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ADVANCING DIGITAL TECHNOLOGY ADAPTATION IN SRI LANKAN CONSTRUCTION FIRMS

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ABSTRACT

The persisting reliance of the construction industry on traditional technologies has perpetuated inefficiencies, particularly in coordination and collaboration. Addressing the slow adoption of contemporary digital innovations, this study aims to both investigate the technical advancements and barriers impeding their integration into the Sri Lankan construction industry and find out how to facilitate their adoption. Drawing from a convenience sample of 72 professionals with diverse experiences and an expert group with over a quarter-century in the field, a mixed-methods analysis entailing NVivo for qualitative data and SPSS for quantitative insights was employed. The study spotlights Building Information Modelling (BIM), 3D printing, and augmented and virtual reality as acclaimed technological strides, with unmanned aerial vehicles being less recognised. Identified obstacles include high maintenance costs, skill deficits, and industry-specific challenges, with proposed strategies such as professional training, awareness campaigns, increased investments, and governmental support. Ultimately, the research underscores the importance of digital technology for productivity, accuracy, safety, and innovation in construction, aiming to guide AEC firms in overcoming digital integration barriers and facilitating the adoption of these technologies.

Keywords: *Adopting; Advantages; Construction Industry; Digital Technology; Failure.*

1. INTRODUCTION

The construction sector is fundamental to the economic proliferation of nations, contributing significantly to the annual revenue generation across the globe. However, in Sri Lanka its progression is impeded by resistance to technological evolution, resulting in productivity that trails behind that of sectors where technology is rapidly advanced (Barbosa et al., 2017). As urban landscapes expand, the demand for efficient housing and infrastructure emerges as a double-edged sword; while posing challenges, it simultaneously beckons the industry towards a technological metamorphosis (Chen et al., 2022). This study focuses on the Architecture, Engineering, and Construction (AEC) industry in Sri Lanka, examining the digital technology adoption among various types of

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construction firms, including engineering firms, quantity surveying firms, architectural firms, and project management firms.

In this era, scientific innovations are not merely adjuncts but pivotal forces capable of catalysing industry-wide revolutions. These advancements promise to decomplexify construction processes by providing enhanced methodologies for project planning, design, and maintenance, underpinned by the strategic interpretation of visual data (Day & Schoemaker, 2000). The crux of the issue, however, lies in the sluggish pace at which the construction sector adopts these innovations, a pace which stifles productivity and dampens the industry's efficiency (Sabol, 2008).

The impetus for this research stems from the critical necessity to elevate the performance and efficiency of the construction industry through the assimilation of emergent technologies. It is imperative to address the imperative goals of augmenting efficiency, productivity, safety, and sustainability, thereby propelling the sector toward the adoption of avant-garde technological advances in its operational processes (Loosemore, 2014). The spectrum of digital technology, encompassing data generation, storage, and processing, ushers in an era of unprecedented interaction among humans, machines, and inter-systemic digital platforms (Ibem & Laryea, 2014).

Despite the acknowledged need for such technologies, their adoption is stymied by obstacles that are deeply rooted within the industry's framework, often leading to an escalation in project failures and abandonments. Motivated by this pressing issue, this research aims to investigate the technical advancements and challenges hindering technology adoption in the Sri Lankan construction industry, with the dual goal of understanding these barriers and devising effective methods to facilitate the adoption and integration of digital technologies. This study seeks to enhance the uptake of digital innovations and streamline construction processes, ultimately improving productivity, safety, and efficiency in the sector. The digitalisation of the AEC sector promotes innovation and requires an integrated, data-driven approach among stakeholders (Ikediashi & Ogwueleka, 2016). Addressing the current state of digital collaboration and tool utilization in construction is paramount; enhancements in this domain are essential to boost the adoption of technology and streamline construction processes effectively (Oesterreich & Teuteberg, 2016).

