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Original Article

Assessing the Level of Construction Mechanization in Kenya: A Survey of Highrise Building Projects in Nairobi

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ABSTRACT

This paper examines the construction mechanization level in high-rise building projects in Kenya. It focuses on Site Preparation and Earthworks (SPE), Scaffolding and Formwork (SF), Concreting (C), Walling (W), Plastering and Flooring (PF), Tiling and Painting (TP), and Building Services (BS). Mechanization, defined as the replacement of manual labour with machines, is analyzed through a quantitative survey involving 125 accredited construction site supervisors with the unit of analysis being the construction project. The findings reveal that SPE tasks predominantly utilize Hand Tools (43%) and Automated Hand Tools (41%), with Machines accounting for only 16%. Comparatively, SF tasks show slightly lower mechanization levels, primarily relying on Hand Tools (50%) and Automated Hand Tools (41%). Concreting is the most mechanized work category with most of the tasks primarily executed using Automated Hand Tools (67%) and Machine/Workstation (26%). Walling tasks mainly rely on Hand Tools (54%) and Automated Hand Tools (33%). PF, TP, and BS tasks predominantly rely on Hand Tools (70%, 77%, and 68% respectively). Consequently, more than half (53%) of the activities in the building construction sector in Kenya 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). The mechanization levels for the various work categories are as follows; SPE=52%, SF=47%, C=64%, W=48%, PF=41%, TP=38%, and BS=39%. The overall mechanization level for the construction industry of Kenya was found to be 47%, indicating a substantial reliance on manual methods. Despite the advantages of mechanization, such as improved efficiency and safety, its application in Kenyan construction remains limited. The study highlights the need for increased mechanization to enhance productivity and safety in construction practices.

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INTRODUCTION

Mechanization in a broad sense is the process of adopting the use of machines in carrying out tasks that would otherwise be done by manual labour (Hwang et al., 2020). From this perspective, mechanization can be understood as the process of substitution or complementing human labour with machines to make work easier. Mechanization thus implies a complete or partial replacement of human labour with machines that could either be automated, or operated by just one or a few experts. Where the machine is automatic, a computerized system is used to instruct the machine on which operation to undertake (Vadukkumchery & Myneni, 2023).

While the level of mechanization depends on the extent to which machines have been incorporated to replace human labour, automation is a dimension of mechanization which means the total replacement of human labour with machines that use Artificial Intelligence (AI) to perform an activity (Kamaruddin et al., 2016). Automated machines work but under the instruction of a programme that controls the behaviours of the machines. Understandably therefore, mechanization can be applied at the design level, and in actual construction processes such as digging trenches, earth moving, paving, lifting, and hoisting, bar cutting machines, bar straightening machines, concrete making machines, core drill, plastering and painting and 3D printing (Calvetti et al., 2020).

Though mechanization is known to have its disadvantages, the majority of researchers agree that the potential advantages such as the ability to handle tough activities, cost-saving in large quantities of work, better quality of work, adherence to project schedules, better prediction of behaviour, and ease of supervision and control by far outweigh the disadvantages (Vishwakarma et al., 2022; Kamaruddin et al., 2018; Sharmila et al., 2018; Grover & Solanki, 2023; Iheama et al., 2017; Calvetti et al., 2021; Kamaruddin et al., 2016; Vadukkumchery & Myneni, 2023). Unfortunately, however, the level of construction mechanization in Kenya is unknown. The study aimed to investigate the level of mechanization among high-rise construction building projects in Kenya.

METHODOLOGY

This study adopted a quantitative approach since it sought to sample a population, study the sample, and make generalizations about the population. Further, this study adopted a survey research design. The method involves collecting data from a sample drawn from a target population to identify the extent and nature of relationships between variables. This research is normally conducted especially when the population is too large and therefore too costly and unpractical (Sekaran, 2003). This method made it possible for data to be collected effectively without any manipulation of the research context.

The unit of analysis for this study was construction projects. The respondents for the survey however comprised accredited construction site supervisors who were required to answer questions regarding the construction project. The target population was based on the number of registered construction projects. This enabled the researcher to visit construction sites to confirm the extent of mechanization in the

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construction projects. A sample size of 125 construction projects was established using formulae from Cochran (1977) and Bartlett et al. (2001). Since simple random sampling ensures that all the target participants get an equal opportunity to participate in the study, it was used to select the construction projects from the target population. The study chose the site agent or clerk of works (whoever was first available) as the accredited construction site supervisor to respond to the questionnaire.

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)

RESULTS AND DISCUSSION

Site Preparation and Earthworks (SPE)

The results for the extent of construction mechanization of Site Preparation and Earthworks (SPE) have been presented in Table 2. The table comprises the frequencies and means for each task and subtask under SPE. Three (3) tasks were considered under SPE; (i) Site clearance, (ii) Setting out, and (iii) Earthworks. These were further broken down into various subtasks.

As seen in Table 2, none of the tasks were Completely Manual or Completely Automated (robotized). The majority of the subtasks under Site clearance and Setting out were carried out using Hand Tools (76%) while the remaining (24%) were done using Automated Hand Tools. Under Earthworks, trench and column excavation were mostly done using Automated Hand Tools (55% and 62% respectively) while the remaining was excavated using Hand Tools and Machines (workstations). As for Basement excavation, most of the work was done using Machines (workstations) to a tune of 70%. This was followed by Automated Hand Tools (29%) and Hand Tools (1%) respectively. Transportation of soil/rock was not any different from Basement excavation. The use of Machines (workstations) was the most common (55%) followed by Automated Hand Tools (43%) and Hand Tools (2%) respectively.

