Prasadinee, W.K.R., Chandanie, H. and Nanayakkara, N.B., 2026. Sustainability impacts of industry 4.0 in construction project management. In: Waidyasekara, K.G.A.S., Jayasena, H.S., Chandanie, H. and Tennakoon, G.A. (eds). *Proceedings of the 14th World Construction Symposium*, 10-11 July 2026, Sri Lanka. pp. 1624-1636. DOI: https://doi.org/10.31705/WCS.2026.118. Available from: https://ciobwcs.com/papers/

SUSTAINABILITY IMPACTS OF INDUSTRY 4.0 IN CONSTRUCTION PROJECT MANAGEMENT

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ABSTRACT

Construction projects frequently face time and cost overruns due to ineffective Construction Project Management (CPM). The integration of Industry 4.0 (I4.0) digital technologies has emerged as a transformative approach to enhance traditional CPM practices. While I4.0 adoption offers considerable benefits, its sustainability implications remain underexplored. Given that I4.0 applications can produce both positive and negative impacts across sustainability dimensions, this study adopts a Triple Bottom Line (TBL) perspective to examine the environmental, economic, and social implications of implementing I4.0 technologies in CPM in Sri Lanka. A mixed-method approach was employed, with data collection in two phases: Phase I involved five expert interviews, and Phase II comprised a questionnaire survey. Qualitative and quantitative data were analysed using manual content analysis and the Relative Importance Index (RII) method, respectively. The findings reveal that I4.0 applications positively impact TBL sustainability: environmentally, through reduced resource use, lower construction waste, and early detection of environmental risks; economically, via improved project tracking, scheduling, and timely completion; and socially, through fewer manual errors, greater transparency, and accountability. Negative implications were also identified: environmentally, high energy demand and electronic waste; economically, high implementation costs and expenses for recruiting and training skilled personnel; and socially, workplace inequalities, digital surveillance, and potential job losses. This study provides an empirical, TBL-based evaluation of I4.0-enabled CPM practices in Sri Lanka, addressing a largely unexplored area and offering insights into sustainable digital transformation in the country's construction industry.

Keywords: *Construction Project Management; Industry 4.0; Sri Lanka; Triple Bottom Line.*

1. INTRODUCTION

Resource depletion and global financial crises highlight the importance of effective Construction Project Management (CPM) (Ifeanyi et al., 2025). CPM is a continuous process encompassing planning, execution, monitoring, and control throughout a project's lifecycle, from initiation to closure (Alvarenga et al., 2020). Effective CPM ensures project success by achieving timely delivery, budget adherence, and quality

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outcomes as per agreed terms (Zheng & Qiang, 2022). However, traditional CPM practices face numerous challenges (Pakhale & Pal, 2020), which can be mitigated through the integration of digital technologies (Zhu et al., 2022).

The technological evolution, pioneered by I4.0, is distinguished for the integration of cyber-physical systems, automation, and real-time data exchange (Folgado *et al*., 2024). Driven by the principles of I4.0, these advancements encouraged the industries to re-evaluate traditional practices and embrace more data-centric, automated workflows (Khan *et al*., 2023). Hence, the construction industry integrated digital technologies, including the Internet of Things (IoT), Big Data, Augmented Reality (AR), Virtual Reality (VR), Building Information Modelling (BIM), Artificial Intelligence (AI), Blockchain, Robotics, Drones and other related advancements as a response to I4.0. (Srivastava *et al*., 2022). Integration of I4.0 in construction industry yields enormous benefits for the construction industry, including reduced rework, reduced coordination problems, better communication between various stakeholders, reduced document errors, fewer claims, reduced paperwork, reduction in time and cost overrun, and reduction in lifecycle cost among the many benefits (Pakhale & Pal, 2020), and hindered due to technological incapacity among industry practitioners, their inherent resistance to change, inadequate technological infrastructure, and deficiencies in the legal framework and its enforcement (Karunaratne & Abeynayake, 2023). Most significantly, I4.0 technologies are capable of making both positive and negative impacts on the sustainability of the construction industry in the CPM context (Balasubramanian *et al*., 2022).