2. LITERATURE REVIEW

2.1 CURRENT STATE OF THE CONSTRUCTION INDUSTRY

The contemporary construction industry stands at a crossroads, where the adoption of sustainable practices is essential for growth across social, economic, cultural, and transit domains. This shift towards sustainability is driven by escalating resource scarcity, economic growth and demographic expansion, compelling the sector to embrace green construction methodologies (Jayalath & Gunawardhana, 2017). The transition demands a departure from traditional artisanal techniques towards enhancing the workforce's technical prowess to integrate and operationalise advanced technology seamlessly. A smarter construction industry promises significant improvement in accuracy, productivity and efficiency.

The pace of the construction process is closely tied to field performance, which hinges on optimising costs and timelines, meticulous on-site material management, effective

equipment utilisation, and innovative visualisation techniques (Srivastava et al., 2022). These elements are crucial in steering the industry towards a technologically adept future, emphasising the importance of digital fluency in reshaping construction landscapes.

2.2 CONSTRUCTION INDUSTRY 4.0 (CI4)

The advent of Industry 4.0 (I4) heralds a transformative era where emerging trends and technologies redefine manufacturing processes, extending their impact on the construction sector by promising substantial social and economic advantages. This evolution introduces a holistic approach to managing product lifecycles, with profound implications for health, energy, and urban development (Baur & Wee, 2015). Central to this shift is the principle of technology transfer, which facilitates the relocation of technological capabilities across units, enriching the industry's innovation landscape (Bozeman et al., 2015).

Technological advancements under the I4 umbrella are categorised into five domains i.e. (i) communication, (ii)data collection, (iii) analytics, (iv) automation in construction, and (v) visualisation and planning. Each plays a pivotal role in enhancing operational outcomes such as safety, efficiency, quality, productivity, and sustainability (Chen et al., 2022; Frank et al., 2019). Despite the benefits, the sector faces significant hurdles, notably the shortage of skilled personnel and the prohibitive costs associated with deploying these new tools (Sacks et al., 2018).

At the core of the construction technology framework are the cloud-based common data environment and Building Information Modelling (BIM), which safeguard project data throughout its lifecycle and provide sophisticated modelling and simulation capabilities crucial for the industry's advancement (Oesterreich & Teuteberg, 2016). This strategic integration of I4 principles promises unparalleled efficiency and innovation, contingent upon overcoming barriers to technology adoption and skill enhancement.

2.3 EMERGING DIGITAL TECHNOLOGIES IN THE CONSTRUCTION INDUSTRY

The construction sector has increasingly harnessed digital technology, marking a pivotal shift towards enhancing its processes and outcomes. Bilal et al. (2016) detailed the integration and impact of big data analytics in construction, demonstrating its potential to refine the construction process when combined with other digital innovations. Further exploration by Cai et al. (2019) examined the current landscape of automation and robotics within the industry, providing insights into their applicability and the pathways for successful implementation.

Visualisation technologies, specifically Augmented Reality (AR) and Virtual Reality (VR), have been thoroughly investigated by Guo et al. (2017) who underscored their significance in advancing construction health and safety management while acknowledging the challenges of broader adoption. Similarly, Tay et al. (2017) scrutinised the advancements and hurdles in adopting 3D printing and additive manufacturing, offering a comprehensive overview of the sector's evolving technological needs and future directions.

Key technological innovations shaping the future of construction include BIM, AR, VR, Artificial Intelligence (AI), cybersecurity, Unmanned Aerial Vehicles (UAV), cloud-based project management, blockchain, and laser scanners. BIM emerges as a cornerstone technology, facilitating intricate model creation that encapsulates digital representations

of physical and functional characteristics of places (Sacks et al., 2018). This is complemented by CAD's role in generating and visualising both 2D and 3D models, with BIM's capability extending to generating up to 6D models, thereby promoting an integrated project information-sharing ecosystem across the construction lifecycle (Begić & Galić, 2021; Takim et al., 2013).

