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EXPLORING OPPORTUNITIES AND CHALLENGES IN INTEGRATING INDUSTRY 4.0 FOR ADVANCEMENTS IN THE SRI LANKAN CONSTRUCTION SECTOR

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ABSTRACT

Industry 4.0 (I4.0) holds significant potential for the construction sector by introducing advanced technologies and innovative practices that enhance efficiency, productivity, safety, and sustainability. However, the Sri Lankan construction industry is still in the early stages of adopting these novel technologies. Therefore, this research investigates the potential opportunities and challenges of implementing I4.0 in the Sri Lankan construction industry. A survey approach was employed, incorporating a comprehensive literature review and a questionnaire conducted among building and construction professionals in Sri Lanka. The findings revealed that respondents identified efficient resource management, optimised construction processes, energy efficiency, and waste management as the top opportunities of I4.0. Conversely, they ranked high initial costs, a lack of skilled workforce, resistance to change, and limited industry standards as significant challenges. To unveil the benefits of I4.0, policymakers and industry professionals must collaborate to mitigate these challenges. Key recommendations include strategic investments, robust training programs, enhanced industry standards, and effective change management strategies.

Keywords: *Construction Industry; Industry 4.0; Sri Lanka.*

1. INTRODUCTION

I4.0, known as the Fourth Industrial Revolution, is a concept that guides the adoption and implementation of advanced digital technologies to achieve the desired transformations in industrial processes (Popkova et al., 2019). It comprises several technological pillars, including the Internet of Things (IoT), Big Data and Analytics, Artificial Intelligence (AI) and Machine Learning (ML), Cloud Computing (CC), Cyber-Physical Systems (CPS), Additive Manufacturing (3D Printing), Augmented Reality (AR) and Virtual Reality (VR), Blockchain Technology, Robotics, and Drones.

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These technologies are dramatically transforming various industries, enhancing efficiency, productivity, safety, and sustainability (Daribay et al., 2019). The construction industry is one of the sectors reaping significant benefits from this concept.

Alaloul et al. (2016) emphasised that the construction industry, compared to others, has a unique potential to incorporate the I4.0 concept into its practices. Consequently, several recent studies have focused on the adoption of I4.0 technologies in the construction industry. Research by Gálvez-Martos et al. (2018) and Yang et al. (2020) identified that I4.0 technologies could be successfully integrated to enhance core construction capacities in project management, cost control, contract administration, procurement, and health and safety management. Additionally, the World Economic Forum (2016) highlighted that these technologies help make construction more environmentally friendly and sustainable. Moreover, Moshood et al. (2020) and Balasubramanian et al. (2021) noted that I4.0 presents a fantastic opportunity to advance sustainability in the construction sector in terms of social, environmental, and economic aspects. Recognising this potential, many countries are developing national policies to incorporate I4.0 initiatives within the construction sector to compete in the global economy (Bortolini et al., 2017), with this adoption being more visible in developed countries.

Despite the rapid development of the buildings and construction sector in developing countries, the adoption of technological aspects remains relatively low. Sri Lanka is one such country. Therefore, this study aims to investigate the potential challenges and opportunities of implementing I4.0 to advance the Sri Lankan construction sector. This paper initially presents a comprehensive literature review on I4.0 technologies and the general opportunities and challenges associated with their implementation. Subsequently, it discusses the findings related to the specific opportunities and challenges in the Sri Lankan construction industry and offers recommendations for overcoming these challenges.

2. LITERATURE REVIEW

2.1 INDUSTRY 4.0 AND OPPORTUNITIES TO IMPROVE THE CONSTRUCTION INDUSTRY

The construction industry, once known for its reliance on traditional methods and tools (Tay et al., 2017), is currently benefiting from I4.0 technologies, enhancing project quality, efficiency, safety, and sustainability (Maskuriy et al., 2019). All the technological pillars identified in Figure 1 can be leveraged to improve the construction sector in different ways.

