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DEVELOPING A YOUNG INVENTREPRENEUR THRU FORWARD LEARNING APPROACH

Nagappan Annamalai

Abstract

This paper explores the enhancement of creative problem-solving skills in young minds using the License 2 Inventrepreneur (L2I) method, which aligns with national education goals. The study provides a detailed introduction to the L2I framework and its practical application through case studies involving elementary students. Methodologies employed include design thinking and TRIZ (Theory of Inventive Problem Solving). Data collected from the pilot program indicate substantial improvements in the inventrepreneurial skills of students. The findings suggest that the combination of comprehensive mentorship and hands-on projects within the L2I method significantly boosts students' abilities to devise innovative solutions.

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Index forward learning, Inventrepreneur, Problem solving, Thinking out of box, TRIZ

1.0 INTRODUCTION

The development of young inventrepreneurs through a forward learning approach is a crucial aspect of preparing the next generation for success in an ever-evolving world of creativity, technology, and innovation (Ho *et al.,* 2018). Utilising an integrated strategy that combines invention and entrepreneurship education, marketing, and the fostering of soft skills empowers young generations to cultivate an inventrepreneurial mindset, enabling them to thrive in an increasingly competitive global economy.

National education goals emphasise raising the creative capabilities of young minds, a necessity in today's rapidly changing world. The acquisition of core inventrepreneurship competencies is instrumental in nurturing young minds to become critical and creative thinkers. These competencies enhance scientific literacy and stimulate creativity, encouraging students to become inventive. However, there is a pervasive lack of familiarity among teachers regarding inventrepreneurship and its classroom importance. Teachers require further professional development to improve their competencies in designing and implementing inventrepreneurship curricula that align with national standards.

Furthermore, teachers should possess a foundational reserve of STEAM (Science, Technology, Engineering, Art, and Mathematics) interdisciplinary knowledge to guide students in thinking creatively and solving practical problems. STEAM education, an interdisciplinary approach, provides young minds with opportunities to apply academic concepts in real-world contexts, fostering critical thinking, reasoning, teamwork, and investigation skills. These skills, alongside 21st-century skills such as creativity, communication, and collaboration, are essential for young minds to succeed in the modern workforce and remain competitive in the era of information and knowledge.

In response to this educational imperative, public schools are increasingly focusing on enhancing instruction and facilitating connections between student achievement and career interests in mathematics and science. Recognising the importance of preparing students for the demands of the 21st-century workforce, many federal and state agencies are funding STEAM and inventrepreneurship education programs and research. This initiative positions Malaysia as a potential global leader in invention and entrepreneurship competitiveness.

Given this context, it is crucial for teachers to possess comprehensive STEAM interdisciplinary knowledge and skills to guide young minds in thinking creatively and solving practical problems. Consequently, further professional development is necessary for teachers to effectively incorporate inventrepreneurship learning in the classroom, nurturing scientific literacy and creative thinking abilities among young students. As noted by Osman and Saat (2014), "all young minds need to develop their capabilities in science, technology, engineering, art, and mathematics to levels much beyond what was considered acceptable in the past."

Recognising this need, the License 2 Inventrepreneur (L2I) method was developed to nurture creative thinking skills. L2I is a structured educational framework designed to foster inventrepreneurial skills among young minds. This method integrates elements of design thinking, creative problem-solving methodologies such as TRIZ (Theory of Inventive Problem Solving), and entrepreneurship principles. By providing students with the necessary tools and mindset, L2I aims to empower them to innovate and develop solutions aligned with real-world challenges.

TRIZ provides structured methodologies for systematically generating creative solutions. Within the L2I method, TRIZ principles help young minds identify and solve contradictions,

thereby enhancing the effectiveness of the problem-solving process.

In conclusion, developing young inventrepreneurs through the L2I method aligns with national education goals and addresses the demands of an innovation-driven future. Investing in comprehensive professional development for educators and integrating forward learning approaches in education are essential steps towards equipping young minds with the skills necessary to navigate and succeed in the 21st-century landscape.

The L2I method employs a comprehensive approach to foster creativity, problem-solving, and entrepreneurial skills among young minds. This method integrates various educational components, as illustrated in Figure 1.

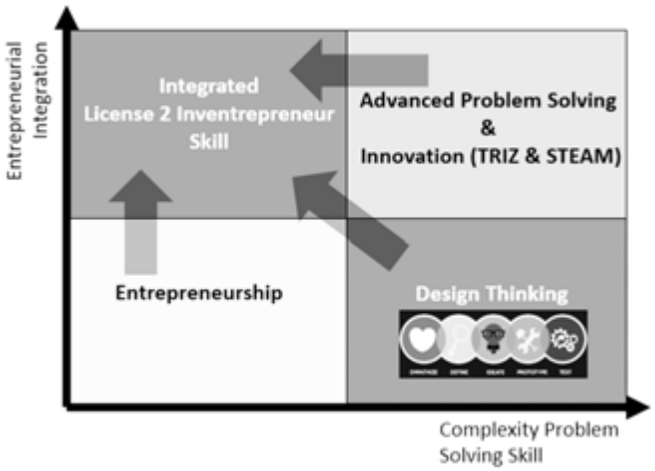

Figure 1: Integrated educational framework for young inventrepreneurs

Each quadrant addresses a unique aspect of the educational approach: 1) Entrepreneurship - focuses on fundamental entrepreneurial skills such as business planning and financial literacy. 2) Design Thinking - encourages empathetic and creative problem-solving through stages like empathise, define, ideate, prototype, and test. 3) Advanced Problem Solving & Innovation which incorporates TRIZ elements and STEAM principles to tackle complex problems with innovative solutions. And finally, 4) Integrated License 2 Inventrepreneur Skills - represents the holistic integration of entrepreneurship and advanced problem-solving methodologies.

By integrating the L2I method into the forward learning approach, educational institutions can create a robust framework that prepares students for future challenges. This comprehensive strategy not only nurtures academic knowledge but also fosters innovation, creativity, and entrepreneurial spirit, thereby developing well-rounded individuals.

2.0 FORWARD LEARNING APPROACH

Young inventrepreneurs are a crucial component of our future economy. Nurturing their interest in innovation and business from an early age is pivotal for their development. Forward learning approaches center on promoting critical thinking, problem-solving skills, and creativity. By integrating real-world challenges and addressing them through programs like Young Entrepreneur in the elementary curriculum, young minds can think outside the box and gain a profound understanding of the practical application of their knowledge (Martin, 2015).

One effective method to foster young inventrepreneurs is to provide them with mentorship opportunities and hands-on experiences. Encouraging students to explore their interests and passions while guiding them through the process of bringing their ideas to life can have a transformative impact. Moreover, imparting knowledge about business fundamentals such as market research, technology trends, product development, costing (profit and loss), and marketing strategies equips them with the essential skills needed to succeed as future entrepreneurs.

An entrepreneurial mindset is cultivated by fostering resilience, adaptability, and a willingness to take calculated risks. It is critical to create an environment where failure is seen as a learning opportunity, and where persistence and determination are celebrated.

By embracing a forward learning approach through the License 2 Inventrepreneur (L2I) method and providing the necessary support and resources, we can inspire and empower the next generation of inventrepreneurs to make a positive impact on the world. The L2I method teaches young minds to think critically, solve problems creatively, and embrace inventrepreneurship as a key aspect of their educational journey. Through project-based and hands-on learning, students can apply their creative knowledge and skills in a practical and meaningful way. The forward learning approach can be visually represented as shown in the following Figure 2.

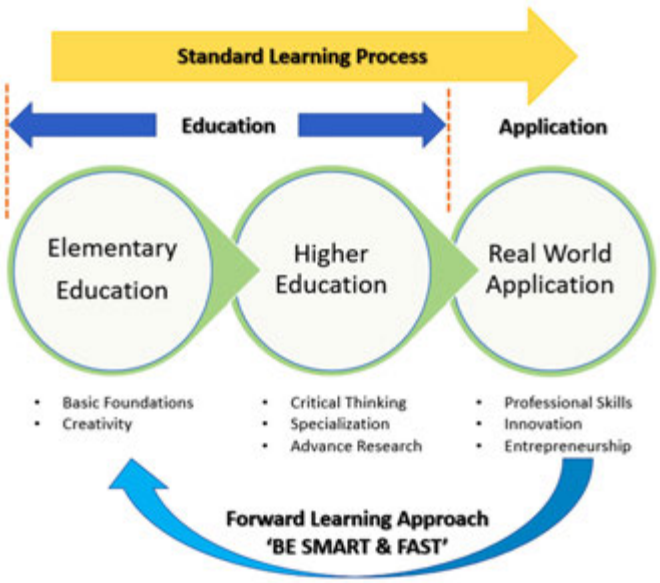

Figure 2: The forward learning approach

This figure illustrates the progression from elementary education to higher education, culminating in real-world application. Each phase highlights key components and skills developed at each stage. The integration of the L2I method at early stage of education ensures that students are equipped with a comprehensive set of skills, blending academic foundations with practical, entrepreneurial, and innovative competencies.

As part of this integrative approach, students work collaboratively in teams, experiment with new ideas, and develop a deeper understanding of the subject matter. Design thinking methodologies, such as empathising with the problem, defining the problem statement, generating ideas, and prototyping, enable young minds to approach challenges from diverse perspectives and devise innovative solutions (Brown, 2009; Kelley & Kelley, 2013). These skills are invaluable not only for future entrepreneurs but for individuals navigating their personal and professional lives (Pink, 2006).

Therefore, it is essential for educators to integrate these approaches into the curriculum and provide young minds with the necessary tools and guidance to develop their critical thinking, problem-solving, and entrepreneurial abilities. To enhance young minds' creative problem-solving abilities and foster an entrepreneurial mindset, it is crucial to address barriers they may face in starting businesses, such as a lack of business skills, fear of failure, and limited access to resources (Meitriana *et al.,* 2020).

Through the L2I method's design thinking phases, students develop essential skills such as empathy, problem definition, ideation, prototyping, and testing. These competencies are critical for both individual and collaborative inventrepreneurial projects, positioning young minds to thrive in an increasingly complex and dynamic world.

2.1 Design Thinking

The License 2 Inventrepreneur (L2I) method incorporates a design thinking approach that creates a flexible learning environment, where young minds take responsibility for their own learning while fostering essential inventrepreneurial skills such as creativity, problem-solving, self-confidence, and collaboration (Val *et al.,* 2019). By utilising the design thinking approach, students are empowered to identify the root causes of problems and explore a variety of potential solutions (Briggs, 2013). This process not only boosts their confidence and critical thinking abilities but also trains them to think creatively (Sorensen & Davidsen, 2017). In essence, design thinking holds significant potential for nurturing inventrepreneurial attitudes among future professionals.

Design thinking consists of five basic phases (Figure 3): 1) Empathise – get to know the humans you are designing for, 2) Define – come up with answers for the problems or problem statements (root cause analysis), 3) Ideate – get creative and generate as many ideas as possible, 4) Prototype – create a demo of what you want to produce, and 5) Test – validate the prototype with actual users.

Empathise means to profoundly understand, and it is the centerpiece of human-centered design thinking. To create an inventive solution to a problem, it is essential to observe and engage with the users. This process builds a comprehensive understanding of how individuals think and feel, what they value, and how they perceive things beyond the immediate focus area. Empathy almost always involves some form of direct engagement with the people affected by the problem. Methods of engagement can include in-depth conversations, interviews, or detailed step-by-step observations on how individuals perform certain tasks. By immersing themselves in the users' experiences, designers can gain invaluable insights that drive the creation of truly meaningful solutions.

Figure 3: 5 basic phases of design thinking

The Define phase involves precisely articulating the meaning, scope, and nature of the problem statement. Insights gained during the empathy phase often lead to a reassessment and redefinition of the originally perceived problem. This phase is critical as it requires concentrating on the core issues with depth and clarity, ensuring that the problem statement is clearly framed and actionable. Defining the problem involves being clear about the criteria for evaluating competing ideas and ensuring that the problem statement remains within the domain of actionable insights. Often, we may assume that we know what the problem is, but this phase allows us the time and space to develop, refine, and reframe the problem statement until we uncover the actual issue that needs to be addressed.

Meanwhile ideate means to form or create an idea or innovation. In this stage the young minds with design thinking skill will spark off ideas with a combination of L2I method. Ideas generated through some creative activities namely 1) thinking out of box, 2) connecting the dots, 3) Simplify and make efficient (trimming) 4) exploring technology trend (S-Curve), 5) devil's advocate which to identify contradiction and finally 6) TRIZ 40 inventive principles which is known as solution bait. Now you have understood users and their requirements / need in empathise stage and have analysed observation in the define stage. Having this solid stage or foundation, the problem solver can start to think out of the box, to identify new solution and alternate way to view the problem statement. The critical point in this phase is where we want to focus on novelty over relevance. Novelty means something new and fresh, while relevance means something significant or important. If we have novel ideas which is relevance, then that is the sweet spot where we get to innovate. In ideation, the focus would be on novelty first than the relevance.

A prototype is a simple experimental model of a proposed solution, used to test and validate ideas. In other words, it is a mock-up of what we aspire to create. Young minds should build representations of one or more of the proposed ideas to be showcased. Why prototype? We use prototyping to explore and confirm that the problem we have identified, the solution we have ideated on, and the problem we are attempting to solve are aligned. This approach encourages young minds to gather more data on what works and what doesn't. It provides an opportunity for discussion about their creations, promoting a deeper understanding of the design process. Embracing potential failures is crucial, as it helps students become comfortable with experimentation. They should create as many variations as possible and refine them through iterations.

A prototype is a rough conceptual model that can be built using readily available raw materials. It can take forms such as a paper prototype, an animatic (where graphics or animations demonstrate the movements), a storyboard, a role-play activity, or even a wall post with sticky notes.

Finally, testing provides the crucial opportunity to gather feedback on your solutions, refine them, and continue learning about end users. While a prototype is a preliminary model you believe to be correct, testing is where you expose it to potential errors and areas for improvement. The testing phase is conducted to refine both the prototype and the solutions, aiming to deepen the understanding of end users and continually iterate on the design. This phase may involve activities like launching, publishing, and debugging to evaluate the proposed solutions comprehensively. Testing is part of design thinking's infinite loop, signifying that improvement is a continuous process. It requires consistent refinement, reflection, and learning from the tests conducted to enhance the solution continuously.

The forward learning approach emphasises developing young inventrepreneurs through the design thinking framework. By fostering creativity and problem-solving skills, we empower young minds to think critically, innovate, and explore new possibilities (Marsela *et al.,* 2024). Through hands-on activities and collaborative projects, we encourage them to embrace a holistic approach that includes empathy, experimentation, and iteration. By nurturing a growth mindset and providing a supportive environment, we aim to inspire the next generation to become visionary thinkers and creators, equipped with the essential skills needed to navigate and overcome future challenges.

2.1.1 Experimentation of Forward Learning

The forward learning approach using the design thinking method, as described in the previous section, was piloted at an elementary school in Penang, Malaysia, involving young minds aged 11 to 12 years. This initiative was launched through the 30th Young Entrepreneur (YE) Program for the year 2023, with the support of the Penang Education Department, Junior Achievement (JA) Malaysia, and Flextronics, which served as the northern region area chair for the year. The pilot effort aimed to:

a. Assess the relevance of the method and tools for both educators and young minds,
b. Measure the effectiveness of the L2I method on invention and entrepreneurial skills, and
c. Evaluate the perception of inventrepreneurship among the participants.

Traditionally, the YE program has focused on secondary school students aged 13 to 17 years. The YE'23 program concluded with a total of 441 students aged 13 to 17, 18 students aged 11 to 12 as part of the pilot program, and participation from 64 teachers and 75 corporate advisors, totaling 598 participants (Figure 4).

For the first time, younger students were exposed to the program and mentored by corporate advisors through the design thinking phases. They were asked to bring actual problems they observed around them. These problems were well-defined and streamlined based on the relevance of the case study, which helped them work as a team to ideate and invent. This paper will share two case studies illustrating the application of the L2I method by these elementary students.

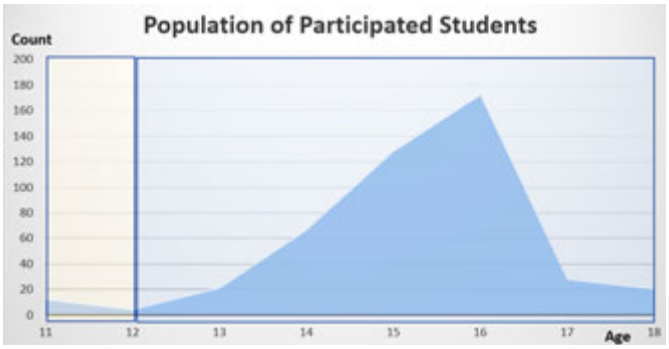

Figure 4: Population of participated students YE'23

a) Case Study 1:

One of the projects undertaken by the student team addressed a common, yet frustrating problem: the habitual misplacement of essential items such as keys, purses, and wallets by a student's mother. This issue was brought to the team's attention during their brainstorming sessions.

To better understand the problem, the students conducted interviews with the primary user—the student's mother. This thorough engagement helped the team empathise with her daily challenges, grasping the inconvenience and stress caused by losing important items frequently.

Once they had a clear understanding, the team investigated existing technologies and historical solutions to tackle the issue. They employed an S-Curve analysis to evaluate past technological trends and anticipate future innovations in item-tracking solutions. This methodical approach enabled them to identify gaps in the current market and opportunities for innovative advancements.

Figure 5: Technology trends of GPS tracker

Through comprehensive brainstorming sessions, the team developed an S-Curve (Figure 5) as part of their solution-finding process. They focused not only on creating an innovative product but also on ensuring it met key STEAM criteria: it had to be safe, effective, and affordable for everyday use.

Leveraging their insights, the students designed a GPS tracker tailored to the needs identified in their research. The product was prototyped and rigorously tested to ensure it was user-friendly, reliable, and met the desired safety and affordability standards.

The GPS tracker team successfully managed to sell over 50 units, achieving a 100% sales profit. Among the seven STEAM inventive creations developed during the program, the GPS tracker emerged as the most popular product. This success highlights not only the ingenuity of the students but also the practical impact of their efforts.

In summary, this case study underscores the effectiveness of a methodical approach to problem-solving and innovation. By thoroughly understanding user needs, evaluating existing technologies, and focusing on safety and affordability, the students were able to create a highly marketable and useful product. This success story serves as a testament to the potential of young inventrepreneurs to address real-world challenges with creativity and practical solutions.

b) Case Study 2:

Students observed difficulties in maintaining visibility while writing in low-brightness environments. Although options such as adding more tube lights or additional table lamps existed to remedy the situation, these solutions posed a cost-increase challenge. The root of the problem was the need for a cost-effective brightness solution. To address this, the team of students generated ideas through the S-Curve method (Figure 6) and conceived a creative solution: a built-in light source within a holder.

The students began prototyping their design through initial sketch drawings (Figure 7) and gained approval from their team, teacher, and corporate advisors.

