mahdi Hosseynzadeh K. 2019. "The Effect of Green Architecture on Human Health." *International Journal of Scientific Research in Science, Engineering and Technology*, August,v0.

Smith, M., Whitelegg, J. and Williams, N.J., 2013. *Greening the built environment*. Routledge.

Steemers, K. and Manchanda, S. 2010. Energy efficient design and occupant well-being: Case studies in the UK and India. *Building and Environment*, 45(2), pp.270–278.
Tokbaevich, N.C., Dashuai, C., Korchueva, S.A., Lin, J. and Yuhao, Z. 2024. Green Architecture: Green Building Concepts to Ensure a Green Future. *E3S Web of Conferences*, [online] 533, p.02032.

Uğur, Latif O., and Neşe L. 2018. "An Examination of the LEED Green Building Certification System in Terms of Construction Costs." Renewable and Sustainable Energy Reviews.

Yas, Z. and Jaafer, K., 2020. Factors influencing the spread of green building projects in the UAE. *Journal of Building Engineering*, *27*, p.100894.

Yasir L., Mohd, Syed khursheed A., and Khubaib A. 2017. "GREEN BUILDING: CONCEPTS AND AWARENESS." International Research Journal of Engineering and Technology. www.irjet.net. v.(2).

Zuo, J., and Zhen Yu Z. 2014. "Green Building Research-Current Status and Future Agenda: A Review." Renewable and Sustainable Energy Reviews. v.22 (2).

BUILDING BETTER: THE PROMISE OF SOCIETY 5.0 FOR CONSTRUCTION INDUSTRY REFORM

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BUILDING BETTER: THE PROMISE OF SOCIETY 5.0 FOR CONSTRUCTION INDUSTRY REFORM

ABSTRACT

The construction industry is known for its complexity and numerous challenges, necessitating contemporary approaches to achieve sustainability. This research proposes Society 5.0 as a transformative framework that integrates advanced technologies with a human-centric approach to address these issues through a comprehensive literature review. By mapping 40 identified problems in the construction sector to 11 objectives of Society 5.0, including cyber-physical integration, smart environment, smart people, and intelligent decision-making, the study illustrates how this framework can offer practical solutions. The study demonstrates that Society 5.0 provides effective strategies for enhancing worker safety, cost management, and environmental sustainability. The developed integration unlocked several research areas for applying Society 5.0 principles in the construction industry to minimize prevailing problems.

Keywords: *Construction Industry; Problems; Society 5.0.*

INTRODUCTION

BACKGROUND

In the 21st century, there is a growing prominence towards a ‘global development paradigm’ (Gore 2015; Scholte & Söderbaum 2017), which goes far beyond the North-South international development (Sumner & Tribe 2008; Mönks et al. 2017). This approach advocates for a 'one-world' perspective that focusses on global prosperity through greater mutual learning, and collaborative actions across the global North and South (Marchetti 2004; McFarlane 2006; Mehta *et al.* 2006; Sumner 2011). The main reason for this transformation is the increasing number of severe global issues including resource depletion (Chaudhary & Akhtar 2024), high carbon emissions (Bai & Ru 2024; Freire-González et al. 2024), significant waste generation (Chandrappa & Das 2024; Lu et al. 2024), high energy consumption (Wang & Azam 2024; Wang et al. 2024), excessive water consumption (Dias & Ghisi 2024), noise pollution (Bouzir *et al.* 2024; Singh 2024), and the urban heat island effect (Iungman *et al.* 2024), with recent statistics indicating that the construction industry is accountable for the majority of these impacts.

Accordingly, the buildings and construction sector make a considerable contribution to global climate change, accounting for approximately 21% of worldwide greenhouse gas emissions, while in 2022, buildings were responsible for 34% of global energy consumption and 37% of energy and process-related carbon dioxide (CO2) emissions (United Nations Environment Programme 2024). Moreover, between 2015 & 2022, cumulative investments in energy efficiency in buildings were $1,050 billion less than required, while the expected cumulative growth of green building certifications was 7% points below the necessary level (Sev 2009; Khaertdinova *et al.* 2021). Other indirect impacts, including ocean warming, acidification, and plastic pollution are causing significant damage to marine ecosystems, with an estimated 17 million metric tons of plastic entering the oceans in 2021, a figure expected to double or triple by 2040 (United Nations 2023). Moreover, in 2022, 2.2 billion people lacked safely managed drinking water, 3.5 billion lacked basic handwashing facilities, and 2.2 billion lacked safely managed sanitation (United Nations 2023).

On the other hand, construction industry is currently experiencing numerous problems including low productivity (Domljan & Domljan 2024), shortage of skilled workers (Akomah *et al.* 2020), payment issues (Haron & Arazmi 2020), late instructions from architect or engineer, increasing project cost, project delays (Jaffar *et al.* 2011), shortage of materials/equipment (Caldas *et al.* 2015), additional work/variation in client's (Wambeke *et al.* 2011), design change (Aslam *et al.* 2019), poor planning and scheduling , unforeseen site conditions (Amarasekara *et al.* 2018), poor/inaccurate estimate, lack of effective communication (Gamil & Rahman 2018), cash flow issues including insufficient cash flow analysis, poor

budgetary control, inadequate supplier management, difficulties in obtaining financial support (Omopariola *et al.* 2019), vague contract terms, complex construction methods (Zou *et al.* 2007), inappropriate materials, obstacles of surrounding works, lack of experience in management and supervision (Kaming *et al.* 1997), inaccurate feasibility surveys and constraints caused by the local culture. These adverse effects highlight the thriving need for implementing a strategic approach aimed at minimising the negative impacts and problems of the construction industry, that primarily focuses on the people, as well as environmental and socio-economic sustainability.

