A Framework for Optimizing the Level of Mechanization and Manpower in Construction Projects in Kenya

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Abstract

Mechanization has become a defining feature of modern construction, offering efficiency, precision, and cost savings. Yet, in Kenya, the extent of mechanization in high-rise building projects remains uneven and poorly documented. This study investigates the level of mechanization across major construction activities and develops a framework for optimizing the balance between mechanization and manpower. A mixed survey design was adopted, combining quantitative assessment of mechanization levels with qualitative insights from accredited site supervisors. Data were collected from 113 usable questionnaires across 125 randomly selected projects in Nairobi. Descriptive results revealed that more than half of construction activities (53%) rely on hand tools, while automated hand tools account for 31%. Concreting and site preparation emerged as the most mechanized tasks, whereas finishing works such as plastering, painting, and building services remain predominantly manual. Qualitative findings highlighted mechanization's dual influence: it enhances safety, efficiency, and morale, but also raises concerns about accidents, job insecurity, and welfare erosion. Respondents proposed strategies such as smart systems, advanced tools, and safety monitoring technologies to optimize mechanization. The study concludes that mechanization in Kenya's construction industry is moderate (47%) and unevenly distributed. It recommends policy reforms, structured training, welfare investments, and strategic deployment of mechanization to enhance productivity while safeguarding worker welfare. It also recommends the adoption of the proposed framework.

Keywords: Construction Mechanization, Framework, Kenya, Welfare, Productivity

Introduction

Mechanization in construction refers to the systematic adoption of machines and equipment to perform tasks traditionally executed by manual labour, with the aim of improving efficiency, precision, and safety (Hwang et al., 2020). Globally, mechanization has become a defining feature of modern construction, driven by the need to address labour shortages, rising costs, and demands for higher quality and faster project delivery. In advanced economies such as Europe, North America, and Asia, mechanization is deeply integrated into construction processes, ranging from earthmoving and concreting to advanced automation such as robotic bricklaying, 3D printing, and Building Information Modelling (Calvetti et al., 2020). These innovations have transformed construction into a capital-intensive industry, reducing reliance on manual labour while creating new demands for technical skills. However, scholars caution that mechanization also introduces risks of worker displacement, skill redundancy, and psychosocial stress if not accompanied by inclusive labour policies and structured training frameworks (Vadukkumchery & Myneni, 2023).

At the regional level in Africa, mechanization adoption remains uneven. Large infrastructure projects such as highways, bridges, and energy facilities increasingly rely on heavy equipment, yet small and medium-scale projects continue to depend heavily on manual labour (O. Adebowale & Agumba, 2023). Studies in Nigeria (Idoro, 2011) and South Africa (Iheama et al., 2017) highlight both opportunities and challenges: mechanization improves efficiency and site organization, but poor equipment maintenance, inadequate training, and weak safety protocols often lead to accidents and reduced worker welfare. This duality reflects broader structural issues in African economies, including high unemployment, reliance on informal labour markets, and limited access to advanced technologies. Mechanization is, therefore, not only a technical process but also a socio-economic transformation that must be managed holistically.

In Kenya, the construction industry is a critical driver of economic growth, contributing approximately 5.6% to GDP and playing a central role in the country's Vision 2030 development agenda (KNBS, 2024). Nairobi, in particular, has witnessed rapid expansion in high-rise building projects, driven by urbanization, population growth, and demand for modern housing and commercial spaces. Yet, despite this growth, the level of mechanization remains relatively low, with most activities still relying on hand tools and semi-automated equipment. Recent surveys indicate that concreting and site preparation are among the most mechanized tasks, while finishing works such as plastering, painting, and building services remain predominantly manual (Vadukkumchery & Myneni, 2023). This uneven adoption reflects cost constraints, limited technical capacity, and weak regulatory enforcement.

Critically, mechanization in Kenya has produced mixed outcomes for workers. On one hand, it reduces physical strain, improves site organization, and enhances safety monitoring. On the other hand, it has been linked to job insecurity, wage suppression, and increased accident risks due to inadequate training and poor equipment maintenance (Legishion et al., 2024; Research and Markets, 2023). The paradox is that while mechanization is perceived as a pathway to modernization, it simultaneously generates anxiety about welfare and employment. This underscores the need for a structured framework that balances mechanization with manpower, ensuring that efficiency gains are not achieved at the expense of worker welfare.

It is against this backdrop that the present study develops a framework for optimizing mechanization and manpower in Kenya's construction projects. By integrating global best practices with local realities, the framework seeks to harness the benefits of mechanization—efficiency, precision, and competitiveness—while mitigating its adverse effects on worker welfare, safety, and job security. This contribution is particularly significant given the paucity of empirical studies on mechanization levels in Kenya and the urgent need to align construction practices with sustainable development goals and national policy priorities.

Methodology

Research Design

This study adopted a mixed-methods approach and a survey research design to explore the influence of mechanization on the performance and welfare of construction workers in Kenya. Unlike purely quantitative approaches that emphasize numerical productivity indices, the qualitative design was also considered to capture nuanced perceptions, lived experiences, and contextual realities of workers and supervisors. This approach is particularly relevant given the contested nature of mechanization, which simultaneously promises efficiency gains and raises concerns about job security, safety, and welfare (Creswell & Poth, 2018).