During the prototyping phase, the team encountered challenges. The first functional prototype was cumbersome due to the weight of the battery and switch, and the raw materials were costly. To make the solution affordable, the students sought out lighter and cheaper materials, successfully reducing material costs by 24%. Another issue arose with the use of a soldering machine to connect wires, which was both dangerous and skill-intensive. The team innovatively replaced this method with hot glue, only to face feedback regarding poor connections. They overcame this by enhancing the product with adhesive 3M tape and strong glue, resulting in a robust and easy-to-assemble design.

The product was sold at RM15 during the YE'23 Sales Fair. Though some customers initially felt the price was high, the team managed to make a profit. With approximately 16 units of stock remaining, the team ingeniously decided to target internal customers—students—by marking down the price to clear the stock with minimal profit.

The youngest managing director remarked, "Creative and inventive thinking in handling business issues involves the ability to adapt, experiment with ideas and possibilities, and continuously seek ways to improve products. For instance, we've invented products from scratch such as the writing light holder, GPS tracker, can-drink recycled keychains, and glow-in-the-dark bookmarks."

The L2I method is a dynamic approach that fosters creative problem-solving, empathy, and innovation. It encourages inventrepreneurship in young minds by equipping them with the necessary skills and mindset to identify and tackle real-world challenges, develop innovative solutions, and establish successful ventures. Through the L2I approach, students

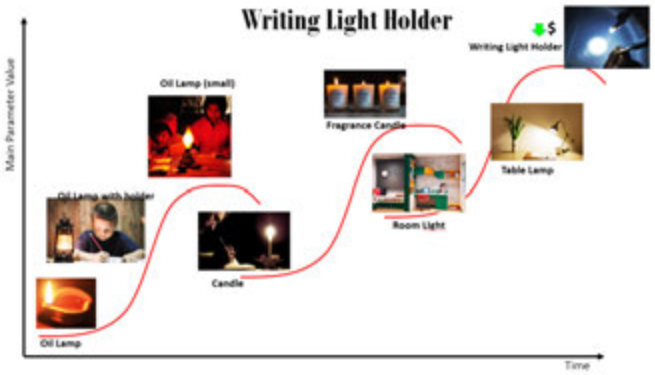

Figure 6: Technology trends of writing light holder

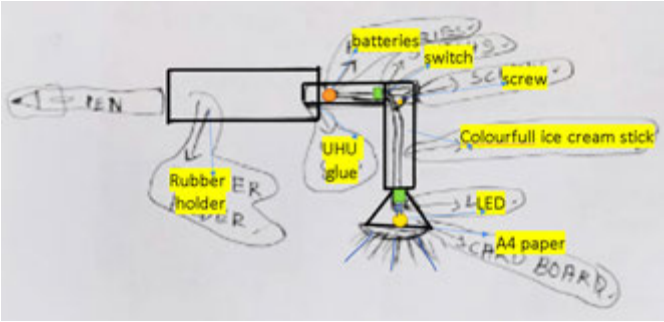

Figure 7: Prototype sketch writing light holder

learn to solve problems from a user-centered perspective, understanding the needs and desires of their target audience. This empathy-driven approach empowers them to gain valuable insights into customers' experiences, identifying opportunities for inventrepreneurial ventures. Additionally, L2I fosters creativity by encouraging students to explore multiple possibilities through ideation and prototyping (Nagappan, 2022).

3.0 CONCLUSION

The overall approach elaborates on the national education goal of enhancing the creative capabilities of young minds and underscores the importance of generating innovative solutions in challenging situations. The author discusses the inherent inventiveness of young minds and stresses the necessity for entrepreneurial motivation among students. Additionally, the author highlights the critical role of problem-solving skills, emotional management, and creative thinking, facilitated through ideation and design thinking methodologies. The concept of "License to Inventrepreneurship" (L2I) is introduced as a forward-learning approach designed to cultivate creative problem-solving and entrepreneurial skills in students.

The L2I method employs a forward-learning approach that synergises STEAM (Science, Technology, Engineering, Art, and Mathematics) and design thinking with the core principles of inventrepreneurship. This methodology integrates these interdisciplinary subjects with principles of invention and entrepreneurship, providing students with a holistic understanding of the interconnectedness of these fields while nurturing their problem-solving and creative thinking abilities. Through this approach, young minds are given the opportunity to engage with real-world scenarios and develop practical problem-solving skills.

In essence, the L2I method is an educational initiative aimed at equipping young minds with a comprehensive education that prepares them for future challenges. Beyond providing a well-rounded academic foundation, the L2I method seeks to nurture an inventrepreneurial mindset in students. This mindset encourages critical thinking, risk-taking, and the confident pursuit of their ideas (Brown, 2018). The L2I method guides young minds through a series of stages, which include identifying and analysing problems, generating potential solutions, acquiring necessary knowledge, making informed decisions, developing prototypes or products, testing and evaluating solutions, and ultimately socialising and completing their projects.

In summary, the License to Inventrepreneurship (L2I) method offers a robust educational framework that not only enhances academic knowledge but also fosters innovative thinking and entrepreneurial spirit. By guiding students through comprehensive stages of problem-solving and product development, the L2I method aims to create a generation of visionary thinkers capable of navigating and addressing the complexities of the future.

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PROFILE

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ENHANCING MECHANICAL BEHAVIOUR OF LIGHTWEIGHT FOAMED COMPOSITE USING PALM OIL EMPTY FRUIT BUNCH FIBRE

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Abstract

The inclusion of Palm-oil Empty Fruit Bunch Fibre (PEFBF) into Lightweight Foamed Composite (LFC) presents a viable sustainable material by reducing cement and sand usage, replacing it with foam and natural fibre. This approach achieves both waste utilisation and material conservation, while conserving LFC's inherent lightweight and functional properties. By incorporating 1.25% volume fraction of PEFBF into LFC at a density of 1300 ± 50 kg/m³, mechanical analysis up to 90-days was conducted through compression, splitting tensile and flexural test. Scanning Electron Microscopy-Energy Dispersive X-ray spectrometry (SEM-EDX) analysis was conducted to examine the microstructural bonding and chemical composition. Results indicated that LFC-PEFBF required a higher water-cement ratio to prevent fibre agglomeration, as the inclusion of PEFBF tended to reduce the LFCs consistency and flowability. Moreover, LFC-PEFBF compressive strength showed modest increment, while splitting tensile and flexural strength demonstrated significant increases of up to 16% and 9%, respectively. A performance index evaluation confirmed the positive impact of PEFBF on LFC's mechanical properties under same densities. SEM-EDX analysis revealed that PEFBF's higher surface roughness, improved fibre-matrix bonding, and effective stress-transfer contributed to the enhanced mechanical behaviour after 56 days of curing. These findings suggest that LFC-PEFBF offers a viable and sustainable solution for civil construction applications, promoting innovative and environmentally friendly building practices.

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Compressive strength, Flexural strength, Lightweight foamed concrete, Palm-oil empty fruit bunch fibre, Splitting tensile strength

1.0 INTRODUCTION

The ever-growing demand for construction materials coupled with the depletion of natural resources and environmental concerns is pushing the boundaries of innovative civil construction material in the construction industry. For Lightweight Foamed Concrete (LFC), the material utilises cellular technology which replace portion of cement and sand with foam, significantly contributing to environmental impact control for the industry. Likewise, LFC offers several practical and economic advantages including lightweight properties and functional characteristic. The use of lower-density concrete significantly reduces the self-weight of structures, allowing for smaller civil structural design, which in turn reduces construction costs. Additionally, LFC's innate thermal insulation, fire resistance, and sound insulation contributes to more comfort, safety and durable lifestyle.

The integration of natural fibres aligns seamlessly with LFC core purpose of being lightweight, sustainable, and environmentally friendly. These fibers, derived from abundant and sustainable plant sources, offer a more environmentally sustainable alternative to synthetic fibers. While fiber production can exhibit considerable variability due to multiple factors, agricultural innovations have substantially improved natural fibre production efficiency. Likewise, these short, discrete, and thin fibre were incorporated into LFC to increase cracking resistance and improve stress energy absorption, leading to an enhanced mechanical strength and structural integrity. Besides, natural fibre reinforced LFC was renowned for its ease of use and affordability, as the production requires a lower level of technological sophistication and raw materials are predominantly sourced locally, contributing to its economic viability.

As the world's second-largest palm oil producer, Malaysia contributed 25% to the total production of 18.39 million metric tons in 2023, with production projected to increase by 7% annually, reaching 19.7 million metric tons in 2024 (USDA, 2024). The prosperity of the palm oil industry has led to a correspondingly higher volume of waste generation, including Palm oil Frond (POF), Palm-oil Empty Fruit Bunch (PEFB) and Palm Oil Trunk (POT). Among the biomass waste, PEFBs comprise a substantial portion of biomass waste, with approximately 30 to 60 kilograms discarded for every 100 kilograms of fresh fruit bunches processed (Suksaroj *et al.,* 2023). The Palm-oil Empty Fruit Bunches Fibre (PEFBF) is a waste product recovered from the PEFB through a retting process following oil extraction (Momoh & Osofero. 2020) Research indicates that the addition of PEFBF to foam concrete can enhance their mechanical properties without compromising their lightweight nature. Study has revealed that with proper dosage, PEFBF can improved foam concrete compressive strength by up to 14 %, splitting tensile strength increased by 47%, and flexural strength improved by 18% compared to control mix, demonstrating the effectiveness of its fibre-matrix

bonding (Rao & Ramakrishna, 2022). Additionally, the addition of PEFBF to LFCs tends to reduce water absorption by filling LFCs void pores with fibres. The thermal conductivity also decreases with more PEFPF was added, due to its inherent low thermal conductivity and cellular porous structure. The dimensional stability, measured by linear shrinkage and expansion of specimen under air curing and tropical weather curing, indicates that LFC with PEFBF exhibits positive effect in dimensional stability and effectively reduces dimensional changes (Lim *et al.,* 2018).

The existing research on PEFBF incorporated composites, while promising, often involve various densities and lacks the long-term strength evaluation associate with microstructural analysis to comprehensively characterise its mechanical behaviour. Therefore, this study presents the feasibility of mixing the PEFBF into LFC, at density of 1300 ± 50 kg/m³, evaluating its mechanical behaviour including compressive, splitting tensile and flexural strengths up to 90-days of curing. The optimum water to cement ratio of LFC-CTR and LFC-PEFBF were obtained by selecting the peak performance from the compressive strength tests on trial mix. A Scanning Electron Microscopy - Energy Dispersive X-rays spectrometry (SEM-EDX) analysis was conducted to identify the fibre-matrix microstructure bonding and chemical composition.

2.0 MATERIALS AND METHODOLOGY

2.1 Materials

This research utilised Orang Kuat branded Ordinary Portland Cement (OPC), fine aggregates, water, SikaAER-50/50 foaming agent, and natural Palm-oil Empty Fruit Bunch Fibre (PEFBF). The OPC, certified under MS ISO 9001, MS ISO 14001, OHSAS 18001, and MS EN 197-1:2014, was sieved to 300 µm and stored in an airtight container. Fine sand, dried in an oven at 100°C for 24 hours to remove moisture, was passed through a 600 µm sieve and had a fineness modulus of 2.27, as determined by sieve analysis (Lim *et al.,* 2013). Tap water with a specific gravity of 1.0 was used for mixing and curing, with the curing tank maintained at a room temperature of 25°C. Foaming agent SikaAER-50/50, compliant with ASTM C796, was combined with water and compressed air to generate foam bubbles with a density of 45 ± 5 kg/m³. PEFBF shown in Figure 1, has specific gravity of 1.3 (Rao & Ramakrishna, 2021), diameter of 0.55 mm, and a length of 20 ± 10 mm was washed, natural dried, and stored as the fibre reinforcement material.

Figure 1: Palm-oil Empty Fruit Bunch Fibre (PEFBF)

2.2 Mix Proportions

In this study, the absolute volume method was applied in designing the mix proportions of both LFC-CTR and LFC-PEFBF. Noted that cement to sand ratio was 1:1 and the PEFBF dosage refer to 1.25% volume fraction. The foam content was adjusted based on the density, while optimised water-to-cement ratio was derived from trial mixes. Table 1 demonstrates the mix proportions of 1m³ LFC for each mix.

Table 1: Mix proportions

Material (kg per 1m³ of composite)	Mix Code	
	LFC-CTR	LFC-PEFBF
Cement	500 [15.87%]	500 [15.87%]
Fine aggregates (sand)	500 [18.86%]	500 [18.86%]
Water	280 [28%]	280 [28%]
PEFBF	-	16.25 [1.25%]
Foam /Air bubbles content	[37 ± 2%]	[36 ± 2%]
Density	1300 ± 50 kg/m³ [100%]	
W/C ratio	0.56 to 0.66 by interval of 0.02	
Foaming ratio	1 (foaming agent) : 20 (water)	

Note: The [%] expressed in terms of volumetric percentage per 1m³ of composite

2.3 Specimens Preparation and Testing Methods

To establish the optimal water-to-cement (W/C) ratio for achieving maximum compressive strength, a series of trial mixes were subjected to compressive strength testing at 7, 14, and 28 days. Using the determined optimal W/C ratio, LFC-CTR and LFC-PEFBF specimens were fabricated for subsequent compressive, splitting tensile, and flexural strength evaluations. To investigate the interfacial bonding and chemical composition of the LFC-PEFBF composite, Scanning Electron Microscopy with Energy-Dispersive X-Ray Spectrometry (SEM-EDX) analysis was performed on the LFC-PEFBF samples. Prior to casting, essential fresh property tests, including flow table, inverted slump, and fresh density test were conducted.

2.4 Density Test

Following the standardisation ASTM C138 (2021), the fresh LFC-CTR and LFC-PEFBF samples, were prepared in a 1-litre container. The container was initially tared to zero on a weighing machine. After overfilling with the fresh LFC mixture, the material was compacted through gentle tapping on the container's sides to ensure uniform consolidation. Excess LFC was struck off, and any residual material on the exterior was wiped clean. The container and its contents were then weighed to determine the fresh density of the LFC samples.

The process is repeat with foam addition until reaching target density of 1300 ± 50 kg/m^3 in accordance with manufacturer's specification (Jones & McCarthy, 2005).

2.5 Flow Table Test

The flowability of the LFC, prior to the incorporation of foam, was evaluated through the flow table spread test, conducted in accordance with ASTM C 230 (2021). This standard protocol entails positioning the LFC mortar within a conical mold on the flow table, subsequently removing the mold and subjecting the mortar to 25 drops at a controlled speed of approximately 100 revolutions per minute. The resulting spread of the mortar was then quantified by measuring its average diameter from four distinct angles.

2.6 Inverted Slump Test

The inverted slump test, as outlined in ASTM C 1611 (2021), measures the workability of fresh LFCs. The test involves placing a dampened slump cone on a level surface, filling it with LFC mortar without tamping or vibrating, and then lifting the cone vertically to a height of 23 ± 8 cm within 3 seconds. The largest and smallest diameters of the spread are measured to the nearest 5mm. For this project, measurements were taken from four angles, and the difference between the largest and smallest diameters was considered in the analysis.

2.7 Compression Test

Compressive strength testing was conducted on 100mm cubic specimens of LFCs according to BS EN 12390-3 (2019). An Instron 5582 testing machine was used to apply a compressive load at a specified rate until failure. Prior to testing, the specimens were oven-dried for 24 hours after removal from water storage, then subjected to evaluation up to 90 days of curing. Dimensional measurements were taken to determine the cross-sectional area. The specimens were then centred in the testing machine and loaded at a constant rate of 0.02 mm/s until failure. The mean compressive strength of three specimens was calculated for each lightweight foamed concrete mix.

2.8 Splitting Tensile Test

Splitting tensile strength testing was performed on 100mm diameter x 200mm height cylindrical specimens of LFC according to BS EN 12390-6 (2019). Similarly, an Instron 5582 testing machine was used to apply an axial load at a specified rate until failure. Prior to testing, the specimens were oven-dried for 24 hours, removed from water storage, with testing conducted throughout 90-days curing period. The specimens were placed in a steel mould with thin plywood bearing strips at the top and bottom to distribute the load evenly. A constant loading rate of 1.2 mm/min was applied until failure. The mean splitting tensile strength of three specimens was calculated for each lightweight foamed concrete mix.

2.9 Flexural Test

Flexural strength testing was conducted on 25mm x 25mm x 250mm prismatic specimens of LFCs according to BS EN 12390-5 (2019). Identically, an Instron 5582 testing machine was used to apply a centre-point load at a specified rate until failure. To standardise testing conditions, specimens were oven-dried for 24 hours prior to evaluation, ensuring complete drying before evaluation up to 90 days of curing. Support blocks were positioned at 10mm offsets from both ends of the specimens. A constant loading rate of 0.1 mm/min was applied until failure. The mean flexural strength of three specimens was calculated for LFC mix.

3.0 MATERIALS AND METHODOLOGY

3.1 Compression Test (Trial Mix)

Figure 2 shows the compressive strength development of LFC-CTR and LFC-PEFBF at 7, 14, and 28 days for different water-cement (W/C) ratios.

Both mixes exhibited a general trend of increasing compressive strength with decreasing W/C ratio and increasing age. However, LFC-CTR demonstrated slightly higher compressive strength values than LFC-PEFBF at early ages, while LFC-PEFBF exhibited higher compressive strength at 28 days. The optimal W/C ratios for both mixes were found to be 0.58 and 0.62, respectively, where their highest compressive strength values were achieved. These results suggest that the incorporation of PEFBF requires more water to achieve optimal strength development, potentially preventing fibre balling and agglomeration (Wang *et al.,* 2024).

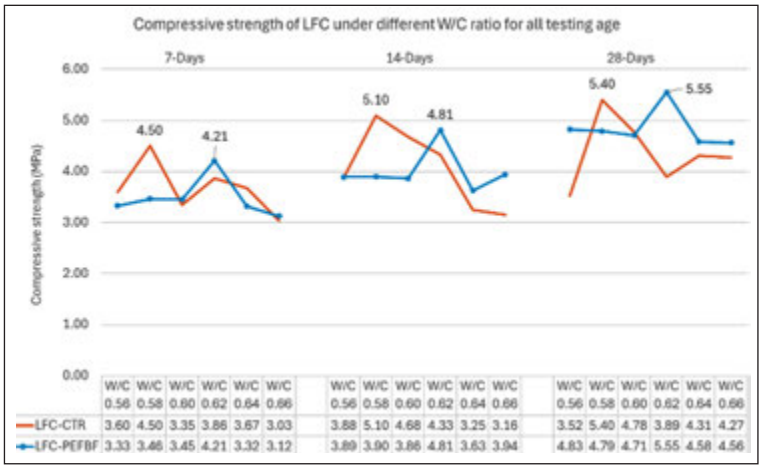

Figure 2: Trial mix results

3.2 Fresh Properties

To assess the workability and fresh properties of the LFC-CTR and LFC-PEFBF, a series of tests including fresh density, flow table, inverted slump test was conducted. Table 2 summarises the results, including the optimal water-to-cement (W/C) ratio, fresh density, flow table spread, average inverted slump diameter, consistency, and stability.