Accordingly, Society 5.0 (S5.0) is a contemporary approach introduced by the Japanese government as one of the foremost solutions for many global issues. S5.0 is a human-centred, sustainable and technology-driven approach, that integrates cyberspace and physical space with the aim of achieving a "super smart society" (Narvaez Rojas *et al.* 2021; Magni *et al.* 2024). Moreover, S5.0 serves as the foundation for balanced economic advancement and high-quality living for all citizens, regardless of their demographics, with the ultimate goal of creating a super intelligent society (Deguchi *et al.* 2020). Furthermore, several studies have empirically demonstrated that S5.0 can enhance the achievement of sustainable development goals, particularly through enabling technologies in Industry 5.0 (I5.0) such as digital twin, virtual reality, augmented reality, blockchain, internet of things, artificial intelligence, robotics and big data analytics (da Costa Tavares & do Carmo Azevedo 2021; Zengin et al. 2021; Kasinathan et al. 2022; Mourtzis et al. 2022). Therefore, this research aims to explore how the visionary goals of Society 5.0 (S5.0) can be used to minimise the problems of the construction industry. Accordingly, there is a possibility that this approach will pave a strategic way towards sustainable construction and ultimately contribute to a prosperous and secure future for all nations.

RESEARCH PROBLEM

Numerous empirical studies emphasised that the construction industry play a vital role in achieving national, social and economic development in any country (Hillebrandt 1985; Bakhramovich 2018; Ma *et al.* 2024; Mahmood *et al.* 2024). However, the industry faces various challenges to retain in the market. Based on the background, S5.0 can be identified as a strategic model to achieve future societal development, along with high merging between cyber-physical space with the ultimate aim of improving the quality of human life. However, the implementation of this concept within the construction industry is yet to be researched, not only due to its novelty, but also because of the absence of a comprehensive framework for S5.0 implemented construction industry. Furthermore, there is a lack of studies exploring how the goals of S5.0 can overcome the problems in construction industry. Therefore, this research aims to explore the potential of overcoming the prevailing problems in the construction industry through the objectives of S5.0. Consequently, the research question is how S5.0 can be used to minimise the problems of the construction industry.

RESEARCH METHODOLOGY

This research aims to fill the knowledge gap by answering the research question, "How can Society 5.0 be used to minimize the problems in the construction industry?". Consequently, a comprehensive literature review has been carried out separately for S5.0 and construction industry problems by referring to journals, conference proceedings, books, and electronic resources. Subsequently, the literature review has been used to map these two.

LITERATURE REVIEW

SOCIETY 5.0: A VISION FOR THE FUTURE

Society has evolved from several previous revolutionary attempts (Fukuyama, 2018; Mavrodieva & Shaw, 2020; Nair, Tyagi, & Sreenath, 2021), particularly due to the transformation of energy resources and development in communication (Yıkılmaz 2020).

Accordingly, the main historical societal stages are Society 1.0 (hunting society), Society 2.0 (agrarian society), Society 3.0 (industrial society), Society 4.0 (information society) and Society 5.0 (super smart society). Following Figure 1 presents the evolution of human societies, leading to Society 5.0.

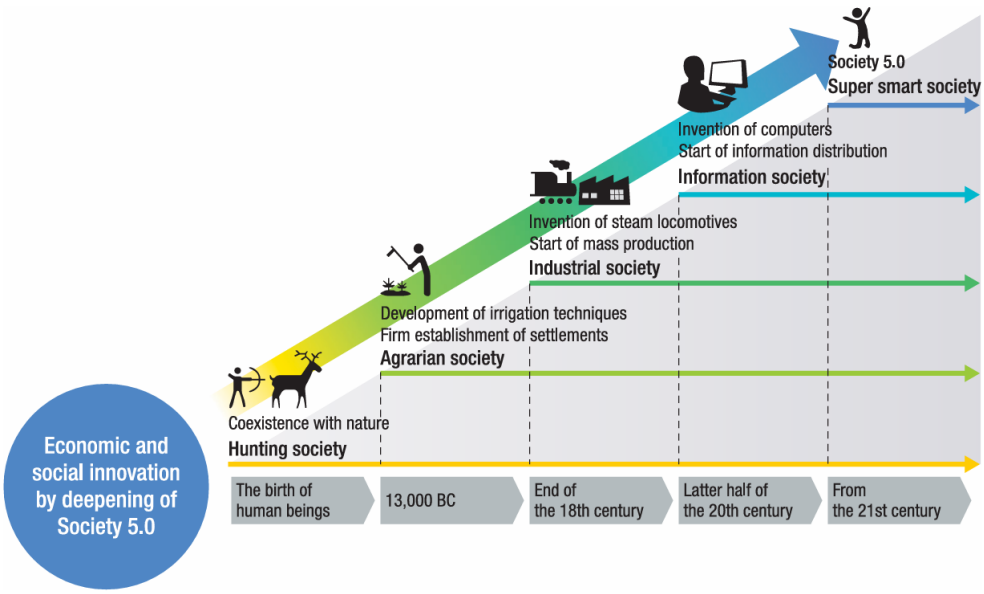

Figure 1: Evolution of Human Societies, Leading to Society 5.0 *(Source: (Fukuyama 2018)*

Accordingly, Society 1.0 refers to the hunting period, during which people lived in temporary accommodations and maintained a harmonious coexistence with nature; Society 2.0 refers to agricultural era, when humans began to settle into permanent communities and develop more complex societies; Society 3.0 refers to the period that aligns with the industrialisation where mass production has increased through the replacement of human and animal-powered systems with steam power based mechanical systems; Society 4.0 refers to the information society, where mechanical systems transitioned to automation and robotization with the increased use of electronic and information technologies (Fukuyama 2018; Yıkılmaz 2020; Nair et al. 2021; Gülen & İdil 2024).