The overall aggregation showed that the use of Hand Tools and Automated Hand Tools was almost similar at 43% and 41% respectively. Machines (workstations) were less commonly used at 16% while Completely Manual and Completely Automated (robotized) methods of carrying out SPE works were completely absent.

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Table 2: Mechanization of Site Preparation and Earthworks

Task	Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
Site clearance	a) Barricading out worksite	_	83(73%)	30(27%)	_	–	2.27	.44
	b) Cutting the vegetation	_	83(73%)	30(27%)	_	–	2.27	.44
	c) Removing tree stump	_	95(84%)	18(16%)	_	_	2.16	.37
	d) Light demolition works	_	90(80%)	23(20%)	_	–	2.20	.40
Setting out	a) Site clearance	_	74(65%)	39(35%)	_	_	2.35	.48
	b) Excavations	_	33(29%)	80(71%)	_	_	2.67	.47
	c) Foundations	_	35(31%)	78(69%)	_	_	2.69	.46
Earthworks	a) Trench excavation	_	25(22%)	62(55%)	26(23%)	_	3.01	.42
	b) Column base excavation	_	16(14%)	70(62%)	27(24%)	–	3.10	.36
	c) Basement excavation	_	1(1%)	33(29%)	79(70%)	_	3.69	.64
	d) Transporting soil/rock	_	2(2%)	49(43%)	62(55%)	–	3.53	.60
Overall Percentage/Mean		**0%**	**43%**	**41%**	**16%**	**0%**	**2.62**	

(Fieldwork, 2024)

As seen in Table 2, the three subtasks with the highest level of mechanization were Basement excavation, (mean=3.69, 74%), Transporting soil/rock (mean=3.53, 71%), and Column base excavation (mean=3.10, 62%). The least mechanized tasks were; Barricading out the worksite and Cutting the vegetation (mean=2.27, 45%), Removing tree stumps (mean=2.16, 43%), and Light demolition works (mean=2.16, 43%). Interestingly. The first four ranking subtasks fell under Earthworks followed by the three subtasks of Setting out and lastly the four subtasks under Site clearance. As expected therefore, Earthworks (mean=3.33, 66%) was the most mechanized task under SPE followed by Setting out (mean=2.57, 51%) and Site clearance (mean=2.23, 45%) respectively. The overall level of mechanization for SPE works was a mean of 2.72 (54%).

The standard deviation results (ranging between 0.36 and 0.64) indicated that the data was not heavily spread out across all measured indicators of the mechanization of site preparation and earthworks variable. The normality tests revealed that the data was 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 were 0.227 and 0.451 respectively.

Pulling down heavy trees, demolition works and mass excavation are some of the activities involved in SPE works. These activities cannot practically be achievable using manual methods. According to the Food and Agriculture Organization (2024), use of equipment such as the 240hp Crawler tractor achieves efforts of up to 2,000 times compared to manual methods. This therefore explains why Earthwork activities are among the most mechanized in a construction project as seen in Table 2. According to Brosnan (2023), correct use of heavy equipment ensures site preparation work can both be carried out efficiently and effectively (to a high standard) and that workers remain safe throughout.

Basement excavation was the most mechanized activity not just within this work category, but also in the entire construction project because hydraulic excavators are mostly used to achieve both efficiency and effectiveness. Due to the mass excavation, it is also practically impossible to

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achieve efficiency using manual methods. Transportation of excavated soil and rock was also established to be among the most mechanized activities even when compared to activities in other work categories. This is primarily due to the use of tippers and other haulage equipment to economically and practically dispose off excavated material from construction sites.

Trench excavation posted a comparatively high level of mechanization (mean=3.01, 60%) and ranked fourth out of the eleven (11) subtasks considered. Previous research also indicates a considerable use of machines for this task. For example, Idoro (2011) reports that in Nigeria, mechanical excavation of trenches is employed to a tune of 67% compared to 33% use of manual methods. However, the same study contradicts the findings of this study by reporting a relatively low use of equipment (33%) to remove excavated material compared to the high usage reported in Table 2 (mean=3.53, 71%)

Scaffolding and Formwork (SF)

The results for the extent of construction mechanization of Scaffolding and Formwork (SF) have been presented in Table 3. Four (4) tasks were considered under SF; (i) Erecting base lift and subsequent lifts, (ii) Installing deck, (iii) Dismantling scaffold, and (iv) Formwork (fixing and removing). These were further broken down into various subtasks.

As seen in Table 3, none of the tasks were Completely Automated (robotized) while there was a negligible (1%) use of Machines (workstations). The only use of Machines (workstations) was recorded in 'Soil compaction' (3%) under the task of 'Erecting base lift and subsequent lifts' whereby the majority of the other subtasks under this task were carried out using Automated Hand Tools (49%) and Hand Tools (35%) with the use of Completely Manual methods being less common (13%). The task of 'Installing deck' was mostly carried out using Hand Tools (50%) followed by Automated Hand Tools (45%) and Completely Manual (5%) respectively. Dismantling scaffolding was also mostly carried out using Hand Tools (65%) followed by Automated Hand Tools (28%) and Completely Manual (7%) respectively. Notably, 'Hoisting of materials down to the ground' was only carried out using Hand Tools and Automated Hand Tools. 'Formwork fixing and removal' was majorly carried out using Hand Tools (64%) and Automated Hand Tools (36%) with negligible use of Completely Manual methods (less than 1%).