Both LFC-CTR and LFC-PEFBF exhibited comparable workability characteristics, with both mixes demonstrating high flow table spread and average inverted slump diameter. However, LFC-PEFBF had a slightly lower fresh density and workability indicators compared to LFC-CTR, due to the presence of PEFBF fibres. The consistency and stability values were within acceptable limits for both mixes. LFC-CTR exhibited

Table 2: Summary of fresh properties

Sample	Optimum W/C Ratio	Fresh Density (kg/m^3)	Flow Table Spread, (number of drop)	Average Inverted Slump Diameter (mm)	Consistency[a]	Stability[b]
LFC-CTR	0.58	1348	>250 (9 drops)	650	1.045	1.074
LFC-PEFBF	0.62	1260	>250 (13 drops)	605	0.954	0.934

[a]*Note 1: Consistency refer to fresh to target density ratio, closer to unity indicate well balanced mix design.*
[b]*Note 2: Stability refer to fresh to hardened density ratio, closer to unity indicates minimal changes in air, water, and other components during hydration process.*

a consistency and stability greater than unity, indicating that the hardened mix was lighter than its fresh state. This is due to bubble coalescence during the hardening process, resulting in larger pores and a reduction in hardened density. Conversely, LFC-PEFBF had a consistency and stability slightly lower than unity, suggesting bubble bursting and buoyant foam collapse, due to lower paste viscosity and longer paste setting time (Xiao *et al.,* 2023).

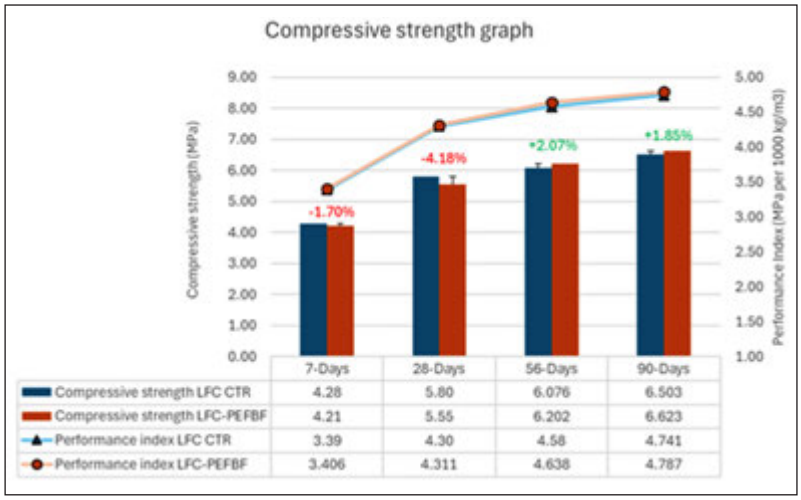

Figure 3: Compressive strength graph

3.3 Compression Test

Figure 3 shows the comparison of compressive strength for LFC-CTR and LFC-PEFBF at different curing age. The performance index, calculated as compressive strength per 1000 kg/m^3 density, provides a more nuanced comparison on different LFC at same density.

Both LFC types exhibited an increase in compressive strength over time, provided with higher strength of LFC-CTR (5.8MPa) than LFC-PEFBF (5.55MPa) at standard 28-days curing age. However, LFC-PEFBF demonstrated a slower initial strength gain but surpassed LFC-CTR at 2% increment rate in late-stage development, especially at 56 days. This suggests that PEFBF inclusion in LFC requires a longer curing period for optimal hydration and fibre-matrix bonding. The increased hydration products at later ages facilitate improved stress transfer, leading to superior compressive strength in LFC containing fibre. Notably, LFC-PEFBF's slightly higher performance index indicates that palm oil empty fruit bunch fibre enhances the structural efficiency of LFC. A similar finding, with the overall performance index of natural fibre inclusion outperforming the control mix but with no significant compressive strength enhancement, was found in previous research (Lim *et al.,* 2018).

3.4 Splitting Tensile Test

Figure 4 demonstrates the comparative analysis of splitting tensile strength for LFC-CTR and LFC-PEFBF. The summary of splitting tensile strength result associated with performance index is illustrated in Figure 4.

The splitting tensile strength analysis of LFC-PEFBF reveals distinct trends from compressive strength analysis. Notably, LFC-PEFBF consistently demonstrated a marginally higher splitting tensile strength gain than LFC-CTR throughout the curing period. Figure 4 demonstrates its significant early strength gain of 23%, followed by a slight decline to 19% in later stages. Subsequently, a 13% strength gain suggesting the possible of LFC-PEFBF ongoing strength development after 90-days of curing. Nonetheless, a more pronounced gap disparity between the performance index lines of the two LFCs, highlighting the significant tensile strength enhancement provided by LFC-PEFBF. Similar findings reported by Abbas *et al.* (2022) attribute the substantial improvement in tensile strength to the strong interlock and adhesive bond between the natural fibres and the cement matrix. This enhanced internal confinement effectively counteracts lateral expansion under transverse loading conditions, leading to splitting tensile strength improvement.

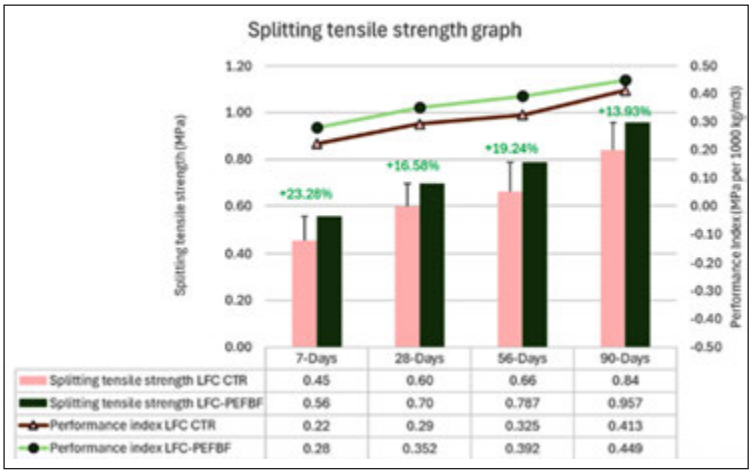

Figure 4: Splitting tensile strength graph

3.5 Flexural Test

This study investigates the flexural strength development of LFC CTR and LFC-PEFBF over a 90-day curing period. The results presented in Figure 5 demonstrate a clear comparison between the two materials.

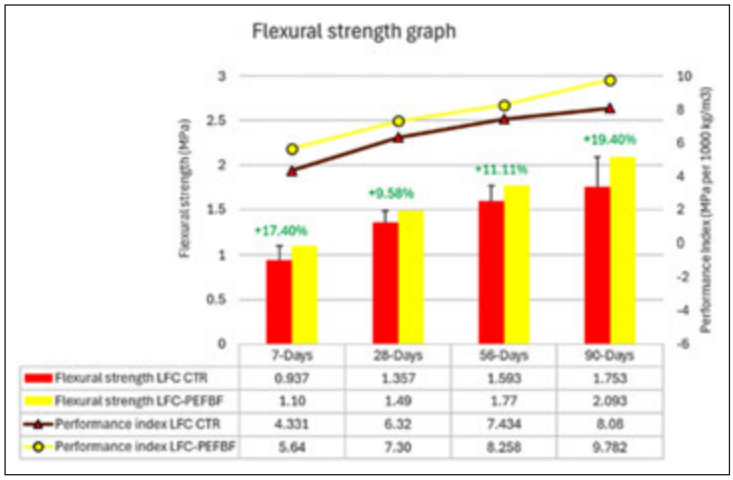

Figure 5: Flexural strength graph

Similar to splitting tensile analysis, LFC-PEFBF exhibited a 17.40% increase in flexural strength compared to LFC-CTR at 7 days. This trend continued throughout the curing period, with LFC-PEFBF demonstrating a 19.40% higher flexural strength than LFC-CTR at 90 days, indicating continuous strength development at later ages. The significantly increment in performance index further supports the development of an effective fibre bridging mechanism within LFC. By bridging across microcracks the natural fibres act as cracks inhibitors, facilitating fracture energy absorption and increasing fracture energy capacity, improving structural integrity and flexural strength (Abbas *et al.* 2022).

3.6 SEM-EDX Test

A Scanning Electron Microscope - Energy Dispersive X-rays spectrometry (SEM-EDX) test was conducted to provide highly precise magnified images of concrete details by scanning the specimen surface and presenting the chemical composition exist. Figure 6 illustrates the SEM result of LFC-PEFBF under various magnifications, and Figure 7 presents the result of EDX test of LFC-PEFBF.

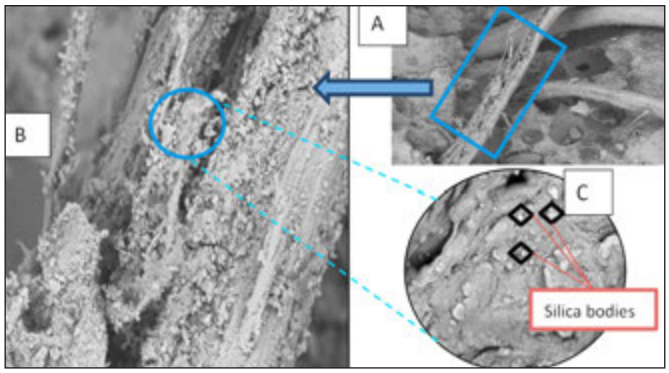

Figure 6: Microstructural images of LFC-PEFBF at curing age of 56 days: (A) 60x, (B) 500x, (C) 1000x, of magnification

The SEM micrograph reveals the synergistic interaction between PEFBF and the LFC matrix. Figure 6A shows the LFC's cellular structure infiltrated with PEFBF, forming an interconnected fibre network. Figure 6B highlights the complete coverage of the PEFBF surface with hydration products, indicative of robust fibre-matrix bonding for efficient stress transfer. Figure 6C demonstrates the PEFBF high surface roughness, presenting the mechanical interlocking mechanism between fibre and matrix, contributing to enhanced strength. Additionally, Figure 6C reveals the presence of silica bodies naturally occurring on the PEFBF surface. While silica bodies have been shown to enhance fibre-matrix interface strength by limiting sliding motion (Omar *et al.,* 2014), some studies suggest that alkaline treatment to remove these bodies can create a rougher surface and expose more amorphous regions of the fibre, potentially leading to improved bonding characteristics (Ibrahim *et al.,* 2015).

EDX analysis in Figure 7 reveals the elemental composition of the LFC with and PEFBF. The LFC primary compound are made of calcium (Ca), silicon (Si), and oxygen (O), representing key components of mortar and concrete. The PEFBF contains organic chemical compound such as carbon (C) and oxygen (O). From Figure 7, after 56-days of curing, surface of LFC-PEFBF demonstrate a higher concentration of calcium (Ca) and silicon (Si) from the cement paste, suggesting a successful covering and adhesion of the binder onto the fibre surface. These findings confirm the effective integration of PEFBF into the cement-based matrix, leading to enhanced mechanical properties.

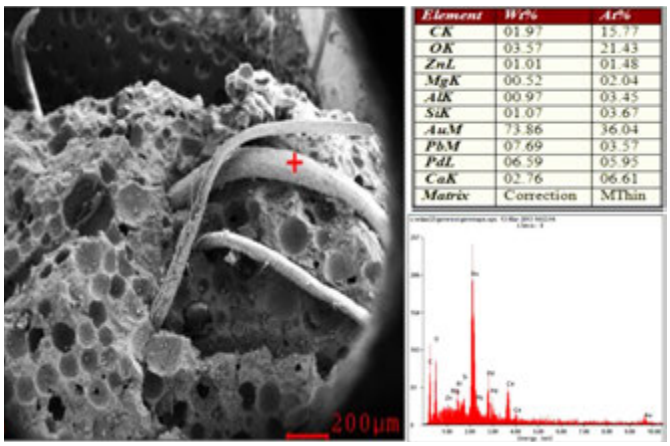

Figure 7: EDX report of LFC-PEFBF

4.0 CONCLUSION

Based on the result data obtained the aim and objectives of this research are accomplished. Within the scope of work of research, the following conclusions are drawn:

1. The optimised W/C ratios for LFC mixes identified to maximise strength along 90-days of curing presenting LFC-CTR at 0.58 and LFC-PEFBF at 0.62. All specimens achieved target density of 1300±65 kg/m³ within tolerance.
2. For fresh properties and workability, LFC-CTR outperformed LFC-PEFBF, suggesting the inclusion of fibre slightly reducing the workability.

3. Compression test results indicate that LFC-PEFBF requires a longer curing period to achieve optimal hydration and develop stronger bonds with PEFBF, exhibiting superior compressive strength after 56 days compared to that of LFC-CTR.
4. The incorporation of PEFBF into LFC significantly improving its splitting tensile and flexural strengths, achieving a notable standard 28-days strength improvement up to 16% and 9%, respectively. These enhancements underscore the potential of LFC-PEFBF to serve as a durable and reliable material for structural applications, contributing to the construction of more resilient buildings.
5. SEM-EDX analysis confirms the enhanced surface roughness of PEFBF, fostering superior mechanical interlock within the LFC matrix. The abundance of calcium and silicon on the PEFBF surface indicates effective coverage and improved bonding with the matrix after 56 days of hydration.

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AUTHORS CONTRIBUTIONS

- **Siong Kang Lim:** Conceptualisation, study design, and supervision.
- **Hao Yee Richmond Chong:** Data collection, methodology, and formal analysis.
- **Ming Kun Yew:** Writing—original draft preparation and literature review . ■

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FACTORS INFLUENCING TOLL LANE PAYMENT MODE

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Abstract

The efficient operation of a toll-lane system is one of the key aspects of promoting sustainable mobility. Successful implementation of initiatives in a toll-lane system can occur if the response from users is highly encouraging. The efficiency of the toll-lane systems is highly dependent on the type of payment method available at the toll plaza. Thus, the objectives of this study are to identify (i) the preferred mode of payment among toll-lane users in the Klang Valley, (ii) the factors that influence the mode of toll-lane payment, and (iii) the queue time at a toll plaza for each mode of toll-lane payment. This study uses a questionnaire to collect various types of information necessary to meet the study objectives. Results reveal that radio frequency identification detection (RFID) is the most preferred payment mode among road users. Also, the findings indicated that factors such as convenience, the number of lanes available for the toll-lane payment mode, benefits, and availability influence the preference for toll-lane payment modes. This study provides valuable insights for transportation authorities' efforts to optimise toll-lane operations and improve the road user experience.

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Queue time, RFID, SmartTAG, TnG, Toll-lane, Toll payment

1.0 INTRODUCTION

Growing populations and urbanisation exacerbate the strain on transportation systems and infrastructure (Bari *et al.,* 2023). The increase in this trend has impacted the traffic flow on open roads. This situation has compelled road users to rely on toll highways, which are more efficient for free-flow travel. A toll highway is a type of road that requires payment for each passage. The toll highway has high mobility, but it is less accessible than local roads, which have more accessibility than mobility. Toll highways have become a preferred option for road users seeking to avoid traffic congestion and reduce travel time. However, toll plazas on toll highways usually act as bottlenecks in the free flow of traffic and cause congestions (Parmar *et al.,* 2013; Saad *et al.,* 2019).

The payment for usage at a toll highway, also known as toll collection, is a type of road pricing that recovers the costs associated with the road's construction and maintenance. The direct method involves collecting tolls directly from automobiles using the toll highway (Kumawat and Chandramore, 2014). There are two distinct methods of collecting tolls: manual toll collection (MTC) and electronic toll collection (ETC). MTC is a system that requires road users to either present a ticket or pay cash directly to the tollgate operator when passing through the toll plaza. On the other hand, ETC is a method that allows road users to make toll payments using sensors and transponders. Malaysia initiated the development of the ETC system in 1994 and completed its nationwide implementation by July 2004 (Yusoff *et al.,* 2006). The commonly used ETC collections in Malaysia are Touch N Go (TnG), SmartTAG, and radio frequency identification (RFID). The ETC method also implemented credit and debit cards as a payment option in July 2023 (Azizan, 2023).

Toll plazas frequently encounter significant traffic congestion and extended waits during periods of high demand, such as the morning and evening peak hours. Several factors contribute to the congestion, including the bottleneck effect upstream and downstream of the toll plaza. Drivers competed for service upstream, but sometimes the various lane configurations and different tolling systems confused them (Iseki and Demisch, 2012; Parmar *et al.,* 2013; Saad et al., 2019; Karim *et al.,* 2020; Jiang *et al.,* 2021; Aksoy *et al.,* 2024). Following the completion of payments, constrained road space and overlapping driving decisions may significantly vary the initial motion states of vehicles downstream, leading to frequent speed and lane changes beyond the toll plaza (Abuzwidah, 2019; Saad et al., 2019). This will disrupt traffic flow and diminish traffic capacity, thereby increasing accident risks (Li *et al.,* 2016; Abuzwidah and Abdel-Aty, 2018; Jiang *et al.,* 2021).

Conversely, numerous studies indicated that traffic accidents were common at toll plazas (Mohamed *et al.,* 2001; McKinnon, 2013; Abuzwidah and Abdel-Aty, 2015; Abuzwidah and Abdel-Aty, 2018; Saad *et al.,* 2019; Xing *et al.,* 2019; Xing *et al.,* 2020; Jiang *et al.,* 2021). Between 1994 and 1997, 32%

of traffic accidents on toll highways transpired near the primary toll plazas in Central Florida (Mohamed *et al.,* 2001). McKinnon (2013) disclosed that rear-end and sideswipe collisions frequently occurred in Massachusetts toll plazas from 2010 to 2012.

In Malaysia, drivers predominantly contributed to congestion upstream of the toll plaza, particularly during peak hours, by inadvertently selecting incorrect ETC toll payment lanes. Another factor contributing to the congestion upstream is the potential lack of sufficient credit on users' devices to enable toll payment (MStar, 2024). Furthermore, either the sensors and transponders fail to detect the road users' devices, or they encounter difficulties during the installation and placement of the RFID tags (Malaysia Kini, 2022; Tee, 2022; Yeo, 2022; Khadir, 2023). Road users who fail to successfully pay the toll often reverse or switch lanes to use an alternative payment method (Mstar, 2024). Consequently, significant congestion has occurred, particularly during peak hours, occasionally resulting in accidents at the toll plaza (Leong, 2022; Yeo, 2022; Sinar Daily, 2023).

Thus, this study aims to address issues related to congestion and accidents at toll plazas by examining the influence of toll lane payment configuration layouts on toll operations, specifically the number of lanes offered for different payment modes and the positioning of different payment modes on toll plazas. Thus, the first objective of this study was to identify the preferred mode of payment among toll-lane users in the Klang Valley. This is to determine and compare the preferred mode of payment among Malaysians when they pass the toll plaza. The second objective of the study was to identify the factors that influence the mode of toll-lane payment among road users. Understanding the preferences of road users is crucial for the toll operation provider to offer a sufficient variety of toll lane payment options, thereby reducing the likelihood of congestion and accidents at the toll plaza. Furthermore, the third objective involves determining the average waiting time at a toll plaza for each toll-lane payment mode. Obtaining this information would be useful to suggest the number of toll-lane payment configurations that should be in operation during peak periods. On the other hand, the collected data could suggest the arrangement of different types of toll payment modes.