Unit of Analysis and Population

The unit of analysis for this study was construction site workers. The respondents for the survey, however, comprised accredited construction site supervisors who were required to answer questions regarding the construction project and the site workers. These respondents were selected because of their dual role: they manage mechanization deployment while also observing its effects on worker performance and welfare. They were also selected for two additional reasons: first, to prevent bias resulting from self-reported data, and second, they were more academically competent to respond to the questionnaire. They were well-positioned to evaluate both organizational practices and worker welfare. Due to the unavailability of a published register of construction workers or supervisors, the target population was based on the number of registered construction projects. Therefore, the target population comprised accredited construction site supervisors, including site agents and clerks of works, who were directly involved in overseeing high-rise construction projects in Nairobi, Kenya.

Sampling Strategy and Sample Size

The target population was derived from the number of registered high-rise construction projects worth more than KShs 100 million, as listed by the National Construction Authority (NCA). A sample size of 125 projects was determined using Cochran's formula (Cochran, 1977) for large populations, adjusted with Bartlett's correction formula to account for finite population size (Bartlett et al., 2001). Simple random sampling was employed to ensure representativeness and minimize bias, giving each project an equal chance of selection.

$$n_o = \frac{t^2 \times s^2}{d^2} = \frac{1.96^2 \times 1.25^2}{0.15^2} = 266$$

Where;

- t = value for a selected alpha level of .025 in each tail = 1.96 (the alpha level of .05 indicates the level of risk the researcher is willing to take that the true margin of error may exceed the acceptable margin of error.)
- s = estimate of standard deviation in the population = 1.25. (estimate of variance deviation for 5-point scale calculated by using 5 [inclusive range of scale] divided by 4 [number of standard deviations that include almost all of the possible values in the range]).
- Where d = acceptable margin of error for mean being estimated = .15. (number of points on primary scale * acceptable margin of error; points on primary scale = 5; acceptable margin of error = .03 [error researcher is willing to except]).

In the second phase, the sample size is adjusted using the correction formula below. The adjustment applies because the estimated sample size exceeds 5% of the population (i.e., 235×5% = 12).

$$n = \frac{n_0}{1 + {}^{n_0}/_{Population}} = \frac{266}{1 + {}^{266}/_{235}} = 125$$

Where;

- n_o = 266 (Obtained from the Cochran's formula)
- Population size = 235. (Number of building projects worth more than KShs. 100 million registered by the National Construction Authority in Nairobi County)

Hence, n = 125 construction projects

Operationalization of Mechanization

The extent of construction mechanization (M) was evaluated across the various work elements found in a typical building construction project. This evaluation was based on a tool developed by Hwang et al. (2020). This tool has been presented in Table 1, which shows the definition for each level of mechanization and examples. This table was also shared with the respondents so that they could fully understand the meaning and description of every mechanization level. This helped ensure the collected data had validity.

Table 1: Level of Mechanization Scale

Mechanization Level	Definition	Example
Completely Manual	Workers are on-site and use non-machineries or *simple tools* without mechanisms to work	Shovel, saw, and hammer, etc.
Hand tool	Workers are on site and use equipment with mechanisms (but not machines)	Hand winch, claw hammer, and spirit level, etc.
Automated hand tool	Workers are on site and use machinery to work on the construction project	Electric laser leveler, electric drill, electric bolt wrench, etc.
Machine/Workstation	Workers operate a machine/workstation to complete the construction task	Crane, excavator, and pump, etc.
Completely Automated/Robotized	Workers are not required to operate or monitor the machine and the machine will complete the work activities by itself.	Robotic tiling machine, bricklaying robot, etc.

Adapted from: (Hwang et al., 2020)

Data Collection

Data were collected through structured questionnaires comprising both closed and open-ended questions. Part I captured background information (professional experience, project value, project duration), Part II measured the level of construction mechanization, while Part III focused on qualitative perceptions of mechanization's influence on performance and welfare. The open-ended questions allowed respondents to articulate positive and negative effects of mechanization, as well as strategies for optimizing its deployment. Questionnaires were administered physically at construction sites to enhance response rates and validity.

Data Analysis

Quantitative data were analyzed using SPSS version 25. Descriptive statistics (means, standard deviations, skewness, kurtosis) were used to summarize responses on the level of mechanization in construction projects. Qualitative data were analyzed using thematic analysis supported by word cloud visualization. Responses were coded into categories reflecting positive influences, negative influences, and recommended strategies. Frequency analysis was conducted to identify dominant themes, while narrative synthesis was used to interpret underlying meanings and contradictions. This dual approach ensured both descriptive richness and analytical rigor (Braun & Clarke, 2019).

Ethical Considerations

Ethical clearance was obtained from Jomo Kenyatta University of Agriculture & Technology and the National Commission for Science, Technology and Innovation (NACOSTI). Respondents were assured of confidentiality, anonymity, and voluntary participation. Informed consent was sought prior to questionnaire administration, and data were stored securely to protect participant privacy.

Results And Discussion

Response Rate

A total of 125 questionnaires were administered physically to the randomly selected construction sites. As shown in Table 2, a total of 116 questionnaires were received back. However, three of the questionnaires were discarded due to incompleteness. Two of these questionnaires had large sections left blank. Therefore, the number of usable questionnaires was 113, which was equivalent to a response rate of 90.4%. In these questionnaires, the number of missing values was negligible.

Table 2: Response Rate

Distributed	Total Returned	Non-Usable	Usable	Response Rate	Remark
125	116	3	113	90.4%	Acceptable

(Author, 2025)

Background Information

Three aspects were included in the background information section. These included professional experience, project value, and project duration. Their results have been analyzed and discussed in the following sections.