The overall aggregation showed that the use of Hand Tools was the most common (50%) method of working under the Scaffolding and Formwork work category. This was closely followed by Automated Hand Tools at 41%. Completely Manual methods came a distant third (8%) while Machines (workstations) reported almost negligible use at 1%. Again, Completely Automated (robotized) methods of carrying out SF works were totally absent.

Table 3: Mechanization of Scaffolding and Formwork

Task	Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
Erecting base lift and subsequent lifts	a) Soil compaction	_	38(34%)	53(47%)	22(19%)	_	2.86	.71
	b) Laying sole plates	17(15%)	43(38%)	53(47%)	–	–	2.32	.72
	c) Placing standards into jacks	24(21%)	38(34%)	51(45%)	–	–	2.24	.78
	d) Fitting transoms to standards	14(12%)	46(41%)	53(47%)	–	–	2.35	.69
	e) Inserting and connecting	17(15%)	35(31%)	61(54%)	–	–	2.39	.73

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Task		Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
		ledgers to the base of the scaffold							
	f)	Installation of diagonal bracing	18(16%)	33(29%)	62(55%)	–	–	2.39	.74
	g)	Tying scaffold to building	16(14%)	44(39%)	53(47%)	–	–	2.33	.71
Installing deck	a)	Securing deck to standards, transoms, and ledgers	12(11%)	50(44%)	51(45%)	–	–	2.35	.66
	b)	Installing toe boards	6(5%)	57(50%)	50(44%)	–	–	2.39	.58
	c)	Installing guardrails	–	62(55%)	51(45%)	–	–	2.45	.50
Dismantling scaffold	a)	Clearing loose materials on platform	10(9%)	76(67%)	27(24%)	–	–	2.15	.55
	b)	Removal of hessian net	17(15%)	67(59%)	29(26%)	–	–	2.11	.63
	c)	Dismantling of deck, transom, ledgers, and standards	5(4%)	79(70%)	29(26%)	–	–	2.21	.50
	d)	Hoisting of materials down to the ground	–	71(63%)	42(37%)	–	–	2.37	.48
Formwork (fixing and removing)	a)	Foundations formwork	–	70(62%)	43(38%)	–	–	2.38	.48
	b)	Columns formwork	1(1%)	69(61%)	43(38%)	–	–	2.37	.50
	c)	Lift shafts formwork	2(2%)	70(62%)	41(36%)	–	–	2.35	.51
	d)	Beams & Slab formwork	–	79(70%)	34(30%)	–	–	2.30	.46
Overall Percentage/Mean			**8%**	**50%**	**41%**	**1%**	**0%**	**2.35**	

(Fieldwork, 2024)

As seen in Table 3, the two subtasks with the highest level of mechanization were; Soil compaction, (mean=2.86, 57%), and Installing guardrails (mean=2.45, 49%). The least mechanized tasks were; 'Dismantling of deck, transom, ledgers, and standards' (mean=2.21, 44%), 'Cflearing loose materials on platform' (mean=2.15, 43%), and 'Removal of hessian net' (mean=2.11, 42%). 'Erecting base lift and subsequent lifts' (mean=2.41, 48%) was the most mechanized task under SF closely followed by 'Installing deck' (mean=2.40, 48%), 'Formwork fixing and removing' (mean=2.35, 47%), and Dismantling scaffold (mean=2.21, 44%) respectively. Notably, however, all the tasks recorded low levels of mechanization with closely spaced means (having a range of only 0.2). It was therefore not surprising that the overall level of mechanization for SF works was a mean of 2.35 (47%).

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The standard deviation results (ranging between 0.46 and 0.78) indicated that the data was not heavily spread out across all measured indicators of the mechanization of scaffolding and formwork variable. The normality tests revealed that the data was 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 were 0.227 and 0.451 respectively.

Findings reported by Vadukkumchery and Myneni (2023) showed that both Scaffolding and Formwork had mechanization levels of 1.08 which if converted to match the scale used in the current study translated to 1.80. The results in the current study therefore post relatively higher levels of mechanization in these two work categories (2.35). Sharmila et al. (2018) observed that system formwork matched the average utilization in most construction projects. This is not different from the current study whereby the mechanization level of both Scaffolding and Formwork matched the overall level of mechanization in high-rise building projects (2.35).

Concreting (C)

The results for the extent of construction mechanization of Concreting (C) have been presented in Table 4. Five (5) tasks were considered under Concreting; (i) Rebar preparation, (ii) Material batching, (iii) Mixing, (iv) Concrete pouring, and (v) Vibrating. These were further broken down into various subtasks.