UAVs are highlighted for their capacity to gather diverse image data, including high-definition visuals and thermal imaging, through varied sensing methods, enhancing the precision of 3D building models and facilitating regular inspections throughout a building's service life (Guo et al., 2017; Mader et al., 2016). The distinction between AR and VR is articulated through their respective applications, with AR augmenting real-world environments and VR creating entirely simulated settings (Balali et al., 2018; Milgram & Kishino, 1994).

Blockchain technology, recognised for its transformative potential across various sectors, promises to secure transactions within a decentralised network, ensuring the integrity of digital records (Hamida et al., 2017; Zheng et al., 2017). Meanwhile, terrestrial 3D laser scanning offers a comprehensive suite for geospatial surveys, construction monitoring, and heritage conservation, embodying the diversity of laser scanning technologies available (Holgado-Barco et al., 2014; Jaselskis et al., 2005).

2.4 OBSTACLES IN ADOPTING DIGITAL TECHNOLOGIES IN CONSTRUCTION

Navigating the digital transformation within the AEC sector reveals significant interoperability challenges among associations and professions. These complications arise from attempts to trade, offer, or incorporate data and business models through existing data frameworks or authorised practices, often leading to a failure in effectively connecting different systems (Sacks et al., 2018). This difficulty can be attributed to various factors such as the fragmented nature of the industry, the diversity in data requirements, the flexibility of data methodologies, the necessity for innovation skills, and the trade-offs involved in achieving broad business objectives through the development of interoperable programs and frameworks.

Training, or rather the lack thereof, emerges as another significant hurdle. The absence of specialised digital training modules within educational institutions places additional pressure on the industry to equip its workforce with the necessary skills, further complicating the adoption of digital technologies (Holt et al., 2015). The scarcity of technically proficient staff represents a substantial barrier to embracing technological innovations within construction practices (Hamida et al., 2017).

Moreover, the importance of ensuring secure and appropriate access to information within cooperative IT environments cannot be overstated. Ongoing challenges related to privacy, security, and evolving standards necessitate continuous revisions to support a nuanced exchange of information and mitigate obstacles to the widespread adoption of digital technologies (Lapierre & Cote, 2007). Additional studies by Zhang et al. (2019) and Arif et al. (2020) highlight the critical need for robust training programs and secure IT environments to overcome these barriers, emphasising the global relevance of these challenges.

3. METHODOLOGY

This study employed a mixed-method approach to investigate the barriers and facilitators of digital technology adoption in the Sri Lankan construction industry. Initially, a comprehensive literature review was conducted, and NVivo software was utilised to perform thematic analysis, identifying key themes such as high maintenance costs, skill deficits, and the importance of BIM. These themes guided the formulation of research questions. A pilot survey was then administered to a small sample of industry practitioners to refine these questions, ensuring clarity and relevance. The main survey, conducted using convenience sampling, targeted a larger group of construction professionals, including engineers, quantity surveyors, architects, and project managers. The survey data were analysed using basic statistical methods to identify trends and insights.

To validate the survey findings, structured interviews were conducted with experienced professionals, also selected through convenience sampling. These interviews provided deeper insights into the barriers and facilitators of digital technology adoption. The interview data were analysed using NVivo to identify recurring themes and validate the survey results. This mixed-method approach allowed for a comprehensive exploration of the digital adoption landscape in the Sri Lankan construction sector, combining quantitative data with qualitative expert validation. The methodology ensured that the study was grounded in both theoretical insights and practical experiences, providing a robust foundation for the analysis and recommendations.

4. DATA COLLECTION AND ANALYSIS

4.1 DEMOGRAPHIC PROFILE OF RESEARCH PARTICIPANTS

Table 1 presents the educational background and work experience of the 72 research participants, ranging from Diploma to master's degree holders. A significant share, especially engineers, reports five to ten years of industry experience, suggesting a mid-career level expertise prevalent in the study sample. Other roles such as Quantity Surveyors (QSs) and Architects are represented, with some professionals bringing over 20 years of experience to the mix. This demographic diversity reflects varied levels of familiarity with digital technologies within the construction sector.

