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RESEARCH ARTICLE

Assessment of Impact of Mechanization in Construction Projects in India

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Abstract

Objectives: To assess the impact of mechanization in construction activities of high-rise apartment projects in India. **Methods:** Initially, the current scenario of mechanization in the country is captured with the help of review of literature, questionnaire survey and case studies. As it is found to be low, especially in activities like masonry, plastering, painting etc, a list of advanced equipment to be adopted for executing these activities is proposed. To explore the impact of the proposed equipment on time and cost associated with the activities, a comparative analysis between the usage of these equipment and manual execution is conducted. Finally, in an attempt to validate the positive impact of these proposed equipment on a construction project, a schedule comparison is done along with return-on-investment analysis and payback period calculations. **Findings:** The study demonstrates a 55 to 75% savings in time and 40 to 67% savings in cost in activities on its own when mechanization is employed. As far as a project is concerned, a reduction of 11.26% in its duration is achieved just by mechanizing masonry and wall finishes' activities in addition to the conventionally mechanized activities. **Novelty:** There is a hesitation among construction professionals in Kerala to employ equipment in non-mechanized activities owing to the lack of thorough context-based analysis on the same. This study attempts to analyse the impact of mechanization by proposing equipment based on the availability of indigenous equipment and technology, skilled operators and local market rates specific to Kerala. Hence, the findings will help industry professionals realize the benefits mechanization can reap when the right equipment is employed.

Keywords: Assessment; Equipment; Impacts; Indian Construction Industry; Mechanization Level

1 Introduction

During the industrial revolution, the growing demand for infrastructure and industrialization pushed the construction industry towards equipment usage to meet shorter timelines and innovative designs. As the importance of equipment usage increased day by day in the industry, manual methods gave way to mechanical means to increase productivity, meet tight schedules, complex specifications and designs and effectively use

new materials in the market. Studies have shown that adopting mechanization in construction activities has a positive impact on the cost, time and quality of the project[1]. Also, in industrialized countries, most of the manual methods are turning obsolete and redundant due to a shortage of skilled labour. Despite all these benefits, there are a few barriers that restrain the mechanization of construction activities like high capital investment, high cost of operating, maintaining and upgrading, a requirement for skilled resources, lack of availability of technology etc[2].

1.1 Mechanization in Construction Industry in India

Construction Industry is one of the secondary sectors of the economy in India and it accounts for around 10% of the country's GDP. The Industry is on a boom since the expansion of the IT Industry and other businesses. With the expansion of infrastructure, several new challenges have emerged, such as a large number of projects, strict time constraints, quality and safety assurance, unexpected soar in the prices of commodities like cement, steel, bricks, sand, etc. essentially required for the development of construction projects, and looking at out-of-the-box solutions. The above-mentioned factors along with the increasing shortage of labour are accelerating mechanization in construction activities in the country. With each passing year, the industry is more and more dependent on advanced equipment, the latest technology and innovative materials to meet the growing infrastructure and building needs. Thus successful completion of a construction project within its targeted schedule and budget constraint is hugely influenced by the selection of the appropriate equipment for executing the tasks in that project[3].

1.2 Global Scenario

According to[4], Mechanization helps improve the quality of work, productivity, health and safety of workers on site. Also, the major barrier to mechanization is the cost of procuring, operating, maintaining and upgrading the equipment/technology. The need for skilled resources to operate the equipment is another major barrier according to this study. Reduced building production cost, better quality, the standard of work, improved productivity and reduced project duration are a few positive impacts of mechanization according to a study conducted by[5]. As part of the field survey in the study, a few selected activities were compared to how the activities were executed at the site versus the same executed manually and a 35% average cost reduction was observed in mechanized excavation & concreting operations over manual labour.

Also, from a study based on Portugal's construction Industry in 2016, it was observed that 57.85% of savings in time and 51.67% of savings in cost was incurred by mechanical labour with mat preparation robots, floor finishing robots, quality inspection robots, drones and proximity detection sensors as compared to manual labour[6].

From a study based on the assessment of mechanization in building projects in 2019, it was observed that mechanization is adopted for work types involving heavy lifting or excavation in Singapore. According to the study assessment of the mechanization level of each work type and further, the overall project will expose the areas where mechanization can be enhanced to utilize the advantages of mechanization[2].

[7] this study suggests that a well-thought-out selection and procurement plan for the equipment considering the activity type of the equipment, economic and cost analysis of its utility, maintenance factor, operation cost, procurement method etc influences the overall cost of construction. According to this study, excavation, earthwork and piling works are the most mechanized activities in Nigeria Structural steel works and demolition/site clearance are others which come just below the former activities in the most mechanized category.

1.3 Indian Scenario

In India, Mechanization is employed for heavy-duty works that involve lifting, transporting, transferring, digging, and cutting. Mechanization is observed to enhance project duration and project control in mainly commercial and factory projects. Also, in the case of high-investment projects, mechanization is not a financial burden on the contractors due to the widespread usage of machinery in such projects. In the case of the residential sector, excavation and transportation of concrete are the most mechanized activities. In most of the construction sectors, masonry and plastering work are the least mechanized activities. Mechanization has brought a boom in the Indian equipment industry along with it comes the need for training workers to operate the equipment. Apart from this, it is observed that the use of equipment and plants brings better control over the site and project, it also reduces the duration of the project bringing in more business opportunities in India[8].

In India, there is still room for mechanization given the current level of adoption in the construction industry[8]. From the review of the literature, it is evident that studies on the mechanization of construction activities in India are focused on understanding the current scenario and awareness among industry experts. Studies emphasizing the context-based factors (local market rates, insurance, procurement mode, availability of equipment and technology) are less explored. Assessing and

comparing the impact of mechanization as opposed to manual labour on critical factors associated with successful project completion in the context of India will help encourage the adoption or upgradation of mechanization in those activities that are less mechanized or labour-intensive.

2 Methodology

The study aims to gather an understanding of the impact of mechanization on the construction industry in India through a review of published data from journals, conferences and web-based reports. As part of the initial study, the current awareness and level of mechanization in the Indian construction industry are explored through a self-administered structured questionnaire survey. The choosing of practitioners or industry experts engaged in heavily mechanized high-rise apartment projects ensures more familiarity/knowledge on the topic, thus ensuring a meaningful database for the study. Relative Importance Index (RII) method is used to rank the mechanization level of the figured-out construction stages and activities. It is a technique that is used for rank factors assessed by respondents, collected employing a survey.

