

How Do Aluminum Formwork Systems Perform in High-rise Residential Buildings in India with Respect to Construction Efficiency and Reusability Under Real Site Conditions?

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ABSTRACT: In India, building tall residential buildings often uses aluminum formwork systems because they allow for quick construction and can be reused. However, there is rarely an assessment of how well these systems perform in real construction sites. To fill this gap, the study looks into how efficient these systems are and how reusable they are in actual site conditions. Using firsthand data from an ongoing high-rise project, such as schedules, labor deployment, on-site observations, and repair records, the study measures efficiency by examining how long it takes to complete each floor and the amount of labor used. Reusability is evaluated by looking at how many times the Formwork can be reused, how often repairs are needed, and how much material is wasted. The results of this study provide practical insights and a method for better planning and management of formwork systems. The study concludes that with proper planning, handling, and management on-site, aluminum formwork can lead to faster construction across multiple floors, fewer repairs, and more reuse cycles.

KEYWORDS: High-rise Construction, Aluminum Formwork Systems, Formwork Reusability, Construction Efficiency, Labor Productivity, Floor Cycle Time.

■ Introduction

In India, high-rise residential construction is always associated with tight schedules, high material demands, repetitive structural layouts, and labor efficiency requirements. In such projects, effective planning and faster construction are crucial for overall project performance. Construction speed in high-rise buildings is strongly influenced by the type of formwork system used.¹ The selection of an appropriate formwork system directly affects labor productivity, material usage, construction cycle time, and surface finish quality. The relationship between formwork systems and project performance has been examined in several engineering studies by Thiyagarajan *et al.* and Hurd.^{2,3} Formwork is a temporary system used to support, hold, and shape freshly placed concrete until it gains sufficient strength to carry loads. Formwork accounts for a significant portion of the total cost and time in reinforced concrete structures, especially in wall-slab systems. Studies on high-rise construction also show that repetitive floor layouts improve the efficiency and reusability of formwork systems.⁴ Aluminum formwork systems are designed for repetitive high-rise construction as they are modular and panel-based. These systems use prefabricated aluminum panels to cast slabs and walls in a largely monolithic manner, allowing construction cycles to be repeated floor by floor. Previous studies comparing aluminum and conventional formwork systems indicate that the lower weight and higher dimensional accuracy of aluminum panels enable faster erection and de-shuttering, which reduces construction time and labor dependence.⁵ These studies also suggest that aluminum formwork systems can achieve high reuse cycles when managed properly. However, several studies have clearly suggested

that the actual performance of aluminum formwork systems depends strongly on site-related factors such as handling practices, storage conditions, workforce skill levels, and planning quality.^{1,6} In practice, aluminum formwork performance is often judged based on supplier recommendations or past experience rather than direct measurement on construction sites. This creates a research gap, as project-based information on construction speed, labor productivity, reuse cycles, repair frequency, and material losses is rarely documented for Indian high-rise projects. Without empirical evidence, engineers and project managers rely mainly on assumptions that may not reflect actual site performance. Prior studies of formwork systems have similarly indicated the need for empirical, site-specific data so that assumed performance benefits can be validated.^{1,4} Therefore, a site-based evaluation is required to support technical decision-making and improve formwork management practices in the Indian construction context. This study addresses this gap by evaluating the performance of aluminum formwork systems at a real high-rise residential construction project in India. The central research question is: Do aluminum formwork systems, when properly planned, handled, and managed, give better and improved construction efficiency and higher reuse performance across successive floors in real site conditions? The study specifically examines construction efficiency using floor cycle time and labor deployment as indicators, and material reusability using achieved reuse cycles, repair frequency, and material wastage. This study addresses this gap by carrying out a site-based evaluation of aluminum formwork systems used in a high-rise residential construction project in India. The study focuses on construction efficiency,

measured using indicators such as floor cycle time and labor requirement, and material reusability, measured using achieved reuse cycles, repair frequency, and material wastage.

■ Material and Methods

This study follows an empirical, site-based research approach. The analysis is based mainly on primary data collected directly from a real high-rise residential construction project in India. Secondary literature is used only to support background understanding, selection of performance indicators, technical calculations, and standard engineering practices.

Study Area and Project Description:

The selected project for this case study research is Sobha International City, located in Sector 109, Gurugram, near the Dwarka Expressway. Refer to Figures 1 and 2. The project is developed by SOBHA Limited, a reputed, well-established real estate developer known for large-scale residential projects and quality construction practices.