Professional Experience

The professional experience was grouped into five categories, namely: 1-5, 6-10, 11-15, 16-20, and above 20 years. The results are presented in Figure 1. The highest frequency was recorded between 6-10 years (n=48, 42.5%) while the lowest was reported for the group above 20 years (n=9, 8%). Those with minimal professional experience of between 1-5 years were not considerably high, as they only had a frequency of 13 (11.5%). Since an overwhelming majority (n=100, 88.5%), it is evidently clear that the respondents had adequate experience and exposure in the construction industry to provide results rich in “validity”.

Figure 1: Professional Experience
Source (Author, 2025)

Project Value

In this section, the researcher enquired about the current project value. The aim of this was to better understand the context and provide an explanation for the reported levels of mechanization, since high-value projects are expected to embrace machines and technology more than smaller projects. In this regard, the study only considered projects that were worth more than Kshs 100 million. This is to avoid skewed results since very small projects would record negligible levels of mechanization and thus need a study on their own. The majority of the projects (n=103, 91.2%) had their contract sums between Kshs 100 and 900 million, with only 10 (8.8%) being worth over KShs 100 million. As shown in Figure 2, the highest frequency (n=43, 38.1%) was reported in “Kshs 301-500 million”, followed by “Kshs 101-300 million” (n=28, 24.8%)

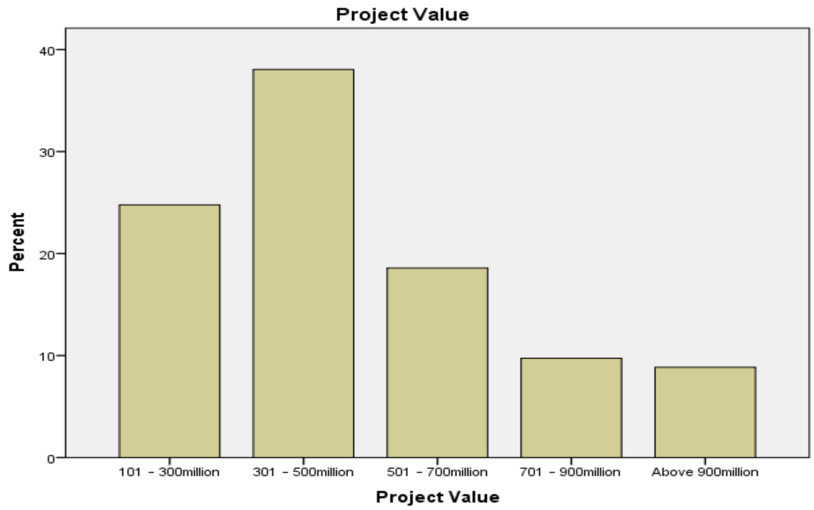

Figure 2: Project Value
Source (Author, 2025)

Project Duration

The project duration was measured in weeks based on intervals of 36 weeks. As seen in Figure 3, the results were fairly distributed demonstrating a bell curve with the majority of the projects (n=97, 85.8%) lying between 37 and 144 weeks. Projects with durations below 36 weeks and above 144 weeks recorded frequencies of 7 (6.2%) and 9 (8.0%), respectively. The highest frequency was reported between 73-108 weeks (n=57, 50.4%).

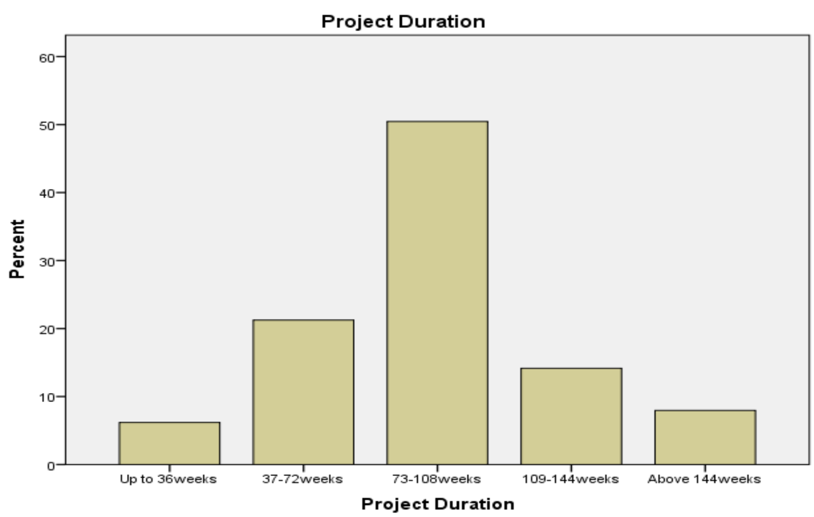

Figure 3: Project Duration
Source (Author, 2025)

Level of Mechanization

Assessing the level of mechanization in construction projects is not only important but also critical, since it reports how well the assessed project is in terms of mechanization and reveals the directions for improvement (Pan et al., 2018). The results for the overall extent of Construction Mechanization (M) have been presented in Table 3 and Figure 1for all seven (7) major work categories in a typical high-rise project.

As demonstrated in Table 3, more than half (53%) of the activities in the building construction sector are carried out using Hand Tools. This is then followed by Automated Hand Tools with an approximate usage of 31%. Completely Manual methods and Machines (workstations) are used almost similarly at 9% and 7% respectively. None of the activities in construction are Completely Automated (robotized).