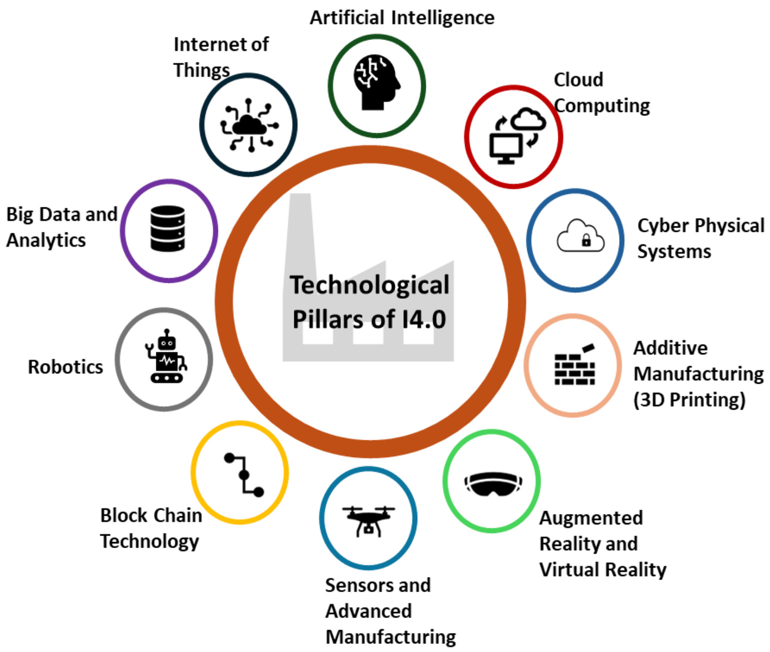

Figure 1: Technological pillars of I4.0

Technologies such as IoT and data analytics enable efficient resource management through real-time monitoring and analysis (Kumar & Shoghili, 2018; Javaid et al., 2022). Predictive maintenance, powered by these technologies, helps prevent costly equipment breakdowns (Agostinelli, 2023; Ferreiro et al., 2016). Optimised construction processes are achieved through Building Information Modelling (BIM), which minimises errors and wastage via 3D printing and simulations (Liu et al., 2015; Turner et al., 2020).

Construction projects can reduce waste by optimising material usage through real-time data collection, monitoring, and data analytics (Balasubramanian et al., 2021). Intelligent sensors monitor the number of resources used, while automated systems identify material recycling and reuse options (Costa et al., 2022). Energy efficiency is improved with smart HVAC systems, lighting, and renewable energy integration, optimising energy use based on real-time conditions (Newton, 2022; Minoli et al., 2017).

Achieving green building certification is simplified with tools that track energy use and sustainability indicators (Bonilla et al., 2018; Balasubramanian et al., 2021). Additionally, architects and engineers can produce highly customised and unique building designs using augmented reality and virtual reality technologies (Pech & Vrchota, 2022).

Regardless of the physical location, real-time collaboration technologies such as cloud computing enable all parties involved in construction projects to collaborate effectively (Erboz, 2017). These platforms facilitate better communication, faster decision-making, and rapid problem-solving (Saini et al., 2019).

Further, IoT sensors such as drones enhance construction site safety by tracking the real-time positions of workers, identifying hazardous situations, lowering risks, and ensuring the safety of both the public and workers (Javaid et al., 2022; Yasar & Gillis, 2024).

Improved safety procedures ensure the well-being of people and contribute to more sustainable construction projects (Oke & Arowoiya, 2021).

2.2 CHALLENGES OF IMPLEMENTING I4.0 FOR THE CONSTRUCTION INDUSTRY

Despite the substantial opportunities and promising sustainable and efficient construction practices offered by I4.0 technologies, several challenges hinder their full implementation.

One significant obstacle is the high initial cost associated with adopting I4.0 technologies. Integrating sensor systems, IoT devices, VR equipment, and customised automated machinery, as well as replacing outdated systems incompatible with I4.0 innovations, poses a substantial financial burden on construction companies, especially smaller ones (Sony & Aithal, 2020; Oesterreich & Teuteberg, 2016). Additionally, the lack of a skilled workforce proficient in digital technology operations, data analysis, and automation system troubleshooting is a major barrier (Huang et al., 2019).