Table 1: Demographic profile

Academic Qualification	**Diploma**		**Higher Diploma**				**Bachelor's Degree**			**Master's Degree**		**Other**
Years of experience	**0-5**	**5-10**	**0-5**	**5-10**	**10-20**	**>20**	**0 -5**	**5-10**	**10-20**	**10-20**	**> 20**	**5-10**
Engineer	-	2	-	-	5	2	2	10	5	2	1	-
QS	3	-	7	3	3	-	6	8	3	2	-	1
Architect	-	-	-	-	-	-	2	2	-	-	1	-
PM	-	-	-	-	-	-	-	-	-	-	2	-

4.2 FAMILIARITY AND APPLICATION OF DIGITAL TECHNOLOGIES IN THE CONSTRUCTION INDUSTRY

The survey data, visualised in Figure 1 reveals the current state of digital technology awareness among industry professionals. Notably, BIM is widely recognised in Sri Lanka, with 96% of respondents indicating familiarity. In contrast, knowledge of UAVs is considerably low, with only 8% awareness. The awareness levels for other digital technologies including AR/VR, Blockchain, Laser Scanning, and 3D Printing fall between these extremes, suggesting an intermediate understanding within the sector. The survey further suggests cloud systems and data collection apps are recognised yet not detailed in Figure 1.

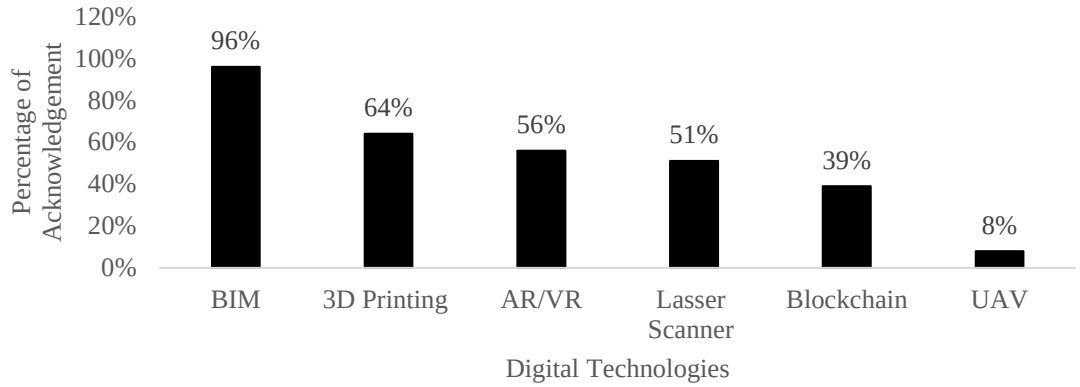

Figure 1: Knowledge of the digital technologies

4.3 PERSISTENCE OF CONVENTIONAL METHODS IN THE CONSTRUCTION INDUSTRY

The Sri Lankan construction industry's enduring reliance on traditional technologies is primarily due to several significant obstacles. Foremost among these is the high expense associated with the adoption of new digital technologies, which includes both upfront and hidden costs. This financial burden deters many firms from undertaking such initiatives. An inherent resistance to change further amplifies this reluctance, compelling organisations to adhere to familiar systems and procedures to guarantee successful integration. Additionally, the insufficient provision of training within the industry stifles both awareness and application of novel technologies in project execution.

The scarcity of professionals proficient in digital technologies further accentuates this challenge. Financial limitations also constitute a major obstacle, as organisations grapple with allocating sufficient resources toward technological investments that promise to enhance project management and efficiency.

In addition, restrictive government policies, which may involve imposing additional taxes or raising the costs of digital equipment, hinder technological progress by limiting accessibility for key industry players such as Project Managers (PM). Collectively, these challenges emphasise the construction industry's continued preference for traditional methods despite the clear advantages that digital innovations can offer.