Table 3: Overall Extent of Mechanization

	Work Category	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	Percentage	SD	Rank
1	Site Preparation and Earthworks (SPE)	0%	43%	41%	16%	0%	2.62	52%	.22	2
2	Scaffolding and Formwork (SF)	8%	50%	41%	1%	0%	2.35	47%	.40	4
3	Concreting (C)	0%	7%	67%	26%	0%	3.18	64%	.36	1
4	Walling (W)	11%	54%	33%	2%	0%	2.40	48%	.36	3
5	Plastering and Flooring (PF)	9%	70%	14%	1%	0%	2.07	41%	.15	5
6	Tiling and Painting (TP)	18%	77%	5%	0%	0%	1.88	38%	.15	7
7	Building Services (BS)	17%	68%	13%	1%	0%	1.97	39%	.13	6
	Overall Mean	9%	53%	31%	7%	0%	2.35	47%		
	Rank	3	1	2	4	0				

(Author, 2025)

As seen in Table 3, the three work categories with the highest level of mechanization were: Concreting (mean=3.18, 64%), Site Preparation and Earthworks (mean=2.62, 52%), and Walling (mean=2.40, 48%). The least mechanized work categories were: Plastering and Flooring (mean=2.07, 41%), Building Services (mean=1.97, 39%), and Tiling and Painting (mean=1.88, 38%). The levels of mechanization ranged between 1.88 (38%) and 3.18 (64%). The overall level of Construction Mechanization was established to be a mean of 2.35 (47%). A ranking of all the individual subtasks has been provided in the Appendices

The standard deviation results (ranging between 0.134 and 0.407) indicated that the data were not heavily spread out across all measured indicators of the mechanization variable. The normality tests revealed that the data were normally distributed, as seen in the skewness and kurtosis values lying between -1.0 and +1.0. The reported standard error for the skewness and kurtosis results was 0.227 and 0.451 respectively.

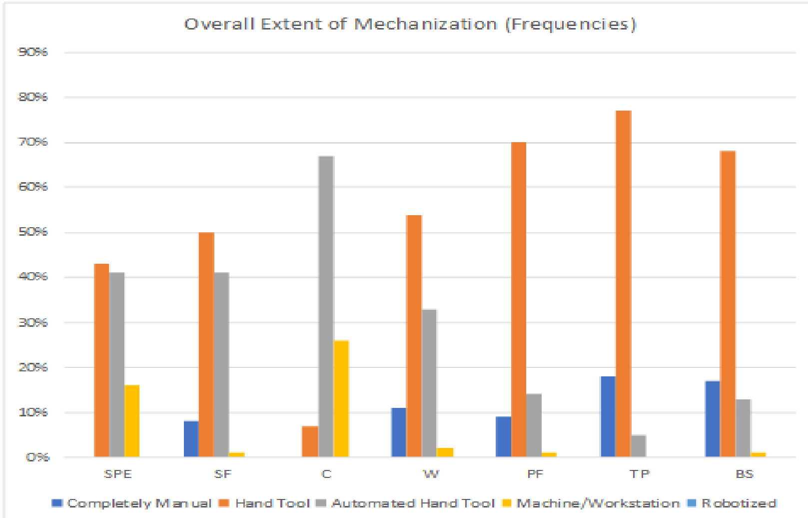

Figure 4: Overall Extent of Mechanization (Frequencies)
(Author, 2025)

According to a study based on India's construction industry (Vadukkumchery & Myneni, 2023), earthwork works (RII=2.33), batching and mixing (RII=2.31), and concreting (RII=2.26) are the most mechanized tasks in the construction of a high-rise building in India. The same study reported masonry to be the least mechanized activity followed by formwork activities (RII=1.08), scaffolding works (RII=1.08), painting (RII=1.18), and tiling/laying activities (RII=1.18). Though the study in India used a 3-point scale (low, moderate, high), the results are not very different from the ones presented in Table 3, whereby Concreting emerged as the most mechanized construction activity. Similarly, Painting was among the least mechanized activities. Just like the study in India as well, Site Preparation and Earthworks also ranked highly in the comparison among various work categories. In both studies as well, the mechanization of Building services ranked lowly. Another study by Vishwakarma et al. (2022) also established that mechanization and automation is least adopted in painting and other finishing works such as plastering and most utilized in earthworks.

However, the results in Table 3 contradict the findings by Sharmila et al. (2018) which found masonry activities to be the least mechanized. However, these two studies agree that Plastering is one of the least mechanized activities. Vishwakarma et al. (2022) also found masonry to be among the least mechanized activities. Notably, Sharmila et al. (2018) also agrees that excavation is among the most mechanized activities in commercial construction projects.

As indicated earlier, the tool adopted in this research was adapted from Hwang et al. (2020). After developing the tool, the authors validated it by implementing it using 14 Singapore-based construction companies. Though their survey had a small sample size, their results were not very different from the ones reported in Table 3, especially on the general overview of the ranking of the mechanization levels in different work categories. Concreting, which was the most mechanized activity in the current study, was not considered by Hwang et al. (2020). In both studies, Site Preparation and Earthworks were highly mechanized, while the least mechanized were Tiling and Painting, which were reported to have a mechanization level of 43% in Hwang et al. (2020). Their study also established the level of mechanization in Scaffolding and Formwork to be 46% and 45 respectively, while the current study combined the two activities and obtained a mechanization level of 47%. Hwang et al. (2020) reported an overall level of mechanization of 49%, which was higher by only two percentage points than the current study.

Qualitative Data on the Influence of Mechanization

Positive Influence of Mechanization

The qualitative findings revealed that respondents perceived mechanization as enhancing safety, improving the quality of work, reducing physical strain, and fostering collaboration among teams. Words such as *enhanced*, *improved*, and *greater* were frequently associated with better management of resources, precision in construction processes, and improved communication. These perceptions align with global evidence that mechanization reduces manual drudgery and increases accuracy in construction tasks (Pan et al., 2018).