We structure the remaining sections of the paper as follows: Section 2 contains a comprehensive analysis of existing literature, whereas Section 3 outlines the specific methodology used in the study. Section 4 encompasses the results and discussions, while Section 5 presents the conclusions.

2.0 LITERATURE REVIEW

The road pricing scheme refers to the collection of direct costs for the use of toll highways, including taxes based on distance or time, as well as urban congestion pricing (Milenković *et al.,* 2018). Factors, such as the type of vehicle and the distance travelled, frequently determine the collection of this toll. Toll collections could be MTC or ETC. The MTC method involves collecting tolls using cash, credit card, or debit card, and directly paying them to the toll plaza operator while the automobile passes through the facility. Usually, MTC requires the road users to stop entirely upon reaching the toll plaza to complete the toll payment.

There are several ETC methods. For example, the ETC system in Indonesia employs a smart card (Joewono *et al.,* 2017), often referred to as a chip card or integrated circuit card, which is a compact card containing an embedded integrated circuit. This toll payment system is a collaborative venture between the card-issuing bank and the toll road operator. In 1998, Singapore introduced the toll collection mechanism known as electronic road pricing (ERP). The ERP system employs information and communication technology to oversee and regulate road usage (Parayil and Yeo, 2005). This road user bypasses the toll booth without having to halt or slow down the vehicle. To pass through the ERP gantries, the road user simply needs to exhibit a gadget on the car dashboard.

The first toll highway in Malaysia was the North-South Expressway, spanning 20 km and linking Tanjung Malim and Slim River, which was opened on March 16, 1966. The system operated on a closed-toll basis, using MTC. Users would obtain a ticket upon entering the toll road and settle the tolls upon exiting. Consequently, Peninsula Malaysia has seen the construction of an increasing number of toll highways to enhance its transportation infrastructure. Additionally, there is an open toll system for collecting tolls, in which road users are required to pay a toll when they reach the toll plaza (Kumawat and Chandramore, 2014). The Malaysian government introduced the ETC system in 1994. By July 2004, Malaysia had fully established the ETC system (Yusoff *et al.,* 2006). By August 14, 2017, all toll plazas in Malaysia had transitioned to exclusively accepting ETC. In Malaysia, there are multiple ETC payment methods available, such as TnG, SmartTAG, and RFID. Since 2023, ETC has authorised credit and debit card acceptance.

The capacity analysis directly determines the quantity of toll lanes, which is the primary design factor for a toll plaza (Bari *et al.,* 2022). The toll booth configuration for each toll plaza varies depending on its location and purpose. Typically, the number of channels for each payment mode varies considerably. Several factors affect toll payment mode, including variable payment, accident prediction, quality of service, tollbooth operator conduct, and the inclination to own an ETC device (Bari *et al.,* 2023). Since not all modes of payment are available at toll plazas, consumers may have different choices and reasons for choosing the type of payment mode they prefer to use. Occasionally, malfunctions in certain payment modes can impact the overall performance of the toll plaza operation. For example, PLUS Malaysia Berhad, one of the toll highway operators, formally apologised for the malfunction of its RFID technology at multiple toll plazas in early January 2024 (Tee, 2022).

Moreover, the primary driver of willingness-to-pay is self-interest, which involves assessing the balance between the benefits and costs in relation to individual income and frequency of usage (Yusuf *et al.,* 2014). The user's willingness to accept all payment methods is a function of their ownership of the mode of payment. This is because not all highway users want to have access to every mode of payment. This is due to the perception that each approach may be redundant, as faucets are not always used or applicable in all scenarios. Additionally, queue formation at toll booths is an important issue in the toll road system (Joewono *et al.,* 2017). This occurs due to the

transaction time required to pass through the toll booth. Each mode of payment has its own transaction time. For instance, a cash lane takes 15 seconds, TnG takes six seconds, and SmartTAG only takes three seconds. When a vehicle enters the toll area, it should carefully consider all the available circumstances and choose an option that minimises the duration of the queue (Bari *et al.,* 2022). Travel time is considered an element of a journey's perceived quality. Highway toll plazas are structures located on the highway that require automobiles to slow down or come to a full stop to make a payment for the services offered by the plaza operator (Knorr *et al.,* 2014). An automated toll collection system may verify vehicles enrolled in a toll payment program by matching a unique code affixed to the windscreen of each vehicle with the database kept in the processor (Lima *et al.,* 2019). So, toll highway users are more likely to choose modes that will reduce their travel time and queue when driving through the toll booth.

3.0 METHODOLOGY

In this study, factors influencing toll-lane payment modes were identified by the questionnaire surveying method. We divided the data collection into two types: online questionnaire surveys for the pilot study and face-to-face interviews for the data collection stage. Figure 1 displays the flow chart of the research methodology.

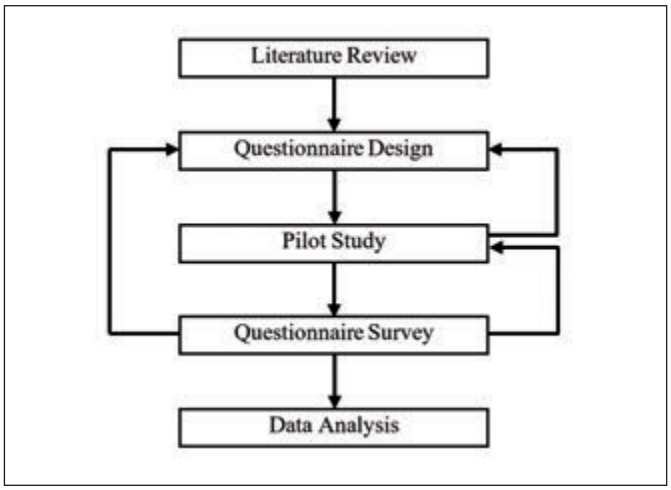

Figure 1: Flow chart of the research methodology

The study commences with a comprehensive literature review, which entails gathering preparatory information from many sources, such as journal articles, books, newspapers, and other relevant publications. After completing the literature review, we designed a questionnaire to gather the essential data for this study. The questionnaire covers several factors that are likely to affect the toll-lane payment. The questionnaire consisted of 27 questions divided into 8 sections, including a screening. We conducted a pilot study using Google Forms for one week in early January 2024. 43 participants provided responses during this period, and we used 28 of them to improve the questionnaire.

We eliminated and incorporated some questions into the questionnaire to improve its quality after the first pilot study. The enhanced version of the questionnaire comprises five different sections, totalling 24 questions. We conducted the second pilot study using Google Forms for one week in late January 2024. The study received a total of 38 responses, with 16 of them later confirmed as valid. We conducted face-to-face interviews with 100 people working within Universiti Pertahanan Nasional Malaysia (UPNM) in February and March 2024, following the second pilot study.

The survey questionnaire comprised four sections. The first section comprised an eligibility screening to ascertain the respondents' qualifications for participation in the survey. The eligibility screening surveyed only respondents who commuted to work on a toll highway at least four days per week over the past year. The second section of the survey gathered data from respondents regarding their preferred toll payment method and the rationale behind their choice. The third section of the questionnaires collected information on the services offered at the toll plaza. This included the promptness of service upon arrival, the frequency of immediate service, and, in the event of a delay, the length of the queue during weekday mornings and evenings when commuting to and from work. We also investigated their experiences using the toll highway over the weekend. The final section of the questionnaire examined the demographics of the respondents.

After data verification and validation, the analysis used a total of 100 responses from the face-to-face interview. We conducted data analysis using the Statistical Package for Social Science (SPSS) and Microsoft Excel.

4.0 RESULTS AND DISCUSSIONS

Table 1 presents a summary of the respondents' demographic characteristics. Most respondents were aged 26-40 years old (48%), male (62%), government employee (56%), and with monthly income between RM 2,500 and RM 4,999 (51%).

Regarding the preferred mode of toll-lane payment amongst the respondents (as shown in Figure 2), 39% of respondents indicated that they preferred using RFID as their means of

Table 1: Descriptive statistics

Variable	Description		N (%)
Responses	**Total Number of Responses**		**100**
Gender	Gender of the respondents	Male	62 %
		Female	48 %
Age	Age of respondents	< 25 years old	8 %
		26-40 years old	54 %
		> 40 years old	38 %
Occupation	Occupation of respondents	Government employee	56 %
		Private sector employee	33 %
		Self-employed	10 %
		Retiree	1 %
Income	Monthly income of respondents	< RM 2,500	11 %
		RM 2,500 – 4,999	51 %
		RM 5,000 – 7,499	29 %
		RM 7,500 – 9,999	6 %
		> RM 10,000	3 %

toll payment. RFID is a superior option compared to other modes. Road users prefer RFID due to its user-friendliness, convenience, dependability, simplicity, and speed. Additionally, it eliminates the need for road users to stop their vehicles at the toll plaza, thereby preventing lengthy queues. In the United States, the use of RFID in ETC is a highly efficient and effective method to address the issue of traffic queues at toll booths (Ulatowski, 2007). Kim (2008) asserts that an embedded RFID tag in an automobile allows the driver to pass through the toll booth without stopping. This is possible because the RFID reader scans the data quickly, completing the entire payment procedure in approximately 5 seconds.

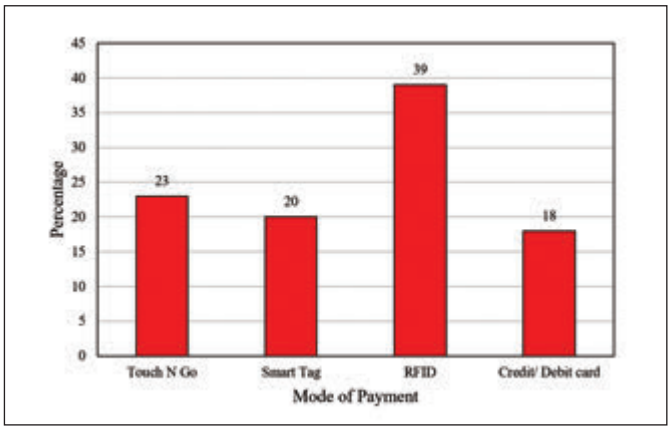

Figure 2: Preferred toll lane mode of payment

TnG ranks as the second most preferred method for paying tolls, accounting for a substantial 23% of the total. This is due to the extensive use of TnG in all forms of ground transportation in Malaysia. TnG can be easily accessed by using an identity card. The current TnG card introductions incorporate near-field communication (NFC), making it easier for road users to top up TnG cards via smartphone-based mobile applications (Dias *et al.,* 2014). Conversely, there are more payment options offered at the toll plaza.

Consequently, the third preferred mode is SmartTAG, accounting for 20% of the total. SmartTAG employs RFID technology, necessitating the prefixing of the TnG card to the device. The SmartTag is efficient because it does not require road users to fully stop at the toll plaza to make a toll payment. Credit or debit cards were the least preferred mode of payment for tolls, accounting for 18% of the total. Due to their recent introduction and limited availability at the toll plaza, credit or debit cards have not gained widespread use. Road users prefer this mode because they receive more rewards or benefits when using their credit or debit cards.

We surveyed the respondents to understand the factors that influence their decision to use the toll-lane payment method. Users of TnG, SmartTAG, RFID, and credit/debit cards reported preferences for these payment methods due to their user-friendliness, convenience, dependability, simplicity, and speed in transactions, with approval rates of 74%, 65%, 64%, and 83%, respectively. 74% of TnG users asserted that TnG offers user-friendliness, convenience, dependability, simplicity, and speed, while 17% indicated that TnG typically offers more payment channels at the toll plaza. The remaining TnG users indicated that TnG typically offers them greater advantages or promotions. Of the SmartTAG users, 65% asserted that SmartTAG is user-friendliness, convenience, dependability, simplicity, and speed; 15% indicated that SmartTAG typically offers more payment channels at the toll plaza; another 15% stated that SmartTAG device generally provides more benefits or promotions; and the remaining users reported that SmartTAG is their sole device for toll payment. Among RFID users, 64% asserted that RFID is user-friendliness, convenience, dependability, simplicity, and speed; 21% indicated that RFID typically offers more payment channels at toll plazas; 13% reported that RFID is their sole device for toll payment; and the remainder stated that RFID generally provides additional benefits or promotions. Among credit and debit card users, 83% asserted that utilising these cards for toll payments is user-friendly, convenient, dependable, simple, and speedy, while the remainder indicated that they derive greater advantages from using credit or debit cards.

The survey also asked respondents about the queuing time for their preferred mode of payment when they approach the toll plaza during the weekday and weekend. Bari *et al.* (2022) suggested that service time is a critical parameter to evaluate the efficiency of a toll booth. Typically, in this study, TnG experiences the longest queue during weekday morning peak hours, weekday evening peak hours, and weekends (Figure 3). The extended duration of service for TnG, which requires road users to halt their vehicles upon reaching the toll booth, lower the window, physically interact with their cards, and await clearance before they can leave the toll booth, largely accounts for this.

According to Figure 3, the TnG lanes had the highest average queuing time of 3.52 minutes during the morning peak on weekdays. Subsequently, the credit or debit card takes around 1.62 minutes, followed by SmartTAG at 1.45 minutes, and RFID at 0.83 minutes. RFID and SmartTAG toll lanes are significantly more efficient than TnG toll lanes, with RFID lanes being over four times (odds ratio = 4.24) more efficient and SmartTAG lanes being over two times (odds ratio = 2.43) more efficient. As RFID and SmartTAG employ RFID technology, shorter service times—approximately 5s, as indicated by Kim (2008)—could lead to lower queuing times at the toll plaza during peak hours.

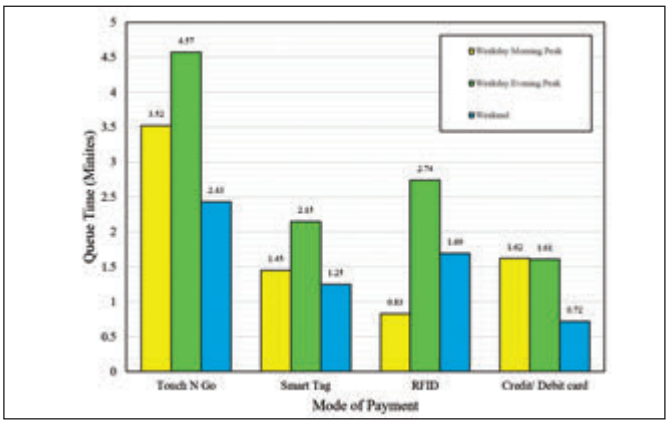

Figure 3: Queue time during weekday morning peak, weekday evening peak and weekend (Ave. Min.)

During the evening peak hours on weekdays, the TnG toll lanes experienced the longest average waiting time of 4.57 minutes. Following that, the RFID takes around 2.74 minutes, followed by SmartTAG at 2.15 minutes, and credit or debit cards at 1.61 minutes. RFID and SmartTAG toll lanes are considerably more efficient than TnG toll lanes. RFID lanes exhibit a 1.67 times higher efficiency (odds ratio = 1.67), while SmartTAG lanes have an efficiency that is almost 2.13 times higher (odds ratio = 2.13). While credit or debit cards and TnG have similar service times at toll plazas, during weekday evening peak hours, credit or debit cards are 2.83 times more efficient than TnG (odds ratio = 2.83). This means that using credit or debit cards results in a significantly faster transaction process.

The average queue time for credit and debit cards during the weekday morning and evening peak periods are nearly identical, with an odds ratio of 1.01. Typically, the average queue time is greater during weekday evening peaks for RFID, SmartTAG, and TnG lanes compared to weekend morning peaks. During the weekday evening peak, the average queue times in RFID, SmartTAG, and TnG lanes are 3.3, 1.48, and 1.3 times higher, respectively, compared to the morning peak.

The average time spent queuing in line at the toll plaza on weekends is significant. RFID and SmartTAG are generally more efficient ways of paying than TnG, with efficiency rates of 1.43 and 1.9 times higher, respectively. Using a credit or debit card is the most convenient way to pay on weekends, resulting in a queue at the toll plaza that is 3.38 times shorter than TnG lanes. Overall, we observed a similar weekend queuing time pattern to the weekday evening pattern, albeit with a lower average queue time.

To summarise, ETC technologies such as RFID, SmartTAG, and TnG, as well as credit/debit cards, offer effective options for alleviating traffic congestion in comparison to MTC. Previous studies had suggested that ETC technologies have the potential to alleviate traffic congestion at toll plazas (Abuzwidah and Abdel-Aty, 2015; Abuzwidah and Abdel-Aty, 2018; Lai *et al.,* 2021) by allowing vehicles to pass through the toll booth without stopping, hence increasing traffic flow. Studies conducted in Taiwan have demonstrated that ETC technologies facilitate drivers' ability to traverse the toll lane at an average velocity of around 50 kilometres per hour (Lai *et al.,* 2021). Similarly, the implementation of RFID technology in India has the potential to improve toll collection efficiency and reduce operational costs at toll plazas (Dhilipkumar and Arunachalaperumal, 2020).

5.0 CONCLUSIONS

The objectives of this study are to identify (i) the preferred mode of payment among toll-lane users in the Klang Valley, (ii) the factors that influence the mode of toll-lane payment, and (iii) the queue time at a toll plaza for each mode of toll-lane payment. The questionnaire survey revealed that the respondents overwhelmingly favour using RFID as their preferred payment mode for toll plaza transactions. This is because the system has the capacity to offer a simplified and accelerated transaction process for toll payments. To pay the toll, the vehicle only needs to reduce its speed rather than stop completely. TnG is the second most preferred option, with SmartTAG as the subsequent choice. Credit or debit cards are the least preferred method of payment.

Each road user has their own unique rationale for selecting their preferred mode of payment while using toll highways. The primary factors influencing the selection of a given mode were its user friendliness, convenience, dependability, simplicity, speed, and other relevant considerations. Each mode demonstrates unique attributes and efficacy, leading individuals to select it based on their specific needs. However, it is suggested that toll highway service providers could provide sufficient toll lane payment mode to ease congestion at the toll plaza, especially during weekday peak hours. For instance, options to pay with RFID could also be enhanced by providing an alternative to pay with a credit or debit card at the same lane to avoid road users having to reverse or switch lanes to use an alternative payment method in case the transponder fails to detect their RFID.

According to the results, TnG consistently has the longest wait time at the toll plaza, taking an average of 3.5 minutes to complete the toll payment process. The large number of TnG users or transaction methods that require a vehicle to stop completely and physically interact with their cards could potentially be the cause of the significant delay at the toll plaza. To promote sustainable transportation at the toll plaza, the concessionaire should consider increasing the number of lanes for each payment method based on the preferences of the drivers. Alternatively, the concessionaire could organize the toll payment methods in a hierarchy based on choice, prioritizing the most-chosen method over the least-favoured one.