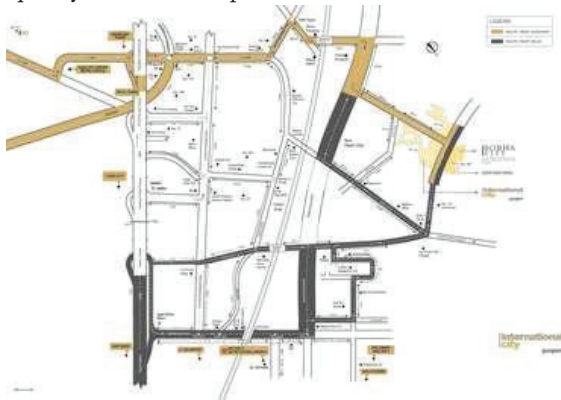


Figure 1: Project location map: Sobha International City, Sector 109, Gurugram.

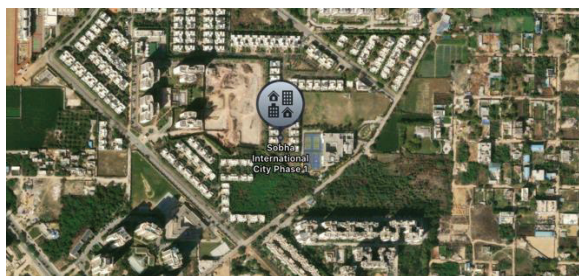


Figure 2: Satellite image: Sobha International City.

The project consists of high-rise residential towers with repetitive floor layouts and reinforced concrete wall-slab structural systems, as shown in Figure 3. Aluminum formwork is used for the wall and slab construction on multiple floors. The repetitive structural configuration and organized construction layout make this project suitable for evaluating construction efficiency and material reusability of aluminum formwork systems. The location near the Dwarka Expressway provides good accessibility for material movement, labor mobilization, and equipment operation, which supports continuous construction activities.

Refer to Table 1 for project information such as location, building type, number of floors, and typical floor area.

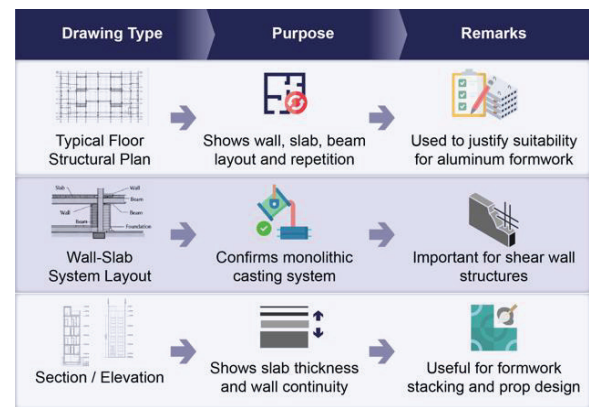


Figure 3: Analysis of structural drawings justifying aluminum formwork system suitability.

Table 1: Project information gathered from the site engineer at Unimax International, part of the Max Group.

Parameter	Details
Project Name	Sobha International City
Location	Sector 109, Gurugram, Haryana, India
Developer	SOBHA Limited
Project Type	High-rise residential development
Structural System	Reinforced concrete wall-slab system
Formwork System Used	Aluminum formwork system
Number of Towers (Studied)	2
Number of Floors per Tower	G+20 to G+30
Typical Floor Area	3000–3500m ² per floor
Construction Method	Monolithic wall and slab casting
Site Layout	Organized layout with repetitive floor configuration
Connectivity	Located near Dwarka Expressway

Data Sources and Data Collection:

Data were collected through direct site-based observation and review of construction records. Laboratory testing was not involved in this study. Observations were carried out during ongoing construction activities to understand actual site conditions, including formwork erection, concreting, stripping, handling, and storage of aluminum formwork panels.

Primary Data Sources:

Primary data were collected from the following sources:

Site observations during the erection, concreting, and de-shuttering of formwork; construction schedules showing actual floor cycle durations; labor deployment records for typical floors; reuse and repair records maintained by the formwork team; interviews and informal discussions with site engineers and supervisors; using multiple data sources helped improve the reliability, accuracy, and consistency of the collected information. Appendices referenced: Appendix A: Sample of site observation sheets and Appendix B: Interview questionnaire format.

Performance Indicators:

The following parameters were selected for evaluation using commonly adopted indicators from previous formwork studies:

Construction Efficiency, Floor cycle time (days per floor), Labor deployment per floor, Reusability, Number of reuse cycles achieved, Repair frequency, Material wastage

These indicators are widely used in studies related to formwork performance.

Procedure

- Data collection was carried out floor by floor during regular site visits. The sequence of activities followed during data collection included:
- Observing aluminum formwork erection and de-shuttering processes across multiple floors
- Recording actual floor cycle times from construction schedules
- Collecting labor deployment data from site records
- Reviewing reuse and repair information with the formwork team
- Cross-checking collected data with site engineers to ensure accuracy
- To ensure consistency across different floors and reduce errors in reporting, this procedure is followed.

Engineering Design Checks:

Standard engineering checks related to fresh concrete pressure, load on props, panel deflection, and safe de-shuttering were considered as part of normal construction practice to ensure safe and repeatable use of aluminum formwork systems on site. These checks were to maintain safety and quality controls during construction.