Regarding S5.0, the key focus of this study, numerous empirical studies have presented various definitions and objectives. The concept of Society 5.0 was first introduced by the Japanese government in April 2016 as part of the Fifth Science and Technology Basic Plan as a human-centric model that integrates advanced technologies, such as artificial intelligence, big data, and the Internet of Things, to balance economic growth with societal well-being through the merging of cyber and physical spaces (Nair et al. 2021; Gülen & İdil 2024). Consequently, this study identifies the key objectives of S5.0 as follows: human-centric society, cyber-physical integration, knowledge-intensive and data-driven society, sustainability and smart environment, smart economy, intelligent technology, smart governance, smart community, smart people, intelligent decision-making, and real-time problem solving. Accordingly, this study focuses on identifying the potential to minimise the problems of the construction industry through the application of S5.0 objectives.

PROBLEMS IN THE CONSTRUCTION INDUSTRY

The construction industry in any country plays a significant role not only in economic development by generating output, creating employment, and generating income, but also in social development through the production of buildings and infrastructure (Sev 2009; Khaertdinova *et al.* 2021). Despite the numerous benefits provided by the construction industry, it faces various problems that significantly restrict the development of the industry (Ofori 2000; Alaloul *et al.* 2018), where numerous studies have presented multiple categories and perspectives on the problems within the construction industry. Accordingly, financial issues such as payment issues (Haron & Arazmi 2020), cash flow issues (Mbachu 2011), financial resource issues, and market issues (Najjir *et al.* 2012) are some of the key drawbacks of construction industry, which can lead to serious consequences that may negatively impact the overall outcome of the project (Abdul-Rahman *et al.* 2011). On the other hand, several studies highlighted that, there is a critical requirement of consciously addressing the health and safety issues in the construction industry(Lingard 2013; Oswald *et al.* 2018). Moreover, another major problem in the construction industry is its great susceptibility to unethical conduct, such as collusive tendering, bribery, and corruption due to conflicts of interest (Adnan *et al.* 2012). In addition to that, numerous environmental issues create significant negative impacts, ranging from the excavation phase of the construction project to the waste produced by the project (Dräger & Letmathe 2022; Sandanayake 2022). Accordingly, by referring to numerous studies, the following problems have been identified as key issues in the construction industry, as demonstrated in Table 1.

Table 1: Problems in the Construction Industry

No.	Problems of the Construction Industry	References	No.	Problems of the Construction Industry	References
A	**Financial Problems**		**B**	**Project Delays and Time Overruns**	
A1	Inaccurate cost estimate	[1], [2], [3], [4]	B1	Additional works due to changes to the approved plan	[6]
A2	Negative variation in material and machine prices	[4], [5], [6]	B2	Design changes during the construction stage	[6], [15], [16]
A3	Fluctuations in labour costs	[7]	B3	Unforeseen site conditions	[3], [17], [18]
A4	Insufficient financial resources	[6], [8], [9], [22], [23], [24]	B4	Delays in material delivery	[19], [20], [21], [22]
A5	Late payments	[10], [11], [12]	B5	Poor site management and supervision	[20], [22]
A6	Poor cash flow management	[13], [14]	B6	Equipment availability and failure	[19], [20]
C	**Health and Safety Problems**		B7	Adverse weather conditions	[6], [21], [22], [23], [25]
C1	Inadequate use of personal protective equipment	[30], [31], [32], [33]	B8	Poor skills and experience of labour	[6], [22], [23], [24]
C2	Inadequate training and education programs	[31], [32]	B9	Slow decision-making procedure	[22], [23], [24], [25]
C3	Use of defective tools and machines	[30], [32], [33]	**D**	**Quality Problems**	
C4	Negligence and carelessness of workers	[30], [32], [33]	D1	Complex construction methods	[5], [6]
C5	Unsafe working conditions and practices	[30], [32], [33]	D2	Insufficient tolerance information in specifications	[26], [27]

E	Environmental Problems		D3	Poor workmanship	[19], [28], [29]
E1	Waste generation	[34],[35],[36], [37],[38],[39]	D4	Ineffective quality control documents	[28]
E2	Noise pollution	[34],[35],[37],[38]	**F**	**Other problems**	
E3	Air pollution	[35], [37],[39]	F1	Changes in government policies	[5], [6]
E4	Water pollution	[35], [37]	F2	Vague contract terms	[4], [5], [6]
E5	Land pollution	[35], [37],[38]	F3	Shortage of materials	[5], [6]
E6	Dust Generation from construction activities	[34],[35],[36], [38],[39]	F4	Lack of experience in management and supervision	[6]
E7	Greenhouse gas emissions	[34],[35],[37],[38]	F5	Poor communication	[26], [27]
E8	Operations with high potential soil erosion	[34],[35],[37],[38]	F6	Incomplete documents/ drawings	[20]
			F7	Ineffective planning and scheduling	[19], [21]
			F8	Labour shortage	[19]