This study only considers respondents working in UPNM premises. We recommend enhancing this questionnaire survey by including a wider range of toll highway users to effectively address the issue of congestion and accidents at the toll plaza. Alternatively, we could compare the data collected from the questionnaire with real-time data from various toll agencies for verification purposes.

AUTHORS' CONTRIBUTIONS

- **Muhammad Ashraf Abd Mokti:** Data collection, Methodology, and Formal analysis, Writing—original draft preparation and literature review
- **Choy Peng Ng:** Conceptualisation, Study Design, and Supervision, Formal Analysis, Data validation, Visualisation, and Software Implementation, Literature Review, Writing—review, editing, and final manuscript approval
- **Faridah Hanim Khairuddin:** Supervision, Literature Review, Writing—review, editing, and final manuscript approval
- **Vikneswaran Munikanan:** Supervision, Literature Review, Writing—review, editing, and final manuscript approval
- **Chee Fui Wong:** Writing—review, editing, and final manuscript approval. ■

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SUSTAINABLE CONSTRUCTION IN NIGERIA: A COMPREHENSIVE SOCIOECONOMIC IMPACT ASSESSMENT

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Abstract

This study explored how sustainable construction affects Nigeria's economy and society, using Structural Equation Modeling (SEM) and Geospatial Analysis for a detailed review. With a 94.6% response rate from key figures in Nigeria's construction industry, the research found that sustainable construction greatly improves economic growth, creates jobs, and increases market value. It also promotes social well-being and supports environmental protection. The study highlighted the essential role of new technologies and community resilience in enhancing these benefits. It pointed out that advanced technologies and resilient practices need to be integrated into construction for even greater impact. Additionally, the study found that urban areas are adopting sustainable practices more quickly and reaping more benefits than rural regions. These findings offer valuable guidance for policymakers, industry experts, and researchers, stressing the importance of promoting sustainable construction for long-term economic stability and environmental care in Nigeria. The study ended by suggesting targeted efforts to spread sustainable practices, particularly in less developed regions, and recommended future research into the long-term effects of these practices on global sustainability issues.

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1.0 INTRODUCTION

The construction industry worldwide is undergoing a significant transformation towards sustainability, aimed at minimising environmental impact and maximising social and economic benefits (Mamilla & Kumar, 2024). This shift is particularly visible in the adoption of green building practices, which integrate eco-friendly techniques to enhance economic efficiency, reduce the industry's environmental footprint, and promote social development, thus aligning with global sustainability goals (Chen *et al.,* 2023). In rapidly urbanizing countries like Nigeria, sustainable construction has become a key priority, driven by the need to balance economic development with environmental conservation. Despite its essential role in driving economic growth, Nigeria's construction sector significantly contributes to environmental degradation through overconsumption of resources, high greenhouse gas emissions, and poor waste management practices (Suleman *et al.,* 2023).

The dual challenge facing Nigeria's construction industry involves supporting economic growth while reducing its environmental impact. The sector relies heavily on non-renewable resources, with energy-intensive processes that lead to substantial carbon emissions (Labaran *et al.,* 2022). Additionally, inadequate waste disposal exacerbates pollution and depletes natural resources (Ibrahim & Parsa, 2021). To address these issues, there is a growing imperative for adopting sustainable construction practices, such as using environmentally friendly materials, enhancing energy efficiency, and implementing effective waste reduction strategies. These practices not only reduce environmental harm but also support economic and social progress (Akinshipe *et al.,* 2019).

The momentum for sustainable construction is gaining traction due to global environmental imperatives and local demand for sustainable development (Akindele *et al.,* 2023). Green building technologies, such as solar energy systems, rainwater harvesting, and recycled materials, have proven effective in reducing buildings' carbon footprints, contributing to climate change mitigation efforts (Obada *et al.,* 2024). These practices also present opportunities for economic diversification, job creation, and innovation in energy-efficient technologies (Ugwuanyi, & Nwatu,, 2021).

While the environmental and economic benefits are well-documented, sustainable construction in Nigeria also offers significant social advantages. These include job creation, improved public health through better building standards, and reduced energy costs for consumers (Genovese & Zoure, 2023). However, challenges such as high initial costs and the need for supportive government policies persist (Suleman *et al.,* 2023). This study aims to explore the relationship between sustainable construction practices and their socioeconomic impacts in Nigeria, analysing how these practices influence job creation, economic growth, social well-being, and environmental sustainability. The research findings will provide actionable insights for policymakers, industry leaders, and communities to support the successful integration of sustainable construction into Nigeria's development plans (Akinadewo *et al.,* 2023).

1.1 Conceptual Framework for Evaluating the Socioeconomic Impacts of Sustainable Construction

Assessing the socioeconomic effects of sustainable construction requires a well-rounded and comprehensive theoretical framework, capable of capturing the diverse and complex aspects of sustainability. One of the most commonly utilised approaches for this is the Triple Bottom Line (TBL) framework, originally introduced by John Elkington in 1997. The

TBL model offers an integrated perspective on sustainability by focusing on three crucial areas: social, environmental, and economic impacts (Elkington, 1997).

The social component of the TBL framework places emphasis on improving community well-being, ensuring fair labour practices, upholding human rights, and involving stakeholders in key decisions. In the context of sustainable construction, this aspect assesses how building projects affect local populations by considering factors such as enhancing living standards, ensuring equal access to resources, and encouraging community participation in decision-making. Additionally, it evaluates labour conditions within the construction industry, promoting fair wages, safe workplaces, and opportunities for workforce development and growth (Rostamnezhad & Thaheem, 2022). By focusing on the social pillar, sustainable construction helps to empower communities, advance social justice, and improve overall quality of life.

The environmental pillar of the TBL framework addresses the ecological consequences of construction activities. This dimension includes resource conservation, minimising waste, lowering carbon emissions, and advancing broader environmental preservation initiatives. Sustainable construction methods aim to reduce resource consumption, minimise waste production, and lower greenhouse gas emissions by integrating energy-efficient designs, using renewable resources, and incorporating green technologies (Gu *et al.,* 2023). For example, utilising energy-saving heating, ventilation, and air conditioning (HVAC) systems, installing solar panels, and implementing rainwater harvesting techniques are ways sustainable construction projects demonstrate environmental responsibility. By reducing the ecological impact of construction, the environmental pillar ensures long-term ecological stability and resilience (Elkington, 1997).

The economic aspect of the TBL framework examines the financial performance and cost-effectiveness of sustainable construction practices. This pillar evaluates the economic sustainability of green building projects by analysing factors such as long-term financial savings, return on investment, and the overall economic advantages generated by sustainable practices. While the initial costs of green construction may be higher due to advanced technologies and materials, these expenses are often recouped through energy savings, reduced maintenance costs, and greater operational efficiency over time (D'Agostino *et al.,* 2019). Additionally, eco-friendly buildings generally experience an increase in property value and attract higher premiums in the real estate market, reinforcing their economic benefits (Rostamnezhad & Thaheem, 2022).

The TBL framework has become widely adopted across multiple industries, including construction, as a comprehensive tool for evaluating the impact of projects on society, the environment, and the economy. By providing a balanced and holistic perspective, the TBL framework enables decision-makers to assess the true value and far-reaching implications of sustainable construction efforts. It also helps identify potential synergies and trade-offs among the three dimensions, guiding the creation of policies and practices that support a sustainable, equitable, and environmentally conscious built environment (Gu *et al.,* 2023).

1.2 Overview of Key Findings from Prior Research

Recent scholarly work on sustainable construction has offered in-depth insights into its diverse impacts across the environmental, economic, and social dimensions. This growing body of research highlights the considerable advantages of sustainable building practices, while also acknowledging the obstacles that need to be addressed in order to fully realise these benefits. This section summarises the core findings from recent studies, focusing on the global and regional effects of sustainable construction.

1.2.1 Reducing Environmental Impact

Sustainable construction is recognised for its significant ability to decrease environmental harm, particularly in terms of lowering energy consumption, cutting greenhouse gas emissions, and improving resource efficiency. Recent research has underscored the role sustainable practices play in mitigating climate change by reducing carbon footprints. A meta-analysis by Chen *et al.* (2022) examined green building projects across multiple regions and showed that sustainable construction can cut energy consumption by 30-50% compared to traditional methods. This reduction is primarily achieved through the integration of energy-efficient technologies, such as advanced insulation, smart management systems, and renewable energy sources like solar panels.

Furthermore, the use of lifecycle assessment (LCA) in sustainable construction has been crucial for optimising resource use and minimising waste. Buyle *et al.* (2013) found that LCA has become a standard practice during the design stage of green buildings, leading to a 40% reduction in material waste and promoting increased recycling of construction materials. Their study also emphasised the importance of using sustainable materials, such as low-carbon concrete and recycled steel, which help reduce a building's overall environmental footprint throughout its lifecycle (Althoey *et al.,* 2023).

1.2.2 Economic Feasibility and Cost Benefits

The economic advantages of sustainable construction have been a prominent focus of many studies, particularly regarding long-term savings and return on investment (ROI). Research by Akinadewo *et al.* (2023) provided a detailed analysis of the financial performance of green buildings, demonstrating that while the upfront costs of sustainable construction are typically 15-20% higher than those of conventional buildings, the operational savings and higher asset values more than compensate for these expenses. Their research indicated that sustainable buildings generally achieve payback periods within five to ten years due to reduced energy and water usage, lower maintenance costs, and increased durability.

Supporting these findings, Abdulsalam *et al.* (2024) explored the financial benefits and market advantages of green-certified buildings. Their study revealed that green-certified properties tend to command higher rental and sales prices, which reflects their appeal in the real estate market. Additionally, various government incentives, such as tax breaks, grants, and subsidies, further enhance the economic attractiveness of sustainable construction (Saka, *et al.,* 2021). The rise of green bonds as a funding mechanism for sustainable projects

has also gained momentum, offering lower interest rates and appealing to environmentally conscious investors (Akinshipe *et al.,* 2019).

1.2.3 Social Impact and Community Benefits

The social implications of sustainable construction go beyond its environmental and economic contributions, encompassing substantial improvements in public health, social equity, and community development. Recent research has highlighted the role green buildings play in improving the quality of life for occupants and surrounding communities. A comprehensive study by Suleman *et al.* (2023) found that green buildings, through better air quality, increased natural lighting, and enhanced ventilation, contribute to reduced respiratory issues, improved mental health, and greater overall satisfaction among occupants. Zhong *et al.* (2022) echoed these findings, noting that biophilic design features, such as green roofs and indoor plants, not only enhance air quality but also foster a connection to nature, which has been linked to improved mental well-being.

Sustainable construction also plays a vital role in strengthening community resilience. Research by Mahajan *et al.* (2022) emphasised the importance of engaging local communities in the planning and execution of sustainable projects. Their findings demonstrated that when communities are actively involved in decision-making, the resulting projects are better aligned with local needs, fostering stronger social ties and promoting greater community resilience. This participatory approach ensures that the socioeconomic benefits of sustainable construction, such as job creation and enhanced infrastructure, are equitably distributed across different population groups (Genovese & Zoure, 2023).

1.2.4 Barriers to Broader Adoption

Despite the growing recognition of the benefits associated with sustainable construction, several barriers still hinder its widespread implementation, particularly in developing regions. One of the primary obstacles is the higher initial cost of sustainable materials and technologies. While the long-term cost savings are well-documented, the upfront investment required can be prohibitive for many developers, especially in low-income areas. Akindele *et al.* (2023; Ogunseye *et al.,* 2023) found that in Sub-Saharan Africa, the lack of access to affordable green building materials and technologies is a significant challenge to the adoption of sustainable construction practices.

Another major obstacle is the limited knowledge and expertise among construction professionals regarding sustainable practices. Genovese & Zoure (2023) highlighted that inadequate training and education on sustainable building methods contribute to the slow adoption of green construction in many regions. This knowledge gap is further exacerbated by weak regulatory frameworks and a lack of enforcement mechanisms, both of which are essential for supporting and promoting green building initiatives (Akinadewo *et al.,* 2023).

1.3 Research Gaps

Despite growing interest in sustainable construction, significant gaps remain, particularly in understanding its socioeconomic impacts within Nigeria's construction sector. Although global studies have highlighted the benefits of sustainable construction, there is limited empirical research specifically quantifying these impacts in Nigeria. Existing studies often lack detailed analyses of how sustainable practices influence key factors like job creation, economic growth, income distribution, and poverty reduction within the local context (Tafesse *et al.,* 2022). This gap is critical given Nigeria's status as one of Africa's largest economies and its rapidly expanding urban areas, where the construction industry plays a central role in development (Suleman *et al.,* 2023).

Moreover, current research frameworks often apply broad, global models to evaluate sustainable construction, without considering the unique socioeconomic and cultural conditions in Nigeria. There is a need for studies that adapt these models to better reflect the local context, including the significant role of the informal sector, which operates under different economic and regulatory conditions (Akinadewo *et al.,* 2023). The absence of research addressing the contributions and challenges of the informal sector further complicates the development of effective policies for sustainable construction.

Another notable gap is the insufficient focus on barriers to sustainable construction adoption in Nigeria. While some studies have identified issues like high costs, lack of awareness, and weak regulatory frameworks, more in-depth research is needed to explore how these challenges are influenced by local economic conditions, cultural attitudes, and the availability of green technologies (Akinshipe *et al.,* 2019). Addressing these factors is essential for developing targeted strategies to overcome obstacles and promote broader implementation of sustainable practices.

Finally, while the economic advantages of sustainable construction, such as lower operating costs and higher property values, are widely discussed in global literature, there is a shortage of localised studies examining these benefits in Nigeria. Without robust financial data specific to the Nigerian context, policymakers and investors may hesitate to commit to sustainable projects, slowing the scaling of sustainable construction practices (Abdulsalam *et al.,* 2024).

These research gaps directly lead to the aim of this study: to provide a comprehensive analysis of the socioeconomic impacts of sustainable construction in Nigeria. By focusing on the specific conditions and challenges within the country, this research seeks to generate actionable insights that can inform strategies to accelerate sustainable construction and support Nigeria's broader development goals.

2.0 METHODOLOGY

This research employed a quantitative methodology to assess the socioeconomic impacts of sustainable construction within Nigeria's construction industry. A diverse range of stakeholders, including contractors, developers, policymakers, and community representatives, were engaged to ensure a comprehensive evaluation of the industry's influence. The total workforce in Nigeria's construction sector is estimated at around 10,000 individuals (Ibrahim, *et al.,* 2024). A stratified random sampling approach was used to obtain a representative sample, accurately reflecting the diversity of roles within the industry.

2.1 Determining the Sample Size

The sample size was calculated using the Krejcie and Morgan formula, a widely recognised method for determining appropriate sample sizes in research. With a population size of 10,000 individuals, the calculated sample size was 370 respondents, ensuring a 95% confidence level and a 5% margin of error (Zhang, & Yong, 2021; Nwogu & Emedosi, 2024). The stratified random sampling technique ensured adequate representation across various segments of the construction sector, including construction managers, site labourers, government officials, and community leaders.

2.2 Data Collection Methodology

Data were collected using a structured survey distributed to the selected participants. The survey was designed to assess the socioeconomic effects of sustainable construction practices from different perspectives. It comprised three main sections: demographic data, economic impact, and social impact.

2.2.1 Design of the Structured Questionnaire

The questionnaire (Table 1) was crafted to measure the socioeconomic impacts of sustainable construction, covering areas such as economic growth, job creation, property value, social well-being, environmental sustainability, and technological advancements. Section A. collected demographic information, including gender, age, educational background, years of professional experience, job role, company size, type of construction firm, geographical location, years of operation, and annual turnover.

Section B. focused on Sustainable Construction (SC), evaluating the effectiveness of sustainable practices in minimising environmental damage, enhancing energy efficiency, and optimising resource use. This section also assessed government policies and the potential of sustainable construction to extend building lifespans. Section C. explored Economic Growth (EG) and examined the impact of green practices on economic expansion, property values, cost reductions, and the creation of green jobs.

Section D. evaluated how sustainable construction contributes to job creation and demand for skilled labour. Section E focused on Market Value (MV), assessing how green buildings influence property values, attract investments, and affect market trends. Section F. looked into Social Well-being (SWB), considering improvements in public health, access to green spaces, and quality of life enhancements. Finally, Section G. examined Environmental Sustainability (ES), including the effectiveness of practices in reducing carbon emissions, conserving resources, fostering biodiversity, and mitigating climate change. Each of the questions in each section was given a label for easy usage and recognition by the software used for data analyses.

2.3 Data Analysis Techniques

The data analysis employed descriptive statistics, multiple regression analysis, and Structural Equation Modeling (SEM) to examine the socioeconomic impacts of sustainable construction in Nigeria. Descriptive statistics summarised demographic characteristics and response patterns related to the study's variables, providing a foundational overview.

Multiple regression analysis was used to assess the relationships between sustainable construction practices and various outcomes, such as economic growth and job creation. This approach allowed for understanding the contribution of different sustainable practices while controlling for other variables, thereby isolating the most significant predictors of socioeconomic benefits (Cohen *et al.,* 2013).

SEM was utilised to analyse the complex relationships among observed variables (survey data) and latent variables (e.g., social well-being, environmental sustainability). It was particularly suitable for testing direct and indirect effects and for examining the interconnected pathways between sustainable practices and their broader impacts. SEM's ability to assess model fit through indices such as the Comparative Fit Index (CFI) and Root Mean Square Error of Approximation (RMSEA) provided a robust framework for validating the study's hypothesised relationships (Kline, 2021; Hu & Bentler, 1999). This method enabled a comprehensive understanding of how sustainable construction influences various socioeconomic dimensions by accounting for mediating factors and latent constructs (Byrne, 2016).

2.3.1 Demographic Information Analysis

Section A. gathered demographic data, including gender, age range, educational attainment, years of experience, job roles, company size, firm type, location, operational duration, and annual turnover. This information was crucial for understanding the sample's diversity and ensuring wide representation within the industry.

2.3.2 Development of Hypotheses and Hypothetical Model

Structural Equation Modeling (SEM) was employed to analyse the complex relationships between observed variables, such as survey responses, and latent variables, including constructs like economic growth, social well-being, and environmental sustainability. SEM was an ideal choice for this study because it allows for the exploration of both direct and indirect effects of sustainable construction practices on various socioeconomic outcomes. This technique is particularly robust, as it can handle multiple dependent and independent variables at once, offering a comprehensive understanding of the relationships between different factors involved in the study (Byrne, 2016; Kline, 2021). Based on a thorough literature review, the following hypotheses were developed to guide the SEM analysis:

H1: Sustainable construction practices have a positive direct effect on economic growth within the Nigerian construction sector. (Supported by Ries, *et al.,* 2006; Tafesse *et al.,* 2022).

H2: Sustainable construction practices positively influence job creation in the construction industry. (Supported by D'Agostino *et al.,* 2019 ; Sovacool *et al.,* 2023).

H3: Sustainable construction practices lead to an enhancement in the market value of properties. (Supported by Oke & Aigbavboa, 2017; Kauskale *et al.,* 2022).

H4: The adoption of sustainable construction practices contributes to improved social well-being in local communities. (Supported by Zhang, & Yong, 2021; Adshead *et al.,* 2007).