Detailed formulas, assumptions, and sample calculations based on relevant codes and standards are presented separately in Appendix C.

Data Analysis Method:

The collected data, which refer to Figure 4, were analyzed using simple comparative and trend-based methods: Planned and actual floor cycle times were compared to study construction efficiency; labor deployment trends were reviewed across repeated floors; reuse cycles and repair records were analyzed to identify patterns related to panel type and handling practices.

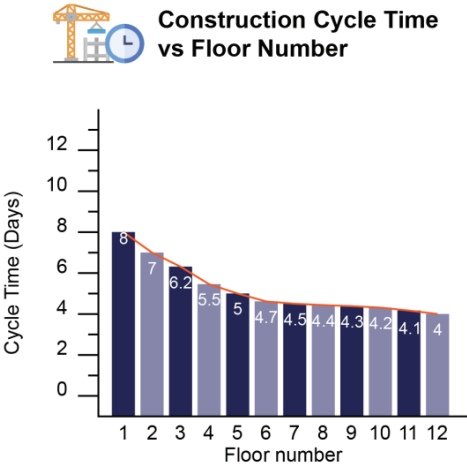


Figure 4: Decreasing floor-wise construction cycle over progressive floors.

Data Limitations and Adjustments:

During the Initial stages of construction, complete records for some floors were not available, and repair information for a few panels was not clearly updated. These issues were taken care of through discussions with the site supervisor and by observing additional floors. In cases where exact values were

not available, average values were used. Such adjustments are commonly adopted in practical construction site studies.

Results and Discussion

Construction Efficiency:

The aluminum formwork system requires a floor cycle time of 8 to 9 days per floor in the studied project. Previous studies on conventional formwork systems report typical floor cycle times in the range of 12 to 15 days per floor, which are used here only for reference from the literature.

Table 2: Construction efficiency benchmark.

Parameter	Present Study (Aluminum Formwork)	Literature Benchmark (Conventional Formwork)
Observed Floor Cycle Time	8–9 days per floor	12–15 days per floor
Data Source	Site construction schedules, Sobha International City, Gurugram	Thiyagarajan <i>et al.</i> (2017) ¹ ; Supriyono <i>et al.</i> (2025) ⁴
Construction Type	Repetitive high-rise residential, R.C. wall-slab system	Conventional timber/plywood formwork, multi-story R.C. structures
Remarks	Cycle stabilized after 3–4 repetitions following initial learning period	Typically longer due to sequential assembly and lower panel reusability

This comparison clearly shows a difference in construction time when aluminum formwork is used under repetitive conditions. During the initial floors of the project, the cycle time was slightly higher due to a combination of factors. These included the initial learning period as workers became familiar with the aluminum formwork system, as well as the greater structural complexity typically associated with lower floors. Lower floors commonly contained more complex reinforcement layouts, higher fresh concrete pressure due to larger concrete head, a higher density of openings such as doors and windows, and more detailed corner and junction connections. These conditions increased the time required for accurate panel setting, alignment, and support, which contributes to longer cycle times independent of worker experience. However, after 3 to 4 repetitions, the structural layouts became more uniform, and workers better developed familiarity with the aluminum formwork system. As a result, the cycle time became stable and consistent, indicating improved workflow and coordination. Labor deployment ranged between 70 and 90 workers per floor. The proportion of skilled labor was approximately 25 to 30 percent, while the remaining workforce mainly consisted of semi-skilled labor. For this research study, skilled labor refers to workers who have previous experience in aluminum formwork operations, including carpenters and formwork supervisors who can independently interpret construction drawings, align panels correctly, and operate lifting equipment. Semi-skilled labor refers to workers with general construction site experience who are assigned repetitive tasks such as carrying panels, prop placement, and routine cleaning, under the direct supervision of skilled workers. These labor categories are consistent

with standard labor classifications generally followed on Indian construction sites.

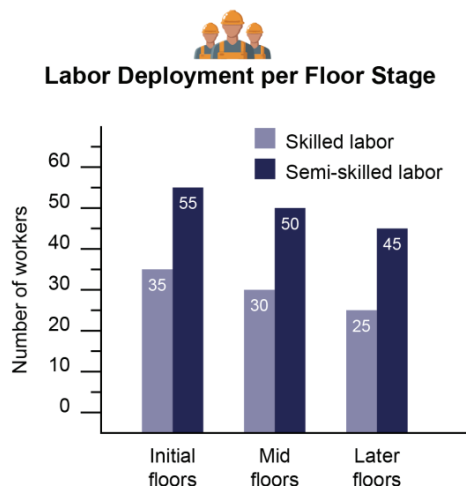


Figure 5: Labor deployment for aluminum formwork operations is decreasing per floor stage over time.