4.4 IMPEDIMENTS TO TECHNOLOGY ADOPTION IN CONSTRUCTION

The research reveals, through a graphical analysis, in Figure 2, that the most prominent barriers obstructing the implementation of new technologies in Sri Lanka are due to high costs of technological upkeep, inadequate relevant skills within the industry, and a long-standing history of poor technology adoption rates. With 83% of experts identifying the prohibitive maintenance expenses, 58% recognising the lack of a skilled workforce, and 57% noting the industry's resistance to new technology integration, these issues are at the forefront of concerns hindering modernisation in the construction sector.

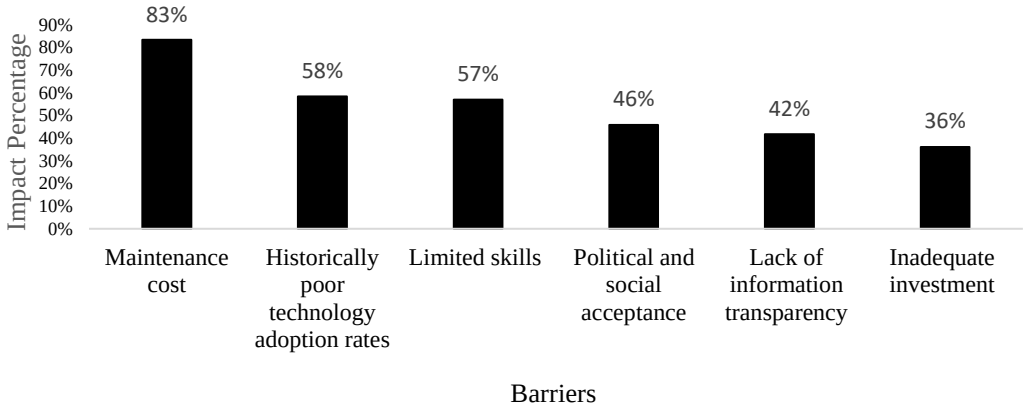

Figure 2: Barriers to implementing new technologies

Table 2 reveals respondents' perceptions of barriers to digital technology implementation, categorised by profession. Engineers, constituting 83% of surveyed and engineers, increasingly cite high maintenance costs as a hindrance. QSs, 81% of their total, similarly highlighted this concern.

The high cost of digital technology has challenged the implementation of digital technology in the AEC industry in Sri Lanka, the lack of trained staff in digital tools for construction participants, and the lack of skilled labour. The findings of this current study are that the cost of purchasing and maintaining digital tools and the lack of training among staff are the main reasons for not implementing digital technology within the construction industry.

Table 2: Barriers to the implementation of new technologies according to the profession

Barriers	Engineer	QS	Architect	PM	Value
High Maintenance cost	25	30	4	1	25%
Historically poor technology adoption rates in the industry	22	19	1	-	18%
Limited relevant skills base in the construction industry	17	20	3	1	18%
Political and social acceptance	17	13	1	2	14%
Existing weak Information transparency and transmission	7	20	3	-	13%
Inadequate mechanisms and investment in research and development	5	16	4	1	11%

4.5 IMPLICATIONS OF NOT ADOPTING DIGITAL TECHNOLOGY

Survey findings from the Sri Lankan construction sector highlight the significant implications of not adopting digital technologies. Notably, 75% of respondents indicate that implementing digital technologies could result in substantial cost savings. Similarly, 68% believe that digital technologies could lead to higher productivity levels. Furthermore, 64% suggest that efficiency levels could be improved, while 58% indicate that labour and workforce-related issues could be mitigated. Additionally, 44% of respondents believe that digital technologies could enhance safety levels. These findings are visually summarised in Figure 3**.**