Globally, numerous studies have examined digitalisation in the construction industry (D'Alberto et al., 2025; Johari et al., 2024). However, existing research on I4.0 and sustainability has predominantly focused on social aspects (Calvetti et al., 2020; Sherratt et al., 2020), with limited attention given to a comprehensive TBL perspective that integrates economic, environmental, and social dimensions. Nevertheless, scholars have emphasised the importance of adopting a TBL approach, as the impacts of I4.0 may vary or even conflict across these dimensions (Balasubramanian et al., 2022). In addition, the application of digitalisation within CPM remains underexplored (Marnewick & Marnewick, 2022), especially within the Sri Lankan context. Accordingly, this study aims to explore the sustainability impacts of I4.0 in construction project management in Sri Lanka, and was achieved through identifying the implications on TBL sustainability from the implementation of I4.0 applications in CPM practices in Sri Lanka, as well by identifying the strategies to enhance sustainable digitalising CPM.

2. LITERATURE REVIEW

2.1 SUSTAINABILITY THROUGH A TRIPLE BOTTOM LINE (TBL) LENS

Sustainability is a holistic concept concerned with long-term resource management and its impacts (Saunders & Hughes, 2018). The widely recognised definition from the Brundtland Report (1987) describes it as meeting present needs without compromising future generations. Over time, sustainability has evolved beyond environmental concerns to include economic and social dimensions (Choi & Ng, 2011; Ford & Despeisse, 2016). Accordingly, it is understood through the Triple Bottom Line (TBL), balancing environmental, economic, and social aspects (Holden et al., 2014).

Environmental sustainability focuses on maintaining ecological balance and responsible resource use; economic sustainability emphasises long-term growth while preserving resources; and social sustainability addresses the impacts of business and technological activities on people (Choi & Ng, 2011).

2.2 SUSTAINABILITY IMPLICATIONS OF DIGITALISATION IN THE CONSTRUCTION INDUSTRY

Sustainability concepts play a crucial role in construction projects (Stanitsas *et al*., 2021). The construction industry has a significant impact on the environment, contributing to the generation of two to three billion tonnes of building waste annually due to its high global consumption of natural resources (Jain, 2021). Additionally, the industry holds economic and social significance, contributing 5–7% to the Gross Domestic Product (GDP) in many countries (Alaloul *et al*., 2021), and employing millions of people (Babalola & Aigbavboa, 2022). Consequently, a strong link exists between construction and the three pillars of sustainability i.e. (i) economy, (ii) society, and (iii) environment (Goh *et al*., 2020). Integrating I4.0 technologies in the construction industry impacts both positively and negatively for sustainability (Wang & Guo, 2022). Therefore, adopting a TBL perspective is essential, as the sustainability impacts of I4.0 technologies may conflict across economic, environmental, and social dimensions (Balasubramanian *et al*., 2022). Figure 1 illustrates the positive and negative implications on TBL sustainability from I4.0 applications in construction.

Economic - Positive Implication
- Reduced cost of construction projects and operational costs at site
- Reduced project completion time
- Improved project tracking and scheduling
- Reduced material misplacement
- Increased productivity and efficiency of projects
- Reduced costly design variations at advanced stages of projects
- Reduced human bias and subjectivity in decision-making
- Reduced delays and unforeseen costs in construction

Economic - Negative Implications
- Increased cost of implementation of I4.0 applications
- Uncertain return on investment
- Increased cost of security on I4.0 applications
- Increased cost of recruiting, training and retaining the technology professionals
- Increased costs of subscriptions and upgrades relevant to I4.0 applications
- Costly delays and disruptions to the construction process due to technology failures

