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Industry 4.0 and Construction Project Labour Productivity (CPLP) in Kenya:
Opportunities and Risks

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Abstract
The persistent stagnation of labour productivity in the construction sector poses a critical challenge to economic growth in developing countries, including Kenya. The Fourth Industrial Revolution (4IR) has been widely promoted as a transformative solution capable of reversing this trend through digitalisation, automation, and data-driven decision-making. This study critically evaluates whether the adoption of 4IR technologies constitutes a viable pathway (panacea) to improving Construction Project Labour Productivity (CPLP) or whether it introduces implementation risks (sinking sand) that undermine expected gains. Anchored in post-positivist and pragmatic research paradigms, the study draws on previously developed CPLP predictive models based on empirical project data from Nairobi. The models demonstrate that Project Information Flow (PIF) and Project Materials Flow (PMF) jointly explain 88.0% of the variations in CPLP. A reflexive qualitative analysis is then employed to interrogate the practical feasibility of translating these theoretical gains into on-site productivity improvements. Findings indicate that while 4IR technologies can significantly enhance PIF and PMF, their effectiveness depends on human capacity, infrastructure readiness, and change management. Without these enabling conditions, technology adoption risks becoming counterproductive. The study concludes by proposing a strategic implementation framework to convert 4IR potential into measurable productivity outcomes.

Keywords: *Construction project labour productivity, industry 4.0, project information flow, project materials flow, Kenya, predictive modelling, digital transformation, developing countries*

INTRODUCTION

As the rapidly changing world influences construction and its practitioners, predicting the exact path this whirlwind of change will take for the industry is increasingly complex; no one yet fully understands or can forecast it. It is undeniable that the technological advances of Industrial 4.0 have affected most areas of life (Joseph et al., 2022). The Fourth Industrial Revolution (4IR) is driven by the rapid emergence and convergence of previously unseen technologies (The Council for Scientific and Industrial Research, 2018). The World Economic Forum (2016) suggested that by adopting innovations such as 3D printing and scanning, advanced building materials, augmented reality, autonomous equipment, Building Information Modelling (BIM), and drones—alongside the internet of things (IoT), robotics, digital twins, machine learning, and

digital material management—firms can increase productivity, streamline project management and procedures, and enhance quality, safety, and health standards (Kraus et al., 2022; Zulu et al., 2022). This is particularly relevant for an industry that many experts believe should accept chaos as a guiding theory of study. However, the extent of this doesn't remain easy to gauge or predict.

The challenge of Construction Project Labour Productivity (CPLP) is severe. Kenya, for example, significantly lags behind global benchmarks, with Finland surpassing its performance by over 11 times and the UAE by more than 22 times on major projects (Murianka et al., 2024a; Legeto et al., 2013). Despite a growing body of global literature on 4IR in construction, there remains limited empirical and contextualised analysis

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of how these technologies interact with labour productivity determinants at the project level in Kenya.

This study addresses this gap by examining the implications of 4IR adoption through the lens of empirically validated Construction Project Labour Productivity (CPLP) models. The objectives of the study were to: (i) examine the conceptual relationship between 4IR technologies and CPLP determinants; (ii) assess the likely productivity outcomes of 4IR adoption based on CPLP predictive models; and (iii) propose strategic implementation pathways suited to the Kenyan construction context.

The paper is organised as follows: Section 2 reviews relevant theoretical and empirical literature; Section 3 outlines the research methodology and CPLP modelling framework; Section 4 presents the results and discussion of the findings; and Sections 5 and 6 present conclusions and recommendations.

THEORY

Various theories exist regarding how the Fourth Industrial Revolution (4IR) will impact the construction industry. (i) Phenomenal improvement: 4IR provides the tools necessary to break historical productivity ceilings; (ii) Industry decimation: High-productivity work (e.g., prefabrication, 3D printing) shifts statistically to the manufacturing sector, causing construction to decline; (iii) Labour Substitution: Automation and robotics substantially displace human labour, reducing workforce size and costs; (iv) Conservative Stagnation: The industry's fragmentation, complexity, and risk aversion will cause it to resist fundamental change. While each has its proponents and critics, none is without merit. The jury is still out on which will ultimately dominate, with the empirical evidence to date insufficient to establish a clear leader. A review of the paradigms in light of the aforementioned points follows.

Phenomenal Improvement Paradigm
Industry 4.0 (4IR) technologies clearly have great potential for the construction sector. According to Yang et al. (2019), traditional construction methods are inadequate for delivering competitive results, and boosting productivity will depend on adopting advanced technological tools. Automation and robotics can improve construction output and help address issues such as labour shortages and safety risks, especially in high-rise projects (Cai et al., 2018). The increasing use of Building Information Modelling (BIM) could transform adaptability and efficiency in construction, making operations safer and more streamlined (Adebowale & Agumba, 2023). Overall, these technologies and their benefits offer significant opportunities for growth in the construction industry.