Integrating advanced technologies while adhering to existing rules presents significant regulatory and compliance challenges. Building codes and standards often require updates to accommodate novel construction methods and materials introduced by I4.0 technologies which is a current challenge (Kozlovska et al., 2021).

The lack of standardised protocols in the construction industry further complicates I4.0 implementation. Establishing best practices is challenging without standard guidelines, necessitating collaboration with regulatory bodies to create standardised procedures (Kozlovska et al., 2021). Data security and privacy require significant attention. Construction firms must establish explicit privacy policies, ensure data encryption, and implement robust cybersecurity measures while adhering to data protection laws (Erboz, 2017).

Calculating the Return on Investment (ROI) for I4.0 investments is another challenge due to the time required for significant cost and efficiency reductions to materialise. Construction firms need precise parameters for calculating ROI and regular assessments of their technological expenditures (Demirkesen & Tezel, 2022).

The significant volume of data generated by I4.0 technologies complicates decision-making processes in construction. Advanced data analytics and visualisation tools are essential to streamline decision-making and accelerate the process (Erboz, 2017). Moreover, the unique nature of each construction project demands specialised solutions, which are often resource-intensive and time-consuming, underscoring the necessity for construction firms to exhibit adaptability (Maskuriy et al., 2019)

Lastly, cultural and organisational resistance further complicates the adoption of technologies. Traditional corporate cultures and practices can impede the transition to technology-driven processes, necessitating a deliberate change management approach, open communication, and leadership commitment (Muñoz-La Rivera et al., 2021). Ethical considerations also arise, particularly concerning employment displacement due to automation and robotics (Brown, 2018).

3. RESEARCH METHOD

This study employed a survey supported by a literature review and a questionnaire. The literature review enabled the identification of opportunities and challenges in implementing I4.0 technologies. These identified challenges and opportunities were incorporated into a five-point Likert scale (1=strongly disagree to 5=strongly agree), and respondents were asked to rate them accordingly.

Building professionals primarily involved in building and civil engineering projects within public and private sector construction organisations in Sri Lanka were targeted as respondents. The questionnaire survey was conducted online through Qualtrics software. The survey reached 60 professionals, resulting in 40 complete responses. Figures 2 and 3 illustrate the distribution of respondents and their work experience in the construction industry, respectively.

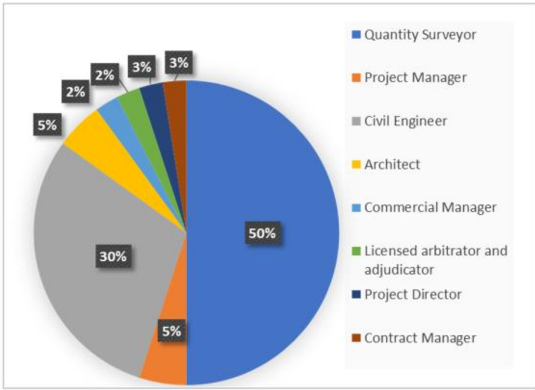

Figure 2: Distribution of respondents

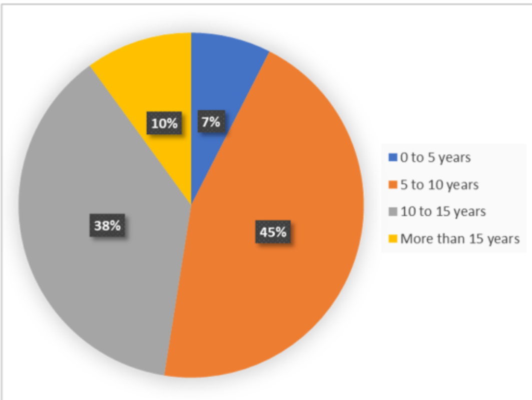

Figure 3: Work experience of respondents

The collected data were subsequently analysed using descriptive statistics and the Relative Importance Index (RII), enabling the systematic ranking of identified opportunities and challenges based on their perceived importance. This approach facilitated a clear understanding of the relative significance of each factor, guiding further discussions and strategic decision-making processes.