Social – Positive Implications
- Improved onsite workers' mental and physical well-being
- Improved security and safety
- Improved transparency and trust
- Improved accountability of all stakeholders
- Improved large-scale training
- Reduced manual errors and reworks
- Improved workforce skills
- Increased stakeholder communication and collaboration
- Increased employee productivity
- Reduces the need for manpower by automating a number of site inspection processes and defect management processes
- Creation of new jobs

Social – Negative Implications
- Increased data privacy issues
- Increased data breaches
- Increased digital surveillance of employees and reduce the employment relationships
- Inequalities at the workplace on wages and career advancements
- Increased job losses

Environmental – Positive Implications
- Reduced resource consumption and wastage in construction
- Reduced energy consumption in construction
- Reduced paper-based documentation
- Reduced environmental footprint from construction
- Enhanced end-of-life recovery of materials/ components
- Reduced carbon dioxide emission in construction
- Reduced environmental accidents due to early detection and predictive analytics

Environmental - Negative Implications
- Increased e-waste generation
- Increased energy usage for I4.0 applications

Figure 1: Literature findings (implications of industry 4.0 applications in CPM practices on TBL sustainability)
(Source: Balasubramanian et al., 2022)

Environmental sustainability involves preserving natural systems and ensuring resource use does not exceed ecological limits (Moghayedi et al., 2021). Industry 4.0 (I4.0) technologies present both positive and negative environmental implications. Positively, they enable process optimisation, efficient resource use, reduced waste, and lower energy consumption through real-time data and analytics (Ford & Despeisse, 2016; Balasubramanian et al., 2022). However, they may also increase energy demand and generate electronic waste (Ford & Despeisse, 2016).

Economic sustainability focuses on maintaining long-term financial stability (Balasbaneh & Sher, 2026). Digitisation contributes positively by translating environmental efficiencies into cost savings, including reduced labour, inspection, and administrative costs, thereby lowering overall construction expenses (Balasubramanian et al., 2022).

Social sustainability ensures equitable access to resources, opportunities and services, while upholding and justly distributing human rights to enhance the quality of life in society (Pieterse, 2011). Social sustainability has both positive and negative implications. The positive implications include the improved health and safety of workers (Holden *et al*., 2014). This is promising, because construction is one of the sectors that constitute the largest percentages of worker death by accidents and injuries. Moreover, Construction 4.0 will generate several new types of jobs, especially jobs in science and technology (Ejsmont *et al*., 2020). However, there are several adverse societal implications of I4.0. More discourse from an ethical and humanitarian perspective is required on the potential loss of jobs of unskilled blue-collar workers and their future role in the sector due to I4.0 (Yılmaz & Bakış, 2015). An increase in the surveillance of employees raises questions about employee freedom and privacy. More discourse is required on the data-related privacy, cyber-security, and data breaches surrounding I4.0 (Balasubramanian *et al*., 2022).

3. RESEARCH METHODOLOGY

This study examines the effective implementation of sustainable digitalisation in CPM, aligned with the three pillars of sustainability. A mixed-method approach was adopted, combining quantitative analysis to identify positive and negative TBL implications, and qualitative analysis to explore strategies for sustainable digitalisation in CPM. Accordingly, expert interviews and questionnaire surveys were employed as key research strategies. Data collection and analysis formed the core of the methodology (Chalmers & Armour, 2019), conducted in two phases as outlined below.

3.1.1 Phase I: Expert Interviews

Expert interviews were conducted with five professionals experienced in I4.0 applications in construction and CPM to refine the sustainability implications identified in the literature, with specific relevance to the Sri Lankan context. In selecting the experts, a problem and expertise-centred approach is appropriate than a convenience approach (Von Soest, 2022). Existing literature on expert interviews provides limited guidance regarding an exact sample size (Saunders & Townsend, 2016). Instead, the authors suggest that the sample should be sufficiently large to achieve data saturation while remaining small enough to facilitate in-depth analysis. Accordingly, emphasis is placed on justifying the adequacy of the selected sample rather than adhering to a predetermined number of participants. Therefore, employing purposive sampling, this study engaged five experts who satisfied the established selection criteria. The sample size was deemed adequate upon reaching data saturation, with priority given to the depth and richness of insights rather than the quantity of participants. The respondent profiles are presented in Table 1.