[1] (Ekung *et al.* 2021), [2] (Oparin *et al.* 2016), [3] (Akintoye & MacLeod 1997), [4] (Gransberg & Riemer 2009), [5] (Zou *et al.* 2007), [6] (Le-Hoai *et al.* 2008), [7] (Esfahani & Shahandashti 2020), [8] (Kaming *et al.* 1997), [9] (Abdul-Rahman *et al.* 2006), [10] (Peters *et al.* 2019), [11] (Bolton *et al.* 2022), [12] (Abdul-Rahman *et al.* 2014), [13] (Al-Joburi *et al.* 2012), [14] (Shash & Qarra 2018), [15] (Aslam *et al.* 2019), [16] (Yap *et al.* 2016), [17] (Amarasekara *et al.* 2018), [18] (Kumaraswamy & Chan 1998), [19] (Thapanont *et al.* 2018), [20] (Mukuka *et al.* 2015), [21] (Kog 2018), [22] (Alaghbari *et al.* 2007), [23] (Mahamid *et al.* 2012), [24] (Akogbe *et al.* 2013), [25] (Larsen *et al.* 2016), [26] (Milberg & Tommelein 2020), [27] (Talebi *et al.* 2020), [28] (Shammas-Toma *et al.* 1996), [29] (Seymour *et al.* 1997), [30] (Abdelhamid & Everett 2000), [31] (Alkilani *et al.* 2013), [32] (Hamid *et al.* 2018), [33] (Kadiri et al. 2014.), [34] (Muhwezi *et al.* 2012), [35] (Zolfagharian *et al.* 2012), [36] (Li *et al.* 2010), [37] (Gangolells *et al.* 2009), [38] (Gangolells *et al.* 2011), [39] (Tam *et al.* 2000)

Numerous studies have categorised the problems in the construction industry in various ways, and this study adopts six main categories commonly identified by many researchers: financial problems, project delays and time overruns, health and safety concerns, quality issues, environmental challenges, and other issues. As indicated in Table 1, this study identifies 40 key problems which are collectively exerted a significant negative influence on the construction industry. Accordingly, financial issues, such as late payments and poor cash flow, often lead to project delays and cost overruns, while health and safety concerns, including inadequate training and unsafe working conditions, reduce workforce productivity and increase accident risks. Additionally, poor quality control and environmental challenges, such as waste generation and pollution, further degrade project outcomes. These widespread problems, as evidenced by multiple studies, result in higher operational costs, reduced efficiency, and extended project timelines, ultimately threatening the industry's long-term sustainability and profitability.

LITERATURE FINDINGS

Combining all the literature findings of the study, the application of S5.0 objectives is comprehensively described in relation to minimising the problems faced by the construction industry. These findings are indicated in Table 2, which presents the 11 S5.0 objectives categorized as follows: human-centric society, cyber-physical integration, knowledge-intensive and data-driven society, sustainability and smart environment, smart economy, intelligent technology, smart governance, smart community, smart people, intelligent decision-making, and real-time problem solving. The identified impacts of these objectives were then correlated to the problems within the construction industry, categorised into six groups: financial problems, project delays and time overruns, quality issues, health and safety concerns, environmental challenges, and other related problems, as outlined in the Table 2.

Table 2: Addressing Construction Industry Problems through the Integration of S5.0 objectives

Visionary Goals of S5.0	Problems in the Construction Industry													
Human-Centric Society	C2	C4	C5											
Cyber-Physical Integration	B1	B2	B3	F5	F7									
Knowledge-Intensive & Data-Driven Society	A1	A4	B3	B5	B8	C2	D1	D2	D4	F4	F6			
Sustainability and Smart Environment	B7	E1	E2	E3	E4	E5	E6	E7	E8					
Smart Economy	A1	A2	A3	A4	A5	A6	F3	F8						
Intelligent Technology	B4	B6	C3	D1	D4	F3								
Smart Governance	B5	B9	C3	C4	F1	F2	F4	F5						
Smart Community	E2	F5												
Smart People	B5	B8	C1	C2	C3	C4	D3							
Intelligent Decision	A1	A2	A3	A6	B1	B9	D2	F6						
Real-Time Problem Solving	A1	A2	A3	A4	A6	B1	B2	B3	B4	B6	C2	C4	D4	F3

According to Table 2, a **human-centric society** focuses on addressing problems such as workers negligence and carelessness, unsafe working conditions, inadequate training. This is achieved by encouraging the industry to prioritise worker safety, well-being, and quality of life while simultaneously adapting to better working conditions, proper safety standards, and methodical training programs. Moreover, **cyber-physical integration** will help to reduce human errors, improve efficiency, and perform better management of complexities through real-time monitoring and automation. It helps to address problems such as design changes, ineffective planning and scheduling, and variations. According to the Table 2, a **knowledge-intensive and data-driven society**, can overcome problems such as inaccurate cost estimate, complex construction methods, poor labour skills and experience, lack of experience in management and supervision and poor workmanship by utilising big data, artificial intelligence and other modeling tools. Furthermore, the focus of **sustainability and smart environment** is to create a sustainable environment where pollution, waste generation, greenhouse gas emissions, and soil erosion caused by construction activities are minimized.

According to Table 2, **smart economy** helps overcome problems related to insufficient financial resources, labour and material shortages, fluctuations in material and machine prices, thereby promoting economic efficiency and productivity. Moreover, **intelligent technology** addresses problems such as delays in material delivery, defective tools and machines, and equipment availability and failure by utilizing robotics, artificial intelligence, and Internet of Things to optimize quality and productivity. On the other hand, **smart governance** enhances transparency and decision-making by integrating intelligent systems into regulatory and management processes. Similarly, **smart community and smart people** aim to address issues such as inadequate use of personal protective equipment, poor site management and supervision, poor workmanship, and poor communication through a collaborative approach and continuous learning. Moreover, **intelligent decision-making** and **real-time problem solving** involve utilizing novel technologies such as big data, artificial intelligence, the Internet of Things, blockchain, and virtual reality in the construction industry to address issues related to ineffective planning and scheduling, design changes, and vague contract terms, thereby reducing delays and inefficiencies. Accordingly, this demonstrates that the majority of problems in the construction industry can be resolved through the integration of the S5.0 concept. However, there is a need to conduct a proper empirical investigation to identify the exact relationships between these problems and S5.0.