H5: Environmental sustainability mediates the relationship between sustainable construction practices and economic growth. (Supported by Jung *et al.,* 2020; Al-Emran & Griffy-Brown, 2023).

H6: Social well-being mediates the relationship between sustainable construction practices and job creation. (Supported by Gu *et al.,* 2023 Akindele *et al.*, 2023).

H7: Sustainable construction practices have a positive effect on environmental sustainability, leading to reduced carbon emissions and resource conservation. (Supported by Jaradat *et al.,* 2024; Gu *et al.,* 2023).

H8: Technological innovation in sustainable construction positively influences economic growth and market value of properties. (Supported by Li *et al.,* 2022; Hair *et al.,* 2020).

H9: Sustainable construction practices enhance community resilience, contributing to long-term social and economic stability. (Supported by Al-Emran & Griffy-Brown, 2023; Kauskale *et al.,* 2022).

H10: There is a positive relationship between public health improvements and the adoption of sustainable construction practices, mediated by enhanced environmental quality. (Supported by Islam *et al.,* 2019; Gou *et al.,* 2021).

The hypothetical SEM model, as illustrated in Figure 1, represents the relationships between sustainable construction practices (independent variable), economic growth, job creation, market value, social well-being, environmental sustainability, technological innovation, community resilience, and public health (dependent variables). The model also includes mediating effects of environmental sustainability, social well-being, and public health improvements.

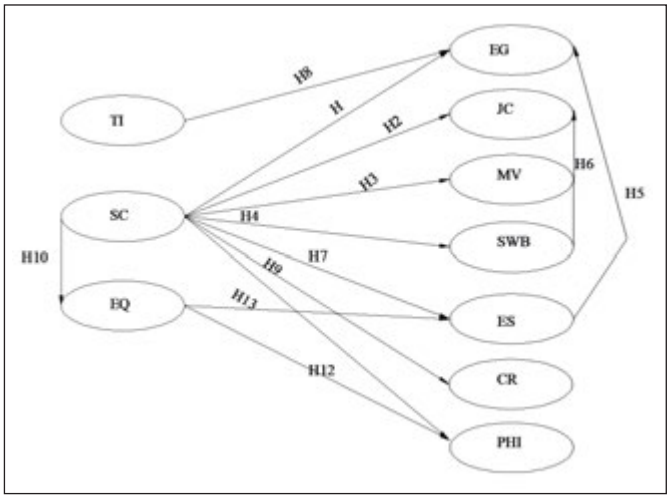

Figure 1: Hypothetical SEM model for sustainable construction practices

2.3.3 Model Specification and Estimation

The SEM model was specified using maximum likelihood estimation (MLE) to estimate the complex relationships. Confirmatory factor analysis (CFA) validated the constructs, ensuring internal consistency and construct validity. Model fit was evaluated using indices such as Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA), with thresholds set at CFI > 0.90, TLI > 0.90, and RMSEA < 0.08 (Hu & Bentler, 1999).

2.4 Geospatial Analysis

Geospatial analysis using Geographic Information System (GIS) tools provided insights into regional differences in sustainable construction implementation. By mapping spatial data, such as construction project locations and demographic information, this analysis revealed patterns and trends. Spatial regression models examined geographic variability, identifying regions that may need targeted interventions (Gu *et al.,* 20231; Jung *et al.,* 2020).

2.5 Descriptive and Inferential Statistical Analysis

Descriptive statistics, including means and standard deviations, were calculated to identify central trends. Inferential methods, such as chi-square tests and t-tests, were used to assess the significance of relationships, verifying the validity of SEM and geospatial analysis results.

2.6 Synthesis of Results

The integration of SEM, Geospatial Analysis, and statistical techniques provided a multidimensional understanding of sustainable construction's socioeconomic impacts. This approach offered insights into sustainable methods' contributions to economic development, job creation, social welfare, environmental preservation, technological advancement, community resilience, and public health. These findings can guide policymakers and industry stakeholders in promoting sustainable construction practices across Nigeria.

3.0 RESULTS AND DISCUSSION

3.1 Survey Response Rate

Out of the 370 surveys distributed to individuals within Nigeria's construction industry, 350 were successfully completed and returned, resulting in a notably high response rate of 94.6%. Such a strong response lends credibility to the study's findings and enhances the generalisability of the results across Nigeria's construction sector (Sekaran & Bougie, 2019). The high level of participation likely reflects the increasing importance of sustainable construction practices within the industry and the heightened interest of its stakeholders in the subject matter.

3.2 Initial Data Analysis

3.2.1 Assessing Validity

To ensure the validity of the constructs used in the study, Confirmatory Factor Analysis (CFA) was conducted, focusing on both convergent and discriminant validity. Convergent validity was evaluated using the Average Variance Extracted (AVE) for each construct, with all AVE values exceeding the benchmark of 0.50, as demonstrated in Table 2. These findings affirm that the measurement indicators are effectively capturing the theoretical constructs they were designed to measure (Hair *et al.,* 2020).

Table 3: Speed-Density curve estimation

S/N	Question	Label	Citation
Sustainable Construction (SC)			
1	To what extent do you believe sustainable construction practices reduce environmental impact?	X21	(Vatalis *et al.,* 2011)
2	How effective are sustainable materials in reducing construction waste?	X22	(D'Agostino *et al.,* 2019)
3	Do you believe green building technologies lead to more efficient resource consumption in construction?	X23	(Chen *et al.,* 2023)
4	How significantly has the adoption of sustainable practices improved energy efficiency in construction projects?	X24	(Jaradat *et al.,* 2024)
5	To what extent do you agree that sustainable construction enhances the longevity of building structures?	X25	(Obada *et al.,* 2024)
6	How effective are government policies in promoting the adoption of sustainable construction practices?	X26	(Akindele *et al.,* 2023)
Economic Growth (EG)			
7	To what extent do sustainable construction practices contribute to overall economic growth in your community?	Y11	(Saka, *et al.,* 2021)
8	How effective are sustainable construction practices in reducing operational costs for businesses in the construction industry?	Y12	(Labaran *et al.,* 2022)
9	Do you believe that sustainable construction practices result in increased property values in the market?	Y13	(Ibrahim, *et al.,* 2024)
10	To what extent has sustainable construction led to the expansion of green jobs in the construction industry?	Y14	(Akinshipe *et al.,* 2019)
11	Do you perceive sustainable construction as having a long-term positive effect on national economic development?	Y15	(Ries, *et al.,* 2006)
12	How would you rate the impact of sustainable construction on reducing overall energy costs for businesses?	Y16	(Abdulsalam *et al.,* 2024)
Job Creation (JC)			
13	Do you believe that the adoption of sustainable construction practices has contributed to job creation in the construction industry?	Y21	(Saka, *et al.,* 2021)
14	How effective is the use of green building materials in creating new employment opportunities?	Y22	(Obada *et al.,* 2024)
15	To what extent has sustainable construction encouraged the development of green construction training programs?	Y23	(D'Agostino *et al.,* 2019)
16	Do you agree that the increase in sustainable projects has led to more skilled labour in green construction technologies?	Y24	(Al-Emran & Griffy-Brown, 2023)
17	How significantly has the increase in green building projects affected the demand for specialised construction workers?	Y25	(Tafesse *et al.,* 2022)
18	How do you perceive the role of sustainable construction in addressing unemployment in the construction sector?	Y26	(Ugwuanyi, & Nwatu, 2021)
Market Value (MV)			
19	To what extent do you believe sustainable buildings have a higher market value compared to conventional buildings?	Y31	(Chen *et al.,* 2022)
20	How significantly does the integration of green technologies influence property values in the market?	Y32	(Ugwuanyi, & Nwatu, 2021)
21	Do you agree that sustainable construction has made properties more attractive to investors?	Y33	(Abdulsalam *et al.,* 2024)
22	How would you rate the impact of sustainable construction on the appreciation of property values over time?	Y34	(Akinshipe *et al.,* 2019)
23	To what extent has the demand for sustainable buildings influenced market trends in property pricing?	Y35	(Ries, *et al.,* 2006)
24	How do sustainable features contribute to the perceived quality and marketability of properties?	Y36	(Ugwuanyi, & Nwatu, 2021)
Social Well-Being (SWB)			
25	Do you believe sustainable construction practices contribute to improving the social well-being of the surrounding communities?	Y41	(D'Agostino *et al.,* 2019)
26	To what extent has sustainable construction improved access to green spaces in urban areas?	Y42	Obada *et al.,* 2024)
27	How would you rate the impact of sustainable construction on enhancing public health outcomes in the community?	Y43	(Ries, *et al.,* 2006)
28	Do you believe sustainable construction leads to improved indoor air quality, benefiting building occupants' health?	Y44	(Tafesse *et al.,* 2022)
29	How effective are sustainable construction methods in promoting equitable access to resources and infrastructure?	Y45	(Abdulsalam *et al.,* 2024)
30	To what extent do sustainable building practices enhance the quality of life for the occupants and surrounding communities?	Y46	(Al-Emran & Griffy-Brown, 2023)
Environmental Sustainability (ES)			
31	Do you agree that sustainable construction practices significantly reduce carbon emissions?	Y51	(Adshead *et al.,* 2007)
32	How effective are sustainable construction projects in minimising the depletion of natural resources?	Y52	(Suleman *et al.,* 2023)
33	To what extent does the use of renewable resources in construction contribute to environmental sustainability?	Y53	(Obada *et al.,* 2024)
34	How would you rate the impact of sustainable construction on conserving biodiversity in construction areas?	Y54	(Jaradat *et al.,* 2024)
35	Do you perceive that green building technologies help reduce pollution levels during construction?	Y55	(D'Agostino *et al.,* 2019)
36	How effectively does sustainable construction address issues related to climate change mitigation?	Y45	(Chen *et al.,* 2022)
Technological Innovation (TI)			
37	How do you rate the impact of technological innovations on advancing sustainable construction practices?	X11	(Li *et al.,* 2022)
38	To what extent has the adoption of new technologies improved energy efficiency in sustainable construction?	X12	(Abdulsalam *et al.,* 2024)
39	How effectively do new materials and technologies reduce construction costs in sustainable projects?	X13	(Li *et al.,* 2022)
40	To what extent does the adoption of innovative technologies in construction contribute to the development of green jobs?	X14	(Obada *et al.,* 2024)
41	To what extent does the adoption of innovative technologies in construction contribute to the development of green jobs?	X15	(Obada *et al.,* 2024)

42	How significantly has technological advancement reduced construction time and improved efficiency in sustainable construction practices?	X16	(Al-Emran & Griffy-Brown, 2023)
43	Do you agree that innovative technologies in construction reduce overall project costs while enhancing sustainability?	X16	(Chen *et al.,* 2023)
Community Resilience (CR)			
44	How effective are sustainable construction practices in enhancing the resilience of local communities against environmental challenges?	Y61	(Akinshipe *et al.,* 2019)
45	To what extent does sustainable construction contribute to community cohesion and social stability?	Y62	(Ugwuanyi, & Nwatu, 2021)
46	How do green building practices help communities adapt to climate-related risks?	Y63	(Suleman *et al.,* 2023)
47	Do you believe that sustainable construction enhances community preparedness for natural disasters?	Y64	(Moshood *et al.,* 2024)
48	To what extent do you agree that sustainable building materials contribute to strengthening the resilience of community infrastructure?	Y65	(Al-Emran & Griffy-Brown, 2023)
49	How would you rate the role of sustainable construction in promoting long-term resilience in urban development?	Y66	(Akindele *et al.,* 2023)
Public Health Improvement (PHI)			
50	To what extent do you believe sustainable construction practices contribute to public health improvement through better air and water quality?	Y71	(Saka, *et al.,* 2021)
51	How effectively do sustainable construction projects address issues related to reducing exposure to hazardous materials?	Y72	(Nwogu & Emedosi, 2024)
52	Do you agree that green buildings promote healthier lifestyles for occupants by providing access to natural light and ventilation?	Y73	(Suleman *et al.,* 2023)
53	How significantly do you believe that the use of non-toxic materials in construction enhances occupant well-being?	Y74	(D'Agostino *et al.,* 2019)
54	To what extent does the inclusion of green spaces in construction projects promote physical and mental health benefits for the community?	Y75	(Adinyira *et al.,* 2024)
55	How effectively do sustainable construction practices improve public health outcomes in urban environments?	Y76	(Jaradat *et al.,* 2024)
Environmental Quality (EQ)			
56	How significantly do green building practices contribute to improving overall environmental quality in urban areas?	X31	(Akinadewo *et al.,* 2023)
57	To what extent do you believe sustainable construction reduces environmental degradation and improves air and water quality?	X32	(Suleman *et al.,* 2023)
58	How would you rate the effectiveness of green buildings in reducing pollutants during the construction phase?	X33	(Moshood *et al.,* 2024)
59	Do you agree that sustainable construction practices enhance biodiversity conservation within urban developments?	X34	(Suleman *et al.,* 2023)
60	To what extent do you believe that green infrastructure improves waste management and recycling efforts within construction projects?	X35	(Akinshipe *et al.,* 2019)
61	How significantly do you believe sustainable construction practices contribute to enhancing the overall environmental sustainability of cities?	X36	(Adshead *et al.,* 2007)

Table 2: Convergent Validity (AVE) results

SN	Construct	AVE	Convergent Validity
1	Economic Growth	0.68	Acceptable
2	Job Creation	0.71	Acceptable
3	Market Value	0.64	Acceptable
4	Social Well-being	0.7	Acceptable
5	Environmental Sustainability	0.75	Acceptable
6	Technological Innovation	0.67	Acceptable
7	Community Resilience	0.69	Acceptable
8	Public Health Improvement	0.72	Acceptable

Table 3: Reliability testing results

SN	Construct	Cronbach's Alpha	Composite Reliability (CR)
1	Economic Growth	0.88	0.89
2	Job Creation	0.9	0.91
3	Market Value	0.85	0.87
4	Social Well-being	0.89	0.9
5	Environmental Sustainability	0.91	0.92
6	Technological Innovation	0.86	0.88
7	Community Resilience	0.87	0.88
8	Public Health Improvement	0.9	0.91

3.2.2 Reliability Testing

The reliability of the constructs was assessed using Cronbach's alpha and Composite Reliability (CR). As illustrated in Table 3, all constructs exhibited Cronbach's alpha and CR values above the recommended 0.70 threshold, confirming high internal consistency and reliability (Nunnally & Bernstein, 1994). This indicates that the items used in the questionnaire consistently measure the intended constructs, thereby supporting the robustness of the data.

3.3 Testing of the Hypothetical Model

3.3.1 Initial Hypothetical Model

To explore the relationships between sustainable construction practices and various socioeconomic outcomes, such as economic growth, job creation, property values, social well-being, environmental sustainability, technological advancement, community resilience, and public health, an initial Structural Equation Model (SEM) was constructed. This model was tested using the maximum likelihood estimation (MLE) technique, which is well-suited for complex modelling.

3.3.2 Model Fit and Adjustments

The preliminary analysis of the model produced the following fit statistics: the chi-square to degrees of freedom ratio (Chi-square/df) was calculated at 4.25, suggesting that the model's fit was less than ideal. The Standardised Root Mean Square Residual (SRMR) stood at 0.079, which, while within an acceptable range, still indicated that improvements could be made. The Root Mean Square Error of Approximation

(RMSEA) was found to be 0.075, slightly exceeding the recommended threshold, thus reflecting a moderate model fit. The Comparative Fit Index (CFI) came in at 0.89, and the Tucker-Lewis Index (TLI) was 0.87—both indices showing that the model's fit approached acceptability but did not fully meet the optimal criteria. These results indicate that while the model showed a reasonable fit, there was still room for improvement.

To better align the model with ideal fit thresholds, particularly for RMSEA, CFI, and TLI, additional adjustments were deemed necessary (Hu & Bentler, 1999; Kline, 2021). According to the modification indices, introducing paths between Technological Innovation (TI) and Sustainable Construction (SC), from SC to Public Health (PH), and from Environmental Quality (EQ) to PH, would enhance the model's performance. These refinements were implemented, and the model was subsequently re-estimated, with the final version illustrated in Figure 2.

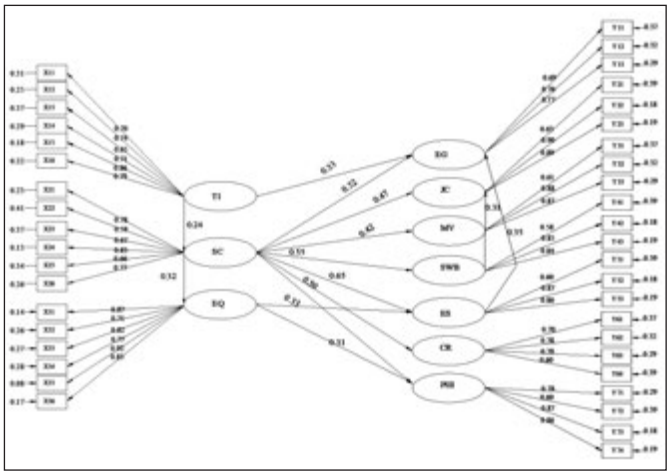

Figure 2: Final SEM model

3.3.3 Final Model Fit

The final model demonstrated a significantly improved fit, as evidenced by the goodness of fit statistics shown in Table 4.

The final model's fit indices all met or exceeded the recommended thresholds, confirming that the model provided a strong representation of the relationships between sustainable construction practices and the studied outcomes.

Table 4: Final model fit statistics

SN	Fit Index	Initial Model	Final Model	Recommended Threshold
1	Chi-square/df	4.25	2.89	< 3
2	SRMR	0.079	0.055	< 0.08
3	RMSEA	0.075	0.049	< 0.06
4	CFI	0.89	0.94	> 0.90
5	TLI	0.87	0.93	> 0.90

3.4 Validation of Hypotheses

The path coefficients and significance levels for the final model are detailed in Table 5. The results robustly support the majority of the hypothesised relationships, with all paths demonstrating statistical significance.

Table 5: Path coefficients and hypotheses testing for final model

Hypothesis	Path	Coefficient (β)	p-value	Supported?
H1	SC→ EG	0.52	<0.001	Yes
H2	SC → JC	0.47	<0.001	Yes
H3	SC → MV	0.42	<0.001	Yes
H4	SC → SWB	0.55	<0.001	Yes
H5	ES → EG	0.35	<0.001	Yes
H6	SW → JC	0.31	<0.01	Yes
H7	SC → ES	0.65	<0.001	Yes
H8	TI → EG	0.33	<0.01	Yes
H9	SC → CR	0.5	<0.001	Yes
H10	PHI → SC → ENQ	0.32	<0.01	Yes

3.5 Discussion of Findings

3.5.1 Economic Effects of Sustainable Construction

The results of the SEM analysis indicated a substantial positive correlation between sustainable construction practices and economic growth in Nigeria's construction sector (β = 0.52, p < 0.001). This conclusion supports previous research, which highlights the economic advantages of sustainable construction, such as reduced operational expenses, improved energy use, and increased property valuations (Ries, *et al.,* 2006 Ibrahim, *et al.,* 2024). Furthermore, the connection between technological innovation and economic expansion (β = 0.33, p < 0.01) underscores the importance of advanced technologies in driving economic progress within the construction industry (Li *et al.,* 2022). These findings suggest that sustainable construction investments yield not only environmental benefits but also significant economic returns.