Table 1: Expert respondent profile

Respondent	Designation	Experience (Years)	Educational Qualification	Professional Qualification	Knowledge area	
					CPM	I4.0
E1	Project Manager	28	B.Sc. Eng, M.Sc.	Chartered Engineer	Well aware	Well aware
E2	Project Manager	25	B.Sc. Eng	Chartered Engineer	Well aware	Well aware
E3	Project Manager	20	B.Sc. Eng	Chartered Engineer	Well aware	Well aware
E4	Project Manager	16	B.Sc. Eng	Chartered Engineer	Well aware	Well aware
E5	Assistant Project Manager	10	B.Sc. Eng	Chartered Engineer	Well aware	Well aware

3.1.2 Phase II: A questionnaire survey

A questionnaire survey was conducted among 38 construction professionals (CPs) experienced in I4.0 applications and CPM, selected through snowball sampling. The sample size is considered sufficient for exploratory quantitative analysis within a specialised professional group. The data collection tool for the questionnaire survey, the semi-structured questionnaire was developed under 02 main sections, Section 1 in identifying the positive and negative implications on TBL sustainability from the I4.0 applications in CPM practices in Sri Lanka and Section 2 to identify the strategies for enhance sustainable digitalising CPM. Section 1 included a Likert scale (1–5, from "Extremely Low" to "Extremely High") to prioritise sustainability implications. Further, the refined list of positive and negative implications on TBL sustainability from the I4.0 applications in CPM practices in Sri Lanka. Section 2 comprised of open-ended questions to identify strategies for sustainable digitalisation in CPM. Additionally, the questionnaire was assessed for validity. Content validity was established through the evaluation of the questionnaire by five experts, who reviewed the items for their appropriateness, relevance, and adequacy in representing the constructs under investigation (Hossan et al., 2025). Furthermore, the qualitative data underwent member checking, whereby survey participants were given the opportunity to review and verify the accuracy of the transcribed data and emerging themes, ensuring that their views were authentically represented (Soysal & Türkmen, 2024). In parallel, inter-coder reliability was assessed within the research team by having two researchers independently code the qualitative data and subsequently compare their coding outcomes to evaluate consistency (Hossan et al., 2025). Further, following the authors, any discrepancies identified were resolved through collaborative discussions until consensus was reached. Collected data were analysed using manual and descriptive methods, with the RII applied for quantitative analysis.

4. RESEARCH FINDINGS, ANALYSIS, AND DISCUSSION

4.1 EXPERT INTERVIEW FINDINGS AND ANALYSIS

4.1.1 Implications on TBL Sustainability from The Implementation of I4.0 Applications in CPM Practices In Sri Lanka

The positive and negative TBL sustainability implications identified through the literature were refined for the Sri Lankan context via expert interviews. Table 2 presents the finalised implications.

In relation to the positive economic implications, E2 emphasised that incorporating I4.0 applications in CPM practices allows faster and more informed decision making as it provides access to real-time data and analytics that enables faster and more informed decision-making, allowing project managers to respond swiftly to changing project requirements, market conditions, and stakeholder preferences, ultimately resulting in timely project completion. E4 stated that "*I4.0 applications have the capability to reduce the construction and operation costs as when I4.0 applications are integrated with the CPM processes it enables a minimal labour-intensive environment*". According to E3, this integration enhances predictive maintenance, which shall minimise cost of maintenance, and manage disputes arising due to poor payment and documentation practices. As per E1, predictive analytics facilitated through the I4.0 applications shall identify the potential risks early and allow proactive mitigation strategies there by avoiding costly disruptions. Negatively, E3 highlighted 'the complexity of integration and interoperability' that described the difficulty of connecting, coordinating, and enabling different digital technologies, systems, software platforms, and stakeholders to work together seamlessly within CPM particularly under I4.0. In relation to positive social implications, E5 stated the fact that integrating I4.0 applications and CPM practices increases the employee productivity where it enables the flexible work arrangements to improve work-life balance. In relation to negative social implications, experts highlighted that digital surveillance of employees in a troublesome manner disrupts the work pattern of employees leading to dissatisfaction, resistance and reduces professionalism.