Industry Decimation Paradigm
The global business environment, including the construction sector, is constantly evolving and becoming more competitive. Moreover, there is growing recognition that the construction industry has a long history of resistance to adopting innovative technologies to boost productivity (Locatelli et al., 2021). The theory of evolution suggests that those who fail to adapt risk extinction. As a result, the manufacturing industry, which is rapidly expanding within Industrial 4.0, is increasingly seen as taking over segments of the construction sector. In pursuit of better performance, leveraging manufacturing efficiency and effectiveness to delegate specific construction tasks is becoming more attractive. Evidence of this includes off-site manufacturing of components, 3D printing, and prefabrication (Ofori & Hua, 2017). As work shifts from on-site production to factory-based manufacturing, the value created is statistically reclassified under manufacturing rather than construction. Ultimately, the remaining on-site work will tend to be less skilled and, in economic terms, less productive (Chartered Institute of Building, 2016). The extraction of the more productive parts of construction would, in the long run, support the case for manufactured buildings, leaving only the much less productive portion of on-site assembly.

Labour Substitution Paradigm
Some studies suggest that the role of human labour in construction will significantly decrease. Currently, the construction industry remains one of the most labour-intensive sectors worldwide. Moreover, labour costs in construction are substantial, accounting for as much as 65% of total construction costs (Kaja & Jauswal, 2022). It remains a complex production factor because of its unpredictability. The McKinsey Global

Institute (2017) reported that labour productivity in construction has grown by only 1% annually over the past two decades. It has also been noted that reducing construction costs is most effectively achieved by lowering labour costs (Hamza et al., 2019) or, ideally, removing them entirely where possible. This has led to a substantial increase in the utilisation of machines and equipment to fully or partially replace human labour (Yang et al., 2019). Advocates believe that Industry 4.0 will further diminish the role of human labour in construction through technologies such as prefabrication, off-site manufacturing, automation, robotics, artificial intelligence, and machine learning.

Conservative Stagnation

Other studies present a bleaker outlook, suggesting that despite the advancements of Industrial 4.0, the construction industry will resist change as it has for centuries. Delgado et al. (2019) describe the industry as conservative regarding technological innovations. This is driven by its complexity, fragmentation, capital intensity, the inherent risks associated with construction, product diversity, labour intensity, technology issues, as well as inadequate research and poor research adoption (Carnegie-Mellon University, 2019). Reports highlight the industry's resistance to adopting advanced technology as a key factor behind its inefficiency. Construction stakeholders have repeatedly cited the nature of the construction environment as the main reason for the industry's reluctance to embrace innovation. Since this environment is unlikely to change, this paradigm posits that construction will largely remain static despite advances in 4IR technologies.

Critique of the Four Paradigms

The Phenomenal Improvement and Labour Substitution paradigms emphasise the clear potential of integrating technology and the economic need for automation. However, they have yet to deliver distinct project-level benefits. Moreover, they tend to oversimplify the vital role of human tacit knowledge. This results in a "productivity paradox, where significant micro-level advances in BIM and robotics do not yet lead to widespread, systemic industry improvements, mainly due to a missing link between implementation and large-scale outcomes. Conversely, the Industry Decimation and Conservative Stagnation paradigms argue that the perceived lack of progress stems from either

shifts in industry boundaries or deep-rooted behavioural barriers. Firstly, the once-dominant "Conservative Stagnation", characterised by risk aversion and fragmentation, is becoming unsustainable in today's construction landscape, where industry-wide changes are evident. Secondly, external factors such as labour shortages, sustainability demands, and digital compliance are often viewed as key mechanisms for overcoming longstanding resistance to change. Overall, these paradigms demonstrate that Industry 4.0 produces varied and geographically widespread productivity effects, highlighting the limitations of both purely technology-driven and macroeconomic explanations.

African and Developing-Country Context

Recent studies from Sub-Saharan Africa indicate that construction productivity challenges are shaped as much by institutional capacity, labour management practices, and infrastructure constraints as by technological availability. Empirical work in countries such as South Africa, Nigeria, Ghana, and Kenya highlights persistent gaps between digital potential and on-site productivity outcomes, often attributed to skills shortages, fragmented project delivery systems, and weak integration between technology adoption and labour workflows. African construction research further shows that productivity improvements are highly context-dependent, with successful interventions requiring alignment with local labour practices, regulatory environments, and resource conditions rather than direct transplantation of global Industry 4.0 models. These findings reinforce the need for project-level analytical frameworks that move beyond technology-centric explanations and instead account for labour governance and workflow coordination within developing-country contexts.

CPLP versus the Four Paradigms

This study positions Construction Project Labour Productivity (CPLP) as an integrative theoretical framework that reconciles the insights and limitations of the four paradigms. Unlike prevailing models that privilege technology adoption, sectoral shifts, or historical inertia, CPLP locates productivity generation at the project–labour–management interface (Murianka et al., 2025). From this perspective, 4IR technologies are neither autonomous productivity drivers nor

inevitable disruptors. Instead, they are conditional enablers whose impact depends on how effectively they are embedded within labour management systems.

First, CPLP reframes the paradigm of phenomenal improvement by explaining why technological capability does not automatically yield productivity gains. Productivity improvements materialise only when technologies are aligned with labour planning, skill development, and supervisory control. This resolves the persistent gap between demonstrated technological potential and weak aggregate outcomes.