As the number of repetitions increased, workers became more familiar with the aluminum formwork system, which led to a gradual improvement in labor productivity. Overall, these results show that aluminum formwork supports shorter and more stable construction cycles in repetitive high-rise construction. Figure 5 shows the number of workers engaged per floor during aluminum formwork operations.

As shown in Figure 6, the floor cycle time reduced and stabilized after repeated use of the aluminum formwork system, reflecting a learning curve effect.

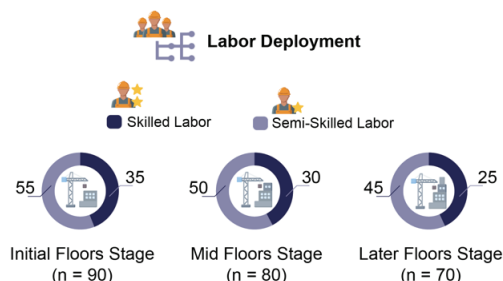


Figure 6: Learning curve effects in aluminum formwork: stabilization of cycle time and reduction in labor deployment across repeated floors.

Reusability:

Aluminum formwork systems offer high reuse potential (refer to Figure 7 and Figure 13) and long service life when compared to timber and plywood formwork systems, which can only be reused a limited number of times. Properly maintained aluminum panels can be reused across multiple construction cycles. According to Thiyagarajan *et al.* (2017), aluminum formwork panels are capable of achieving up to 200 to 300 reuse cycles, reducing the need for frequent replacement of formwork materials. High repetition reduces the total quantity of formwork required over the project duration and lowers long-term construction costs. Aluminum panels with good durability also maintain dimensional accuracy and shape over repeated uses, which helps in achieving consistent concrete quality and reduces rework. In this project, standard wall and

deck panels have shown high rates of repetition with minimal damage, supporting the benefits in terms of durability reported in earlier studies.

In terms of long-term material performance, aluminum panels maintain dimensional accuracy and surface condition across repeated cycles when proper maintenance is followed. According to Thiyagarajan *et al.* (2017),¹ aluminum formwork panel is capable of achieving 200 to 300 reuse cycles under appropriate handling and storage conditions. High repetition reduces the total quantity of formwork required over the project duration and lowers long-term construction costs. The high reuse potential observed in the present project is consistent with these published values and confirms that the durability of aluminum formwork is closely tied to site management practices rather than material limitations alone.

Formwork Panel Reuse Cycles Comparison

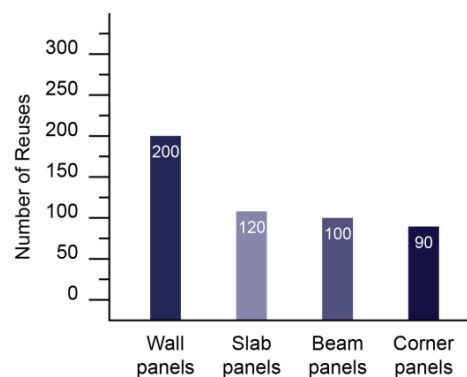


Figure 7: Higher reuse cycles achieved by different aluminum panel types.

These findings indicate that aluminum formwork systems can achieve high reuse levels when proper inspection and maintenance practices are followed on site. Figure 7 shows how the number of reuse cycles changes among different aluminum panel types. Figure 8 shows how often repairs are required and the types of damage observed during repeated use. Site observations gave a practical insight into the on-site performance of aluminum formwork systems.



Damage Frequency by Panel Type

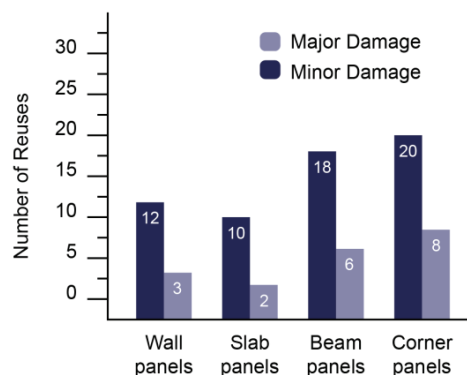


Figure 8: Damage frequency by panel type: corner and beam panels exhibit the highest susceptibility to both minor and major damage.

Most panel damage was observed during the stripping and shifting stages. In several cases, rough handling during the removal of panels caused bending at the edges and minor surface dents. Panels that were handled carefully showed fewer defects and could be reused for a greater number of cycles.



Figure 9: Proper stacking of panels for reducing contact damage and surface wear.

Storage practices also had a significant impact on panel condition. Panels that are stored in designated storage areas with wooden battens placed in between are found in better condition than panels stacked directly on the ground. Proper stacking of panels reduced contact damage and surface wear significantly. These observations show that handling and storage practices play a critical role in maintaining the overall quality of formwork and achieving higher reuse rates.