After the survey, the research proceeds to field study on high-rise apartment construction sites in Kerala, to collect primary data on the equipment usage and productivity as well as its implication on cost in various construction activities. Further, from the inference of the field studies, a list of suitable equipment to be adopted to improve the productivity of construction activities that do not employ mechanization currently in the state is proposed. A comparative analysis between mechanized work and manual work of the selected activities is done to understand the implication of these equipment on cost and time. Finally, the proposed list is validated through a schedule comparison, return on investment and payback period calculation.

2.1 Study area

With India's growing economy and growing population, it is estimated that most buildings that will exist in Indian cities in 2030 have not yet been constructed [(9)]. It is only natural that the increase in urban population is reflected by an increase in urban residential floor area. Here the study will be focusing on Kerala as there is a spurt in the construction of high-rise buildings as part of vertical development in the state to tackle the growing urban population [(10)].

2.2 Questionnaire Survey

A structured questionnaire survey was conducted on experts and practitioners involved in the construction industry in the year 2022. Thirty-two companies pan India involved in the construction of High-rise apartments take part in the survey. The responses of professionals having experience of 10 years and above in the selected firms were recorded as part of the study. 28.1% of the respondents serve as project managers in their respective companies. 50% of the participants have an experience over 20 years.

The survey design included five sections (Sections A, B, 1, 2 and 3). The first section depicts the intention of the survey and the next one collects the personal information of the respondents. The section seeks opinions regarding the impact of mechanization on the construction industry in India on certain crucial project factors. The next section tries to figure out the current mechanization level of residential projects in India, and the mechanization level of construction stages and activities in India qualitatively. The construction stages of a high-rise apartment project and the main activities involved in those stages are listed below:

1. Site clearance and preparation
    (a) Earthworks
    (b) Assembly/ installation
2. Foundation
    (a) Earthworks
    (b) Material Handline
    (c) Formwork
    (d) Reinforcement works
    (e) Batching and Mixing
    (f) Concreting
    (g) Backfilling

3. Grey structure
    (a) Material Handling
    (b) Masonry
    (c) Formwork
    (d) Reinforcement works
    (e) Batching and Mixing
    (f) Concreting
    (g) Scaffolding
    (h) Structural steel works
4. Services
    (a) Material Handling
    (b) Scaffolding
    (c) Plumbing, underground piping and drainage works
    (d) Assembly/ installation
5. Fixing / Installation
    (a) Material Handling
    (b) Assembly/ installation
6. Finishes
    (a) Material Handling
    (b) Scaffolding
    (c) Tiling/ laying
    (d) Painting/ applying and finishing
7. Landscape
    (a) Material Handling
    (b) Assembly/ installation
    (c) Painting/ applying and finishing
    (d) Internal roadworks
    (e) Concreting
    (f) Tiling/ laying

The above stages and activities were finalised after peer reviews, communication with industry experts, and after extensive review of surveys and analyses conducted in the published works.

The concluding section summarizes the factors leading to and not opting for mechanization of the construction activities.

2.3 Field Studies

Field studies were conducted at five high-rise apartment construction sites in Kerala. The field study sites were chosen based on comparability of project scale and cost to obtain the desired data. The activities being executed at the site were continuously observed and details regarding the number of manhours, equipment and duration were noted. Details of the activities already carried out at the site were collected through interviews and detailed conversations with the Site engineers/ Supervisors/ Equipment and Power tool officer. Contractor/consultant personnel involved only in the construction of high-rise apartments were chosen for the study. The authenticity of collected data was confirmed with the help of Contractor's log register, progress reports, weekly site reports, equipment inventory etc.

The details collected are details as shown in Table 1.

The intentions behind the studies were to:

1. Understand the current mechanization level of High-rise apartment construction
2. Study the equipment in use, the procurement, brand, productivity, cost and maintenance details of the same.
3. Understand the local labour and operator rate and working hours

The data collected for the field studies are shown Table 2

Table 1. Field study details

Field Study	Location	No. of Floors	Stage(s) studied
A	Thrissur	1B + G + 16	Foundation and concreting
B	Palakkad	1B + G + 14	Foundation and Painting
C	Thrissur	B + G + 15	Site preparation and foundation
D	Ernakulam	2B + G + 13	Foundation and Masonry
E	Trivandrum	2B + G + 13	Foundation

Table 2. Field study A details

Activity	Quantity	Duration	Equipment	Labour	Productivity	Charge
Mass Excavation	13418 cu.m	60 days	Lnt Komatsu PC130 excavator (1)	1 operator	225 cu.m/day	1000 rupees per day
Manual Excavation	17 cu.m	14 days	Spade, Shovel, Pan	10 helpers	1.2 cu.m/day	500 rupees per day
Filling	2550 cu.m	20 days	Tipper (6) + Hitachi 130 (2)	1 operator each	127 cu.m/day	1200 rupees/hr + 800 Bata per day
Compaction	700 sq.m	15 days	Kirloskar compactor (1)	1 operator	500 sq.ft/day	500 rupees per day
PCC	67 cu.m	15 days	Kirloskar Mixer (1)	1 operator + 2 transporters + 1 mason for leveling	4.5 cu.m/day	500 rupees per day
Pile cap RCC						
Formwork		45 days	Drilling tools			
Reinforcement	28 T	57 days	Bar bending M. (1), Bar cutting M. (1)	10 + 5 helpers		700 + 500 rupees per day
Concreting	315 cu.m	28 days	Mixer (1) Needle Vibrator (1), Electrical Vibrator (1)	1 operator each		500 rupees per day
Plinth beam RCC						
Formwork		19 days	Drilling tools			
Reinforcement	12 T	38 days	Bar bending M. (1), Bar cutting M. (1)	10 + 5 helpers		700 + 500 rupees per day
Concreting	70 cu.m	19 days	Mixer (1) Needle Vibrator (1), Electrical Vibrator (1)	1 operator each		500 rupees per day
Raft RCC						
Formwork		4 days	Drilling tools			
Reinforcement	13 T	2 days	Bar bending M. (1), Bar cutting M. (1)	10 + 5 helpers		700 + 500 rupees per day
Concreting	83 cu.m	1 day	Mixer (1) Needle Vibrator (1), Electrical Vibrator (1), Screed vibrator (1)	1 operator each		500 rupees per day