In Kenya, similar findings have been reported by Ndolo et al. (2024), who noted that mechanization in concreting and scaffolding tasks improved efficiency and reduced delays. Kapliński et al. (2002) also emphasized that mechanization enhances site organization and safety monitoring. However, while respondents highlighted improved morale and training opportunities, previous studies caution that these benefits are often short-lived unless mechanization is accompanied by structured skill development programs (Adebowale & Agumba, 2022). Thus, while the positive perceptions are consistent with international literature, they may reflect aspirational rather than sustained outcomes in Kenya's construction industry.

Negative Influence of Mechanization

Respondents also identified negative effects, including increased risks of accidents, job insecurity, noise pollution, and worker dissatisfaction. Words such as *increased*, *accidents*, and *risk* dominated the responses, reflecting concerns about safety and welfare. These findings corroborate Idoro (2011), who reported that mechanization in Nigeria was associated with higher accident rates due to poor equipment maintenance and inadequate training. Similarly, Sharmila et al. (2018) found that mechanization in India introduced hazards such as noise and air pollution, undermining worker health.

Critically, the Kenyan results highlight a paradox: while mechanization is perceived to improve working conditions, it simultaneously generates anxiety about job security and safety. This duality reflects the sociotechnical imbalance noted by Trist and Bamforth (1951), where technological systems are introduced without adequate integration into social and organizational structures. The literature suggests that these negative outcomes are not inherent to mechanization but stem from weak regulatory enforcement and insufficient investment in safety training (Kamaruddin et al., 2016).

Effective Strategies for Incorporating Mechanization

Respondents proposed strategies such as deploying smart systems, advanced tools, and safety monitoring technologies to optimize mechanization. Suggestions included the use of Building Information Modelling (BIM), drones for safety inspections, and automated material handling systems. These recommendations resonate with recent global trends emphasizing digital integration and smart construction technologies (Hwang et al., 2020; Vadukkumchery & Myneni, 2023).

In Kenya, however, adoption of such advanced systems remains limited to high-value projects, with smaller contractors constrained by cost and technical capacity (Research and Markets, 2023). The qualitative data, therefore, highlight a gap between worker aspirations and industry realities. While respondents envision mechanization as a pathway to modernization and welfare enhancement, structural barriers such as inadequate training, high capital costs, and fragmented regulation hinder implementation.

Comparative Insights

Overall, the qualitative results reveal a nuanced picture: mechanization is perceived as both a driver of modernization and a source of vulnerability. Positive perceptions align with global evidence on efficiency and safety improvements, while negative perceptions echo concerns about accidents, job insecurity, and welfare erosion. The strategies proposed by respondents reflect awareness of global best practices but also expose the limitations of Kenya's construction industry in adopting advanced technologies.

Critically, these findings underscore the importance of adopting a qualitative lens. Quantitative studies often emphasize productivity gains, but qualitative insights reveal the psychosocial dimensions of mechanization — worker morale, anxiety, and aspirations — that are equally important for sustainable workforce development.

A Framework for Optimizing the Level of Mechanization and Manpower in Construction Projects in Kenya

The aim of this framework is to optimize the level of mechanization and manpower in construction projects in Kenya, thereby enhancing performance and improving the quality of work life for construction workers. The framework integrates various theoretical perspectives and practical approaches in exploiting the opportunities and addressing the challenges presented by mechanization in the construction industry.

Rationale for the Framework

The rationale for this framework is founded on the need to balance mechanization with human labour, with the aim of improving productivity while ensuring the welfare of construction workers is taken care of. As seen in this research, mechanization leads to increased efficiency, increased precision and accuracy, and speedy construction. However, it also poses risks such as increased occupational hazards if not managed properly, reduced teamwork, and job displacement. Consequently, a structured approach is necessary to harness the benefits of mechanization while mitigating its adverse effects.

The rationale for the proposed framework is grounded in enhancing economic performance while prioritizing social responsibility within Kenya's construction industry. By addressing productivity challenges through optimum mechanization while simultaneously ensuring the welfare and safety of construction workers are guaranteed, this framework aims to create a balanced approach that fosters sustainable growth in the construction sector in Kenya. It further recognizes the complexities associated with integrating advanced technologies into traditional practices.

Therefore, the rationale for developing a framework to optimize the level of mechanization and manpower in construction projects in Kenya is multifaceted, addressing not only the economic and social aspects but also the operational dimensions of the construction industry. This rationale is informed by the various opportunities and challenges presented by construction mechanization, as well as the need for a sustainable approach that enhances both productivity and the welfare of workers.

Economic Significance

The construction sector is a vital contributor to Kenya's economy, accounting for approximately 5.6% of the Gross Domestic Product (GDP) (KNBS, 2023). As noted in various studies, mechanization plays a critical role in enhancing productivity and efficiency within this sector (Babatunde et al., 2019; Calvetti et al., 2021; Hwang et al., 2020; Iheama et al., 2017; Kamaruddin et al., 2016, 2018; Lamsal, 2024; Vidushi et al., 2022; Vishwakarma et al., 2022). The framework aims to leverage mechanization to: i) increase productivity, ii) enhance cost efficiency, and iii) enhance competitiveness. First, mechanization can significantly reduce the time required to complete construction tasks, leading to faster project delivery. This is essential in Kenya, a country where infrastructure development is crucial for economic growth. Secondly, by optimizing the use of mechanization, construction firms can achieve cost savings through reduced labour costs, reduced rework, speedy construction, and minimized waste. Lastly, in today's globalized construction market, Kenyan construction firms have no choice but to compete with international players. Adopting advanced mechanization techniques can improve competitiveness by enabling construction firms to deliver higher-quality projects more effectively and efficiently.