Second, CPLP extends the industry decimation paradigm by shifting analytical attention to the productivity performance of residual on-site work. As high-volume activities migrate to manufacturing, the productivity frontier of construction increasingly depends on the management of complex, non-repetitive, labour-sensitive tasks. CPLP provides a framework for enhancing productivity precisely within this residual domain, rather than competing with manufacturing-based production.

Third, CPLP moderates the labour substitution paradigm by rejecting the binary framing of labour versus machines. Instead, it conceptualises labour as a productive asset whose performance can be systematically improved through better task design, sequencing, and feedback. Automation is treated as complementary rather than as a substitute in contexts where human adaptability remains critical.

Finally, CPLP challenges the determinism of the conservative stagnation paradigm. By embedding productivity control at the project level, CPLP demonstrates that meaningful gains are achievable without requiring wholesale industry restructuring. Incremental, cumulative improvements in labour productivity can occur even in fragmented, risk-averse institutional environments.

The principal theoretical contribution of this study lies in repositioning construction productivity research away from abstract technological promise toward operationally measurable labour performance. CPLP advances Industry 4.0 discourse by explaining why productivity gains

may be displaced rather than absent, providing a mechanism that links technology adoption to realised outcomes, and reconciling conflicting paradigms within a single, project-centric framework. This contribution addresses a critical gap in construction research: productivity is frequently analysed either at the macroeconomic level or through isolated technological interventions, with insufficient attention to labour governance at the project scale.

Figure 1 synthesises the dominant Industry 4.0 paradigms and shows how their differing assumptions converge at the project level through the Construction Project Labour Productivity (CPLP) framework. The figure positions CPLP—operationalised via Project Information Flow (PIF) and Project Materials Flow (PMF)—as the mediating mechanism that translates technological adoption into realised productivity outcomes, contingent on skills, infrastructure readiness, change management, and regulatory alignment.

Research Gap

Despite extensive discourse on the transformative potential of Industry 4.0 within the construction sector, existing literature remains fragmented along competing paradigms that emphasise technological determinism, sectoral displacement, labour substitution, or institutional inertia. Much of this work is either conceptual, macroeconomic, or technology-centric, offering limited insight into how Industry 4.0 interventions translate into measurable labour productivity outcomes at the project level, particularly in developing-country contexts such as Kenya. Moreover, few studies explicitly link Industry 4.0 adoption to empirically validated productivity determinants, while the role of labour governance, workflow coordination, and on-site implementation conditions remains underexplored. As a result, a critical gap persists in reconciling these paradigms within an integrative framework that explains when and why Industry 4.0 acts as a productivity enabler or poses implementation risk. This study addresses this gap by positioning Construction Project Labour Productivity (CPLP) as a project-level analytical lens that synthesises competing paradigms and links technological adoption to realised productivity outcomes through Project Information Flow and Project Materials Flow.
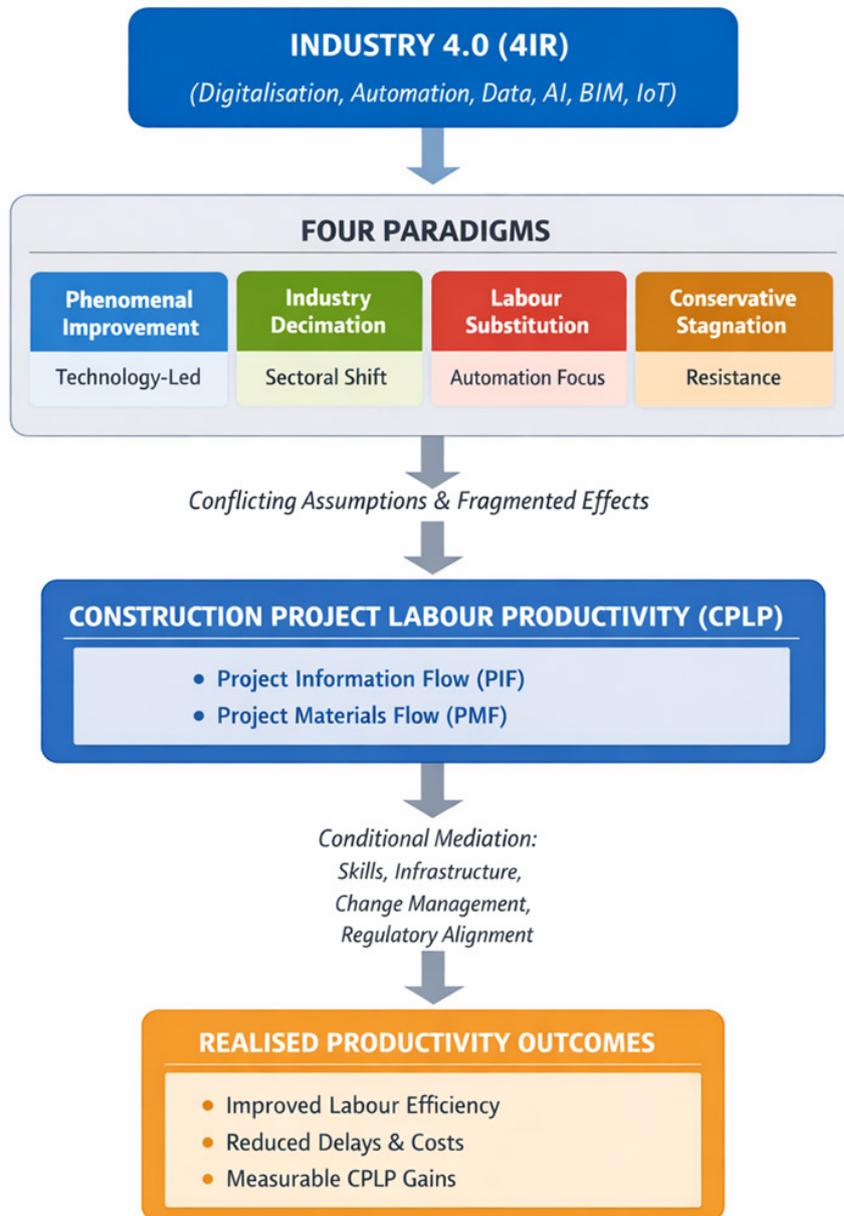
FIGURE 1
Conceptual synthesis of Industry 4.0 paradigms through the CPLP framework
Source: Author's analysis, 2025