4.2 SURVEY FINDINGS AND ANALYSIS

The RII scores reflect the level of importance assigned to each implication. A 60% RII value is taken as the benchmark, and implications with scores below this threshold are not considered applicable to the Sri Lankan construction industry. Table 2 illustrates the ranked list of implications on TBL sustainability from the I4.0 applications in CPM practices in Sri Lanka.

Table 2: Positive and negative implications on TBL sustainability from the I4.0 applications in CPM practices in Sri Lanka

Expert Findings	5	4	3	2	1	RII	Rank
Implications on Environmental Sustainability							
Positive							
Reduced resource consumption and wastage	16	12	6	3	1	0.75	3
Reduced energy consumption	18	12	5	2	1	0.80	2
Reduced carbon emissions, specifically CO2 emissions	21	11	4	2	0	0.85	1

Expert Findings	5	4	3	2	1	RII	Rank
Greater end-of-life recovery of materials/ components	11	12	8	5	2	0.65	4
Reduced Environmental accidents due to early detection and predictive analytics	8	11	9	6	4	0.55	5
Negative							
Greater e-waste	10	13	8	5	2	0.73	2
High energy intensity for large storage and computing power requirements	16	12	6	3	1	0.81	1
Implications on Economic Sustainability							
Positive							
Reduce the cost of construction, operation and maintenance of the project	14	15	6	3	0	0.81	7
Improvement in tracking and scheduling	21	12	4	1	0	0.88	1
Avoid costly design variations at advanced stages of the project	22	11	4	1	0	0.88	1
Lower human bias and subjectivity in decision-making	16	14	6	2	0	0.83	6
Reduced delays, reworks and unforeseen costs	18	13	6	1	0	0.85	5
Project completion as scheduled	20	12	5	1	0	0.87	3
Avoid and mitigate disputes that occur due to poor payment and defective documentation	19	13	4	2	0	0.86	4
Negative							
Increased cost of implementation	22	11	4	1	0	0.88	1
Uncertain return on investments	16	13	7	2	0	0.83	4
The incurrence of costs related to security	10	13	11	4	0	0.75	7
The incurrence of costs related to recruiting and retaining technology professionals and training	19	12	5	2	0	0.85	2
The incurrence of costs related to subscription charges and upgraded costs	18	13	5	2	0	0.85	3
Over-reliance on technology can lead to costly delays and disruptions in the case of technology failure	12	14	9	3	0	0.78	6
The complexity of integration and interoperability	14	14	7	3	0	0.81	5
Implications on Social Sustainability							
Positive							
Improved workers mental and physical well-being	13	14	8	3	0	0.79	8
Improved security and safety at site	16	13	7	2	0	0.83	6
Improved transparency and trust	20	12	5	1	0	0.87	2
Improved accountability of all stakeholders	19	12	6	1	0	0.86	3
Enhances employee skill level through training programs	14	14	8	2	0	0.81	7
Reduced manual errors and reworks	21	12	4	1	0	0.88	1
Improved communication and collaboration through digital platforms	18	13	5	2	0	0.85	4