CONCLUSION

The construction industry is widely recognised for its complexity and unique nature, which has made the industry one of the most problematic industries all over the world. It is not only one of the most challenging industries but also accountable for the majority of global issues. In response to these issues, sustainable development has become integral to modern construction practices, aiming to enhance social, economic, and environmental outcomes. S5.0 offers a contemporary framework that integrates novel technologies and

a human-centric approach to address these challenges. This research illustrates that S5.0's objectives ranging from cyber-physical integration to intelligent decision-making can effectively resolve a wide range of prevailing problems in the industry, including those related to worker safety, cost management, and environmental impact.

By mapping 40 identified construction industry problems to the 11 objectives of S5.0, this study provides evidence of its potential to address and mitigate these issues. By incorporating innovative solutions and a focus on human-centric approaches, S5.0 offers practical methods for overcoming existing barriers. This integration creates the foundation to enhance efficiency, safety, and sustainability in construction practices. This research not only underscores the transformative potential of S5.0 but also sets a foundation for further investigation and practical implementation of these advanced solutions in the construction sector. However, as this study is based on existing literat ure and related articles, the findings have not yet been empirically tested. Therefore, an empirical investigation needs to be carried out to identify the exact methods to minimise the problems in the construction industry through the integration of S5.0. Accordingly, the empirical investigation of minimising the problems in the construction industry through the integration of S5.0 will be the next phase of this research study.

REFERENCES

Abdelhamid, T. S. and Everett, J. G., 2000. Identifying Root Causes of Construction Accidents. *Journal of Construction Engineering and Management*, 126 (1), 52–60.

Abdul-Rahman, H., Berawi, M. A., Berawi, A. R., Mohamed, O., Othman, M. and Yahya, I. A., 2006. Delay Mitigation in the Malaysian Construction Industry. *Journal of Construction Engineering and Management*, 132 (2), 125–133.

Abdul-Rahman, H., Kho, M. and Wang, C., 2014. Late Payment and Nonpayment Encountered by Contracting Firms in a Fast-Developing Economy. *Journal of Professional Issues in Engineering Education and Practice*, 140 (2).

Abdul-Rahman, H., Wang, C., Takim, R. and Wong, S., 2011. Project Schedule Influenced by Financial Issues: Evidence in Construction Industry. *Scientific Research and Essays*, 6 (1), 205–212.

Adnan, H., Hashim, N., Mohd, N., Yusuwan and Ahmad, N., 2012. Ethical Issues in the Construction Industry: Contractor's Perspective. *Procedia - Social and Behavioral Sciences*, 35, 719–727.

Akintoye, A. S. and MacLeod, M. J., 1997. Risk Analysis and Management in Construction. *International Journal of Project Management*, 15 (1), 31–38.

Akogbe, R.-K. T. M., Feng, X. and Zhou, J., 2013. Importance and Ranking Evaluation of Delay Factors for Development Construction Projects in Benin. *KSCE Journal of Civil Engineering*, 17 (6), 1213–1222.

Akomah, B. B., Ahinaquah, L. K. and Mustapha, Z., 2020. Skilled Labour Shortage in the Building Construction Industry Within the Central Region. *Baltic Journal of Real Estate Economics and Construction Management*, 8 (1), 83–92.

Alaghbari, W., Razali A. Kadir, Mohd., Salim, A. and Ernawati, 2007. The significant Factors Causing Delay of Building Construction Projects in Malaysia. *Engineering, Construction and Architectural Management*, 14 (2), 192–206.

Alaloul, W. S., Liew, M. S., Zawawi, N. A. W. A. and Mohammed, B. S., 2018. Industry Revolution IR 4.0: Future Opportunities and Challenges in Construction Industry. *MATEC Web of Conferences*, 203, 02010.

Al-Joburi, K. I., Al-Aomar, R. and Bahri, M. E., 2012. Analyzing the Impact of Negative Cash Flow on Construction Performance in the Dubai Area. *Journal of Management in Engineering*, 28 (4), 382–390.

Alkilani, S. Z., Jupp, J. and Sawhney, A., 2013. Issues of Construction Health and Safety in Developing Countries: A case of Jordan. *Australasian Journal of Construction Economics and Building*, 13 (3), 141–156.

Amarasekara, W. D. L., Perera, B. A. K. S. and Rodrigo, M. N. N., 2018a. Impact of Differing Site Conditions on Construction Projects. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 10 (3).

Amarasekara, W. D. L., Perera, B. A. K. S. and Rodrigo, M. N. N., 2018b. Impact of Differing Site Conditions on Construction Projects. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 10 (3).

Aslam, M., Baffoe-Twum, E. and Saleem, F., 2019. Design Changes in Construction Projects – Causes and Impact on the Cost. *Civil Engineering Journal*, 5 (7), 1647–1655.

Bai, J. and Ru, H., 2024. Carbon Emissions Trading and Environmental Protection: International Evidence. *Management Science*, 70 (7), 4593–4603.

Bakhramovich, I. A., 2018. The Importance of Construction Services in Socio-Economic Development of the Region. *International Journal of Management and Fuzzy Systems*, 4 (2), 24.

Bolton, S., Wedawatta, G., Wanigarathna, N. and Malalgoda, C., 2022. Late Payment to Subcontractors in the Construction Industry. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 14 (4).