RESEARCH METHODS

This study employed a post-positivist/pragmatic paradigm, anchoring a theoretical critique in quantitative empirical data and employing reflexive qualitative analysis to interpret practical barriers. The researchers' positionality and reflexivity are relevant aspects of the study.

Positionality: The researchers' collective experience of over four decades in direct, field-level professional work within the Kenyan Construction Industry is vital to this qualitative study. It was crucial in contextualising the statistical data, shifting the analysis from what drives productivity (the workflow factors) to why CPLP solutions often fail in practice.

Reflexive Function: Reflexivity was employed as a key interpretive lens to develop the "Sinking Sand" variables. The analysis of barriers such as the Digital Divide and on-site connectivity failures is based not on survey data but on more than 40 years of observed logistical and human realities. This ensures that the critique is not only statistically robust but also well-grounded in context, addressing practical constraints faced by local practitioners. The use of the "Panacea/Sinking Sand" dichotomy itself serves as a reflexive tool for examining the gap between theoretical efficiency and operational reality.

Ethical Considerations

Ethical considerations were observed throughout the study. Participation in the original data collection underlying the CPLP models was voluntary, and respondents were informed of the purpose of the research prior to providing data. No personal identifiers were collected, and all responses were treated with strict confidentiality and used solely for academic analysis. Data were anonymised at the point of analysis to protect the identity of participating projects and professionals. The study relied on aggregated project-level data, ensuring that individual respondents, firms, or sites could not be identified. All data were stored securely and handled in accordance with accepted academic research standards for data protection and integrity.

Research Premise

The Fourth Industrial Revolution (4IR) has introduced a range of digital technologies—from mobile applications and interconnected sensors to artificial intelligence—that aim to transform industries. In construction, this has sparked a key debate: is the pursuit of exponential Construction Project Labour Productivity (CPLP) – achieving an annual CPLP increase of above 5% - through these technologies a definitive solution (a panacea), or are there hidden risks that could lead to failure (a sinking sand)? This analysis will examine this question using the CPLP Models and Framework developed (Murianka, 2025; Murianka et al., 2025; Murianka et al., 2024a; Murianka et al., 2024b; Murianka et al., 2024c).

The qualitative study aims to predict the effects of 4IR on Construction Labour Productivity (CLP), particularly at the project level. The research questions guiding this analysis were: (i) What is the conceptual relationship between CLP and 4IR? (ii) What are the anticipated effects of 4IR on CLP based on this relationship? And finally, (iii) What are the proposed implications of these effects for implementation strategy? This study aimed to initiate a discourse for the theoretical exploration of these possibilities, suggesting conjectures rather than certainties, as the formula for development awaits further refinement.

The CPLP Models and CPLP Enhancement Framework

The research on Construction Project Labour Productivity (CPLP) aimed to develop a predictive model and framework to enhance productivity in the Kenyan construction industry. The study, conducted as a quantitative cross-sectional survey of projects in Nairobi, addressed the absence of standardised metrics and management models in the region.

The research was designed as a cross-sectional survey targeting ongoing projects within Nairobi City County, with the sampling frame being a list of projects approved for construction between 2021 and 2023. The sampling unit was also the observation unit, which was a project. The sample comprised housing projects with a maximum project value of not more than 300 million Kenyan Shillings (< Kshs. 300 million). The sample size was determined by the Yamane formula (Kothari & Gang, 2014). A total of 180 projects were selected for the sample using simple random sampling. Senior project staff were asked to complete a questionnaire to collect data. A total of 129 questionnaires were deemed responsive during data collection, yielding a 71.6% response rate. Regression analysis and descriptive statistics were used in the analysis.