Expert Findings	5	4	3	2	1	RII	Rank
Reduced manpower requirement by automating several site inspection processes and defect management processes	17	13	6	2	0	0.84	5
Negative							
Increased data privacy issues	13	14	7	4	0	0.79	5
Diminish opportunities for face-to-face interaction and human connection	15	14	6	3	0	0.82	3
Increased digital surveillance of employees	16	14	6	2	0	0.83	2
Inequalities at the workplace in terms of wages and career advancements (with employees with ICT knowledge tending to get paid more)	18	13	5	2	0	0.85	1
Increased job losses	14	14	7	3	0	0.81	4

The integration of I4.0 technological advancements, including autonomous robots, simulation, horizontal and vertical system integration, AI, the IoT, cybersecurity, cloud storage, additive manufacturing, augmented reality, and big data analytics, into the construction industry has the potential to enhance performance significantly, enabling up to 30% faster production and a 25% increase in efficiency (De Oliveira et al., 2026). Beyond productivity gains, these technologies play a crucial role in promoting environmentally responsible, socially equitable, and economically viable industrial practices (Khan et al., 2025). Therefore, it is essential to examine their impact on the three core pillars of sustainability, environmental, economic, and social, within the various industrial contexts including the construction sector. Globally, there is a growing emphasis on improving the sustainability of the construction industry, driven by persistent challenges such as high carbon emissions, escalating construction costs, compromised health and safety standards, and low productivity levels (Balasubramanian et al., 2022).

I4.0 applications shall address the TBL sustainability concerns in CPM through enhanced waste reduction, optimised energy usage in buildings, optimised energy consumption in building operation, worker health and safety at sites, and lifespan of the buildings (Khan et al., 2025). The authors specified that IoT and AI improves the energy efficiency by reducing the carbon footprint. CPs strongly supported this benefit, as reflected by "reduced carbon emissions, specifically CO_2 emissions" receiving the highest RII score of 0.85. Considering the increased concerns over climatic changes occurring in Sri Lanka over the recent decades (Fonseka et al., 2025), CPs consider the massive responsibility of the industry to engage in reducing the environmental footprint resultant through the construction activities. Relating to the negative impacts, the study emphasised greater e-waste and high energy usage for the advanced technologies. Supporting this, Balasubramanian *et al.* (2022) specifically stated the high energy demand for computer-based applications, AI and big data analytics. Further, CPs highlighted the challenges associated with the limited e-waste management and recycling facilities available in Sri Lanka. They noted that many obsolete IoT devices used on construction sites are ultimately disposed of as landfill waste. Additionally, CPs identified that battery-powered technological equipment contributes to the accumulation of toxic battery waste, as proper disposal and recycling mechanisms are not widely practised within the Sri Lankan context. Mainly, experts emphasised that the positive environmental and social implications are getting converted to positive economic implications. This is justified through the findings of Balasubramanian et al. (2022) that the resource savings from I4.0 technologies are pioneering the effective management of the construction cost, and also the enhanced site safety enables effective worktime reducing the downtimes. Anyhow, all the experts highlighted the higher upfront cost of implementing I4.0 applications, where CPs identified this as the most severe negative implication related to the Sri Lankan context. E3 stated that when considering the developing nature of the Sri Lankan economy affording on these costly advanced technologies by the construction industry is challenging. Franco et al. (2022) emphasised capability of I4.0 technologies in making positive implications on the social sustainability in CPM through initiative such as improving the health and safety of workers, reduced work accidents, and replacement of manual works with digital activities. CPs re-emphasised the reduced manual errors and reworks as a positive implication by ranking it as the highest positive implication with a RII of 0.88. Experts established the possibility of utilising drone technology in structuring construction, mapping, and monitoring. Also, by considering the nature of blockchain technology, E2 highlighted its potential in enhancing the data transparency and trust among stakeholders. CPs stated that the use of Industry 4.0 technologies, such as drones at Sri Lankan construction sites, significantly enhances site monitoring, reduces rework, and promotes transparency among stakeholders, thereby addressing many of the challenges associated with manual project management processes. Negatively, I4.0 endeavours shall impact by threatening the job roles of the professionals (Khan et al., 2025). Anyhow, the spotlight of the Sri Lankan context was the probable inequalities at the workplaces in terms of wages and the career advancements, and the possibility of employees to rely more on digital technologies.