Social Implications

While mechanization presents numerous advantages and benefits, it also introduces challenges related to human labour displacement and issues surrounding the welfare of workers. The framework addresses these concerns by emphasizing: i) skill development, ii) quality of work life, and iii) new jobs. First, as the level of mechanization increases, construction workers should adapt by acquiring new skills required to operate and maintain construction machinery. The framework advocates for continuous training programs that empower construction workers with the necessary competencies. This enhances their employability in the ever-changing job market. Second, it is expected that the integration of mechanization in the construction process should not come at the expense of worker welfare. The framework incorporates measures to ensure safe working conditions, fair compensation schemes, reduced occupational hazards, and improved overall job satisfaction. By addressing these issues, the framework seeks to create a more sustainable and inclusive work environment within construction projects. Third, though some jobs are displaced due to mechanization, new roles such as skilled operators and technicians emerge. The proposed framework encourages strategic workforce planning aimed at identifying new opportunities and preparing workers accordingly.

Operational Efficiency

The operational landscape of construction projects is highly dynamic and always evolving due to technological advancements. The proposed framework aims to enhance operational efficiency through: i) optimized resource allocation, and ii) improved construction project management. By assessing the appropriate level of mechanization for different project types and sizes, managers can allocate resources more effectively. This ensures that the proper balance between men and machines is achieved for each specific project. This ensures problems associated with overspending on unnecessary machinery are avoided. Mechanization changes project management dynamics. The proposed framework encourages managers to adopt best practices in labour planning and management that align with the planned level of mechanization for the project.

Addressing Challenges

The construction industry faces several challenges related to mechanization. These include: i) resistance to change, ii) initial capital investment, and iii) safety concerns. First, there is fear among construction workers that they may lose their jobs and thus resist the adoption of new technologies. The framework highlights the benefits of mechanization for both productivity and worker welfare. The framework is also founded on the idea that mechanization is a necessary complement to manpower and should be applied to enhance the performance of construction workers. Second, purchasing or leasing machinery requires high upfront costs, which can deter firms from investing in mechanization. The proposed framework calls for comprehensive cost-benefit analyses that justify such investments based on both short and long-term gains. And third, according to various studies, increased mechanization has been reported to lead to new safety risks, especially if not managed properly (Barbosa et al., 2017; Kamaruddin et al., 2016; Muro et al., 2019). The framework calls for training programs designed specifically for the safe operation of construction machinery, thereby minimizing accidents on site. This could be achieved using advanced techniques such as Augmented Reality (AR) for on-site training.

Theoretical Underpinnings

The proposed framework is anchored on the following theories, which also happen to be the guiding blueprint for this study.

- Human Capital Theory: This theory posits that investing in the development of workers' skills enhances productivity. The framework advocates for training programs that equip construction workers with the necessary skills required to operate and maintain construction equipment.
- Theory of Capitalism: This theory underscores the role of capital investment in driving economic growth in any country. The framework encourages investment in mechanization as a means of enhancing productivity and competitiveness within the construction sector.
- Theory of Induced Innovation: This theory suggests that technological advancements are driven by economic needs. In a construction project, mechanization can be viewed as an innovation that responds to efficiency demands.
- Socio-Technical Systems Theory: This theory emphasizes the interdependence between social (human) and technical (mechanical) systems. In a construction project, there is a need for a harmonious relationship between workers and machines to optimize the performance of both for the benefit of the project and the stakeholders.

Underlying Principles

The proposed framework for optimizing mechanization and manpower in construction projects in Kenya is built upon ten (10) foundational principles that guide its development and implementation. These principles are designed to promote a balanced approach that enhances productivity while improving the welfare and safety of construction workers.

- Complementarity rather than replacement: The proposed framework emphasizes that, instead of total replacement, mechanization should be used to complement human labour. This principle recognizes that the human element in construction projects is inevitable due to the unique skills and capabilities that workers possess. Such cannot be fully replicated by machines. Therefore, by integrating mechanization optimally, the framework aims to enhance productivity while preserving the essential role of human labour.

- Balanced work allocation: The framework advocates for a strategic allocation of tasks between machines and workers. This means that the very nature and quantity of tasks determine whether they will be assigned to machines or manpower. For instance, repetitive and physically demanding tasks should be mechanized, while complex decision-making processes that require fine motor skills are assigned to workers. Such a balance not only improves efficiency in the construction project but also maintains job opportunities for skilled labour.
- Skill development and adaptability to technological changes: mechanization creates a pressing need for workers to acquire new skills to operate and maintain construction equipment effectively. The proposed framework prioritizes continuous training programs tailored to the evolving technological landscape of the global construction industry. This ensures that construction workers remain competitive in a dynamic job market. This enhances their employability and job security.
- Safety first: The framework places a strong emphasis on safety protocols associated with mechanization. This includes employing advanced and smart systems that ensure workers are safe in the construction environment. The framework recognizes that while mechanization can reduce certain risks, it can also introduce new hazards.
- Quality of Work Life: Beyond physical safety, the developed framework addresses the overall quality of work life for construction workers. This includes considerations such as compensation, working conditions, welfare and social integration. By fostering a conducive and supportive work environment, the framework aims to enhance the morale and productivity of construction workers.
- Performance monitoring: Establishing key performance indicators (KPIs) allows for ongoing assessment of both mechanization and worker performance. This principle ensures that adjustments can be made in real time based on empirical evidence rather than assumptions. Feedback is therefore provided for future projects on whether to deploy machines or manpower in certain situations.
- Feedback mechanisms: Establishing channels for feedback allows construction project stakeholders to voice their concerns or suggestions regarding adopted mechanization practices. This ensures that the framework remains responsive to the needs of those directly affected by its implementation.
- Environmental impact awareness: It has been established in previous research that mechanization has significant environmental implications. Therefore, the framework encourages practices that minimize ecological footprints, such as electrical machinery instead of diesel-powered engines, which emit toxic fumes. This principle aligns with global sustainability goals.
- Informed investment decisions: A critical principle of the framework is conducting thorough cost-benefit analyses before implementing or adopting mechanization. This involves assessing both the financial implications and the potential impacts on productivity, worker satisfaction, and safety.
- Strategic resource allocation: By understanding the costs associated with different levels of mechanization and the available options for adopting mechanization, such as purchasing versus leasing, managers can make informed decisions that align with project goals while optimizing resource use.