The criterion variable was Construction Project Labour Productivity (CPLP), measurable through three attributes: Project Labour Speed (PLS), Project Labour Efficiency (PLE), and Project Labour Cost Competitiveness (PLCC). The predictor variable was Critical Work Flow Factors (CWFF), represented by the eight flows: (i) Project Information Flow (PIF); (ii) Project Materials Flow (PMF); (iii) Project Workers Flow (PWF); (iv) Project Equipment/Tools Flow (PEF); (v) Project Safe Space Flow (PSSF); (vi) Project Prior Work Flow (PPWF); (vii) Project External Conditions Flow (PECF); and (viii) Project Shared

Understanding Flow (PSUF). Each measure of these attributes was rated on a six-point Likert scale and summed to produce a total score for all CWFF surrogates. Analyses were conducted using Microsoft Excel and IBM® SPSS® Statistics v25.

Productivity Definition: Productivity is defined as the ratio of output to input, specifically the quantity produced per employee-hour of effort. This is regarded as a Single Factor Productivity (SFP) measure because it considers only labour input (Murianka et al., 2024a).

Key Determinants: The study identified two key attributes, Project Information Flow (PIF) and Project Materials Flow (PMF), as the most significant factors influencing CPLP. Together, they accounted for 88.0% of the variation in project labour productivity (Murianka, 2025; Murianka et al., 2025; Murianka et al., 2024a; Murianka et al., 2024b; Murianka et al, 2024c).

Predictive model: The study developed several predictive models to forecast CPLP based on the management of Critical Work Flow Factors (CWFF). Multiple regression analysis was performed using IBM® SPSS® Statistics v25, revealing PIF and PMF as significant predictors of CPLP (p=0.000). In the evaluation context, the final predictive model was expressed as a statistical equation (Equation i).

$$CPLPI = 0.043X_1 + 0.246X_2 - 0.057 \ldots\ldots\ldots (i)$$

Where:
CPLPI Construction Project Labour Productivity Index;

X_1=Information Flow,
X_2=Project Materials and Components Flow.

The model was validated using the F-ratio, which was 126.412 at the 99.99% confidence level, thereby confirming its capacity to forecast CPLP within the sample and population (Frost, 2019).

Framework: The CPLP framework synthesised in the study was designed to assist practitioners in managing and improving labour productivity by concentrating on critical workflow factors. The framework emphasised the importance of better managing these crucial flows, where at any point, one or two of the eight could significantly boost project efficiency and decrease challenges such as cost escalation and project delays. The CPLP framework employed a dual approach comprising a guiding statistical model (Equation 2) and a behavioural model (**Figure 2**) to support the measurement, management, and enhancement of CPLP (Murianka, 2025).
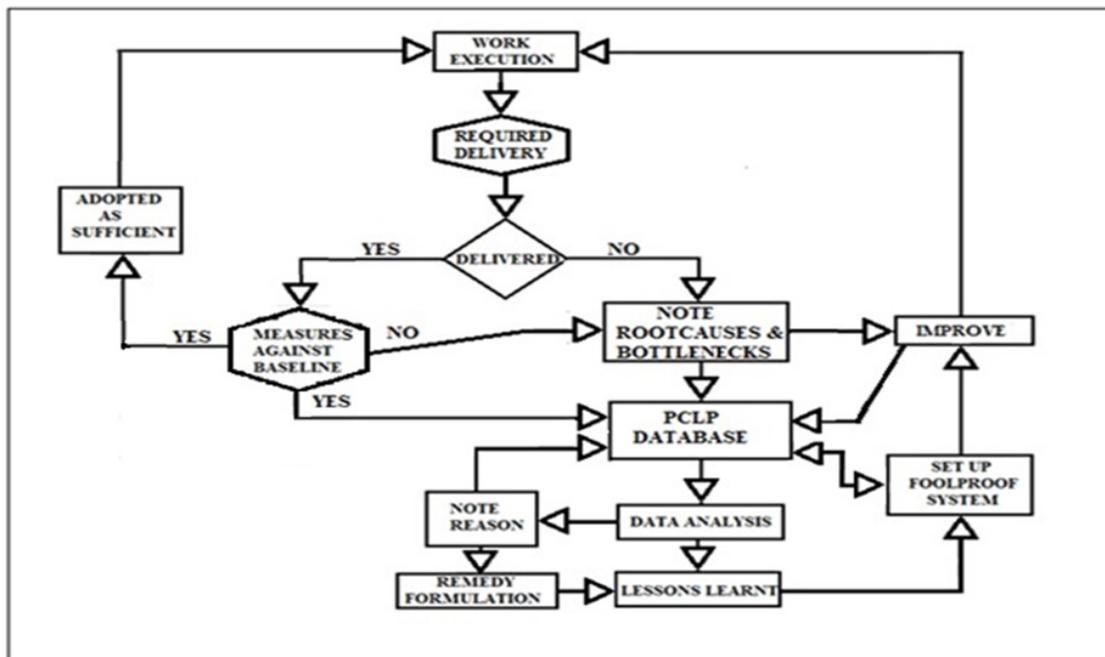

FIGURE 2
The CPLP Behavioural Model Flowchart
Source: Murianka, 2025

$$CPLP' = \frac{1}{1000}[43PIF' + 246PMCF']\dots\dots\dots\dots\dots\dots (ii)$$

The satisfactory condition for project execution to proceed is CPLP'≥ CPLP

Where:
CPLP in the above satisfactory condition is the Baseline CPLP from the database

CPLP' = Predicted CPLP
PIF' = Projected PIF (upon weighting using baseline PIF value)

PMCF' =Projected PMCF (upon weighting using baseline PMCF value)

PIF = Project Information Flow

PMCF = Project Materials and Components Flow

The CPLP flowchart shows that CPLP output is measured against the required delivery. If below the target, root cause analysis occurs (**Figure 2**). If aligned, it is compared to the baseline. If favourable, the work is repeated based on this standard. If not, root causes are reevaluated. When performance is poor, root causes and bottlenecks are constantly addressed with remedial actions. Data on performance, causes, bottlenecks, actions, successes, and failures is stored and analysed. The cycle aims for continuous improvement with each iteration.