Figure 10: The damaged panel during de-shuttering was caused by improper handling.

Figure 9 shows the organized storage of aluminum panels using wooden battens to prevent damage. Figure 10 presents common panel damage caused by improper handling during de-shuttering.

Sustainability, Cost Efficiency, and Environmental Impact:
Sustainability performance is an important consideration in modern high-rise construction, particularly in projects where

repetitive use, material efficiency, and environmental impact are major concerns. Aluminum formwork systems are increasingly adopted not only for construction speed and surface quality, but also for their reusability, recyclability, durability, and long-term environmental benefits. This section discusses the sustainability, cost efficiency, and environmental impact of aluminum formwork systems based on site observations and supported by published research.

Reuse cycles		
Panel Type	Average Reuse Cycles	Remarks
 Wall Panels	150	 Higher life with proper handling
 Slab Panels	120	 Surface needs regular cleaning
 Beam Panels	100	 More stress during stripping
 Corner Panels	90	 Damage-prone during shifting

Figure 11: Wall panels exhibit maximum longevity among formwork components.

Aluminum can be recycled multiple times (refer to Figure 11) without loss of quality or strength, making aluminum formwork suitable for sustainable construction practices. According to the International Aluminum Institute, more than 90% of aluminum used in construction is recyclable, and producing aluminum from recycled material requires only about 5% of the energy needed to produce aluminum from raw bauxite.⁷ This high recyclability means that:

Scrap aluminum obtained from damaged or retired panels can be recycled. End-of-life formwork systems do not become landfill waste. Material value is recovered at the end of service life. In the present project, damaged panels and scrap aluminum were either returned to the supplier or sold to authorized recyclers, supporting circular economy practices (refer to Figure 12).



Figure 12: Scrap aluminum storage and recycling arrangement on site supporting circular economy practices.

Carbon Emissions in Manufacturing and Life-Cycle Impact:
The environmental impact of aluminum formwork systems depends mainly on the energy source used during aluminum production. According to the International Aluminum Institute, aluminum produced using hydropower has a carbon

footprint of approximately 10 tCO₂e per ton, compared to approximately 30 tCO₂e per ton for coal-based production.⁸ In India, electricity generation is largely dependent on coal and thermal power, which increases emissions during aluminum production. However, life-cycle assessment studies show that although initial emissions may be higher, the high reuse rate of aluminum formwork offsets this impact over time. Life-cycle studies on reusable formwork materials report that aluminum formwork systems have a lower overall environmental impact when evaluated over multiple reuse cycles compared to disposable timber formwork. This shows that aluminum formwork systems are environmentally favorable when assessed over their full-service life rather than only at the manufacturing stage, as shown in Figure 13.

Parameter	Reusable Aluminum Formwork	Conventional Wooden Formwork
 Lifespan	>250 times (Over 6 years)	Up to 20–40 time (less than 1 year)
 Reusability and Durability	High reusability, resistant to wear and tear	Prone to wear, swelling and degradation
 Maintenance	Low maintenance, simple cleaning and repair	Frequent repairs, prone to damage in handling
 Initial Cost	High, with return on investment over time	Low, but higher overall across multiple projects
 Overall Life Cycle Cost	Lower in long term due to higher lifespan & reusability	Higher due to frequent replacement and repairs

Figure 13: Aluminum's extensive reusability offsets initial manufacturing emissions, lowering overall life-cycle environmental impacts.

De-Shuttering Efficiency and Time Savings:

Aluminum formwork systems allow safe and early de-shuttering because of their accurate alignment and efficient support systems. According to IS 456:2000, formwork may be removed once the concrete has gained sufficient early strength to carry applied loads safely.⁹

Aluminum formwork systems enable:

1. Faster stripping of wall and slab panels
2. Reduced damage to concrete edges and corners
3. Shorter construction cycle times
4. Early de-shuttering helps reduce overall project duration
5. Equipment and crane running time
6. Indirect energy consumption on site

In the present project, faster de-shuttering contributed to achieving stable floor cycles of 8–9 days per floor, as discussed in Section 3. Refer to Figure 14 for a stripping time comparison of aluminum and conventional formwork systems.