4. RESEARCH FINDINGS AND DATA ANALYSIS

Figures 4 and 5 illustrate the ranking of opportunities and challenges identified by respondents for implementing I4.0 in the Sri Lankan construction sector.

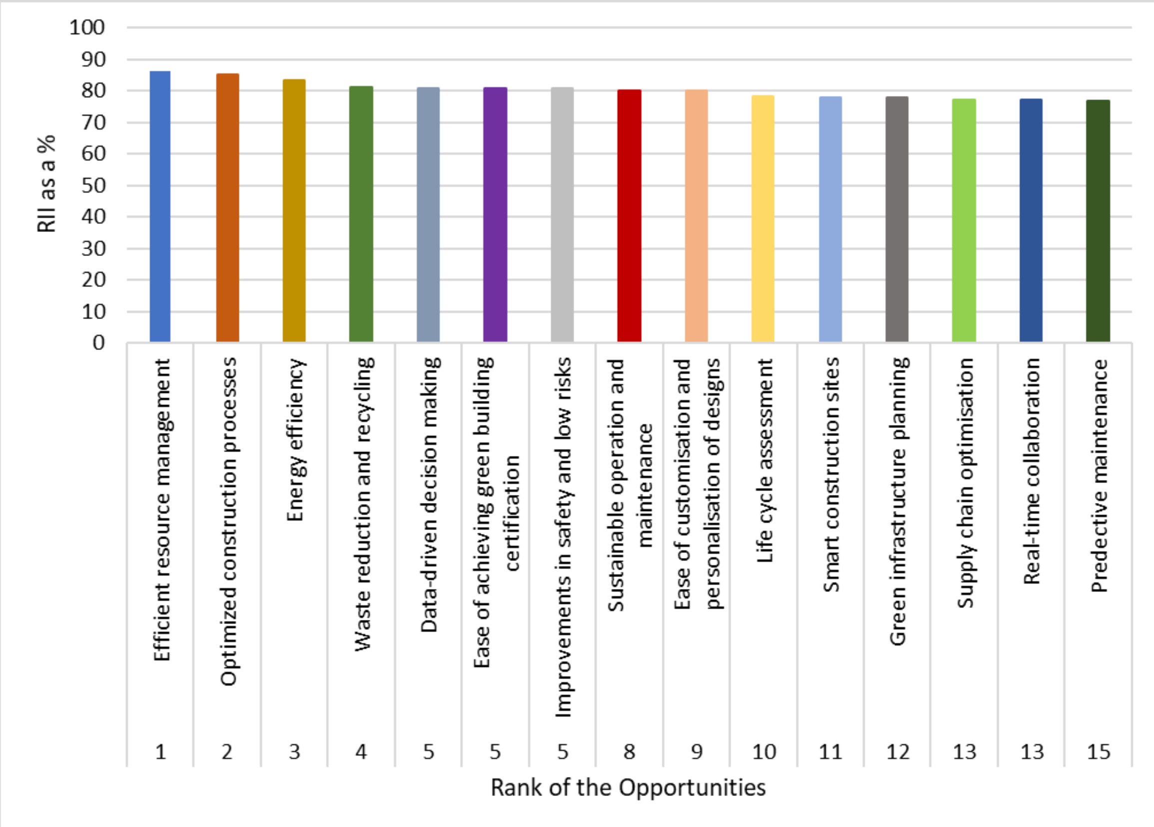

Figure 4: Opportunities for implementing Industry 4.0 in the construction sector in Sri Lanka

As depicted in Figure 4, the top three opportunities, in ascending order, include efficient resource management (86.1%), optimised construction processes (85.0%), and energy efficiency (83.3%). On the other hand, supply chain optimisation (77.20%), real-time collaboration (77.20%), and predictive maintenance (76.70%) were perceived as the least important opportunities.