As seen in Table 4, none of the tasks were Completely Manual or Completely Automated (robotized). The majority of the subtasks under Rebar preparation were carried out using Automated Hand Tools (66%) followed by Hand Tools (20%) and Machines (workstations) (14%). Material batching was only carried out using Automated Hand Tools (67%) and Machines (workstations) (33%). Similarly, 66% of Concrete mixing was done using Automated Hand Tools while the rest was done using Machines (workstations) (34%). The same trend was observed in Concrete pouring (66% Automated Hand Tools and 32% Machines/Workstation) though in this case Hand Tools were also used albeit to a very small extent (2%). 76% of Vibrating concrete was done using Automated Hand Tools while the rest was done using Machines (workstations) (24%).

The overall aggregation showed that the use of Automated Hand Tools was the most dominant method of construction (67%) followed by Machines (workstations) (26%). The use of Hand Tools was minimal at 7% while Completely Manual and Completely Automated (robotized) methods of concreting were completely absent.

Table 4: Mechanization of Concreting

Task	Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
Rebar preparation	a) Cutting	_	22(19%)	75(66%)	16(14%)	_	2.95	.58
	b) Bending	_	23(20%)	74(65%)	16(14%)	_	2.94	.58
	c) Tying	_	24(21%)	74(65%)	16(14%)	_	2.92	.58
	d) Hoisting	_	23(20%)	75(66%)	15(13%)	_	2.93	.57
	e) Placing	_	23(20%)	74(65%)	16(14%)	_	2.94	.58
Material batching	a) Ballast	_	_	75(66%)	38(34%)	_	3.34	.47
	b) Sand	_	_	75(66%)	38(34%)	_	3.34	.47
	c) Cement	_	_	75(66%)	38(34%)	_	3.34	.47
	d) Water	_	_	75(66%)	38(34%)	_	3.34	.47
	e) Additives and admixtures	_	_	83(73%)	30(27%)	_	3.27	.44

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Task	Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
Mixing	a) Concrete mixing	_	_	75(66%)	38(34%)	_	3.34	.47
Concrete pouring	a) Hoisting	_	1(1%)	75(66%)	37(33%)	_	3.37	.48
	b) Transporting horizontally	_	2(2%)	75(66%)	36(32%)	–	3.36	.48
	c) Placing concrete	_	2(2%)	74(65%)	37(33%)	_	3.37	.48
Vibrating	a) Vibrating concrete	_	_	86(76%)	27(24%)	_	3.26	.43
Overall Mean Percentage		**0%**	**7%**	**67%**	**26%**	**0**	**3.18**	

(Fieldwork, 2024)

Compared to the two previous work categories, the level of mechanization in the various tasks and subtasks under Concreting were relatively higher. As presented in Table 4, the three subtasks with the highest level of mechanization were; Hoisting and Placing concrete, (both with a mean of 3.37, 67%), and Transporting concrete horizontally (mean=3.36, 67%). The least mechanized tasks of Concreting were; Bending rebars (mean=2.94, 59%), Placing rebars (mean=2.94, 59%), Hoisting rebars (mean=2.93, 59%), and Tying rebars (mean=2.92, 58%). There was a very narrow range of the mean (between 2.92 and 2.95) for the tasks under Rebar preparation, an indication that the methods used to prepare rebars were pretty much the same. A similar trend was also observed in Material batching whereby three out of the four subtasks had a similar mean. This was however expected since, in practice, the same technique used to batch cement is also used for sand and ballast except for additives.

Out of the four (4) tasks considered under Concreting, the two most mechanized tasks were Concrete pouring and Vibrating both with a mean of 3.34 (67%). Material batching ranked next with a very close mean of 3.33 (66%). Rebar preparation came last with a mean of 2.94 (59%). The overall level of mechanization of Concreting was established to be a mean of 3.18 (64%).

The standard deviation results (ranging between 0.43 and 0.58) indicated that the data was not heavily spread out across all measured indicators of the Mechanization of Concreting variable. The normality tests revealed that the data was 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 were 0.227 and 0.451 respectively.

The findings in Table 4 agree with those by Sharmila et al. (2018) that placing concrete is not only the most mechanized activity within concreting but among the highest ranking among all construction activities in a building project. The situation is also the same for material (cement, ballast, sand, and water) batching and concrete mixing. A different study by Vadukkumchery and Myneni (2023) also reported batching, mixing and placing of concrete to be the most mechanized activities in a building construction project in India. Idoro (2011) however contradicts these findings by reporting that only 33% of concrete batching and mixing is mechanized in Nigeria's construction industry. Table 4 shows Hoisting concrete as the joint-first ranked activity. This is expected since in a high-rise building, such activity would be impossible to accomplish manually. Cranes (ranging from portable gantry cranes to complex tower cranes) are usually used to lift concrete from the ground floor to the upper floors. The hoisting of rebars is relatively lower since on lower floors, workers improvise methods such as rope-pulling to lift rebars. Such improvisation is impossible with concrete. Further, just like in this study, Sharmila et al. (2018) also reported concrete transportation to be among the most mechanized activities in a construction project. This could also be explained by the utilization of cranes.

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Walling (W)

The results for the extent of construction mechanization of Walling (W) have been presented in Table 5. Two (2) tasks were considered under Walling; (i) Preparation, and (ii) Stone laying. These were further broken down into various subtasks.

As seen in Table 5, none of the tasks were Completely Automated (robotized). The majority of the subtasks under Preparation were carried out using Hand Tools (58%) followed by Automated Hand Tools (27%). The remaining were done using Completely Manual (14%) and Machines (workstations) (1%). Similarly, most of the activities under Stone laying were carried out using Hand Tools (49%) followed by Automated Hand Tools (40%). Some of the remaining activities were done using Completely Manual methods (7%) while the rest were done using Machines (workstations) (4%).