3.5.2 Job Generation and Social Benefits

The study revealed that sustainable construction plays a crucial role in creating jobs (β = 0.47, p < 0.001), reinforcing previous findings that highlight green construction as a key contributor to job growth, particularly in industries such as renewable energy, waste management, and the development of sustainable materials (D'Agostino *et al.,* 2019 ; Sovacool *et al.,* 2023). Additionally, the mediating influence of social well-being in the relationship between sustainable construction and job creation (β = 0.31, p < 0.01) suggests that broader social benefits—such as enhanced quality of life and increased social equity—are essential in fostering job opportunities (Zhang, & Yong, 2021). These results align with the view that sustainable construction not only drives economic growth but also strengthens the social cohesion of communities.

3.5.3 Environmental Sustainability and Health Benefits

The analysis showed that sustainable construction practices have a significant positive impact on environmental sustainability (β = 0.65, p < 0.001), which also leads to economic growth (β = 0.35, p < 0.001). This finding is consistent with current research, which emphasises that practices such as

using renewable energy, incorporating energy-efficient designs, and utilising low-carbon materials are critical for reducing the environmental harm caused by construction activities (Jaradat *et al.,* 2024, 2020; Gu *et al.,* 2023). Additionally, the significant link between improvements in public health and sustainable construction, mediated through enhanced environmental quality ($\beta = 0.32$, $p < 0.01$), highlights the role of green construction in creating healthier environments for living and working (Adshead *et al.,* 2007). These findings emphasise the dual role of sustainable construction in both safeguarding the environment and promoting public health.

3.5.4 Property Market Value and Community Resilience

The results confirmed that sustainable construction practices significantly enhance the market value of properties ($\beta = 0.42$, $p < 0.001$). This outcome aligns with previous studies, which have found that properties built with sustainability in mind are often perceived as more valuable due to their long-term cost savings, reduced environmental impact, and improved energy efficiency (Oke & Aigbavboa, 2017; Kauskale *et al.,* 2022). Moreover, the significant positive effect of sustainable construction on community resilience ($\beta = 0.50$, $p < 0.001$) suggests that such practices contribute not only to individual property owners but also to the overall stability and sustainability of entire communities (Al-Emran & Griffy-Brown, 2023). In Nigeria, this is particularly relevant, as sustainable construction practices can help address both economic and environmental challenges faced by communities.

3.6 Comparison with Existing Research

The outcomes of this research are largely in agreement with the current body of work on the socioeconomic impacts of sustainable construction. The positive effects of sustainable practices on economic growth, job creation, and environmental protection are consistent with findings from studies conducted in various regions, including both advanced and emerging economies (Ries, *et al.,* 2006; Tafesse *et al.,* 2022; Gu *et al.,* 2023; Saka, *et al.,* 2021). However, this research adds a valuable contribution by presenting empirical evidence specific to Nigeria, a region often underrepresented in sustainability research on a global scale. By utilising sophisticated methodologies such as Structural Equation Modeling (SEM) and Geospatial Analysis, this study offers a more detailed understanding of how sustainable construction can optimise socioeconomic benefits within the context of a developing nation.

5.0 CONCLUSION

This study provides a comprehensive evaluation of the socioeconomic impacts of sustainable construction practices in Nigeria, employing a quantitative approach supported by Structural Equation Modeling (SEM) and Geospatial Analysis. The research makes significant contributions to the field of sustainable construction, particularly within a developing country context, and offers valuable insights for policymakers, industry professionals, and researchers.

The findings confirm that sustainable construction positively influences various socioeconomic factors, including economic development, job creation, increased property values, social welfare, environmental sustainability, technological innovation, community resilience, and public health. Notably, the study underscores that sustainable construction serves as a catalyst for economic growth in Nigeria, providing benefits such as higher property valuations, expanded employment opportunities, and improved energy efficiency. These results align with prior research, demonstrating that sustainable construction contributes to both economic and environmental progress.

The study also reveals the complexity and interconnectedness of the relationship between sustainable construction and socioeconomic outcomes. For example, the data shows that the impact of sustainable construction on job creation is significantly mediated by enhancements in social well-being, suggesting that the broader societal benefits of sustainable practices are essential for translating economic gains into employment opportunities. Additionally, the findings emphasise the role of environmental sustainability in fostering economic growth, indicating that strategies aimed at reducing carbon emissions and promoting resource conservation are not only environmentally beneficial but also economically advantageous.

The geospatial analysis identifies substantial regional disparities in the adoption of sustainable construction practices across Nigeria. Urban areas such as Lagos and Abuja exhibit higher concentrations of sustainable projects, which correlate with more pronounced socioeconomic benefits in these regions. This finding highlights the need for targeted policies to promote sustainable construction in less developed areas, ensuring that the benefits of sustainability are more equitably shared across the country.

The research also underscores the critical role of technological innovation in driving the economic and environmental advantages of sustainable construction. The observed positive link between technological advancements and economic growth suggests that investments in cutting-edge technologies, including renewable energy systems and energy-efficient materials, are essential for unlocking the full potential of sustainable construction practices.

Overall, this study demonstrates the pivotal role that sustainable construction can play in addressing the dual challenges of economic development and environmental protection in Nigeria. The results provide strong evidence that sustainable construction is not only feasible but also crucial for ensuring long-term socioeconomic stability and resilience in the country. The findings suggest that policymakers and industry leaders should prioritise sustainable construction as a strategic initiative, leveraging its multifaceted benefits to support Nigeria's broader development objectives.

Future research should build on these findings by exploring the long-term impacts of sustainable construction, particularly concerning climate change and global sustainability standards. Additionally, further studies could investigate the barriers to widespread adoption of sustainable construction in Nigeria, offering potential solutions to accelerate the transition towards a more sustainable built environment.

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- **Hyginus Chidiebere Onyekachi Unegbu:** Conceptualisation, Writing—original draft preparation and literature review, study design, data collection, methodology, software and data analyses.
- **Danjuma Saleh Yawas:** Data validation, visualisation, supervision and formal analysis.
- **Bashar Dan-asabe:** Data validation, visualisation, supervision and formal analysis.
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STUDY ON THE IMPLEMENTATION OF QUALITY ASSESSMENT SYSTEM IN CONSTRUCTION (QLASSIC) IN MALAYSIA

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Abstract

Construction quality in Malaysia could be better if more effort were put into it. Ensuring quality in the construction industry is crucial for enhancing residents' quality of life. Hence, CIDB Malaysia has implemented the Quality Assessment System in Construction Industry (QLASSIC) as an industry-specific framework for measuring construction quality. Unfortunately, the adoption of QLASSIC is still not favourable. Hence, this research study aims to analyse the implementation of the QLASSIC in Malaysian construction industry. Four independent variables and one dependent variable were included in the study based on the extensive literature review. The independent variables were knowledge and awareness barriers, cost barriers, regulatory and enforcement barriers, and time-related barriers. The dependent variable was the company's readiness to adopt QLASSIC. In this study, a questionnaire survey was developed to collect the data for analysis by using SPSS software. There were 165 responses collected and used for the data analysis and interpretation. The study found that the adoption rate of QLASSIC is still low and the perception barriers were relatively important to the implementation of QLASSIC as indicated by Spearman's Rank correlation coefficient. The correlation was high among the perceived barriers with the company's readiness to adopt QLASSIC. This research study can be a guideline for QLASSIC adoption and provide valuable insight for future research studies.

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1.0 INTRODUCTION

The construction industry possesses distinct characteristics and qualities that set it apart from other sectors. Its unique nature, future orientation, and diverse range of professions, specialities, and suppliers distinguish it. However, the construction environment has often been criticised for emphasising inferior quality compared to other industries. Criticisms have been directed towards quality, construction processes, participating organisations, and materials, among other aspects. There is a pressing need to enhance and elevate standards, quality, and professionalism across all disciplines within the construction sector (Janipha & Ismail, 2013; Manap *et al.,* 2017).

Ensuring quality in the construction industry is crucial for enhancing the residents' quality of life. Hence, it is imperative to improve the quality of construction projects continually. Since the construction sector significantly contributes to the country's economic growth, improving its quality is essential. Hence, implementing a quality management or assessment system is vital for enhancing the standard of construction work. In Malaysia, the CIDB has implemented the Quality Assessment System in Construction Industry (QLASSIC) as an industry-specific framework for measuring construction quality. QLASSIC assesses and maintains construction project quality requirements to improve Malaysia's construction sector (Manap *et al.,* 2017). The Construction Quality Assessment System (CONQUAS) utilised by Singapore's Building and Construction Authority serves as the basis for this standard's evaluation system. QLASSIC and CONQUAS share important similarities in building categorisation and weight distribution (Ali *et al.,* 2012). Similarly, in Hong Kong, Hong Kong Housing Authority (HKHA) created the Performance Assessment Scoring System (PASS) in 1990, in reaction to numerous complaints of poor building quality. Singapore's CONQUAS, which was deployed in 1989, inspired this system. Furthermore, the Maintenance Assessment Scoring System (MASS) was developed to evaluate and maintain structural quality (Kam & Abdul Hamid, 2012; Manap *et al.,* 2017).

QLASSIC assesses the quality of workmanship in building projects based on the Construction Industry Standard (CIS 7). Consequently, the QLASSIC evaluation will be conducted on the pieces examined for the first time. Rectification or correction made after the evaluation will not be reevaluated (Construction Industry Development Board Malaysia, 2021a). Adopting QLASSIC offers several benefits, including greater quality assurance, a stronger competitive edge and market positioning, as well as improved customer satisfaction.

Despite the introduction of QLASSIC, its adoption in Malaysia faces challenges, primarily due to the lack of government enforcement and other accompanying barriers (Construction Industry Development Board Malaysia, 2021a).

However, research on the barriers to QLASSIC adoption and their impact on company readiness remains limited. This study aims to analyse the adoption of QLASSIC in Malaysian construction industry. Therefore, among the key objectives of this research are to determine the adoption level of QLASSIC among the construction industry, investigate the perceived

barriers affecting the implementation of QLASSIC and establish the correlation between perceived barriers and company readiness to adopt QLASSIC. It is ultimately proposed that the findings of this research will significantly help the construction industry to recognise the challenges in implementing QLASSIC and discover improvement strategies. This study also guides the construction company to prioritise the efforts to overcome the most significant barrier in QLASSIC implementation. Lastly, it provides a knowledge-based approach for future researchers who study similar topics.

2.0 LITERATURE REVIEW

Developers and construction companies always consider quality in building construction. They strive to achieve recognition for their workmanship and establish themselves as superior to their competitors. However, many companies have not yet fully realised the advantages of quality standards. Enhancing an organisation's performance can be achieved by simplifying its procedures, ensuring client satisfaction, and reaching company objectives. This can be accomplished by prioritising quality (Janipha & Ismail, 2013; Manap *et al.,* 2017). Even though adopting QLASSIC offers benefits, its adoption remains low. Some barriers, such as knowledge and awareness, cost, regulatory, enforcement, and time-related barriers, may hinder its adoption.

2.1 Knowledge and Awareness Barrier

There are a significant lack of knowledge regarding QLASSIC (Seman *et al.,* 2021). Although researchers introduced the concept, they emphasised that industry participants still have a restricted comprehension, highlighting a persistent difficulty (Azir *et al.,* 2018). Researchers also emphasised the need for more understanding of QLASSIC, and the essential new technologies required for its application will hinder them from adopting it (Zahrizan *et al.,* 2023). Then, the small construction firms have a limited understanding of the advantages of QLASSIC and view it as an unnecessary cost (Kam & Abdul Hamid, 2015). The lack of industry knowledge in combining QLASSIC with ISO 9001 QMS to improve overall quality performance will cause an obstacle in improving the adoption of QLASSIC (Ali, 2013).

The contractors frequently lack awareness of the QLASSIC system (Seman *et al.,* 2021). Similarly, it had been found that developers in Malaysia, including well-known construction enterprises, possess a restricted level of awareness regarding the QLASSIC quality rating system (Azir *et al.,* 2018). As a result, since developers are unaware of the system, they are unwilling to participate in CIDB for QLASSIC assessment (Sulaiman *et al.,* 2019).

The absence of familiarity among important stakeholders presents substantial difficulties in implementing QLASSIC, hindering knowledge and awareness. It had been found that contractors frequently need more competence and abilities, impeding their capacity to effectively participate in the Quality Assessment System in Construction (QLASSIC) (Seman *et al.,* 2021). The inadequate comprehension of the system also affects developers and contractors in Malaysia, hence impeding its acceptability (Khalid & Tamjehi, 2020). In addition, the companies often encounter difficulties caused by a lack of individuals who possess the necessary skills to carry out QLASSIC evaluations. The persistent hesitance to use QLASSIC is worsened by challenges in identifying competent QLASSIC assessors and facilitating information exchange inside companies (Zahrizan *et al.,* 2023).

2.2 Cost Barrier

There are significant obstacles in implementing QLASSIC: the impression of higher expenses and limited advantages linked to its methods and practices (Sulaiman *et al.,* 2019). Researchers have also emphasised that the high training costs and low benefits provide substantial obstacles to the implementation of QLASSIC from a technical point of view. Industry stakeholders may not fully comprehend the significant advantages of QLASSIC, resulting in a hesitance to allocate time and money towards obtaining certification. Companies that specialise in small projects or restorations may consider QLASSIC accreditation unnecessary, further increasing their reluctance (Zahrizan *et al.,* 2023).

The additional expenses associated with fulfilling the quality criteria for QLASSIC implementation are substantial. Experts in the construction field argue that QLASSIC places financial strain on project budgets, resulting in higher costs throughout the application and construction stages (Construction Industry Development Board Malaysia, 2021b; Manap *et al.,* 2017). Research indicates that incorporating QLASSIC into construction projects might lead to increased financial responsibilities for contractors, impacting the expenses associated with getting QLASSIC certification and the construction costs (Azir *et al.,* 2018).

The QLASSIC evaluation entails supplementary expenses comprising the costs involved with the application and construction procedure and the fees required for implementation (Construction Industry Development Board Malaysia, 2021b; Seman *et al.,* 2021). QLASSIC can also significantly impact construction expenses, potentially leading to increased financial responsibilities for developers. The QLASSIC assessment fees are calculated based on the project's gross floor area. Consequently, a larger project area will result in higher QLASSIC assessment charges (Azir *et al.,* 2018).

2.3 Regulatory and Enforcement Barrier

The lack of adequate government enforcement has been a major obstacle to implementing QLASSIC in building projects. The absence of a sense of urgency results from insufficient implementation of regulations (Kam & Abdul Hamid, 2015). In addition, an absence of promotion and engagement from pertinent authorities, which further hinders the incorporation of QLASSIC into business practices (Zahrizan *et al.,* 2023). The problems are worsened by the lack of strong coercion, such as government mandates, and the effect of competing forces that encourage imitation (Zahrizan *et al.,* 2023). The low acceptance rate of QLASSIC can be related to stakeholders considering it superfluous and the lack of compulsory prerequisites for implementation (Construction Industry Development Board Malaysia, 2021b; Manap *et al.,* 2017).

Additionally, the researchers emphasised the administrative obstacles linked to the implementation of QLASSIC. Organisations seeking QLASSIC accreditation face considerable difficulties due to the complex application and implementation procedures. These regulatory obstacles might discourage businesses from actively participating in the QLASSIC system, thus hindering its general adoption and efficiency in enhancing construction quality (Azir *et al.,* 2018).

Moreover, the application of QLASSIC also raises problems regarding the reliability of the assessor. It had been found that insufficient personnel at CIDB is a significant obstacle, necessitating external assessors' involvement in evaluations (Ali *et al.,* 2014). These assessors, usually persons with specialised knowledge in the construction field, must go through a thorough selection procedure to fulfil the CIDB's requirements for QLASSIC assessors. Nevertheless, a notable concern arises over the possible prejudice from these external evaluators, especially if they are from competitor organisations. This condition will erode the fairness of the evaluations (Ali *et al.,* 2014).

2.4 Time-Related Barrier

Several academics have shown evidence of the intricate temporal barrier in implementing QLASSIC. Some of them found that attaining the minimal criteria specified in the QLASSIC standards frequently results in project delays since extra construction time is needed to rectify or redo work (Seman *et al.,* 2021).

The QLASSIC evaluation process now necessitates more time due to heightened managerial obligations, an increased volume of documentation, and more bureaucratic protocols (Seman *et al.,* 2021). In addition, the assessment process linked to QLASSIC might result in disruptions to construction activities (Azir *et al.,* 2018). The intricate nature of the procedures necessary for compliance also results in additional delays (Lee *et al.,* 2020). Moreover, the QLASSIC assessors frequently require a substantial duration to complete evaluation reports. Consequently, developers delay acquiring QLASSIC reports and scores from CIDB, with certain instances requiring up to six weeks from the assessment date (Subramaniam *et al.,* 2019).

Researchers have emphasised that incorporating QLASSIC into building projects poses a significant problem in managing project schedules. The challenge is managing the conflicting needs of prolonged construction time, evaluation tasks, and training obligations within project timeframes (Azir *et al.,* 2018; Lee *et al.,* 2020; Seman *et al.,* 2021; Zahrizan *et al.,* 2023). Coordinating different tasks within the project timeline will significantly hinder the seamless incorporation of QLASSIC into building projects.

3.0 METHODOLOGY

This study integrated a comprehensive methodology and work plan to examine the objectives outlined. The outlined objectives were to determine the adoption of QLASSIC in the construction industry, investigate the perceived barriers affecting the implementation of QLASSIC, and establish a correlation between perceived barriers and company readiness to adopt QLASSIC. The first step involved establishing a conceptual framework to guide the study. To achieve the stated objective, this study utilised quantitative research methods. Data collection involved using primary and secondary sources, employing tools such as questionnaire surveys and literature studies to gather the needed information. Subsequently, the sampling design outlined the protocols for participants' selection, determined the sample size, and conducted pilot studies to improve the questionnaire. Then, the data gathered from the questionnaire survey were analysed using the Statistical Package for the Social Sciences (SPSS), a software used to analyse data.

3.1 Conceptual Framework

A problem is viewed comprehensively in the conceptual framework. The statistical conceptual framework illustrates the relationship among a study's main concept. Its logical framework helps to see how research ideas link. The framework simplifies the idea definition for the researcher's study problem. The conceptual frameworks might be graphical or narrative, presenting the significant variables or structures to be researched and their hypothesised relationships. The conceptual framework provides several advantages to research (Adom & Kamil, 2018). In this research, the conceptual framework was generated based on the literature review done. From the extensive literature review, the independent variables and dependent variables, which may have a relationship, were established. The conceptual framework of this study is shown in Figure 1.