Bouzir, T. A. K., Berkouk, D., Barrigón Morillas, J. M., Rey-Gozalo, G. and Montes González, D., 2024. Noise Pollution Studies in the Arab World: A Scientometric Analysis and Research Agenda. *Sustainability*, 16 (11), 4350.

Caldas, C. H., Menches, C. L., Reyes, P. M., Navarro, L. and Vargas, D. M., 2015. Materials Management Practices in the Construction Industry. *Practice Periodical on Structural Design and Construction*, 20 (3).

Chandrappa, R. and Das, D. B., 2024. *Solid Waste Management. Environmental Science and Engineering.* Springer, Cham.

Chaudhary, A. and Akhtar, A., 2024. A Novel Approach for Environmental Impact Assessment of Road Construction Projects in India. *Environmental Impact Assessment Review*, 106, 107477.

da Costa Tavares, M.D.C. and do Carmo Azevedo, G.M., (2021). Society 5.0 as a Contribution to the Sustainable Development Report. In: de Carvalho, J.V., Rocha, Á., Liberato, P., Peña, A. ed. *International Conference on Tourism, Technology and Systems 2020,* Colombia. 29-31 October 2020. Singapore: Springer 49-63.

Deguchi, A., Hirai, C., Matsuoka, H., Nakano, T., Oshima, K., Tai, M. and Tani, S., 2020. *Society 5.0*. Singapore: Springer.

Dias, T. F. and Ghisi, E., 2024. Urban Water Consumption: A Systematic Literature Review. *Water*, 16 (6), 838.

Domljan, I., Domljan, V. 2024. Major Challenges in the Construction Industry. In: Karabegovic, I., Kovačević, A., Mandzuka, S. eds. *New Technologies, Development and Application NT 2024.* Sarajevo, 20-22 June 2024. Switerland: Springer Cham, 396-403.

Dräger, P. and Letmathe, P., 2022. Value Losses and Environmental Impacts in the Construction Industry – Tradeoffs or Correlates? *Journal of Cleaner Production*, 336, 130435.

Ekung, S., Adeniran, L. and Adu, E., 2021. Critical Risks to Construction Cost Estimation. *Journal of Engineering, Project, and Production Management*.

Esfahani, A. N. and Shahandashti, M., 2020. Post-hazard Labor Wage Fluctuations: A Comparative Empirical Analysis Among Different Sub-sectors of the U.S. Construction Sector. *Journal of Financial Management of Property and Construction*, 25 (3), 313–330.

Freire-González, J., Rosa, P. E. and Raymond, J. L., 2024. World Economies' Progress in Decoupling from CO2 Emissions. *Scientific Reports*, 14 (1), 20480.

Fukuyama, M., 2018. Society 5.0: Aiming for a New Human-centered Society. *Japan Spotlight*.

Gamil, Y. and Rahman, A. I., 2018. Identification of Causes and Effects of Poor Communication in Construction Industry: A Theoretical Review. *Emerging Science Journal*, 1 (4).

Gangolells, M., Casals, M., Gassó, S., Forcada, N., Roca, X. and Fuertes, A., 2009. A Methodology for Predicting the Severity of Environmental Impacts Related to the Construction Process of Residential Buildings. *Building and Environment*, 44 (3), 558–571.

Gangolells, M., Casals, M., Gassó, S., Forcada, N., Roca, X. and Fuertes, A., 2011. Assessing concerns of Interested Parties When Predicting the Significance of Environmental Impacts Related to the Construction Process of Residential Buildings. *Building and Environment*, 46 (5), 1023–1037.

Gore, C., 2015. The Post-2015 Moment: Towards Sustainable Development Goals and a New Global Development Paradigm. *Journal of International Development*, 27 (6), 717–732.

Gransberg, D. D. and Riemer, C., 2009. Impact of Inaccurate Engineer's Estimated Quantities on Unit Price Contracts. *Journal of Construction Engineering and Management*, 135 (11), 1138–1145.

Gülen, S. and İdil, Ş., 2024. Towards A New Societal Paradigm: The Components, Challenges, and Opportunities of Society 5.0. *Journal of STEAM Education*, 7 (2), 55–73.

Hamid, A. R. A., Majid, M. Z. A. and Singh, B., 2018. Causes of Accidents at Construction Sites. *Malaysian Journal of Civil Engineering*, 20 (2), 242–259.

Haron, C., R. and Arazmi, A. L., 2020. Late Payment Issues of Subcontractors in Malaysian Construction Industry. *Planning Malaysia*, 18 (11).

Hillebrandt, P. M., 1985. The Nature of Construction Economics. *In*: *Economic Theory and the Construction Industry*. London: Palgrave Macmillan UK, 3–9.

Iungman, T., Khomenko, S., Barboza, E. P., Cirach, M., Gonçalves, K., Petrone, P., Erbertseder, T., Taubenböck, H., Chakraborty, T. and Nieuwenhuijsen, M., 2024. The Impact of Urban Configuration Types on Urban Heat Islands, Air Pollution, CO2 emissions, and Mortality in Europe: A Data Science Approach. *The Lancet Planetary Health*, 8 (7), e489–e505.

Jaffar, N., Tharim, A. H. A. and Shuib, M. N., 2011. Factors of Conflict in Construction Industry: A Literature Review. *Procedia Engineering*, 20, 193–202.

Kaming, P. F., Olomolaiye, P. O., Holt, G. D. and Harris, F. C., 1997. Factors Influencing Construction Time and Cost Overruns on High-Rise Projects in Indonesia. *Construction Management and Economics*, 15 (1), 83–94.