Aluminum formwork provides high dimensional accuracy and a smooth surface finish, which improves the quality of cast concrete. According to M.K. Hurd,³ rigid and well-aligned formwork systems reduce honeycombing, concrete leakage,

and surface defects. Improved surface finish often eliminates the need for plastering and reduces remedial works. In the present project, only skim coating finishing was required, and plastering was largely eliminated. This resulted in: Lower consumption of cement, sand, and finishing materials; reduced labor requirement; lower energy use related to rework. Refer to Figure 15 for the concrete surface finish after de-shuttering

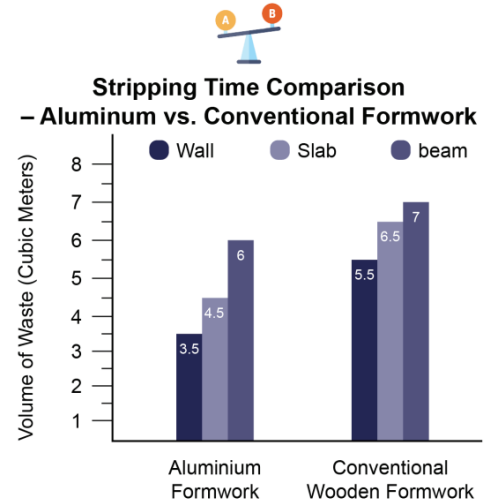


Figure 14: Aluminum formwork reduces stripping time across all components compared to conventional wooden formwork.

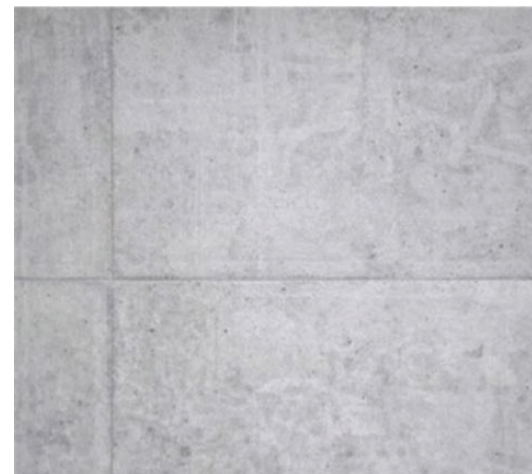


Figure 15: High-quality concrete surface finish achieved directly after de-shuttering.

Reduction in Construction Waste:

Traditional timber and plywood formwork systems generate high levels of construction waste. Refer to Figure 16 for a comparison of waste generation: aluminum vs conventional formwork, because traditional formwork is reused fewer times and disposed of after limited cycles. According to the Central Pollution Control Board (CPCB),¹⁰ construction and demolition waste is a major contributor to landfill volumes in urban India. Reusable aluminum formwork systems reduce timber consumption, plywood disposal, and on-site waste generation. In the present project, timber and plywood waste were minimal due to the extensive use of aluminum formwork.

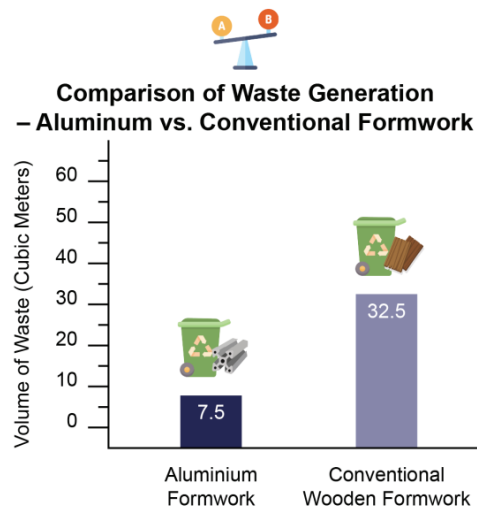


Figure 16: Aluminum formwork drastically reduces construction waste compared to wood.

Although aluminum formwork systems require a higher initial investment, their sustainability characteristics lead to long-term cost efficiency. According to Comparative studies published in IJRESM and IJARET, high reuse reduces cost per use; faster construction cycles reduce overhead costs; and reduced finishing work lowers labor and material expenses.^{4,11,12} As a result, aluminum formwork systems become economically favorable in large projects with repetitive layouts. Refer to Figure 17 for a cost comparison between aluminum & conventional formwork systems.

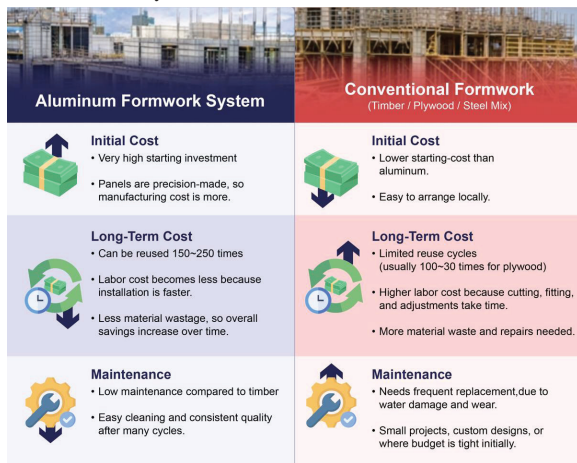


Figure 17: Comparison of Aluminum and Conventional Formwork Systems.