4.3 STRATEGIES FOR ENHANCE SUSTAINABLE DIGITALISING CPM

Questionnaire survey was further utilised in identifying the effective strategies for sustainable digitalising of CPM, addressing economic, social, and environmental considerations. In terms of **environmental** considerations, CPs emphasised the appropriateness of *conducting comprehensive risk assessments* to identify and mitigate negative impacts associated e-waste generation, improper disposal of electronic and battery waste, and also the carbon emissions from the technological infrastructure. Additionally, R9 and R20 emphasised the importance of *promoting sustainability and updating regulations* to support the deployment of sustainable technologies. The particular strategy shall be promoted through incentivising sustainability efforts and promoting collaboration and knowledge-sharing among industry peers and partners. On the **economic** front, respondents emphasised the *need for effective financial planning and investment in research and development to overcome potential challenges associated with digitalisation*, as proposed by R1 and R4. Further, the CPs emphasised that effective financial planning shall be utilised in addressing many negative implications of economic sustainability such as reducing the cost of construction, operation and maintenance of the project, reducing delays, reworks and unforeseen costs, and avoiding and mitigating disputes between the parties involved. Moreover, R3 and R5 highlighted the importance of *educating stakeholders about the economic benefits and productivity gains of I4.0 applications* compared to traditional project management practices.

From a **social** perspective, emphasis was placed on *enhancing cybersecurity to mitigate data breaches*, with R1 suggesting that the *government could reduce implementation costs by lowering taxes on I4.0 equipment and data-related fees*. Additionally, *comprehensive training and education programs*, as advocated by R2 and R5, were highlighted to equip workers at all levels with the necessary digital literacy skills, which shall address the data privacy issues due to unawareness. *Engagement with stakeholders*, as suggested by R3 and R4, emerged as a crucial aspect, involving top-level management support, training and development initiatives, and providing opportunities for implementing novel technologies. This strategy shall become useful in overcoming the negative impacts of I4.0 implementation, such as diminished opportunities for face-to-face interaction and human connection, and also the issues with increased digital surveillance of employees. Overall, the insights provided by the respondents underscore the interconnectedness of economic, social, and environmental factors in the adoption of sustainable digitalisation practices in CPM. By addressing these aspects holistically, stakeholders can work towards achieving greater efficiency, cost-effectiveness, and sustainability in construction projects, thereby contributing to positive outcomes for both the industry and the environment.

5. CONCLUSIONS

This study examined the positive and negative sustainability implications of digitalising CPM through I4.0 technologies in the Sri Lankan construction industry using a TBL perspective. The findings indicate that digitalisation enhances project efficiency, resource optimisation, and decision-making, while introducing environmental, financial, and workforce-related challenges. Environmentally, key benefits include reduced resource use, improved waste management, and early risk detection, though these are offset by increased energy demand and electronic waste. Economically, improved tracking, scheduling, timely delivery, and reduced rework support project performance, whereas high implementation costs, uncertain returns, integration complexity, and skills shortages remain significant barriers. Socially, digitalisation improves transparency, accountability, safety, and error reduction, but raises concerns regarding job displacement, inequality, surveillance, and data privacy. Construction practitioners shall utilise the I4.0 technologies effectively in their projects and mitigate associated risks while managing its economic, environmental and social impacts on the CPM practices. Further, the construction organisations shall utilise the results to shape digital transformation strategies that optimise TBL performance and ensure sustainable implementation of I4.0 in CPM. Future research should adopt longitudinal approaches to better understand the long-term sustainability impacts of I4.0-enabled CPM practices.

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