Design and Development Process

The design and development of the proposed framework for optimizing mechanization and manpower in construction projects in Kenya involved a systematic approach that integrates theoretical insights, empirical data collected from this study, and stakeholder input provided during the validation exercise. This process was critical in ensuring that the developed framework was not only practical but also tailored to the unique challenges and opportunities present in the construction industry of Kenya. The proposed framework has been presented in Figure 5.

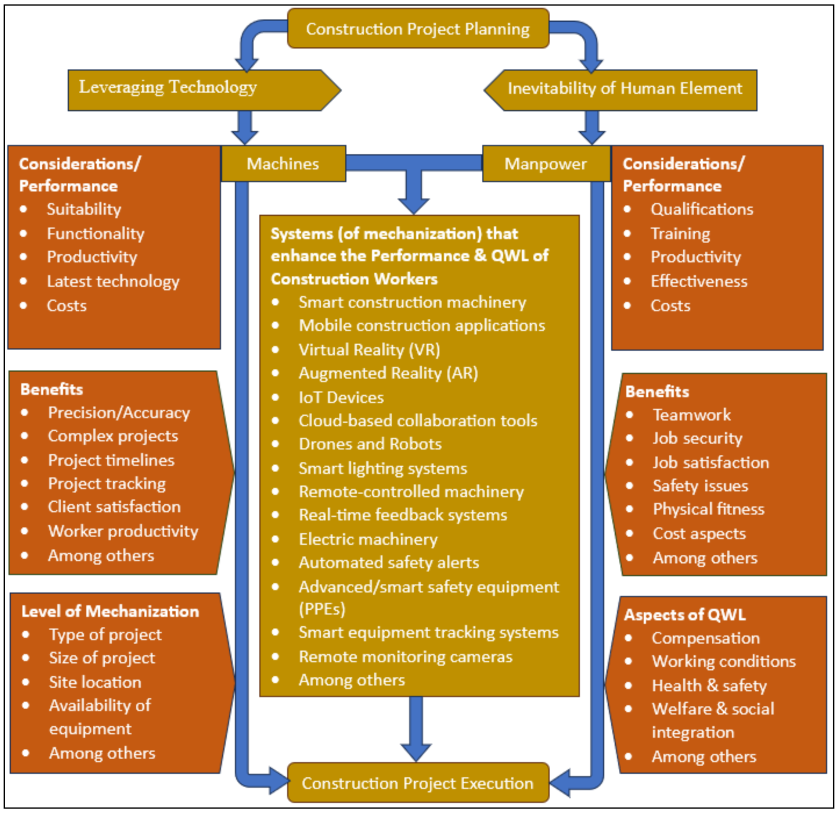

Figure 5: : Framework for Optimizing the Level of Mechanization and Manpower in Construction Projects in Kenya
Source: (Author, 2025)

The framework presents three (3) pathways between construction project planning and execution. These are: (A) leveraging on technology by adopting machines, (B) use of manpower, and (C) combined use of men and machines in construction projects.

Use of Manpower in Construction Projects

This option is founded on the Human Capital Theory, which suggests that humans are the most important resources in a construction project. It is on this basis that the developed framework argues that the use of manpower in construction projects is inevitable.

However, the deployment of manpower in construction projects should depend on factors such as (i) qualifications of the workers, (ii) training received by the workers, (iii) their productivity, (iv) effectiveness, and (v) costs associated with the workers, among other factors. All these aspects were included in the data collection instrument for this research.

The benefits associated with the deployment of human labour have been derived from the negative effects of mechanization suggested by the respondents. The benefits include: (i) more teamwork among construction workers, (ii) higher job security, (iii) higher job satisfaction, (iv) better safety, (v) higher physical fitness, and (vi) lower cost of acquisition, among others.

Aspects relating to the Quality of Work Life (QWL) of construction workers must be considered. These were established in this research to be fundamental in the quest for ensuring dignity for workers. These aspects include: (i) compensation and reward, (ii) working conditions, (iii) health and safety, and (iv) welfare and social integration, among others.

Adopting Machines/Leveraging of Technology

This option is founded on the Capitalism Theory and Theory of Induced Innovation, which advocate for mechanization in a construction project in a bid to enhance efficiency and maximize the profit realized from the project. The use of machines and advanced systems is the trend in today's construction projects.

However, mechanization in construction projects should depend on factors such as (i) their suitability, (ii) functionality, (iii) their productivity, (iv) embracing the latest technology, and (v) costs associated with the acquisition and maintenance, among other factors.

The benefits associated with mechanization have been derived from the positive effects of mechanization suggested by the respondents. The benefits include: (i) more precision/accuracy, (ii) execution of complex projects, (iii) speedy project timelines, (iv) better project tracking, (v) higher client satisfaction, and (vi) higher worker productivity, among others.