The overall aggregation showed that the use of Hand Tools was the most dominant (54%) followed by Automated Hand Tools (33%). Completely Manual methods and Machines (workstations) were less commonly used with reported usages of 11% and 2% respectively. Completely Automated (robotized) methods of walling were completely absent.

Table 5: Mechanization of Walling

Task	Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
Preparation	a) Setting out	46(40%)	61(54%)	6(5%)	_	_	2.65	.58
	b) Mortar preparation	10(9%)	69(61%)	33(29%)	1(1%)	–	2.22	.60
	c) Mortar transportation	1(1%)	72(64%)	39(35%)	1(1%)	–	2.35	.51
	d) Placing and removing excess mortar	5(4%)	61(54%)	45(40%)	2(2%)	_	2.39	.60
Stone laying	a) Hoisting and transporting	_	52(46%)	55(49%)	6(5%)	–	2.59	.59
	b) Aligning	24(21%)	50(44%)	38(34%)	1(1%)	_	2.14	.75
	c) Cutting	_	65(58%)	42(37%)	6(5%)	_	2.48	.59
Overall Mean Percentage		**11%**	**54%**	**33%**	**2%**	**0%**	**2.40**	

(Fieldwork, 2024)

Compared to concreting, the level of mechanization in the various tasks and subtasks under Walling was significantly reduced. As presented in Table 5, the three subtasks with the highest level of mechanization were; Setting out, (2.65, 53%), Hoisting and transporting (mean=2.59, 52%), and Cutting stones (mean=2.48, 50%). The least mechanized tasks of Walling were; Mortar transportation (mean=2.35, 47%), Mortar preparation (mean=2.22, 44%), and Aligning stones (mean=2.14, 43%). Coincidentally, the two (2) tasks of Walling, that is, Preparation and Stone laying, had an exact same level of mechanization with a mean of 2.40 (48%). Due to this, therefore, the overall level of mechanization of Walling was also 2.40 (48%).

The standard deviation results (ranging between 0.51 and 0.75) indicated that the data was not heavily spread out across all measured indicators of the mechanization of the walling variable. The normality tests revealed that the data was 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 were 0.227 and 0.451 respectively.

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The extent of mechanization in walling was not high. This was because in nearly all the projects visited, the walling material was quarry stones. Only a handful of the projects were using precast walling panels. It is in only these projects that the use of Machines/Workstations was reported. Walling using quarry stones is usually achieved using simple Hand Tools while precast concrete panels can only be undertaken using cranes and other lifting equipment.

Plastering and Flooring (PF)

The results for the extent of construction mechanization of Plastering and Flooring (PF) have been presented in Table 6. The former presents the frequencies while the latter presents the means for each task and subtask under PF. Two (2) tasks were considered under PF; (i) Plastering and Screeding, and (ii) Terrazzo flooring. These were further broken down into various subtasks.

As seen in Table 6, none of the tasks were Completely Automated (robotized) while there was a negligible (1%) use of Machines (workstations). Hand Tools were dominantly (72%) used in Plastering and Screeding activities while the adoption of Automated Hand Tools (17%) and Completely Manual methods (10%) was not as popular. The use of Machines (workstations) in this task was very minimal (2%). Terrazzo flooring activities were also majorly carried out using Hand Tools (79%) while Automated Hand Tools (13%) and Completely Manual methods (8%) were used to a lesser extent. Machines (workstations) and Completely Automated (robotized) methods of carrying out Terazzo flooring works were not used.

The overall aggregation showed that the use of Hand Tools was the most dominant (70%) method of working under Plastering and Flooring work category. This was distantly followed by Automated Hand Tools at 14%. Completely Manual methods followed at 8% while Machines (workstations) reported almost negligible use at 1%. Again, Completely Automated (robotized) methods of carrying out PF works were totally absent.

Table 6: Mechanization of Plastering and Flooring

Task		Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
Plastering and Screeding	a)	Mortar batching and mixing	_	83(73%)	28(25%)	2(2%)	_	2.28	.49
	b)	Mortar transportation	3(3%)	82(73%)	24(21%)	4(4%)	–	2.26	.56
	c)	Plastering and screeding surfaces	27(24%)	71(63%)	15(13%)	_	_	1.89	.60
	d)	Cleaning plastered surfaces	15(13%)	90(80%)	8(7%)	_	_	1.94	.44
Terrazzo flooring	a)	Shot blasting	_	79(70%)	34(30%)	_	_	2.30	.46
	b)	Floor preparation and leveling	18(16%)	89(79%)	6(5%)	_	_	1.89	.45
	c)	Design layout	24(21%)	89(79%)	_	_	_	1.79	.41
	d)	Mixing terrazzo		91(81%)	22(19%)	–	–	2.19	.39

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Task	Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
	e) Pouring terrazzo	19(17%)	91(81%)	3(3%)	–	–	1.86	.42
	f) Grinding the floor surface	–	91(81%)	22(19%)	–	–	2.19	.39
	g) Polishing the terrazzo floor	–	94(83%)	19(17%)	–	–	2.17	.37
Overall Mean Percentage		**9%**	**70%**	**14%**	**1%**	**0%**	**2.07**	