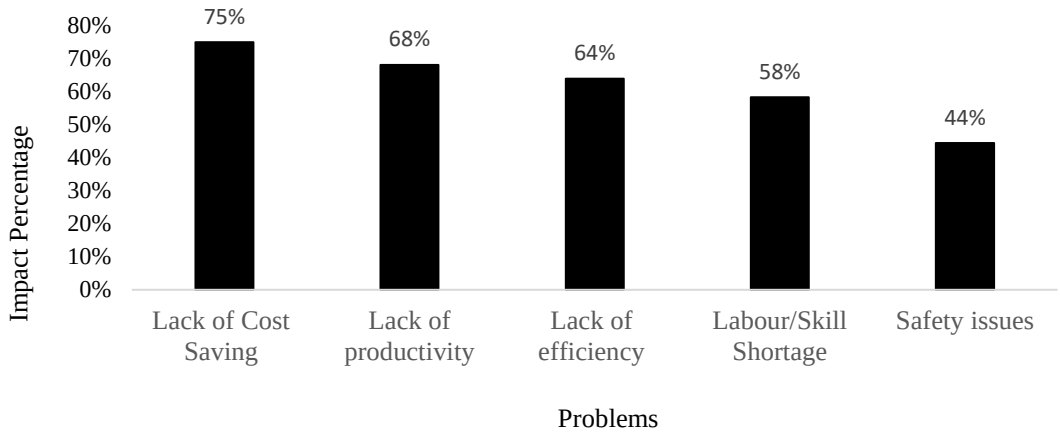

Figure 3: Problems due to non-implementation of digital technology

In Table 3, the consensus among engineers and QS emphasises the lack of high costs as a primary concern, with 71% of engineers and 76% of QS agreeing. These figures underscore financial barriers and skill gaps as significant impediments to digital adoption in the industry.

Table 3: Problems due to the non-implementation of digital technology

Problems	Engineer	QS	Architect	PM	Value
Lack of cost-saving	20	27	5	2	25%
Lack of productivity	21	24	2	2	22%
Lack of efficiency	19	22	3	2	21%
Skill labour shortages	16	19	5	2	19%
Safety issues	15	12	5	-	14%

4.6 ADVANTAGES OF IMPLEMENTING DIGITAL TECHNOLOGY

A survey among construction professionals has highlighted the significant advantages of digital technology, with the greatest impact seen in improved productivity, acknowledged by 90% of respondents. This is closely followed by better safety and more accurate customer communication. These results, depicted in Figure 4, reflect a strong industry recognition of the multiple benefits offered by digital advancements.

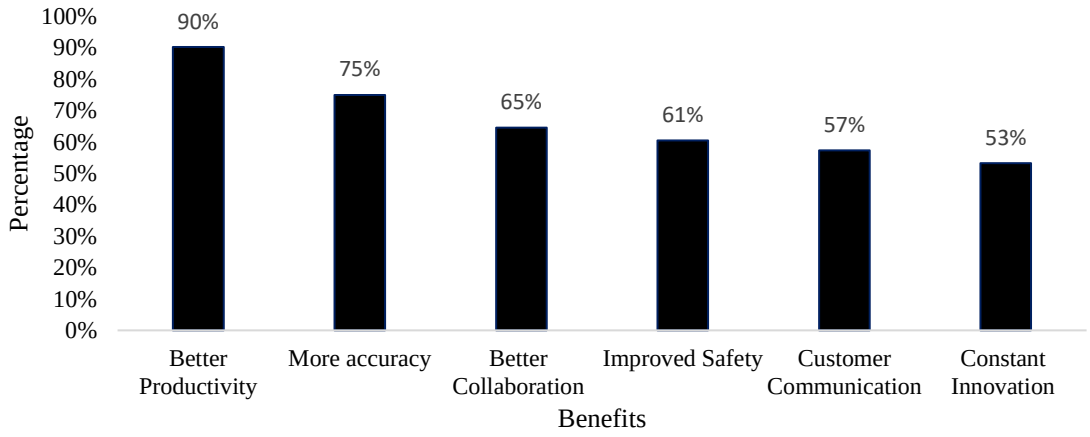

Figure 4: Benefits of implementing digital technology

Table 4 delineates the variances in how different construction professions value these benefits. For engineers and quantity surveyors, the increased productivity afforded by digital tools is paramount. In contrast, architects are more inclined to focus on improvements in customer communication and collaborative processes. The use of technologies such as BIM, Blockchain, and AR/VR are vital for streamlining operations and fostering better collaboration. Additionally, innovations such as laser scanners and UAVs are instrumental in enhancing on-site safety.