Table 3. Field study B details

Activity	Quantity	Duration	Equipment	Labour	Productivity	Charge
Mass Excavation	3000 cu.m	10 days	Lnt PC140 excavator (1)	1 operator	300 cu.m/day	1700 rupees/hr + 1200 rupees per day BATA + 3500 rupees for shifting
Disposal	15 cu.m	10 days	Eicher tipper (1)	1 operator	1.5 cu.m/day	3500 rupees per day
Filling	250 cu.m	2 days	Hitachi 20 mini excavator (1)	1 operator	125 cu.m/day	800 rupees/hr + 800 Bata per day

Continued on next page

Table 3 continued

Compaction			Plate Rammer (1)	1 operator		750 rupees per day for hiring and 750 rupees per day for operator
Dewatering		60 days	Kirloskar 15 hp motor + 10 hp motor + 2 hp motor	1 operator for all		750 rupees per day
Anti-termite treatment	700 sq.m	2 days	Sprayer	1 operator	350 sq.m/day	800 rupees per day
Pile cap PCC	96.73 cu.m	27 days	Mixwell mixer (1), Motor pan, wheelbarrow. Spade, trowel, straight edge	1 operator + 6 helpers for pouring + 4 helpers for leveling		850 rupees per day and 750 rupees per day
Pile cap RCC						
Reinforcement	49 T	45 days	14" cut-off machine (1), Lever	1 operator + 1 helper, 2+3 helpers, 4	1 T / day	750 rupees/day
Concreting	118.21 cu.m	1 day	Concrete pump, pipeline, needle vibrator (3), levelling tools	1 operator, 10 helpers, 1 operator each, 7 helpers for levelling		750 rupees/day
Plinth beam RCC						
Formwork		10 days				
Reinforcement	10 T	21 days	14" cut-off machine (1), Lever	1 operator + 1 helper, 2+3 helpers, 4 helpers	1 T / day	750 rupees/day
Concreting	35.98 cu.m	1 day	Concrete pump, pipeline, needle vibrator (3), levelling tools	1 operator, 10 helpers, 1 operator each, 4 helpers for levelling		750 rupees/day
Grade slab RCC						
Formwork		2 days				
Reinforcement	6 T	14 days	14" cut-off machine (1), Lever	1 operator + 1 helper, 2+3 helpers, 4 helpers	1 T / day	750 rupees/day
Concreting	127.79 cu.m	1 day	Concrete pump, pipeline, needle vibrator (3), levelling tools	1 operator, 10 helpers, 1 operator each, 6 helpers for levelling		750 rupees/day, 800 rupees + 600 rupees per day for levelling
External Finishes						
White cement	3800 sq.m	30 days	Brush, roller	3 painters + 2 helpers		700 rupees per day and 575 rupees per day
Putty (2)	7600 sq.m	90 days	Trowel, putty mixing machine, putty blade	6 painters		700 rupees per day
Primer	3800 sq.m	15 days	Sprayer, Spiderman safety kit	1 sprayer + 2 helpers		800 rupees per day and 575 rupees per day
External paint (2)	7600 sq.m	30 days	Sprayer, Spiderman safety kit	1 sprayer + 2 helpers	253 sq.m/day	800 rupees per day and 575 rupees per day

Table 4. Field study C details

Activity	Quantity	Duration	Equipment	Labour	Productivity	Charge
Demolition	1500 sq.m	4+8 days	Hitachi 130 Excavator, spade, hammer	1 operator, 2 + 1 helper		1100 rupees per day, 900 and 650 rupees per day
Site clearance	607 sq.m	1 + 3 days	Grass cutting machine	1 operator + 5 helpers		650 and 1500 rupees per day
Mass Excavation	2000 cu.m	200 days	Hitachi 130 excavator (1), Hitachi 33 mini excavator (1), Auto level, Dumpy level	1 operator each		1100 rupees/day + 1200 rupees per day
Dewatering		279 days	5 hp pump (2), 1.5 hp mud pump (1), 1.5 hp needle pump (1)	1 operator + 1 electrician	4 hours before work and every 10 minutes at 1-hour intervals	650 rupees and 800 rupees per day
Disposal	1800 cu.m	14 days	Hitachi 140 loader (1), Eicher 1.5 units tipper (4), Eicher 3 units tipper (5)	1 operator		1800 rupees/ hr + 1500/day + 600/- Bata, 1200/- per hour + 500/- BATA per day
Filling	225 cu.m	3 days	Hitachi 33 excavator (1), spade, hammer	1 operator + 5 helpers		1200 rupees/day + 650/- per day
Compaction	300 sq.m	2 days	Greaves compactor (1)	1 operator + 1 helper	150 sq.m/day	650 rupees per day
Anchoring	108 holes	2 days	HILTI injectable adhesive anchors	1 steel worker + 1 HILTI operator	50 holes per day	800/- per hole
Pile cap RCC						
Shuttering	235.20 sq.m (32 piles)	24 days	4" cutting machine (1), 6" cutting machine (1)	1 carpenter + 2 helpers	2 piles a day	900/- + 650/- per day
Reinforcement	29.75 T	24 days	Bar bending machine, 14" bar cutting machine (1), Hand-held steel cutter	(4 steel fixers + 3 carpenter)*2	1 triple pile cap or 3 double pile caps or 12 single pile caps in a day	900 rupees/day and 650 rupees per day
Concreting	160 cu.m	5 days	Mixer, Concrete pump, pipeline, needle vibrator (1), levelling tools	11+1skilled, 1 leveller + 1 helper, 1 operator for vibrator		950 rupees/day for skilled sand 650 rupees per day
Footing RCC						
Formwork	158.25 sq.m (10 nos.)	25 days	4" cutting machine (1), 6" cutting machine (1)	3 carpenters + 2 helpers	6.5 sq.m/day	900/- + 650/- per day
Reinforcement	10 T	6 days	Bar bending machine, 14" bar cutting machine (1), Hand-held steel cutter	(3 steel fixers + 3 carpenter)*2	1 large footing or 3 small footings in a day	900 rupees/day and 650 rupees per day
Concreting	62 cu.m	4 days	Mixer, Concrete pump, pipeline, needle vibrator (1), levelling tools	11+1skilled, 1 leveller + 1 helper, 1 operator for vibrator		950 rupees/day for skilled sand 650 rupees per day