Contribution to Sustainable Development Goals (SDGs):

Aluminum formwork systems support different "United Nations Sustainable Development Goals". They support SDG 9 by promoting the use of advanced construction techniques, SDG 11 by improving housing delivery speed and reducing construction waste, and SDG 12 by supporting reuse, recycling, and circular construction practices. According to the United Nations Environment Program, material reuse and recycling play an important role in achieving sustainable urban development.¹³

Overall Sustainability Assessment:

From an environmental and practical perspective, aluminum formwork systems give several advantages, such as high reusability, full recyclability, reduced construction waste, improved concrete quality, faster construction cycles, and lower long-term cost. Although aluminum manufacturing may involve carbon emissions depending on the energy source, the overall life-cycle performance of aluminum formwork remains favorable when evaluated over multiple reuse cycles.

Effect of Planning and Construction Sequencing:

In this project, proper planning and construction sequencing played an important role in achieving shorter floor cycle times. After the initial learning period, the construction cycle stabilized at 8–9 days per floor, indicating that repetitive sequencing improved productivity and coordination. According to Thiyagarajan *et al.* (2017), aluminum formwork systems always perform better in projects with repetitive floor layouts and fixed construction cycles, as stable sequencing reduces delays and improves coordination between labor and activities.¹ Similarly, M.K. Hurd explains that well-planned formwork operations reduce idle time, ensure continuity in concreting, and minimize rework. In this study, floors completed after the sequencing process became more stable, showed fewer interruptions, and had more predictable cycle times. This supports the hypothesis that improved planning and sequencing contribute directly to better construction efficiency. Refer to Figure 18 for a typical construction sequence flowchart using aluminum formwork.

These findings of this project directly support the study's hypothesis that better planning and construction sequencing directly improve construction efficiency, as evidenced by the stable 8–9 day floor cycle achieved following sequence stabilization in the present project.

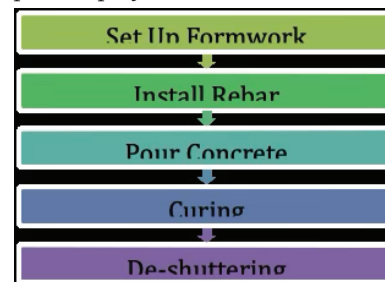


Figure 18: Construction sequence flowchart for improved construction efficiency.

Influence of Labor Skill and Training:

Labor skill level had a clear effect on construction speed and panel condition. During the initial floors, higher cycle times were observed due to unfamiliarity with aluminum formwork systems. After 3–4 repetitions, labor productivity improved and cycle times reduced, refer to Figure 19.

Formwork productivity studies reported in IJARET show that labor efficiency is directly connected with workers' experience in system formwork, due to learning curve effects in repetitive construction activities. Thiyagarajan *et al.* (2017) also reported that trained formwork teams achieve faster erection

and de-shuttering with fewer alignment errors and lower damage rates.



Learning Curve – Productivity Improvement Across Floors

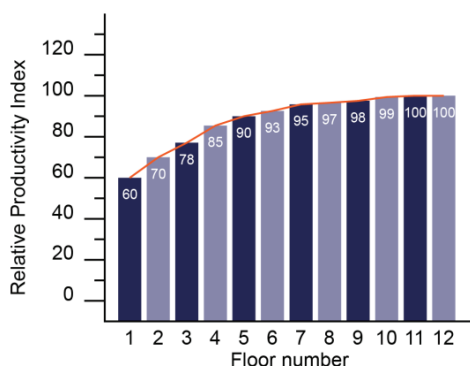


Figure 19: Repeated floor cycles significantly improve relative labor productivity.

In the present project, floors constructed after worker training showed:

1. Faster erection and stripping
2. Reduced dependence on skilled carpenters
3. Lower repair frequency

This indicates that labor training and experience are critical for improving construction efficiency and reducing damage to formwork panels, which supports the hypothesis as well.

This confirms the hypothesis that site management practices, specifically workforce training and skill development, are critical determinants of both construction speed and material performance and directly address the study's research question regarding efficiency under real site conditions.

Effect of Handling Practices during Stripping and Shifting:

The handling methods used for de-shuttering and panel shifting significantly affected the frequency of repairs and damage. In most of the observed cases, it is shown that bending and deformation of edges occurred due to improper stripping or careless handling during shifting. According to M.K. Hurd, poor stripping techniques can cause deformation of panels and reduce their service life.³ ACI 347 also highlights the importance of careful removal and proper lifting methods to avoid damage to both formwork panels and concrete edges.¹⁴ In the present project, refer to Figure 20; it is shown that panels that were stripped carefully and lifted using correct procedures showed fewer repairs, better dimensional stability, and higher reuse potential. This confirms that handling practices directly influence panel durability and reuse performance.

This finding directly supports the hypothesis by demonstrating that handling quality is a controllable site factor that governs reuse performance outcomes, independent of the inherent material properties of aluminum formwork panels.