(Fieldwork, 2024)

As presented in Table 6, the three subtasks with the highest level of mechanization were; Shot blasting, (mean=2.30, 46%), Mortar batching and mixing (mean=2.28, 45%), and Mortar transportation (mean=2.26, 45%). The least mechanized tasks of Plastering and Flooring were; Plastering and screeding surfaces (mean=1.89, 39%), Floor preparation and leveling (mean=1.89, 39%), and Design layout (mean=1.79, 36%). The level of mechanization in Plastering and screeding ranged between 1.89 (Plastering and screeding surfaces, 39%) and 2.28 (Mortar batching and mixing, 45%). On the other hand, the level of mechanization in Terazzo flooring ranged between 1.79 (Design layout, 36%) and 2.30 (Shot blasting, 46%).

By comparison, the two tasks considered under PF, that is, Plastering and Screeding (2.09, 42%) and Terazzo flooring (2.06, 41%) almost had the same level of mechanization. The overall level of mechanization of Plastering and Flooring was established to be a mean of 2.07 (41%).

The standard deviation results (ranging between 0.37 and 0.60) indicated that the data was not heavily spread out across all measured indicators of the mechanization of plastering and flooring variable. The normality tests revealed that the data was 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 were 0.227 and 0.451 respectively.

Spray machines for plastering have become increasingly popular in Europe and other developed parts of the world (Jessica, 2021). Such popularity has been attributed to a number of benefits such as increasing the speed of plastering, reduced manual labour, improved consistency of plaster, less room for human error, and greater uniformity across large-scale projects. Unfortunately, though the use of such machines has in the past been reported here in Kenya, none of the projects visited was using them. This explains the low mechanization level of plastering (mean=1.89, 39%)

Tiling and Painting (TP)

The results for the extent of construction mechanization of Tiling and Painting (TP) have been presented in Table 7. Two (2) tasks were considered under TP; (i) Tiling, and (ii) Painting. These were further broken down into various subtasks.

As seen in Table 7, none of the tasks under TP were completed using Machines (workstations) and Completely Automated (robotized) methods. Again, just like in the tasks under the previous work category, Hand Tools were dominantly (77%) used in Tiling activities while the adoption of Completely Manual methods (18%) and Automated Hand Tools (5%) was not as commonly used. Painting activities were also majorly carried out using Hand Tools (77%) while Completely Manual methods (18%) and Automated Hand Tools (5%) were used to a lesser extent.

The overall aggregation showed that the use of Hand Tools was the most dominant (77%) method

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of working under Tiling and Painting work category. This was distantly followed by Completely Manual methods at 18%. Automated Hand Tools followed at 5% while Machines (workstations) and Completely Automated (robotized) methods reported 0% adoption.

Table 7: Mechanization of Tiling and Painting

Task	Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
Tiling	a) Setting out	18(16%)	90(80%)	5(4%)	_	_	1.88	.43
	b) Hoisting and transporting materials	20(18%)	87(77%)	6(5%)	_	_	1.88	.46
	c) Mortar preparation and placing	21(19%)	84(74%)	8(7%)	_	_	1.88	.49
	d) Placing and leveling of tiles	17(15%)	88(78%)	8(7%)	_	_	1.92	.46
	e) Grouting	21(19%)	87(77%)	5(4%)	_	_	1.86	.46
	f) Cleaning tiled surfaces	23(20%)	84(74%)	6(5%)	_	_	1.85	.48
Painting	a) Hoisting and transporting materials	22(19%)	86(76%)	5(4%)	_	_	1.85	.46
	b) Protecting surfaces not to be painted	21(19%)	87(77%)	5(4%)	_	_	1.86	.46
	c) Smoothing and cleaning surface	22(19%)	86(76%)	5(4%)	_	_	1.85	.46
	d) Mixing of paint	26(23%)	82(73%)	5(4%)	_	_	1.81	.49
	e) Application of sealer coat	28(25%)	83(73%)	2(2%)	_	_	1.77	.46
	f) Application of paint	18(16%)	90(80%)	5(4%)	_	_	1.88	.43
	g) Elevating painters to higher grounds	2(2%)	92(81%)	19(17%)	_	_	2.15	.40
Overall Mean Percentage		**18%**	**77%**	**5%**	**0%**	**0%**	**1.88**	

(Fieldwork, 2024)

Compared to all the previous work categories, the level of mechanization in the various tasks and subtasks under Tiling and Painting was relatively lower. As presented in Table 7, the two subtasks with the highest level of mechanization were; Elevating painters to higher grounds, (mean=2.15, 43%), and Placing and leveling of tiles (mean=1.92, 38%). The least mechanized tasks of TP were; Mixing of paint (mean=1.81, 36%), and Application of sealer coat (mean=1.77, 35%). There was a very narrow range of the mean (between 1.85 and 1.92) for the tasks under Tiling, an indication that the methods used to prepare rebars were pretty much the same. Though slightly wider, the situation was not so different in Painting where the means ranged between 1.77 (35%) and 2.15 (43%). By comparison, the two tasks considered under TP, that is, Tiling (1.89, 39%) and Painting (1.88, 37%) almost had the same level of mechanization. The overall level of mechanization of Tiling and Painting was established to be a mean of 1.88 (37%).