Continued on next page

Table 4 continued

Raft RCC						
Reinforcement	2.75 T	3 days	Bar bending machine, 14" bar cutting machine (1), Hand-held steel cutter	(4 steel fixers + 3 carpenter)*2		900 rupees/day and 650 rupees per day
Concreting	27 cu.m	1 day	Mixer, Concrete pump, pipeline, needle vibrator (1), screed vibrator, levelling tools	11+1skilled, 1 leveller (mason) + 1 electrician, 1 operator for each vibrator		950 rupees/day for skilled sand 650 rupees per day, 900 rupees per day for screed vibrator operator

Table 5. Field study D details

Activity	Quantity	Duration	Equipment	Labour	Productivity	Charge
Excavation	4554 cu.m	50 days	Hitachi 110 Excavator, backhoe loader, bobcat	1 operator each	100 cu.m per day	1400 rupees/hr, 1000 rupees/hr, 750 rupees/hr + 500 rupees per day Bata each
Disposal	4554 cu.m	54 days	Tipper (2)	1 operator each	85 cu.m per tipper	1125 rupees per hour, 500 rupees/hr + 500 rupees per day Bata
PCC works	100 cu.m	4 days	Mixer machine, Boom placer, pan, floater, shovel, needle vibrator (2)	1 operator + 14, 7+6 helpers, 1 operator each for vibrator	25 cu.m/day	5000 rupees per cu.m RMC package, 1125 rupees per day for pouring staff (7), 1650 rupees per day for levelling and finishing staff (6+2)
Raft RCC						
Formwork	195 sq.m	8 days	Makita Handheld cutter machine (2), drilling machine (2)	8 + 4 workers	12 sq.m per day by one set of machinery	1650 rupees per day + 1125 rupees per day
Reinforcement	79.2 T	26 days	Bar bending machine, bar cutting machine	7 + 3 helpers	3 T / day	1650 rupees per 12 hours + 1125 rupees per 12 hours, 24-hour duty
Concreting	594 cu.m	4 days	Mixer machine, Boom placer, pan, floater, shovel, needle vibrator (2)	1 operator + 14, 6+4 helpers, 1 operator each for vibrator	25 cu.m/day	5000 rupees per cu.m RMC package, 1125 rupees per day for pouring staff (6), 1650 rupees per day for levelling and finishing staff (4+2)
Masonry	1 cu.m	1 day	Trowel, pan, straight edge, plumb bob, spirit level, mortar board	1 mason + 1 helper	184 bricks/ day	900 rupees / day + 700 rupees / day

Table 6. Field study E details

Activity	Quantity	Duration	Equipment	Labour	Productivity	Charge
Mass Excavation	6670 cu.m	60 days	Hitachi 180 excavator (1)	1 operator	120 cu.m	1200 rupees/hr + 500 rupees Bata per day

Continued on next page

Table 6 continued

Dewatering		90 days	25 hp pump, 10 hp pump (2), 1.5 hp mini pump (1), 3 hp mini pump (1)	1 operator, 1 operator, 1 helper for mini pumps		1500 rupees per day for 25 hp pump and 787.5 rupees per day for the rest
Disposal	6670 cu.m	30 days	Torus (4)	1 operator each	100 cu.m/day each	1200 rupees/ hr + 500/- Bata per day
Filling			Hitachi 180 excavator (1)	1 operator		1200 rupees/hr + 500/- per day Bata
Compaction			Hitachi 20 excavator (1)	1 operator		800 rupees/hr + 500/- per day Bata
Chemical cracking	6 cu.m	14 days	Compressor tractor, Hitachi 180 Breaker excavator	1 operator + 2 helpers, 1 operator		15000/- per month, 1200/- per hour + 500/- Bata per day
Diamond Rock Cutting	1125 cu.m	90 days	Compressor tractor, Core cutting machine, Diamond rope cutting machine, Diamond rope, DG, Electric panel, Hitachi 210 breaker excavator, Hitachi 180 loader	2 operators + 1 helper, 1 operator each for breaker excavator and loader		15000 rupees per month for tractor, 1200 rupees/hr + 500 rupees/ day Bata for breaker excavator and loader
Anchoring for F10	4 holes	2 hours	Tractor compressor, HILTI injectable adhesive anchor	1 operator + 1 operator		187.5/- for 2 hours
PCC for F10	0.63 cu.m	1 hour	Shovel, pan, floater	3 + 1 for pouring, 1 mason + 1 helper for finishing		731.25 rupees per day, mason - 843.75 rupees per day
RCC of F10						
Formwork	18.08 sq.m or 194.61 sq.ft	2 hours	Wood cutting machine, Drilling machine	1, 1 + 6 helpers	72 sq.m per day	14 rupees per sq.ft
Reinforcement			Bar cutting machine, Lever and pin	1 operator, 4 helpers	1 T/ day	
Concreting	6.656 cu.m	45 minutes	Mixer machine, Pipeline, Floater, shovel, Needle Vibrator	1 operator, 5 helpers, 1 helper for finishing		6400 rupees per cu.m RMC package, 731.25 rupees per day for finisher

3 Results and Discussion

3.1 Data Analysis and Findings

1. Time - 87.5% of the respondents Strongly Agree that mechanization reduces the duration of an activity.
2. Cost - 65.6% of the respondents Agree that mechanization reduces the cost of the overall project. But around 25 % have taken a neutral stand over this statement.
3. Performance And Productivity - 81 3% of them agree that mechanization improves performance and productivity
4. Quality - 62.5% of the respondents Agree that mechanization improves the quality of the work executed.
5. Skilled Labour Shortage - 56.3% Agree that the issue of skilled labour shortage can be overcome if mechanization is adopted.
6. Material Wastage - 59.4% Agree that the wastage generated at the site is minimal for mechanized activities.
7. Health And Safety of workers - 62.5% Agree that mechanization improves the health and safety of the workers at the site.
8. Equipment Selection - 62.5% Strongly Agree that equipment selection needs to be carried out with utmost care to make complete use of its potential.