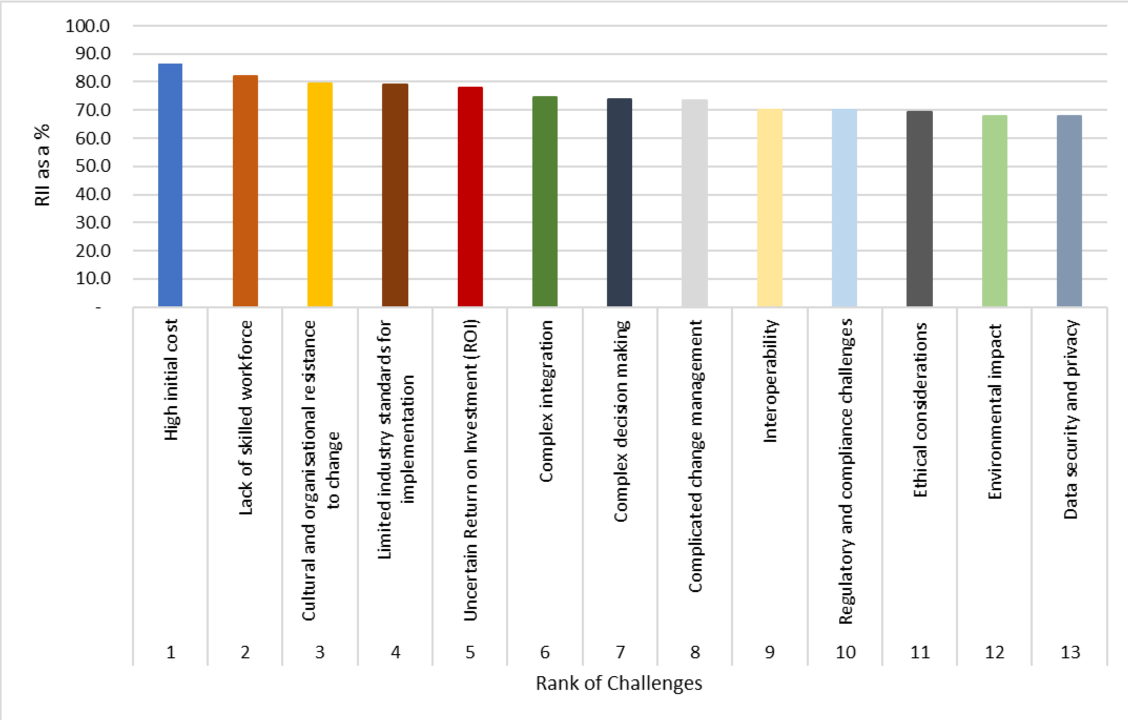

Figure 5: Challenges for implementing I4.0 in Sri Lankan construction industry

According to Figure 5, the top three challenges for implementing Industry 4.0 in the Sri Lankan construction industry are high initial cost (86.6%), lack of skilled workforce (82.2%), and resistance to change (79.4%). Conversely, ethical considerations (69.5%), environmental impact (67.70%), and data security (67.70%) were identified as the least significant challenges associated with adopting Industry 4.0 technologies.

5. DISCUSSION

Efficient resource management emerged as the foremost opportunity in Sri Lanka's adoption of I4.0. Implementation of IoT sensors and related technologies promises meticulous tracking of materials and equipment usage, thereby offering substantial reductions in waste generation and operational costs while enhancing overall sustainability (Al-Garadi et al., 2020). Following closely, respondents highlighted optimisation of construction processes as the second most significant opportunity. Unsurprisingly, optimisation is anticipated to lead to reductions in resource consumption, waste, errors, and project timelines (Maskuriy et al., 2019).

Energy efficiency ranked third among opportunities, highlighting how I4.0 technologies enable adjustments in building temperature and lighting based on occupancy, thereby enhancing overall energy efficiency (Minoli et al., 2017). The ability of construction professionals to make informed decisions on waste minimisation under sustainable practices was recognised as the fourth most important opportunity. Data-driven decision-making, ease in achieving green building certifications, and improvements in safety and risk management ranked fifth among opportunities. These aspects leverage massive data sets generated by I4.0 to support informed decision-making and streamline certification processes (Arowoiya et al., 2020; Balasubramanian et al., 2021). Moreover, IoT sensors integrated as wearable technology further enhance worker safety on construction sites (Oke & Arowoiya, 2021).