The standard deviation results (ranging between 0.43 and 0.49) indicated that the data was not

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heavily spread out across all measured indicators of the mechanization of tiling and painting variable. The normality tests revealed that the data was 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 were 0.227 and 0.451 respectively.

Most of the tasks under Tiling and Painting are usually executed using Hand Tools. They do not require complex machines to achieve. Simple tools like tile cutters are used by skilled workers involved in tiling. The only most common tool used in painting is the spray gun which is mainly used for gloss paints. The study by Hwang et al. (2020) reported only a slightly higher mechanization level of 43% compared to the 37% reported in this study.

Building Services (BS)

The results for the extent of construction mechanization of Building Services (BS) have been presented in Table 8. Two (2) tasks were considered under BS; (i) Plumbing works, and (ii) Electrical works. These were further broken down into various subtasks.

As seen in Table 8, none of the tasks were Completely Automated (robotized) while there was a negligible (1%) use of Machines (workstations). Hand Tools were dominantly (71%) used in Plumbing works while the adoption of Completely Manual methods (16%) and Automated Hand Tools (13%) was not as popular. The use of Machines (workstations) in this task was very minimal (1%) and was only reportedly used in the testing of the installations. Electrical works were also majorly carried out using Hand Tools (66%) while Completely Manual methods (19%) and Automated Hand Tools (13%) were used to a lesser extent. Just like under plumbing works, the use of Machines (workstations) in this task was very minimal (1%) and was also only reportedly used in the testing of the installations.

The overall aggregation showed that the use of Hand Tools was the most dominant (68%) method of working under the Building services work category. This was distantly followed by Completely Manual methods and Automated Hand Tools at 17% and 13% respectively while Machines (workstations) reported almost negligible use at 1%. Again, just like in all other work categories, there was no use of Completely Automated (robotized) methods in carrying out BS works.

Table 8: Mechanization of Building Services

Task	Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
Plumbing works	a) Setting out	42(37%)	67(59%)	4(4%)	_	_	1.66	.54
	b) Hoisting and transporting materials	20(18%)	89(79%)	4(4%)	_	_	1.86	.44
	c) Hacking for pipes	1(1%)	112(99%)	_	_	_	2.00	.00
	d) Pipe cutting and installation	23(20%)	86(76%)	4(4%)	_	_	1.83	.46
	e) Installing fixtures	19(17%)	87(77%)	7(6%)	_	_	1.89	.47
	f) Testing	_	38(34%)	67(59%)	8(7%)	_	2.73	.58
	a) Setting out	38(34%)	75(66%)			_	1.66	.47

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Task	Subtask	Completely Manual	Hand Tool	Automated Hand Tool	Machine/ Workstation	Robotized	Mean	SD
Electrical works	b) Hoisting and transporting materials	20(18%)	89(79%)	4(4%)	_	_	1.78	.49
	c) Hacking for conduits and fittings	36(32%)	74(65%)	3(3%)	_	_	1.71	.51
	d) Conduit cutting and installation	23(20%)	83(73%)	7(6%)	_	_	1.86	.49
	e) Pulling cables through conduits	32(28%)	78(69%)	_	_	_	1.74	.49
	f) Installing fittings	1(1%)	112(99%)	_	_	_	2.00	.00
	g) Testing	_	16(14%)	86(76%)	11(10%)	_	2.96	.48
Overall Mean Percentage		**17%**	**68%**	**13%**	**1%**	**0%**	**1.97**	

(Fieldwork, 2024)

As presented in Table 8, the two subtasks with the highest level of mechanization were; Testing electrical works, (2.96, 59%), and Testing plumbing works (mean=2.73, 54%). The three least mechanized tasks of Building services were; Hacking for conduits and fittings (mean=1.71, 34%), Setting out plumbing works (mean=1.66, 33%), and Setting out electrical works (mean=1.66, 33%). By comparison, the two tasks considered under BS, that is, Plumbing works (2.00, 40%) and Electrical works (1.96, 39%) almost had the same level of mechanization. The overall level of mechanization of Building services was established to be a mean of 1.97, 39%.

The standard deviation results (ranging between 0.00 and 0.58) indicated that the data was not heavily spread out across all measured indicators of the mechanization of building services variable. Notably, both Hacking of pipes and Installing fittings recorded a standard deviation of 0.000 meaning that nearly all (99%) the respondents selected the same method of work in each case (Hand Tools). The normality tests revealed that the data was 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 were 0.227 and 0.451 respectively.

Coincidentally, the extent of mechanization in plumbing works reported in this study (2.00, 40%) was almost similar to that reported by Vadukkumchery and Myneni (2023). In their study, they established the mechanization level of Plumbing, underground piping and drainage works to be 1.256 based on a 3-point scale. When converted to the 5-point scale used in the current study, this value comes to 2.09 (41%). In both Plumbing and Electrical works, testing was the most mechanized activity. This is expected since utilization of equipment such as pumps and generators are common in testing of plumbing and electrical installations.

Overall Level of Mechanization

Assessing the level of mechanization in construction projects is not only important but also critical since it both 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 9 and Figure 1. These results

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are a summary of all the seven (7) work categories discussed in the preceding sections.