The optimal level of mechanization in a construction project depends on (i) the type of project, (ii) the size of the project, (iii) site location, and (iv) the availability of equipment, among others. The goal of this is to ensure projects are correctly matched with the intended levels of mechanization in order to avoid overspending on unnecessary equipment.

Use of Machines to complement Manpower

This option is founded on the Socio-Technical Systems Theory, which emphasizes the interdependence between social (human) and technical (mechanical) systems. It calls for a harmonious relationship between workers and machines to optimize the performance of both for the benefit of the project and the stakeholders. It is the premise of this study.

This pathway incorporates all the aspects already discussed in the two previous options, i.e., (A) manpower and (B) machines. This includes the considerations, benefits, level of mechanization, and aspects of QWL.

Further, this option provides several latest mechanical systems that enhance the Performance and QWL of construction workers, as suggested by respondents. These include; (i) Smart construction machinery, (ii) Mobile construction applications, (iii) Virtual Reality (VR) for training workers on equipment operation, (iv) Augmented Reality (AR) for on-site training and to visualize construction plans in real-time, (v) IoT Devices for real-time monitoring of equipment and site conditions, (vi) Cloud-based collaboration tools for better collaboration among project stakeholders, (vii) Drones for site surveys and inspections and Robots for plastering, (viii) Smart lighting systems, (ix) Remote-controlled machinery for hazardous tasks to protect workers, (x) Real-time feedback systems to enhance safety and increase efficiency, (xi) Electric machinery to prevent noise and harmful fumes, (xii) Automated safety alerts to improve the safety of workers, (xiii) Advanced/smart safety equipment (PPEs), (xiv) Smart equipment tracking systems, and (xv) Remote monitoring cameras among others.

Validation of the Framework

The validation of the framework was achieved through the administration of a questionnaire (Appendix IV). The survey was conducted on 30% of the 116 respondents who had participated in the initial survey. This was based on the suggestion provided by Dawood and Sikka (2009). Therefore, a sample size of 35 was adopted. Out of these, 30 responded, giving a response rate of 85.7%. The validation questions employed a 7-point Likert scale because it increases the variability of responses, hence providing more research validity and reliability as asserted by Kim et al. (2010). Since the information was being sought from respondents who had already participated in the main survey, background questions were not included, and therefore, the questionnaire only had one question. A section for general comments was, however, also provided.

The results presented in Table 4 showed that the perception of participants was very positive, as seen in respondents' means, which were placed close to the maximum rate of agreement. According to this, it is believed that the proposed framework is practical, clear, applicable, comprehensive, and suitable.

Table 4: Framework Validation Results

Criteria	N	Min.	Max.	Mean	Std. Dev
Clarity	30	5	7	6.68	0.352
Practicability	30	6	7	6.78	0.237
Applicability	30	6	7	6.75	0.445
Comprehensiveness	30	5	7	6.65	0.296
Suitability	30	6	7	6.79	0.319

Implications, Conclusions, and Recommendations

Implications

Policy Implications

The study reveals that Kenya's construction industry remains moderately mechanized (47%), with concreting and site preparation being the most mechanized tasks, while finishing works such as plastering, painting, and building services remain largely manual. This uneven adoption highlights the need for policy frameworks that incentivize mechanization across all stages of construction, not just in heavy works. Regulatory bodies such as the National Construction Authority (NCA) and the Directorate of Occupational Safety and Health Services (DOSHS) should integrate mechanization benchmarks into project approvals, while also mandating structured training for machine operators to ensure safety and welfare.

Practical Implications

For contractors, the findings underscore the importance of strategic mechanization. While mechanization improves efficiency, precision, and safety, it also introduces risks such as job insecurity, accidents, and worker dissatisfaction if poorly managed. Firms must therefore balance mechanization with manpower by investing in participatory management, welfare facilities, and skill development programs. Mechanization should be deployed selectively, with attention to both productivity gains and worker welfare outcomes.

Conclusions

This study concludes that mechanization in Kenya's high-rise construction projects is moderate and unevenly distributed across work categories. Concreting and site preparation are highly mechanized, while finishing works remain predominantly manual. Workers and supervisors perceive mechanization as both a driver of modernization—enhancing safety, efficiency, and precision—and a source of vulnerability, introducing risks of accidents, job insecurity, and welfare erosion.

The findings affirm that mechanization is not merely a technical process but a sociotechnical transformation requiring deliberate integration of human, organizational, and policy dimensions. Without structured training, welfare provisions, and regulatory enforcement, mechanization risks becoming a source of worker anxiety rather than empowerment.

Recommendations

The study makes the following structured recommendations;

Policy Reform

- Establish mechanization benchmarks across all construction phases, not just heavy works.
- Mandate structured training and certification for machine operators.
- Strengthen enforcement of occupational safety and health standards.

Organizational Practices

- Adopt balanced mechanization strategies that align machines with human labour.
- Introduce participatory management approaches to reduce worker alienation.
- Invest in welfare facilities such as sanitation, housing, and psychosocial support.

Skill Development

- Implement continuous training programs to equip workers with competencies for operating and maintaining machinery.
- Encourage workforce planning to identify new roles (e.g., operators, technicians) created by mechanization.

Safety Enhancement

- Sustain investment in safety equipment, monitoring technologies, and compliance protocols.
- Deploy digital tools such as BIM, drones, and automated monitoring systems to reduce risks.

Future Research

- Conduct mixed-methods and longitudinal studies to capture both quantitative and qualitative impacts of mechanization.
- Undertake comparative studies across African countries to contextualize Kenya's experience within regional trends.

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