Kasinathan, P., Pugazhendhi, R., Elavarasan, R. M., Ramachandaramurthy, V. K., Ramanathan, V., Subramanian, S., Kumar, S., Nandhagopal, K., Raghavan, R. R. V., Rangasamy, S., Devendiran, R. and Alsharif, M. H., 2022. Realization of Sustainable Development Goals with Disruptive Technologies by Integrating Industry 5.0, Society 5.0, Smart Cities and Villages. *Sustainability*, 14 (22), 15258.

Khaertdinova, A., Maliashova, A. and Gadelshina, S., 2021. Economic Development of the Construction Industry as a Basis for Sustainable Development of the Country. In: *E3S Web of Conferences*, 274, 10021.

Kog, C., Y., 2018. Major Construction Delay Factors in Portugal, the UK, and the US. *Practice Periodical on Structural Design and Construction*, 23 (4).

Kumaraswamy, M. M. and Chan, D. W. M., 1998. Contributors to construction delays. *Construction Management and Economics*, 16 (1), 17–29.

Larsen, J. K., Shen, G. Q., Lindhard, S. M. and Brunoe, T. D., 2016. Factors Affecting Schedule Delay, Cost Overrun, and Quality Level in Public Construction Projects. *Journal of Management in Engineering*, 32 (1).

Le-Hoai, L., Lee, Y. D. and Lee, J. Y., 2008. Delay and Cost Overruns in Vietnam Large Construction Projects: A Comparison with Other Selected Countries. *KSCE Journal of Civil Engineering*, 12 (6), 367–377.

Li, X., Zhu, Y. and Zhang, Z., 2010. An LCA-Based Environmental Impact Assessment Model for Construction Processes. *Building and Environment*, 45 (3), 766–775.

Lingard, H., 2013. Occupational Health and Safety in the Construction Industry. *Construction Management and Economics*, 31 (6), 505–514.

Lu, M., Zhou, C., Wang, C., Jackson, R. B. and Kempes, C. P., 2024. Worldwide Scaling of Waste Generation in Urban Systems. *Nature Cities*, 1 (2), 126–135.

Ma, R., Sun, J. and Yin, J., 2024. Research on the Impact Mechanism of Smart City Construction on Economic Growth—An Analysis Based on the Schumpeterian Innovation Theory Framework. *Systems*, 12 (7), 251.

Magni, D., Del Gaudio, G., Papa, A. and Della Corte, V., 2024. Digital Humanism and Artificial Intelligence: The Role of Emotions Beyond the Human–Machine Interaction in Society 5.0. *Journal of Management History*, 30 (2), 195–218.

Mahamid, I., Bruland, A. and Dmaidi, N., 2012. Causes of Delay in Road Construction Projects. *Journal of Management in Engineering*, 28 (3), 300–310.

Mahmood, S., Misra, P., Sun, H., Luqman, A. and Papa, A., 2024. Sustainable infrastructure, Energy Projects, and Economic Growth: Mediating Role of Sustainable Supply Chain Management. *Annals of Operations Research*.

Marchetti, Raffaele., 2004. Peter Singer, One World: The Ethics of Globalization. *Utilitas*, 16 (3), 332–334.

Mavrodieva, A. V. and Shaw, R., 2020. Disaster and Climate Change Issues in Japan's Society 5.0—A Discussion. *Sustainability*, 12 (5), 1893.

Mbachu, J., 2011. Sources of Contractor's Payment Risks and Cash Flow Problems in the New Zealand Construction Industry: Project Team's Perceptions of the Risks and Mitigation Measures. *Construction Management and Economics*, 29 (10), 1027–1041.

McFarlane, C., 2006. Crossing Borders: Development, Learning and the North – South Divide. *Third World Quarterly*, 27 (8), 1413–1437.

Mehta, L., Haug, R. and Haddad, L., 2006. Reinventing development research. *Forum for Development Studies*, 33 (1), 143–148.

Milberg, C. T. and Tommelein, I. D., 2020. Methods for Managing Tolerance Compatibility: Windows in Cast-in-Place Concrete. *Journal of Construction Engineering and Management*, 146 (2).

Mönks, J., Carbonnier, G., Mellet, A. and de Haan, L., 2017. Towards a Renewed Vision of Development Studies. *Revue internationale de politique de développement*, (8.1).

Mourtzis, D., Angelopoulos, J. and Panopoulos, N., 2022. A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. *Energies*, 15 (17), 6276.

Muhwezi, L., Kiberu, F., Kyakula, M. and Batambuze, A. O., 2012. An Assessment of the Impact of Construction Activities on the Environment in Uganda: A Case Study of Iganga Municipality. *Journal of Construction Engineering and Project Management*, 2 (4), 20–24.

Mukuka, M., Aigbavboa, C. and Thwala, W., 2015. Effects of Construction Projects Schedule Overruns: A Case of the Gauteng Province, South Africa. *Procedia Manufacturing*, 3, 1690–1695.

Nair, M. M., Tyagi, A. K. and Sreenath, N., 2021. The Future with Industry 4.0 at the Core of Society 5.0: Open Issues, Future Opportunities and Challenges. *In*: *2021 International Conference on Computer Communication and Informatics (ICCCI)*. IEEE, 1–7.

Najjir, G., Love, P. and Runeson, G., 2012. Issues for the Global Construction Market. *Construction Economics and Building*, 1 (2), 73–81.

Narvaez Rojas, C., Alomia Peñafiel, G. A., Loaiza Buitrago, D. F. and Tavera Romero, C. A., 2021. Society 5.0: A Japanese Concept for a Superintelligent Society. *Sustainability*, 13 (12), 6567.