Conversely, predictive maintenance was deemed the least important opportunity among the identified 15 opportunities. This finding likely reflects the predominant focus of the surveyed construction project professionals rather than building environment professionals involved in the operational stage of buildings. Surprisingly, real-time collaboration among stakeholders ranked as the second least important opportunity. This may stem from limited awareness of relevant technologies and insufficient proficiency in working in real-time collaboration platforms.

Yet, alongside these opportunities, significant challenges accompany the implementation of Industry 4.0 in Sri Lanka's construction sector. Foremost among the challenges identified is the high initial cost, which stands as a predominant barrier. The adoption of Industry 4.0 technologies involves substantial expenses due to the new high-tech equipment and software required (Kelber, 2020). This financial burden is not unique to Sri Lanka but is similarly observed in other comparable countries.

The next closely ranked challenge is the lack of a skilled workforce capable of effectively utilising and maintaining these novel technological advancements. Competent staff is essential for effective I4.0 adoption (Huang et al., 2019). The current construction workforce in Sri Lanka needs significant training and upskilling to seamlessly integrate these technologies into their operations. Moreover, entrenched resistance to change within organisations and the industry itself poses another significant hurdle. Many experienced professionals in Sri Lanka are accustomed to legacy systems, intensifying their reluctance to adopt new technologies.

Further, respondents highlighted the limited industry standards for implementing Industry 4.0 in Sri Lanka as the fourth-highest challenge. This lack of standardisation complicates the integration of different technologies, necessitating closer engagement between technology experts, IT specialists, and the construction industry (Kozlovska et al., 2021).

Additionally, uncertain ROI, complex integration and decision-making, complicated change management processes, interoperability issues, and regulatory and compliance issues were identified as further challenges of implementing I4.0 in the Sri Lankan construction sector.

Ethical considerations such as job displacement due to technological transformation, environmental impacts such as high energy consumption for these technologies, and data security and privacy were rated as the least impactful challenges for the Sri Lankan construction industry. This is unsurprising for Sri Lanka, where many other pressing issues must be resolved first.

6. RECOMMENDATIONS FOR POLICYMAKERS AND INDUSTRY STAKEHOLDERS

It is evident that the implementation of I4.0 technologies significantly improves the efficiency, productivity, and sustainability of the construction sector. However, for the Sri Lankan construction industry to fully capitalise on these opportunities, it is crucial to address the associated challenges. Policymakers and industry stakeholders must collaborate closely to mitigate these challenges effectively.

Firstly, addressing the high initial costs associated with I4.0 technologies requires strategic investments, funding, government grants, and partnerships with technology providers. Additionally, it is essential to implement robust training and upskilling programs for the current workforce to ensure they are proficient in the use of these technologies.

Policymakers need to establish industry standards for the implementation of Industry 4.0 technologies. Developing clear guidelines and best practices will ensure smooth integration and compliance with existing regulations.

Furthermore, developing and executing robust change management plans will help address resistance within organisations. Fostering a culture that embraces technological advancements by demonstrating the long-term benefits of I4.0 is essential for overcoming resistance to change.

7. CONCLUSIONS

I4.0 presents a transformative opportunity to fully integrate humans and digitally controlled machinery, thereby enhancing the efficiency, productivity, safety, and sustainability of the construction sector. The technological pillars of I4.0 such as artificial intelligence, cloud computing, cyber-physical systems, augmented reality and virtual reality, 3D printing, robotics, and big data support the realisation of these opportunities. However, alongside these opportunities, numerous challenges arise, particularly for developing countries.

This study focused on Sri Lanka, aiming to investigate the opportunities for improvement and the challenges associated with implementing I4.0 in its construction sector. The findings revealed that to fully harness opportunities such as efficient resource management, optimised construction processes, energy efficiency, waste reduction and recycling, and improvements in safety and risk management, several critical challenges must be addressed. These challenges include high initial costs, a lack of skilled workforce, resistance to change, and limited industry standards.

Addressing these challenges will require a concerted effort from policymakers and industry stakeholders, including strategic investments, robust training programs, and the establishment of clear industry standards. By overcoming these barriers, Sri Lanka's construction sector can effectively leverage I4.0 technologies, leading to a more efficient, sustainable, and competitive industry.

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