RESULTS

The regression analysis indicates that Construction Project Labour Productivity (CPLP) is strongly influenced by Project Information Flow (PIF) and Project Materials Flow (PMF). The CPLP predictive model demonstrates that these two variables jointly explain 88.0% of the variation in project labour productivity, confirming their dominance as productivity determinants at the project level. This finding provides an empirical basis for examining how Industry 4.0 (4IR) technologies interact with labour productivity through information and materials flows.

The regression results summarised in **Table 1** show that Project Information Flow and Project Materials Flow are statistically significant predictors of Construction Project Labour Productivity.

The Argument for a Panacea
From a theoretical perspective, 4IR technologies offer a clear pathway to exponential productivity growth. The framework by Murianka et al. (2025) highlights key factors affecting CPLP, such as resource management, task allocation, and real-time information flow. Digital tools directly enhance these factors through several mechanisms.

Real-time data and improved visibility are achieved through mobile applications that remove delays and errors associated with manual reporting. Foremen can record labour hours, task completions, and material usage instantly. This real-time data offers project managers an exceptional level of visibility, enabling immediate adjustments to labour allocation and resource scheduling.

TABLE 1
Multiple Regression Results for CPLP Predictive Model

Variable	Unstandardised Coefficient (β)	Significance (p-value)
Constant	-0.057	—
Project Information Flow (PIF)	0.043	0.000
Project Materials Flow (PMF)	0.246	0.000

Source: Authors' analysis, 2025

Model summary:
$R^2 = 0.880$
F-statistic = 126.412 (p < 0.001)
Confidence level = 99.99%

Predictive analytics further strengthens this potential by enabling project teams to anticipate bottlenecks, material shortages, or labour inefficiencies before they affect productivity. Similarly, enhanced communication and compliance are supported through API-powered links to the National Construction Authority (NCA) project portal, which bypasses traditional bureaucratic barriers. Secure, automated data transfer ensures that compliance and progress reports remain current, saving time and resources that would otherwise be spent on paperwork and manual submissions. The NCA's capacity for remote monitoring further reinforces this efficiency.

The ideal integration scenario involves a project that smoothly passes all approval stages on the NCA portal, collects construction-phase data via a CPLP mobile application, generates actionable productivity insights, and enables digital, off-site inspections through to project completion. In this scenario, the CPLP application is not merely a data-entry tool; it catalyses a more efficient workflow.

The Sinking Sand of Unchecked Adoption
Despite this potential, the journey to an exponential CPLP is fraught with challenges that may turn digital promise into a logistical nightmare. These risks are directly connected to the practical application of CPLP theoretical models.

The digital divide and workforce resistance remain significant constraints. CPLP models assume a capable workforce; however, a large proportion of construction labour lacks technological literacy. Forcing adoption without adequate training can result in frustration, data-entry errors, and resistance, ultimately reducing productivity rather than improving it.

Financial and infrastructural obstacles further complicate adoption. Developing or acquiring sophisticated mobile applications, establishing API integrations, and training large workforces can be prohibitively expensive. For smaller firms or projects, these costs may outweigh expected gains, turning technology adoption into a "sinking sand" of unsustainable expenditure.

Technological failure and over-reliance also pose risks. If mobile applications crash, APIs fail, or on-site internet connectivity is unreliable, data collection can halt entirely. Over-reliance on digital systems without dependable manual backup mechanisms leaves projects vulnerable. In addition, data security and integrity are critical concerns, as breaches or corruption may compromise sensitive financial and compliance information, leading to serious regulatory and legal consequences.

Analysis through the CPLP Framework
Whether 4IR adoption functions as a panacea or a sinking sand ultimately depends on the maturity and strategic foresight of implementation. A shift in focus from technology acquisition to human capital development is therefore essential.

Building on the empirical results demonstrating the centrality of PIF and PMF, **Table 2** synthesises the ways in which strategic implementation choices influence CPLP outcomes.

Skills and training emerge as foundational. Providing a mobile application alone is insufficient; productivity gains depend on structured training that ensures supervisors and foremen can use the system competently. Similarly, while API integration improves information flow, its value is realised only when data accuracy and reliability are maintained. Poor data quality caused by user error or technological instability undermines the entire CPLP framework.

Human and Logistical Hurdles
Although the ideal scenario suggests seamless digital integration, construction sites present complex realities. Workforce digital literacy gaps, data integrity challenges, device management, unreliable connectivity, and resistance to change all complicate implementation.