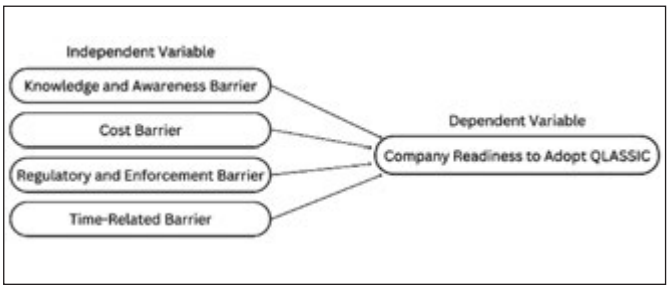

Figure 1: Conceptual framework of the study

3.2 Data Collection

Collecting primary data necessitates methodically making observations or measurements to collect crucial information. Data collection is a crucial research technique, whether for governmental, commercial, or scholarly objectives (Kabir, 2018). In this research, developers, consultants, and on-site contractors were the target population that involved in the quantitative survey, which is a questionnaire. This is because most of them are included in the building projects for which the QLASSIC may be adopted.

3.3 Questionnaire Survey

In this research study, the questionnaire was developed by Google Form. The methods used to reach the respondents were mail questions, online questions, and face-to-face respondents filling out the questionnaire via Google Form. The questionnaire consisted of five sections (Sections A, B1, B2, C, and D). Table 1 displays the summary of the questionnaire.

Table 1: Summary of the questionnaire

Section	Item
A	Section A of the questionnaire focuses on the respondents' profiles, capturing key information such as their education level, the company's main scope of services, their role within the company, work experience in the construction industry, company size, and whether the company has previously or currently adopted QLASSIC.
B1	Section B1 of the questionnaire addresses the awareness and adoption level of QLASSIC among respondents who have previously or are currently implementing it. This section aims to assess the company's adoption status, gather specific details about respondents' experience with QLASSIC, and evaluate the respondents' overall awareness of the system.
B2	Section B2 of the questionnaire focuses on the awareness and adoption level of QLASSIC among respondents who have never implemented the system. This section evaluates the respondents' awareness of QLASSIC and explores their plans or intentions regarding potential future adoption.
C	Section C of the questionnaire addresses the perceived barriers to implementing QLASSIC, assessing respondents' views by rating the barriers they believe hinder the system's adoption.
D	Section D of the questionnaire evaluates the company's readiness to adopt QLASSIC, assessing various factors that indicate their preparedness for implementing the system.

3.4 Data Analysis Using SPSS

After data collection through a questionnaire survey, the data was analysed using SPSS (Statistical Package for the Social Sciences). Descriptive analysis was used to investigate the demographics of respondents in Section A, as well as the awareness and adoption levels of QLASSIC in Sections B1 and B2. To assess the validity and reliability of the findings, data measurements, including reliability, multicollinearity, and normality tests, were carried out on Sections C and D, which used a 5-point Likert scale in the questionnaires. Subsequently, regression analysis, including Spearman's Rank correlation coefficient and multiple linear regression analysis, was conducted to establish the correlation between perceived barriers with the company's readiness to adopt QLASSIC and the effect of the perceived barriers on the company's readiness to adopt QLASSIC.

Table 2: Hypothesis of the study

H_{01}	Knowledge and awareness barriers do not have a significant relationship with the company's readiness to adopt QLASSIC.
H_{A1}	Knowledge and awareness barriers have a significant relationship with the company's readiness to adopt QLASSIC.
H_{02}	Cost barriers do not have a significant relationship with the company's readiness to adopt QLASSIC.
H_{A2}	Cost barriers have a significant relationship with the company's readiness to adopt QLASSIC.
H_{03}	Regulatory and enforcement barriers do not have a significant relationship with the company's readiness to adopt QLASSIC.
H_{A3}	Regulatory and enforcement barriers have a significant relationship with the company's readiness to adopt QLASSIC.
H_{04}	Time-related barriers do not have a significant relationship with the company's readiness to adopt QLASSIC.
H_{A4}	Time-related barriers have a significant relationship with the company's readiness to adopt QLASSIC.

3.5 Hypothesis Development

Since the investigator must assume no variance or connection among variables unless contrary evidence is shown, hypothesis testing may be unclear. Two hypotheses must be developed for this process: null and alternative hypotheses. There is always no distinction between a particular group (A) and another (B), according to the null hypothesis (H0). The contrary, suggesting there is a distinction between a particular group (A) and another (B), is put forward in the alternative hypothesis (H1). The goal is to reject or demonstrate the invalidity of the null hypothesis (Rana *et al.,* 2021). Table 2 shows the proposed hypothesis of this study.

4.0 RESULTS AND DISCUSSION

In this section, the data collected was analysed and discussed. Before the final data collection, the questionnaire underwent a pilot test with 30 participants to determine the improvement needed for the questionnaire design, for the main data collection to proceed. The collected final data was analysed through different analysis methods. In this study, 165 responses were collected from the questionnaire survey.

4.1 Pilot Study

A pilot study is a feasibility study or pre-testing of the questionnaire. In this study, Cronbach's Alpha of the four perceived barriers and company readiness for the pilot test were all above 0.8 as shown in Table 3. Cronbach's Alpha above 0.8 is considered good, which means the pilot test in this study showed at least good reliability of data collected from the questionnaire survey. The data collection can be proceeded since it was proven that the questionnaire survey was easy to understand, hence it requires no revision, and the intention of the questions can be effectively conveyed to the respondents (Siswaningsih *et al.,* 2017).

Table 3: Cronbach's alpha of pilot test

Variables	Cronbach's Alpha
Independent Variables (IV)	
IV1: Knowledge and Awareness Barrier	0.831
IV2: Cost Barrier	0.811
IV3: Regulatory and Enforcement Barrier	0.881
IV4: Time-related Barrier	0.816
Dependent Variable (DV)	
Company's Readiness to Adopt QLASSIC	0.935

4.2 Descriptive Analysis

Descriptive analysis uses statistical techniques to summarise a dataset, offering clear insights from raw data. This approach is widely favoured for its simplicity and accessibility. However, it does not aim to predict future results. Instead, it uses various manipulations to draw important conclusions from historical data (Bush, 2020). Consequently, Table 4 displays the comprehensive demographic profile of the respondents, including their education level, the company's main scope of services, their role within the company, work experience in the construction industry, and company size.

Table 4: Demographic profile of the respondents

	Percentage	Respondent (N=165)
Highest Education Level		
Secondary School (e.g. SPM, STPM, A-Level, UEC)	1.2%	2
Diploma	23%	38
Bachelor's Degree	66.1%	109
Postgraduate (e.g. Master, PhD)	9.7%	16
Company's Main Scope of Service		
Developer / Project Owner	13.9%	23
Architectural Consultant	9.1%	15
Engineering Consultant	18.2%	30
Quantity Surveying Consultant	10.3%	17
Construction Contractor	48.5%	80
Role in Company		
Management (e.g. Director, CEO, COO, General Manager/ Project Manager)	7.3%	12
Architect	15.2%	25
Engineer	29.1%	48
Quantity Surveyor	20.6%	34
Site Supervisor	27.9%	46
Working Experience		
Less than 5 years	29.1%	48
6-10 years	31.5%	52
11-15 years	21.2%	35
16-20 years	13.9%	23
More than 20 years	4.2%	7
Company Size		
Less than 5 employees	0%	0
5 – 29 employees	35.8%	59
30 – 75 employees	41.8%	69
Over 75 employees	22.4%	37

4.2.1 Adoption of QLASSIC

Figure 2 shows the pie chart of the company's QLASSIC adoption. Based on the questionnaire survey, 36% of the respondents' companies have adopted QLASSIC, either in the past or currently. The results indicated that the adoption of QLASSIC has not been favourable since CIDB introduced it in 2006. Eighteen years have gone by, yet adoption remains below 50%.

4.2.2 Awareness and Familiarity of QLASSIC

Figure 3 displays a pie chart of the awareness and familiarity of respondents through QLASSIC. Based on the questionnaire survey, 48% of respondents were not aware or familiar with the QLASSIC, followed by 47% of respondents are moderately aware and familiar with QLASSIC. Only 5% of respondents were very aware of and familiar with QLASSIC. The respondents in this section were lack of experience with QLASSIC, which limit their knowledge of QLASSIC. There has also been a lack of research on QLASSIC, which has limited the dissemination of information about it.

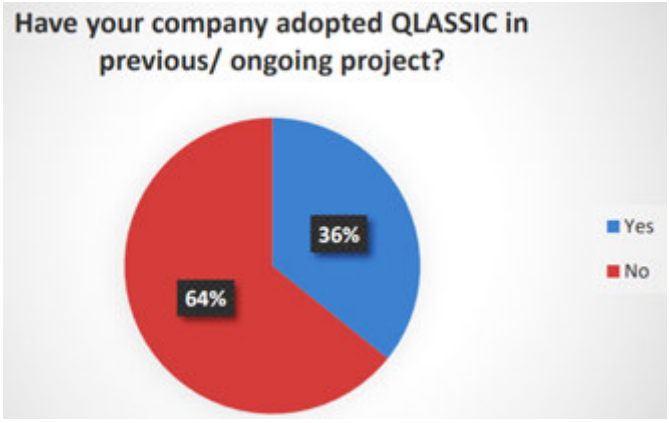

Figure 2: Adoption of QLASSIC

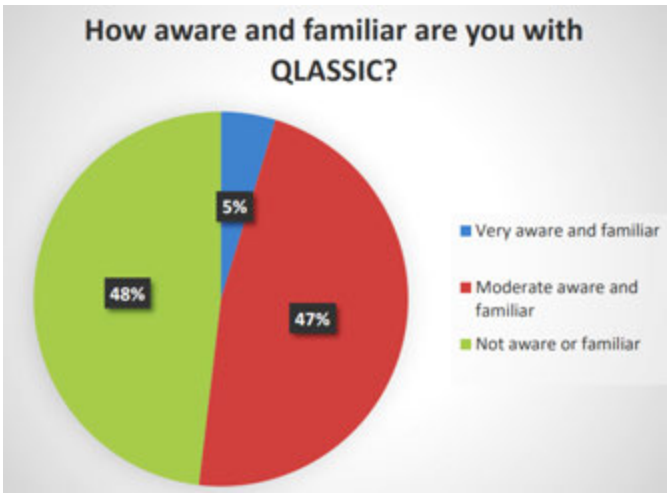

Figure 3: Awareness and familiarity of QLASSIC

4.3 Measurements of the Data

Measuring data is crucial for ensuring the collected information is reliable and valid for subsequent analysis. This process includes conducting reliability tests, multicollinearity tests, and normality tests. The reliability test ensures the reliability of the collected data. If it does not fulfil the criteria, more responses shall be collected to increase its reliability. Multicollinearity test was checked on the collinearity issues of the independent variable. If a multicollinearity issue happens, the independent variables are overlapping. Also, the normality test assessed whether the collected data is normally distributed or not.

4.3.1 Reliability Test

After the final data collection, Cronbach's alpha reliability test was conducted to determine the reliability of the data. Based on the SPSS software, Cronbach's Alpha of the four perceived barriers and company readiness are all above 0.8. If Cronbach's Alpha is lower than 0.7, the extra responses must be collected to increase the reliability of the data. In this study, all the Cronbach's Alpha were above 0.8, which is considered reliable with appropriate responses (Brown, 2002; Siswaningsih *et al.,* 2017). Hence, the data can be used, analysed and proceed. Table 5 shows Cronbach's Alpha on the reliability test.

Table 5: Cronbach's alpha on reliability test

Variables	Cronbach's Alpha
Independent Variables (IV)	
IV1: Knowledge and Awareness Barrier	0.915
IV2: Cost Barrier	0.875
IV3: Regulatory and Enforcement Barrier	0.856
IV4: Time-related Barrier	0.886
Dependent Variable (DV)	
Company's Readiness to Adopt QLASSIC	0.967

Table 6: VIF and tolerance of multicollinearity test

Model	VIF	Tolerance
IV1: Knowledge and Awareness Barrier	2.407	0.415
IV2: Cost Barrier	4.545	0.220
IV3: Regulatory and Enforcement Barrier	4.200	0.238
IV4: Time-related Barrier	4.613	0.217

4.3.2 Multicollinearity Test

The variance inflation factor (VIF) and collinearity tolerance in this research study were obtained from SPSS software and shown in Table 6. The VIFs obtained were acceptable, ranging between 1 and 5, which considered moderately correlated. The tolerance values obtained were greater than 0.2, indicating that multicollinearity is unlikely to occur. Therefore, the independent variables do not overlap and measure the same aspects. Thus, no adjustments or combinations are necessary (Kim, 2019); the results were reliable in this research study.

4.3.3 Normality Test

In this research, the Kolmogorov-Smirnov test was employed and conducted using SPSS software. This is because the Kolmogorov-Smirnov test is suitable for a sample size of more than 50 respondents. The significant value was the outcome, which indicates normality. A significant value (p-value) of more than 0.05 indicates that the data is normally distributed (Mishra *et al.,* 2019). The determination of normality determines the type of correlation analysis method to be used. The Pearson correlation coefficient test was used if the data is normally distributed. Conversely, Spearman's rank correlation coefficient was used for those not normally distributed (Field, 2018). The normality test result in this research study was obtained from SPSS software and shown in Table 7.

Based on Table 7, the data was not normally distributed compared with the criteria because the significant value was less than 0.001, which is less than the criteria (0.05). In other words, the data was more biased toward one side, and the data was more reliable and valid. Hence, Spearman's Rank correlation coefficient was used for correlation analysis.

Table 7: Kolmogorov–smirnov test

	N	Sig
IV1: Knowledge and Awareness Barrier	165	<0.001
IV2: Cost Barrier	165	<0.001
IV3: Regulatory and Enforcement Barrier	165	<0.001
IV4: Time-related Barrier	165	<0.001

4.4 Regression Analysis

Regression analysis, including Spearman's Rank correlation coefficient and multiple linear regression analysis, was conducted to establish the correlation between perceived barriers (IV) with the company's readiness to adopt QLASSIC (DV) and the effect of the perceived barriers (IV) on the company's readiness to adopt QLASSIC (DV).

4.4.1 Spearman's Rank Correlation Coefficient

The degree of linear relationship between two variables was known as correlation. The correlation coefficient is a statistical indicator of the degree of connection among the correlated shifts of two variables. Spearman's correlation coefficient assesses the significance of a monotonic connection among paired datasets. The correlation coefficient is from -1 to +1; closer to -1 or 1 means the correlation strength is stronger (Statstutor, 2018).

Table 8 shows the correlation coefficient between perceived barriers and the company's readiness to adopt QLASSIC. Based on criteria in Statstutor (2018), cost, regulatory and enforcement, and time-related barriers strongly correlate with the company's readiness to adopt QLASSIC. They have a correlation coefficient of 0.721, 0.752 and 0.718, respectively. Whereas, knowledge and awareness barrier with a 0.576 correlation coefficient have a moderate correlation with the company's readiness to adopt QLASSIC.

Table 8: Correlation coefficient between IVs and DV

	Correlation Coefficient
IV1: Knowledge and Awareness Barrier	0.576
IV2: Cost Barrier	0.721
IV3: Regulatory and Enforcement Barrier	0.752
IV4: Time-related Barrier	0.718

Table 9: Value of standardised coefficient beta, β

	Standardised Coefficient Beta, β
IV1: Knowledge and Awareness Barrier	0.141
IV2: Cost Barrier	0.153
IV3: Regulatory and Enforcement Barrier	0.406
IV4: Time-related Barrier	0.278

4.4.2 Multiple Linear Regression

Multiple regression may also find the entire fit (variation described) of the predictive model and the corresponding contribution of each predictor towards the total variance described (Laerd Statistics, 2018). Equation 1 is the standard equation for multiple regression. The slope coefficient, b of the independent variable is β value in the table provided in SPSS after analysis, which concludes in Table 9. It can be subtracted into the equation below, thus knowing which independent variable most affects the dependent variable.

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 \quad (1)$$

$$DV = a + 0.141 IV_1 + 0.153 IV_2 + 0.406 IV_3 + 0.278 IV_4 \quad (2)$$

4.5 Hypothesis Testing

A p-value lower than 0.05 is generally regarded as statistically significant, and the null hypothesis needs to be denied. When the p-value is higher than 0.05, the null hypothesis has been accepted since the divergence from it is not statistically significant (Rana *et al.,* 2021). Hypotheses are developed to undergo hypothesis testing to establish the correlation between perceived barriers and the company's readiness to adopt QLASSIC. After data analysis in SPSS software, p-values are obtained and displayed in Table 10.

Table 10: Significant value of hypothesis testing

	Significant Value, p
IV1: Knowledge and Awareness Barrier	0.010
IV2: Cost Barrier	0.040
IV3: Regulatory and Enforcement Barrier	<0.001
IV4: Time-related Barrier	<0.001

All the *p*-values for the perceived barriers were lower than 0.05. Therefore, the null hypotheses were rejected in this study, and the alternative hypotheses were accepted for each barrier. The alternative hypothesis for each barrier is that the perceived barriers (knowledge and awareness, cost, regulatory, enforcement, and time-related barriers) have a significant relationship with the company's readiness to adopt QLASSIC. Thus, it can be concluded that all the studied perceived barriers had a significant relationship with the company's readiness to adopt QLASSIC.

5.0 CONCLUSIONS

The study contributes to a deeper understanding of the factors influencing the adoption of QLASSIC in the Malaysian construction industry. The descriptive analysis highlighted a persistent low adoption rate, with only 36% of respondents' companies implementing QLASSIC. This indicated that industry-wide adoption remains a significant challenge even 18 years after its introduction by CIDB in 2006. This reluctance to adopt QLASSIC underscores a need to further explore the barriers companies face in aligning with these quality standards.

Further analysis, using Spearman's Rank correlation and multiple regression, revealed a strong relationship between regulatory enforcement and a company's readiness to adopt QLASSIC. Regulatory and enforcement barrier emerged as the most influential factor, followed closely by cost, time, and knowledge barrier. This suggested that while regulatory support is crucial, the time and cost required to meet QLASSIC standards are also significant concerns that influence company's readiness. The study confirmed a statistically significant relationship between perceived barriers and company's readiness to adopt QLASSIC, further solidifying these findings.

In conclusion, several barriers, most notably regulatory and cost-related challenges, hindered the adoption of QLASSIC. This study recommended enhancing industry awareness through on-site training, seminars, and targeted outreach to key stakeholders to improve the adoption rates. It is also suggested that the government make the QLASSIC mandatory to improve the adoption rate. Additionally, reducing implementation costs and streamlining evaluation processes are essential to making QLASSIC more accessible, particularly for smaller companies. Future research should explore other international quality systems, such as Singapore's CONQUAS and Hong Kong's PASS, to provide comparative insights and identify best practices that can be applied locally.

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- **Chung Xiao Yen:** Conceptualisation, study design, data collection, analysis, writing—original draft preparation, visualisation, and software implementation.
- **Wong Chee Fui:** Supervision, guidance on conceptual direction, format and structure, and final manuscript approval.
- **Gan Chin Heng:** Supervision, format and structure, language refinement, and final manuscript approval. ■

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