9. Role of Government Policies And Incentives - A mixed opinion was recorded for the question that varies from Neutral (40.6%) to Agree (43.8%). One of the respondents felt that incentives may increase the chance of contractors exploiting the advantage.

As observed from the survey result, 72% of the respondents reported that the current mechanization level of Indian high-rise apartment construction is low, this calls for more opportunities to improve or put in more efforts to enhance the mechanization level.

Relative Importance Index technique was used to rank the construction stages and activities according to the mechanization level. The equation used to calculate the RII value is given below:

$$RII = \Sigma^{n_i=1} (w_i \cdot x_i) / A.N$$

where,

'wi' = weight assigned by the respondent (in this case 1 for low, 2 for moderate and 3 for high); xi = frequency of each weight (wi); A = Highest weight (3 for high in this case) and N = the number of respondents who participated in the survey.

This method allows to identify the more important criteria and make it possible to cross-compare the criteria basing on the response from the participants of the survey. The higher the value of RII is, the more important the influence of the factor is [11]. RII is compatible for prioritising indicators rated on Likert type scales [12] [13].

Tables 7 and 8 depict the ranking based on the RII technique of construction stages and activities involved in high-rise apartment construction in India respectively.

Table 7. Ranking of Current mechanization level of construction stages involved in high-rise apartment projects in India

Ranking	Construction Stage	RII	Mechanization level
1	Foundation	2.256	High
2	Site clearance and preparation	2.128	High
3	Grey structure	1.718	Moderate
4	Fixing / Installation	1.487	Moderate
5	Services	1.436	Moderate
6	Finishes	1.308	Low
7	Landscape	1.179	Low

Table 8. Ranking of Current mechanization level of construction activities involved in high-rise apartment projects in India.

Ranking	Construction Activity	RII	Mechanization level
1	Earthworks	2.333	High
2	Batching and Mixing	2.308	High
3	Concreting	2.256	High
4	Backfilling	2.231	High
5	Structural steel works	2.051	High
6	Material Handling	1.744	Moderate
7	Reinforcement works	1.667	Moderate
8	Internal roadworks	1.436	Moderate
9	Assembly/installation	1.410	Moderate
10	Plumbing, underground piping and drainage works	1.256	Moderate
11	Tiling/laying	1.179	Low
12	Painting / applying and finishing	1.179	Low
13	Scaffolding	1.077	Low
14	Formwork	1.077	Low

According to the study, earthwork works, batching and mixing and concreting are the most mechanized activities in the construction of a high-rise apartment in India aligning with the observations made during the review of the literature. Whereas Masonry is reported to be the least mechanized activity followed by Formwork activities, scaffolding works, painting/ finishing

works and Tiling/laying activities. Foundation works and Site clearance and preparation are the most mechanized construction stages as they consist of activities earthworks, concreting and batching and mixing. The landscape stage is the least mechanized construction stage considering the context of India.

Despite the availability of advanced equipment like a brick-laying robot, plaster spray machine, slip-form machine etc, the usage of these equipment are observed to be on the lower side in the country, especially in Kerala.

96.9% of the respondents find less project completion time as an encouragement factor to adopt mechanization. 65.6% find reduced cost as an encouraging factor to mechanize construction activities. 46.9% feel that improved project quality and 31.3% find improved project performance encourage the adoption of mechanization of the construction industry in India. 68.8% find high capital investment as the most unfavourable factor in mechanization adoption. 50% find increased maintenance/upgradation costs and 56.3% find the requirement for skilled resources to operate as the other two factors that restrict the mechanization of the construction Industry in India. These findings throw light on the fact that the perception of mechanization of the construction industry is not much different in India as compared to the rest of the world.

3.2 Field study Analysis

The observations from the field studies were found to be aligned with the data collected through the survey. Earthworks and concreting-related works were highly mechanized activities. Similarly, masonry and finishing activities were lowly mechanized activities. To understand the impact of mechanization on cost and time, the observed mechanized activities at the field studies were compared to manual labour as shown in Tables 9, 10, 11, 12 and 13.

Table 9. Site clearance comparison

Site clearance (Filed Study C)					
Quantity	Duration	Equipment	Labour	Productivity	Charges
Mechanized					
1000 sq.m	1.5 days	Cutting machine	(1 operators + 3 helpers	607 sq.m/day	3,450 rupees/day (1,500+ 650*3)
Total	1.5 days	Total operating cost			5,175 rupees
Manual					
1000 sq.m	2.5 days		(3 beldars + 1 coolie)	400 sq.m/day	3,450 rupees/day (900*3 + 750)
Total	2.5 days	Total labour charges			8,625 rupees

Table 10. Excavation comparison 1

Excavation (Filed Study B)					
Quantity	Duration	Equipment	Labour	Productivity	Charges
Mechanized					
3000 cu.m	10 days	Lnt PC 140 Excavator & Eicher tipper(hired)	(1 operator each)	300 cu.m/day	1700 rupees/hr + 1200 rupees per day& 3500 rupees for shifting
Total	10 days	Total operating cost			1,00,500 rupees
Manual					
3000 cu.m	75 days		(10 mazdoor + 1 mate)*2	40 cu.m / day	8,250 rupees/day (750*22)
Total	75 days	Total labour charges			12,37,500 rupees

From Table 14 it is evident that 34.10 % of the time and 40 % of the operating cost can be saved when the activity of site clearance at field study C is mechanized. Similarly, 81.33 % to 86.66 % of the time and 91.87 % to 98.86 % of the operating cost can be saved when excavation of field studies A and B are mechanized, 40 % of the time and 55.47 % of the operating cost can be saved if reinforcement activities at field study B are mechanized and around 83.78 % of the time and 73.29 % of the operating cost can be saved if the external painting of field study B is mechanized. From the observations, it is evident that the more advanced the equipment, the better the productivity and cost savings are. To further reinforce the above observations, a study based on Portugal's construction Industry conducted in 2016 [6] shows that 57.85% of savings in time and 51.67% of savings in cost was incurred by mechanical labour instead of manual labour.