Introducing a mobile application represents not only a technological shift but also a cultural one. Workers accustomed to paper-based systems may perceive digital tools as mechanisms of control rather than as a means of empowerment. Successful adoption, therefore, requires strong leadership commitment and clear demonstration of tangible benefits, such as faster payments and improved material delivery.

These challenges underscore that the pursuit of exponential CPLP is a marathon, not a sprint. While technology is essential, sustainable

TABLE 2
Analysis of CPLP Attributes

Strategic Pillar	Focus Area	Solution	CPLP Factor Addressed
Contextualised training	Digital literacy and buy-in	Implement mandatory, practical, visually oriented training programs that frame the CPLP App as a tool for foreman and worker empowerment.	PIF accuracy & workforce skills
Digital resilience	System robustness	Mandate offline functionality and ruggedised, site-appropriate hardware	Logistical barriers & PIF reliability
Phased adoption	Cost and complexity management	Prioritise lower-cost 4IR tools before high-cost automation	PMF efficiency & financial sustainability
Regulatory alignment	NCA–industry partnership	Finalise secure, standardised API protocols with the NCA	PIF streamlining & compliance

Source: Authors' analysis, 2025

productivity improvement depends on strategies that integrate human, logistical, and cultural considerations alongside digital innovation.

DISCUSSION

Interpreting CPLP Determinants within the Industry 4.0 Debate

Industry 4.0 scholarship has largely framed productivity change as a consequence of technological capability and digital intensity (Kraus et al., 2022; Zulu et al., 2022). However, the regression results demonstrate that Construction Project Labour Productivity (CPLP) is overwhelmingly shaped by Project Information Flow (PIF) and Project Materials Flow (PMF), which together explain 88.0% of the observed variation in labour productivity at the project level. This finding provides rare empirical clarity in a field often dominated by conceptual and macro-level debates. Rather than positioning productivity as a direct outcome of technology adoption, labour substitution, or sectoral transformation, the results confirm that productivity is fundamentally a function of how effectively information and maerials are coordinated within construction projects. Industry 4.0 technologies therefore acquire significance not as autonomous productivity drivers, but as conditional enablers or disruptors of these critical workflow mechanisms (Yang et al., 2019).

Phenomenal Improvement Reconsidered as Workflow Transformation

The phenomenal improvement paradigm asserts that digitalisation, automation, and intelligent systems can break historical productivity ceilings in construction (Yang et al., 2019). The regression findings lend support to this argument, but with an important qualification. Productivity gains materialise not because technologies are advanced per se, but because they enhance information accuracy, visibility, and responsiveness, as well as material availability and sequencing. Automation and robotics improve output only when embedded within well-coordinated workflows, particularly where real-time information reduces supervisory lag and planning errors (Cai et al., 2018). Digital tools that reduce reporting delays, eliminate manual errors, and improve coordination between supervisors, foremen, and suppliers therefore align precisely with the dominant CPLP determinants identified in the model, reinforcing prior arguments on workflow-centred digital value (Adebowale & Agumba, 2023).

The strong explanatory role of PMF further indicates that labour productivity is highly sensitive to material-related disruptions. Idle labour, rework, and inefficient sequencing frequently stem from delayed or poorly coordinated deliveries, a problem repeatedly highlighted in digitally integrated supply chain

studies (Magil et al., 2020). From this perspective, phenomenal improvement is best understood not as a technological leap, but as a systematic re-engineering of construction workflows around reliable information and materials flows, consistent with broader Industry 4.0 transformation theory (Kraus et al., 2022).

Industry Decimation and the Productivity of Residual On-Site Work

Evolutionary perspectives on construction productivity argue that high-value, high-productivity activities will increasingly migrate from sites to manufacturing environments through prefabrication and modularisation (Ofori & Hua, 2017). While this shift is already evident, the CPLP results indicate that productivity challenges do not disappear with decimation; rather, they are displaced. As standardised tasks move off-site, the remaining on-site work becomes more complex, coordination-intensive, and sensitive to disruptions in information and materials flows. This aligns with industry reports noting that residual on-site activities are often the least predictable and most management-dependent (Chartered Institute of Building, 2016).

Under these conditions, productivity depends less on manufacturing efficiency and more on project-level governance. Poor synchronisation between factory outputs and site requirements can amplify inefficiencies rather than reduce them, especially where information and materials flows are weak. The CPLP framework therefore reframes industry decimation not as a productivity solution in itself, but as a structural shift that heightens the importance of PIF and PMF in managing what remains on-site (Locatelli et al., 2021).

Labour Substitution Beyond the Labour–Machine Binary

The labour substitution paradigm is grounded in economic arguments that rising labour costs and low productivity growth necessitate automation (McKinsey Global Institute, 2017). However, the CPLP findings complicate a simple substitution narrative. Labour productivity, as revealed by the model, is not primarily constrained by the presence of labour, but by the conditions under which labour operates. Studies on construction inefficiency consistently show that labour underperforms when materials, information, and sequencing are misaligned, regardless of technology intensity

(Hamza et al., 2019).