As demonstrated in Table 9, 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 9: 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				

(Fieldwork, 2024)

As seen in Table 9, 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 was not heavily spread out across all measured indicators of the mechanization variable. The normality tests revealed that the data was 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 were 0.227 and 0.451 respectively.

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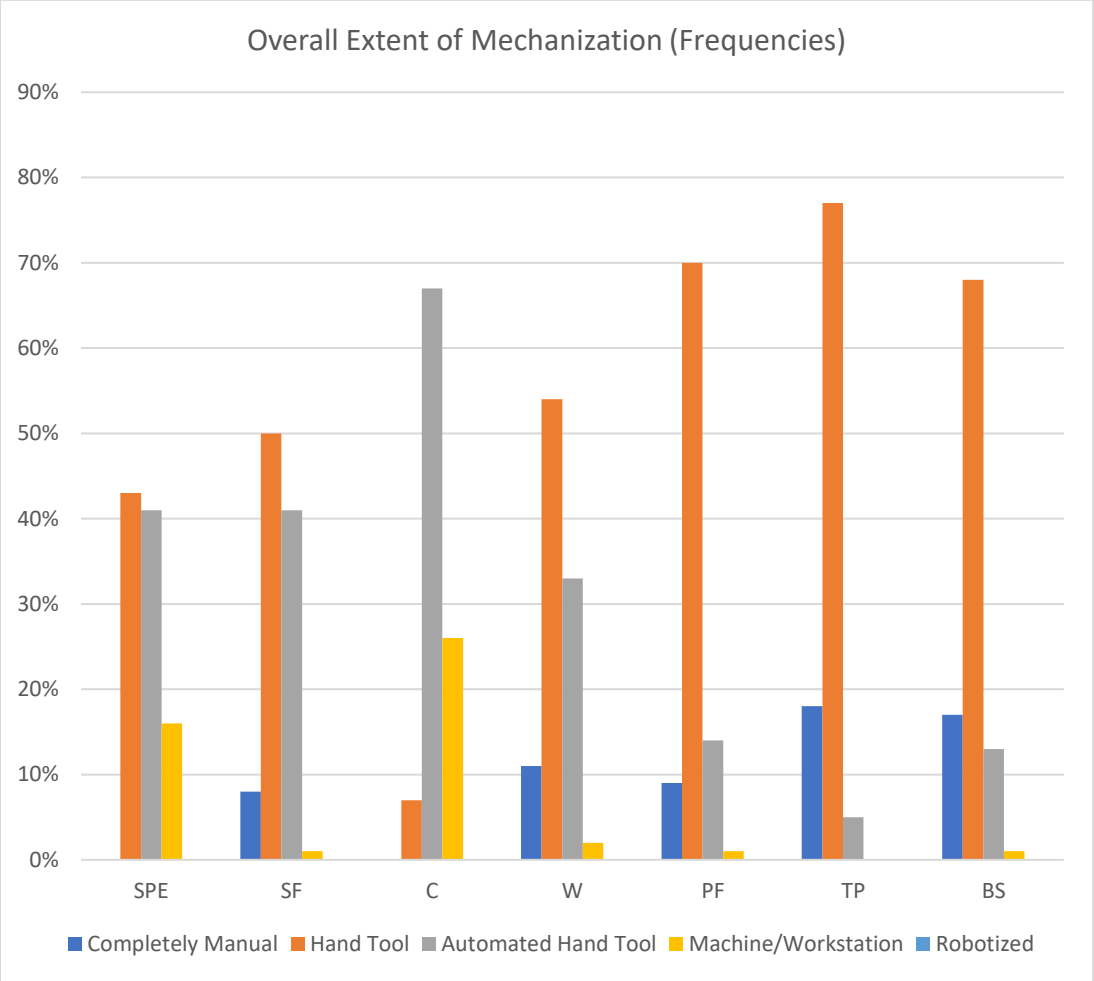
Figure 1: Overall Extent of Mechanization (Frequencies)



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 9 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 9 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

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construction companies. Though their survey had a small sample size, their results were not very different from the ones reported in Table 9, 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.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The study draws the following conclusions; (i) Mechanization levels vary considerably across different tasks within construction projects. Setting out of plumbing and electrical works were the least mechanized activities (33%) while Basement excavation was the most mechanized activity (74%) within the construction process (ii) Mechanization levels vary across different work categories within construction projects. Concreting is the most mechanized work category (64%) while Tiling and Painting is the least mechanized work category (38%) in the delivery of high-rise buildings in Kenya. (iii) The majority of construction activities in Kenya still depend heavily on manual labour rather than mechanization, (iv) Automated tools are underutilized (31%) despite their potential to improve efficiency and safety, and (v) There is a total absence of fully automated (robotized) methods in current practices.

Recommendations

The study makes the following recommendations; (i) There is a need to encourage the adoption of advanced technologies to increase mechanization levels in construction projects in Kenya, (ii) Contractors need to invest in training programs to improve skills related to operating automated machinery, (iii) Increased awareness should be raised among stakeholders about the benefits of mechanization for enhanced project efficiency and safety, (iv) Contractors in Kenya need to foster partnerships with technology providers to enhance access to modern machinery and tools., (v) The government should develop policies that incentivize the use of mechanized methods in both public and private construction projects, and (vi) Further research needs to be conducted to identify barriers and challenges facing mechanization within the Kenyan construction sector.

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