Table 11. Excavation comparison 2

Excavation (Filed Study A)					
Quantity	Duration	Equipment	Labour	Productivity	Charges
Mechanized					
3000 cu.m	14 days	Lnt Komatsu PC 130 Excavator (asset)	(1 operator each)	224 cu.m/day	1000 rupees per day
Total	14 days	Total operating cost			14,000 rupees
Manual					
3000 cu.m	75 days		(10 maz-door + 1 mate)*2	40 cu.m / day	8,250 rupees/day (750*22)
Total	75 days	Total labour charges			12,37,500 rupees

Table 12. Reinforcement comparison

Reinforcement (Filed Study B)					
Quantity	Duration	Equipment	Labour	Productivity	Charges
Mechanized					
10 T	10 days	14” cut-ting machine, Bar bend-ing machine	3 steel fix-ers + 3 carpen-ters	1 T/day	4,950 /-/ day (900+750)*3
Total	10 days	Total operating cost			49,500 rupees
Manual					
10 T	17 days	Level, hand-held cutter	(1 black-smith +1 bel-dars)*3	0.6 T / day	6,540 rupees/day (900+1280)*3
Total	17 days	Total labour charges			1,11,180 rupees

Table 13. External painting comparison

External painting (Filed Study B)					
Quantity	Duration	Equipment	Labour	Productivity	Charges
Mechanized					
3800 sq.m	10 + 21 days	Paint Sprayer gun, Spiderman safety kit	1 sprayer + 2 helpers	370 sq.m/day	1,950 rupees/day (800 + 575*2)
Total	31 days	Total operating cost			60,450 rupees
Manual					
3800 sq.m	63 days	Brush, roller, bucket, tray	3 painters + 3 helpers	60 sq.m/day	3,825 rupees/day (700+575)*3
Total	63 days	Total labour charges			12,40,975 rupees

Table 14. Field study comparison summary

Activity	Mechanical	
	Productivity	Operating Cost
Site clearance	+ 34.10 %	- 40.00 %
Excavation (hired)	+ 86.66 %	- 91.87 %
Excavation (asset)	+ 81.33 %	- 98.86 %
Reinforcement	+ 40.00 %	- 55.47 %
External painting	+ 83.78 %	- 73.29 %

For every comparison in the coming sections, the local market rate 2022 of Kerala as shown in Table 15 , released by the Government of Kerala every year was applied.

Table 15. Labour rate comparison

Labour	LMR 2022 (PRICE)	DSR 2021	Case Studies
Coolie	820	645	750
Blacksmith	900	784	900
Bhisti	900	714	750
Beldar	1280	645	750
Painter	950	714	900
Mate	830	714	750
Mason (pop)	1050	784	950
Mason 1st class	1040	714	900
Mason 2nd class	980	784	700
Mason avg	1010	709	900
Operator	1100	784	1100
Helper	900	645	750

3.3 Recommendation

A piece of specific advanced equipment was proposed for executing masonry and certain finishing activities involved in the construction of a high-rise apartment building, which was then studied in detail and analysed to observe how the time and cost factors were impacted while executing that activity using the proposed equipment. The equipment are proposed to look into the immediate availability to use by enquiring about the usage of the same in neighbouring states. The details of the equipment are shown in Table 16. The below details were collected from the suppliers directly through websites and telephonic conversations with the primary dealers/ site engineers.

Table 16. Equipment details

Kappa PS 180 VM Plaster machine with mixer (Source of information – Kappa machines website and telephonic conversation with Site engineer using the equipment)	
Application	Cement, cement-lime, floor screed, mortars, gypsum plasters
Productivity	112.5 sq.m/day
Cost	4.5 lakh rupees
Maintenance cost	45000 per year
Fuel type	Electric
Operators required	1 operator (Mason avg) + 1 helper + 1 coolie
Operator cost	1010 rupees per day + 900 rupees per day + 820 rupees per day
Asian paints TruCare Graco EH 230 DI Hydraulic Putty sprayer (Source of information – Asian paints website and painting service)	
Application	Putty application and External painting
Productivity	Putty - 400 sq.m/day, Painting - 1200 sq.m/day
Cost	6.5 lakh rupees
Maintenance cost	50000 per year
Fuel type	Electric
Operators required	2 operator (mason - pop)+ 2 beldars
Operator cost	(1050 rupees per day + 1280 rupees per day) * 2
Asian paints TruCare Graco 490 Airless Paint sprayer (Source of information – Asian paints website and painting service)	
Name	Airless Paint sprayer
Application	Internal Painting
Productivity	640 sq.m/day
Cost	2.14 lakh rupees
Maintenance cost	40000 per year
Fuel type	Electric
Operators required	1 operator (painter) + 1 coolie

Continued on next page

Table 16 continued	
Operator cost	950 rupees per day + 820 rupees per day
Craftsmac lock laying robot (Source of information –Craftsmac Lab website)	
Application	Masonry
Productivity	200 blocks/hr and 180 blocks/hr above 3m
Fuel type	Electric
Operators required	1 operator + 1 helper
Operator cost	1100 rupees per day + 900 rupees per day

3.4 Return on Investment and Payback period of the proposed equipment

High investment and maintenance costs were concerns among industry experts while adopting mechanization. To understand the situation better, the return on investment and payback period of the proposed equipment was calculated as shown in Table 17 . The formula used for the calculation of the Payback period was, P = I / (L - E); where P = Payback period; I = Investment cost; L = Annual labour savings; E = Total annual expense

And the formula used for the calculation of Return on Investment was,

ROI = [(S - E) / I] * 100; where ROI = Return on Investment; I = Investment cost; S = Annual savings generated by the use of the equipment, dependent upon the number of workers replaced; E = Total annual expense [6]

Wages were considered from the local market rate 2022 of Kerala as shown in Table 15 , released by the Government of Kerala for the year 2022. The labour required and their respective charges are detailed out in Table 16 as well.

Insurance per year for a group of 150 labourers was assumed to be 1.2 lakhs per annum after enquiring regarding it during the field study (800 rupees per person).

The number of working days considered per month was 26 days.

The overhead charges per year is considered to be 5% of labour cost in accordance to PRICE – Government of Kerala.