Even advanced automation depends on accurate information, timely materials, and coordinated sequencing to deliver productivity gains. Where digital systems are poorly implemented, automation can introduce new bottlenecks, including data inaccuracies and task misalignment. In such cases, labour is not substituted but destabilised, resulting in lower productivity despite higher technological investment. These findings support interpretations that treat automation as complementary rather than substitutive, particularly in labour-intensive environments (Yang et al., 2019; Kaja & Jauswal, 2022).

Conservative Stagnation as an Implementation Outcome

Construction has long been characterised as conservative and resistant to technological change due to fragmentation, risk aversion, and institutional inertia (Delgado et al., 2019). The CPLP results suggest, however, that stagnation often arises not from cultural resistance alone, but from rational responses to unreliable implementation environments. When digital tools introduce uncertainty through poor connectivity, inconsistent data capture, or unclear accountability, practitioners revert to familiar manual systems that, while inefficient, are predictable (Carnegie-Mellon University, 2019).

From this perspective, stagnation reflects a failure of integration rather than a rejection of innovation. Technology adoption that does not demonstrably improve information accuracy or material reliability offers little incentive for behavioural change. This explains why visible digital adoption may coexist with stagnant productivity, as digital systems remain detached from operational control rather than embedded within it (Locatelli et al., 2021; Delgado et al., 2019).

Developing-Country Context and Conditional Productivity Effects

Developing-country construction contexts are characterised by institutional and infrastructural constraints that directly weaken information and materials flows (Joseph et al., 2022). Fragmented procurement systems, delayed payments, skills shortages, and uneven connectivity undermine the very variables identified as dominant productivity drivers in the CPLP model. Consequently,

Industry 4.0 technologies introduced into such environments produce highly uneven outcomes.

Where enabling conditions exist, digital tools can significantly enhance coordination and productivity. Where they do not, technology amplifies existing weaknesses, increasing cost and complexity without delivering proportional gains. This conditionality helps explain the persistent gap between digital potential and on-site performance reported across African and other developing-country construction sectors (Zulu et al., 2022; Kraus et al., 2022).

Panacea versus Sinking Sand through the CPLP Lens

Debates framing Industry 4.0 as either a productivity panacea or a source of new risks are reconciled through the CPLP framework (Murianka et al., 2025). Industry 4.0 functions as a panacea when it strengthens the accuracy, reliability, and continuity of information and materials flows, leading to measurable reductions in idle time, rework, and coordination failures. Conversely, it becomes sinking sand when it introduces financial strain, workflow disruption, unreliable data, and resistance to change.

The strategic pillars identified—contextualised training, digital resilience, phased adoption, and regulatory alignment—directly respond to these risks. Training safeguards information accuracy, while resilient systems protect workflow continuity. Phased adoption manages cost and complexity, and regulatory alignment reduces uncertainty. Together, these measures determine whether technology adoption enhances or erodes labour productivity (Yang et al., 2019; Kraus et al., 2022).

Implications for Construction Practice and Governance

Industry reports have consistently argued that productivity gains in construction depend more on management systems than on technological sophistication alone (Chartered Institute of Building, 2016). The findings suggest that construction firms should therefore prioritise technologies that stabilise information and materials flows before pursuing advanced automation. Investments in reporting accuracy, materials coordination, and supervisory decision support are likely to yield higher productivity

returns than isolated high-tech solutions (McKinsey Global Institute, 2017).

For regulators and policymakers, the results highlight the importance of standardised digital interfaces and governance frameworks that reduce transactional friction rather than add compliance burdens. Supportive regulatory ecosystems are essential if Industry 4.0 is to deliver real productivity gains rather than symbolic digital compliance (World Economic Forum, 2016; Zulu et al., 2022).

CONCLUSION

This study shows that Industry 4.0 technologies can significantly boost construction labour productivity in Kenya by enhancing the flow of project information and materials. However, technology alone is not enough. Productivity improvements rely on human skills, infrastructure readiness, and strategic deployment.

The 4IR offers a unique opportunity, similar to the labour productivity revolution between 1930 and 1965 (average annual growth of 3.2%), crucial for a transformative global impact. As the empirical CPLP models show, managing Project Information Flow and Project Materials Flow are immediate key factors for success.

RECOMMENDATIONS

The construction industry holds the key to vital economic growth, with the potential to boost global output by an estimated USD 1.6 trillion (Sompie, 2024). However, technology is merely an enabler. To achieve a satisfactory solution, the industry must attend to the qualitative warnings inherent in the implementation process. Success will depend not on the sophistication of the machine but on the dedicated investment in the worker using the mobile application. The local and global community must once again find within itself the ability to deliver revolutionary, lasting solutions. The following are specific actionables for various construction industry stakeholders:

i. *Contractors:* Invest in tailored digital training for site supervisors.
ii. *Regulators (NCA):* Standardise interfaces and APIs for digital reporting.
iii. *Policy makers:* Promote gradual

implementation of cost-effective digital tools.

iv. *Training institutions:* include digital construction management in curricula.

LIMITATIONS AND FUTURE RESEARCH

The study relies on secondary model outputs rather than new primary data. Future research should conduct longitudinal studies of live 4IR-enabled projects and develop digital readiness indices for construction firms.

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