Kadiri, Z.O., Nden, T., Avre, G.K., Oladipo, T.O., Edom, A., Samuel, P.O. and Ananso, G.N., 2014. Causes and Effects of Accidents on Construction Sites (A Case Study of Some Selected Construction Firms in Abuja FCT Nigeria). *IOSR Journal of Mechanical and Civil Engineering*, 11(5), 66-72.

Ofori, G., 2000. Globalization and Construction Industry Development: Research Opportunities. *Construction Management and Economics*, 18 (3), 257–262.

Omopariola, E. D., Windapo, A., Edwards, D. J. and Thwala, W. D., 2019. Contractors' Perceptions of the Effects of Cash Flow on Construction Projects. *Journal of Engineering, Design and Technology*, 18 (2), 308–325.

Oparin, S., Chepachenko, N. and Yudenko, M., 2016. Problems in Forming Cost Estimates for Construction Industry. *CBU International Conference Proceedings*, 4, 179–186.

Oswald, D., Sherratt, F. and Smith, S., 2018. Problems with Safety Observation Reporting: A Construction Industry Case Study. *Safety Science*, 107, 35–45.

Peters, E., Subar, K. and Martin, H., 2019. Late Payment and Nonpayment within the Construction Industry: Causes, Effects, and Solutions. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 11 (3).

Sandanayake, M. S., 2022. Environmental Impacts of Construction in Building Industry—A Review of Knowledge Advances, Gaps and Future Directions. *Knowledge*, 2 (1), 139–156.

Scholte, J. A. and Söderbaum, F., 2017. A Changing Global Development Agenda? *Forum for Development Studies*, 44 (1), 1–12.

Sev, A., 2009. How Can the Construction Industry Contribute to Sustainable Development? A Conceptual Framework. *Sustainable Development*, 17 (3), 161–173.

Seymour, D., Shammas Toma, M. and Clark, L., 1997. Limitations of the Use of Tolerances for Communicating Design Requirements to Site. *Engineering, Construction and Architectural Management*, 4 (1), 3–22.

Shammas-Toma, M., Seymour, D. E. and Clark, L., 1996. The Effectiveness of Formal Quality Management Systems in Achieving the Required Cover in Reinforced Concrete. *Construction Management and Economics*, 14 (4), 353–364.

Shash, A. A. and Qarra, A. Al, 2018. Cash Flow Management of Construction Projects in Saudi Arabia. *Project Management Journal*, 49 (5), 48–63.

Singh, V., 2024. Noise Pollution. *In*: *Textbook of Environment and Ecology*. Singapore: Springer Nature Singapore, 275–281.

Sumner, A., 2011. The Global Economic Crisis and Beyond: What Possible Future(s) for Development Studies? *The European Journal of Development Research*, 23 (1), 43–58.

Sumner, A. and Tribe, M., 2008. *International Development Studies: Theories and Methods in Research and Practice*. London: SAGE Publications Ltd.

Talebi, S., Koskela, L., Tzortzopoulos, P., Kagioglou, M. and Krulikowski, A., 2020. Deploying Geometric Dimensioning and Tolerancing in Construction. *Buildings*, 10 (4), 62.

Tam, C. M., Deng, Z. M., Zeng, S. X. and Ho, C. S., 2000. Quest for Continuous Quality Improvement for Public Housing Construction in Hong Kong. *Construction Management and Economics*, 18 (4), 437–446.

Thapanont, P., Santi, C. and Pruethipong, X., 2018. Causes of Delay on Highway Construction Projects in Thailand. *MATEC Web of Conferences*, 192, 02014.

United Nations, 2023. *The Sustainable Development Goals Report*.

United Nations Environment Programme, 2024. *2023 Global Status Report for Buildings and Construction: Beyond foundations - Mainstreaming sustainable solutions to cut emissions from the buildings sector*.

Wambeke, B. W., Hsiang, S. M. and Liu, M., 2011. Causes of Variation in Construction Project Task Starting Times and Duration. *Journal of Construction Engineering and Management*, 137 (9), 663–677.

Wang, J. and Azam, W., 2024. Natural Resource Scarcity, Fossil Fuel Energy Consumption, and Total Greenhouse Gas Emissions In Top Emitting Countries. *Geoscience Frontiers*, 15 (2), 101757.

Wang, X., Lu, Y., Chen, C., Yi, X. and Cui, H., 2024. Total-Factor Energy Efficiency of Ten Major Global Energy-Consuming Countries. *Journal of Environmental Sciences*, 137, 41–52.

Yap, J. B. H., Abdul-Rahman, H. and Wang, C., 2016. A Conceptual Framework for Managing Design Changes in Building Construction. In; *MATEC Web of Conferences*, 66, 00021.

Yıkılmaz, I., 2020. New era: The Transformation from the Information Society to Super Smart Society (society 5.0). *Data, Information and Knowledge Management*, 85–112.

Zengin, Y., Naktiyok, S., Kaygın, E., Kavak, O. and Topçuoğlu, E., 2021. An Investigation upon Industry 4.0 and Society 5.0 within the Context of Sustainable Development Goals. *Sustainability*, 13 (5), 2682.

Zolfagharian, S., Nourbakhsh, M., Irizarry, J., Ressang, A. And Gheisari, M., 2012. Environmental Impacts Assessment on Construction Sites. *In*: *Construction Research Congress 2012*. Reston, VA: American Society of Civil Engineers, 1750–1759.

Zou, P. X. W., Zhang, G. and Wang, J., 2007. Understanding the Key Risks in Construction Projects in China. *International Journal of Project Management*, 25 (6), 601–614.