Table 17. Return on Investment and Payback period calculation

Kappa Plaster machine with mixer	
Investment cost (I)	= 4,50,000 rupees
Total annual expense (E)	= Maintenance cost + Operating cost = 45,000 + (2000 * 26 * 12) = 6,69,000 rupees
Annual labour savings (L)	Benefits obtained from labour = Wage in a year + insurance per year + overhead charges per year (5%) = [(1010 * 26 * 12) + (820 * 26 * 12) + (900 * 26 * 12) + (800 * 3) + (136.5 * 26 * 12)] = 8,96,748 rupees
Payback Period	P = I / (L - E) = 4,50,000 / (8,96,748 - 6,69,000) = 1.9 years
Return on Investment	ROI = (S - E) / I = [(8,96,748 - 6,69,000) / 4,50,000] * 100 = 50.76%
Graco Hydraulic Putty sprayer	
Investment cost (I)	= 6,50,000 rupees
Total annual expense (E)	= Maintenance cost + Operating cost = 50,000 + (4000 * 26 * 12) = 12,98,000 rupees
Annual labour savings (L)	Benefits obtained from labour = Wage in a year + insurance per year + overhead charges per year (5%) = [(1050 * 26 * 12) + (1280 * 26 * 12) + (800 * 2) + (116.5 * 26 * 12)] * 3 = 21,85,680 rupees
Payback Period	P = I / (L - E) = 6,50,000 / (21,85,680 - 12,98,000) = 8.8 months
Return on Investment	ROI = (S - E) / I = [(21,85,680 - 12,98,000) / 6,50,000] * 100 = 137%
Graco Hydraulic sprayer for painting	
Investment cost (I)	= 6,50,000 rupees
Total annual expense (E)	= Maintenance cost + Operating cost = 50,000 + (2900 * 26 * 12) = 9,54,800 rupees
Annual labour savings (L)	Benefits obtained from labour = Wage in a year + insurance per year + overhead charges per year (5%) = [(950 * 26 * 12) + (820 * 26 * 12) + (800 * 2) + (88.5 * 26 * 12)] = 16,61,520 rupees
Payback Period	P = I / (L - E) = 6,50,000 / (16,61,520 - 9,54,800) = 11 months
Return on Investment	ROI = (S - E) / I = [(16,61,520 - 9,54,800) / 6,50,000] * 100 = 109%
Graco Airless Paint sprayer	
Investment cost (I)	= 2,14,000 rupees
Total annual expense (E)	= Maintenance cost + Operating cost = 40,000 + (2000 * 26 * 12) = 6,64,000 rupees
Annual labour savings (L)	Benefits obtained from labour = Wage in a year + insurance per year + overhead charges per year (5%) = [(950 * 26 * 12) + (820 * 26 * 12) + (800 * 2) + (88.5 * 26 * 12)] * 2 = 16,61,520 rupees
Payback Period	P = I / (L - E) = 2,14,000 / (16,61,520 - 6,64,000) = 5.7 months
Return on Investment	ROI = (S - E) / I = [(21,85,680 - 12,98,000) / 6,50,000] * 100 = 208%

The results of the calculation as shown in Table 18 prove that the initial investment in the proposed equipment can be recovered within less than 1 to 2 years. The results are in agreement with the data collected from industry experts using the above machinery in Kerala's neighbouring states regarding the payback period and ROI values.

Table 18. Return on Investment and Payback period calculation summary

Equipment	Values	
	Payback period	Return on Investment
Kappa PS 180 VM Plaster machine	1.9 years	50.76 %
Graco EH 230 DI Putty sprayer	8.8 months	137%
Graco EH 230 DI Putty sprayer for external painting	11 months	109%
Graco 490 air paint sprayer	5.7 months	208%

3.5 Comparative Analysis

To understand the implication of the above equipment usage in their respective activities on time and cost factors, a comparative analysis was done as shown in Table 19 .

Table 19. Comparison

Activity	Mechanical			Manual		
	Equipment & Labour	Productivity	Charges	Labour	Productivity	Charges
Plastering	Kappa Plaster machine with mixer; 2 operators + 1 helper	67.5 sq.m/day	2,920 rupees/day (1010 * 2 + 900)	(1 mason + 1 coolie + 1 bhisti)*3	30 sq.m/day	8,190 rupees/ day (1010 + 820 + 900)*3
Putty application	Graco hydraulic putty sprayer; 2 operators + 2 helpers	240 sq.m/day	4000 rupees/day (1010 * 2 + 900 * 2)	(1 mason + 1 helper)*3	30 sq.m/day	6,690 rupees/ day (1050 + 1280)*3
Internal painting	Graco 490 airless paint sprayer; 1 operator + 1 helper	384 sq.m/day	2000 rupees/day (1010 + 900)	(1 painter + 1 coolie)*3	120 sq.m/day	5,310 rupees/ day (950 + 820) * 3
External painting	Graco hydraulic paint sprayer; 1 operator + 2 helpers	720 sq.m/day	2900 rupees/day (1100 + 900 * 2)	(1 painter + 1 coolie)*3	180 sq.m/day	5,310 rupees/ day (950 + 820) *3
Block masonry	Block laying robot, Pan, trowel; 1 operator + 1 helper	33.6 cu.m / day (200 blocks/hr)	2000 rupees/day (1100 + 900)	(1 mason + 1 helper)*3	9 cu.m/day	6060 rupees / day (1040 + 980)*3

Table 20. Comparative analysis summary

Activity	Mechanical	
	Productivity	Operating Cost
External painting	+ 75.00 %	- 84.39 %
Internal painting	+ 68.75 %	- 86.44 %
Putty application	+ 75.00 %	- 83.85 %
Plastering	+ 55.55 %	- 84.31 %
Block Masonry	+ 73.21 %	- 92.83 %

From Table 20 it is evident that 75 % of the time and 84.39 % of the operating cost can be saved when the Graco EH 230 DI Hydraulic paint sprayer is employed in the activity of external painting. Similarly, 68.75 % of the time and 86.44 % of the operating cost can be saved when the Graco 490 airless paint sprayer is used for painting interior walls; 75 % of the time and

83.857 % of the operating cost can be saved if the putty application is executed with the help of Graco EH 230 DI Hydraulic putty sprayer; around 55.55 % of the time and 84.31 % of the operating cost can be saved if plastering is carried out with the help of Kappa plaster with mixer machine and 73.21 % of the time and 92.83 % of the cost can be saved if Craftsmac block laying robot is employed for the block masonry work. These results are comparable to the field study and literature review observations.