Table 4: Benefits of implementing digital technology technologies according to the profession

Benefits	Engineer	QS	Architect	PM	Value
Better Productivity	26	33	4	2	23%
More accuracy	19	32	3	-	19%
Better Collaboration	17	24	5	-	16%
Customer Communication	15	22	5	2	15%
Improved Safety	16	22	3	-	14%
Constant innovation	18	17	3	-	13%

In a survey conducted among AEC industry professionals, participants highlighted the pivotal role of digital technology in enhancing construction efficiency. Responses emphasised the benefits of digital adoption, such as time-saving, improved construction quality, fewer disputes, and enhanced efficiency, especially in the early design stages through project pre-visualisation. Moreover, they noted that embracing digital tools can help avert ambiguities and stakeholder conflicts. These insights underscore the substantial value and transformative potential of digital technology within the construction sector.

4.7 STRATEGIES TO OVERCOME PROBLEMS

Survey results highlighted challenges faced due to the minimal use of digital technology in the construction sector, inviting strategies to address these issues. Participant A proposed in-depth training for technicians and investment in current staff for a resilient workforce. Participant B advocated for brief, intensive seminars to acquaint existing professionals with new digital tools, enhancing project management capabilities. Participant C underlined the need for increased investment in cutting-edge technologies,

encouraging stakeholder collaboration to mitigate financial risks and propel technological progress.

5. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Considering the data collection and analysis where 96% of respondents recognised BIM as pivotal, yet only 8% were familiar with UAVs, the study delineates a significant discrepancy in digital technology awareness within the construction sector. This disparity, coupled with formidable barriers such as high maintenance costs (identified by 83% of respondents) and a palpable skill deficit within the workforce (noted by 57%), underscores the nuanced landscape of digital adoption. Furthermore, an inherent resistance to change, cited by 58% of professionals, exacerbates the slow pace of digital integration, illustrating a tripartite barrier to the sector's transformation.

The acute recognition of digital technologies' benefits: enhanced productivity and safety, as acknowledged by 90% and a substantial portion of participants, respectively illuminates the potential gains from overcoming these obstacles. However, the gap between recognition and implementation, highlighted by the 76% concern over costs and 58% noting skill shortages, necessitates targeted strategies to bridge these divides.

To directly tackle the 83% of respondents concerned with high maintenance costs, we advocate for innovative cost management and financing strategies. This includes exploring collaborative investments and leveraging governmental and private sector incentives to alleviate the economic burdens, thereby making digital technologies more accessible across the industry.

Addressing the 58% shortfall in skilled personnel, the study emphasises the development and implementation of specialised training programs. These programs aim to equip both current employees and new entrants with essential digital competencies, directly targeting the skill gaps identified in our analysis. Moreover, in response to the 57% of professionals citing resistance to change, fostering a cultural shift towards innovation and openness to technological advancements is crucial. By promoting a more receptive environment for digital integration, it can counteract historical resistance and facilitate smoother digital transformation pathways.

The findings from this study reveal significant barriers to digital technology adoption in the Sri Lankan construction industry, including high maintenance costs, a lack of skilled personnel, and resistance to change. These barriers are consistent with the challenges identified in previous studies. However, the potential benefits of digital technology, such as improved productivity, efficiency, and safety, underscore the need for targeted strategies to facilitate adoption. These strategies should include professional training, increased investment, and governmental support.

In conclusion, this study highlights the critical need for digital transformation in the Sri Lankan construction industry. The dual focus on identifying barriers and facilitating adoption provides a comprehensive approach to addressing the slow pace of digital integration. By implementing targeted strategies, such as professional training and increased investment, the industry can overcome existing challenges and harness the full potential of digital technologies. Future research should continue to explore these areas, providing further insights and recommendations for enhancing digital adoption in the construction sector.

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