3.6 Schedule Comparison

The schedule of Field study A was prepared and substituted with the above-mentioned activities employing the proposed equipment to compare the total duration of the project in the actual scenario and proposed scenario.

Table 21. Schedule Comparison

Schedule WBS	Number of days		
	Actual	Proposed	Time saved
Site preparation works	17	17	
Substructure works	300	300	-
Structure works	210	210	
Blockwork + Internal finishes	601	495	17.63%
External finishes	360	274	23.88%
Total Duration	968	859	11.26%

From Table 21, it is evident that when activities Blockwork + internal finishes and External finishes are considered separately, time savings of 17.63 % and 23.88 % were observed respectively. Also, 11.26% of the overall duration of a project can be reduced just by mechanizing masonry and wall finishes' activities.

4 Conclusion

In India, mechanization is on its way to catching up with the rest of the world. Industry experts and professionals have realized that the project completion time as well as the working cost of the activities can be reduced if the activity is mechanized. But High capital investment, the requirement for skilled resources to operate and Increased maintenance costs that tag along with the adoption still worry them. As observed in foreign countries, Foundation works and Site clearance and preparation are the most mechanized construction stages in India too as they involve the currently highly mechanized activities such as Earthworks, batching & mixing and concreting. But Masonry activities, painting/ finishing works and Tiling/laying activities are yet to be mechanized especially in the state of Kerala. So, here the study attempted to assess the implication of cost and time of masonry work and wall finishes based on factors specific to Kerala to encourage the adoption of mechanization in these activities. And as a result, it is observed that when activities are considered individually, a time savings of 55 to 75 % and cost savings of 40 to 67 % can be incurred if mechanization is employed. Also, an overall reduction of 11.26 % in the duration of a project can be achieved just by mechanizing masonry and wall finishes' activities. In Kerala, despite the availability of indigenous equipment for the execution of activities like masonry work, the usage is found to be on the lower side. The promising results of the analysis will encourage industry professionals to employ advanced equipment like the Block laying robot to improve the productivity of the work.

References

1) Love PED, Teo P, Ackermann F, Smith J, Alexander J, Palaneeswaran E, et al. Reduce rework, improve safety: an empirical inquiry into the precursors to error in construction. *Production Planning & Control*. 2018;29(5):353–366. Available from: https://doi.org/10.1080/09537287.2018.1424961.
2) Hwang BG, Shan M, Ong JJM, Krishnankutty P. Mechanization in building construction projects: assessment and views from the practitioners. *Production Planning & Control*. 2020;31(8):613–628. Available from: https://doi.org/10.1080/09537287.2019.1667547.
3) Deshmukh A. A review on need of implementation of modern construction techniques and equipment in Indian construction sector. *International Journal of Applied Research*. 2017;3(8):379–386. Available from: https://www.allresearchjournal.com/archives/2017/vol3issue8/PartF/3-8-18-990.pdf.
4) Kamaruddin SS, Mohammad MF, Mahbub R. Barriers and Impact of Mechanisation and Automation in Construction to Achieve Better Quality Products. *Procedia - Social and Behavioral Sciences*. 2016;222:111–120. Available from: https://doi.org/10.1016/j.sbspro.2016.05.197.
5) Iheama NB, Alinta-Abel U, Ezeokoli OF. Evaluation Of Mechanization In Building Production As A Way Of Cost Reduction A Study Of Some Construction Sites In Enugu South Local Government Area. *British Journal of Environmental Sciences*. 2017;5(2). Available from: http://www.eajournals.org/wp-content/uploads/Evaluation-of-Mechanization-in-Building-Production-as-a-Way-of-Cost-Reduction-a-Study-of-Some-Construction-Sites-in-Enugu-South-Local-Government-Area.pdf.
6) Kumar P, Balasubramanian V, Raj M, S. Robotics in Construction Industry. *Indian Journal Of Science And Technology*. 2016;9(23). Available from: https://doi.org/10.17485/ijst/2016/v9i23/95974.

7) Babatunde LA, Adegoke BF, Adejumobi MK, Olukoya BF. Professional's View on the effects of Mechanization on Construction Cost of Building Projects In Nigeria. *International Conference of Science, Engineering & Environmental Technology (ICONSEET)*. 2019;4(13):103–111. Available from: https://iaeme.com/MasterAdmin/Journal_uploads/IJCIET/VOLUME_9_ISSUE_13/IJCIET_09_13_201.pdf.
8) Sharmila S, Devadoss RS, Mathew F. Impact Of Mechanisation In Construction Projects In India. *International Journal of Civil Engineering and Technology*. 1998;9(13). Available from: https://iaeme.com/MasterAdmin/Journal_uploads/IJCIET/VOLUME_9_ISSUE_13/IJCIET_09_13_201.pdf.
9) Joshi M. High-Rise Apartment Buildings As A Sustainable Building Typology In The Indian Subcontinent. *International Journal Of Engineering Sciences & Research Technology*. 2018;7(1):27–40. Available from: https://doi.org/10.5281/zenodo.1133555.
10) Chandran A, Chacko CM. EXPLOITATION OF IN-MIGRANT CONSTRUCTION WORKERS IN KERALA: A CASE STUDY. *Scholarly Research Journal for Interdisciplinary Studies*. 2017;4(37). Available from: https://doi.org/10.21922/srjis.v4i37.10825.
11) Gunduz, & Nielsen M, & Yasemin, Ozdemir M. Quantification of Delay Factors Using the Relative Importance Index Method for Construction Projects in Turkey. *Journal of Management in Engineering*. 2013;29. Available from: https://doi.org/10.1061/(ASCE)ME.1943-5479.0000129.
12) Tholibon DA, Nujid MM, Mokhtar H, Rahim JA, Aziz NFA, Tarmizi AAA. Relative Importance Index (RII) In Ranking the Factors of Employer Satisfaction Towards Industrial Training Students. *International Journal of Asian Education*. 2021;2(4):493–503. Available from: https://doi.org/10.46966/ijae.v2i4.187.
13) Rooshdi RM, Majid RR, Sahamir MZ, Ismail SR, A N. Relative Importance Index of Sustainable Design and Construction Activities Criteria for Green Highway. *Chemical Engineering Transactions*. 2018;63:151–156. Available from: https://doi.org/10.3303/CET1863026.