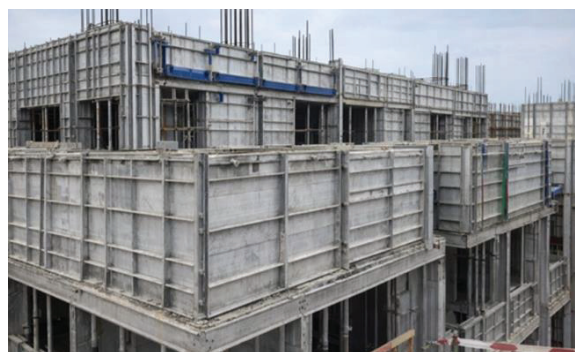


Figure 20: Correct handling and stripping procedures directly enhance panel reuse performance.

Influence of Storage Conditions on Reuse Performance:

Storage conditions had a direct impact on reuse performance. Panels that are stored in designated yards with wooden battens and proper stacking showed less deformation, surface damage, and alignment issues.

According to Thiyagarajan *et al.* (2017), improper stacking and exposure to moisture increase the risk of bending and surface damage.¹ The International Aluminum Institute also states that protection from physical damage improves the service life of aluminum products. In the present study, panels stored with wooden separators and without direct ground contact achieved higher reuse cycles and required fewer repairs. Figure 21 shows correct stacking and storage of aluminum formwork panels, which shows that storage methods play an important role in controlling repair frequency and extending panel life.

This reinforces the study's central argument that when aluminum formwork systems are properly managed, including through adequate storage discipline, they demonstrably deliver higher reuse performance, as proposed in the hypothesis.



Figure 21: Correct stacking of aluminum formwork panels using protective wooden separators directly extends panel reuse life.

Relationship between Site Practices and Reusability:

The reuse cycles recorded in this project, ranging from 200 to 250 repetitions, are consistent with values reported in earlier studies. Thiyagarajan *et al.* (2017) reported that, by following proper handling, storage, and maintenance practices,

aluminum panels can achieve up to 200 reuse cycles.¹ However, panels exposed to frequent impact, poor cleaning, or improper stacking showed earlier damage and required more frequent repairs. This indicates that reusability is influenced not only by material properties but also by site management practices.

Impact on Repair Frequency and Maintenance Cost:

Repair frequency in the project was directly related to handling methods and the type of panels used. Beam and corner panels required earlier maintenance due to higher stress concentration, complex geometry, and repeated handling. Studies reported in IJRESM have clearly indicated that frequent minor repairs can increase maintenance costs if preventive measures are not adopted.^{4,11,12} In the present project, regular inspection and minor repairs after every 10–15 cycles helped prevent major damage and avoid early panel replacement. This shows that timely maintenance improves panel durability and reduces long-term cost.

Overall, these findings confirm that repair frequency should not be considered a constant material property, but rather a factor that changes management practices and that timely maintenance protocols are very important for achieving the reuse potential that the hypothesis anticipated.

Sustainability Implications and Environmental Performance:

Beyond construction efficiency and reusability, the data collected from a real site in this study also offer insights into the broader sustainability performance of aluminum formwork systems. The high reuse cycles observed in this project directly support the environmental and cost-efficiency claims reported in prior research, and are discussed here in the context of life-cycle impact and sustainable construction practice.

Overall Interpretation of Results:

The discussion shows that although aluminum formwork systems have high technical potential, their actual performance depends mainly on: Planning and sequencing quality, Labor skill and training, handling during stripping and shifting, Storage discipline, and regular inspection and maintenance. These findings are consistent with earlier formwork studies. The results support the hypothesis that improved site practices lead to better construction efficiency and higher reuse performance. Aluminum formwork should therefore be considered not only as a material system, but as a management-controlled construction process, where final efficiency, reuse, and cost performance are determined by site practices.

■ Conclusion

This study evaluated the performance of aluminum formwork using data collected from a high-rise residential project at Sobha International City, Gurugram. The results show that aluminum formwork delivers faster construction cycles, high reuse, improved surface finish, reduced waste generation, and long-term cost efficiency as compared to other formwork systems. The engineering calculations are used properly in this project to ensure safe operation and acceptable construction

quality. At the same time, the findings also highlight the role of aluminum formwork in supporting sustainable construction practices and relevant SDG goals. The study demonstrates the importance of site-based evaluation and provides practical guidance for planning and managing aluminum formwork in future high-rise residential projects in India.

Recommendations for Construction Managers:

1. Based on the findings of this study, the following practical recommendations are made for construction managers planning to deploy aluminum formwork systems on high-rise residential projects:

2. Labor training should be conducted before starting formwork operations, with at least 3–4 supervised practice floors recommended to reduce the learning-curve effect on cycle time. Training of workers should specifically cover panel alignment, prop setting, and safe stripping techniques.

3. Storage protocols should require that all aluminum panels be stacked in designated storage yards on wooden battens, with a minimum of 50 mm separation between panels, and protected from direct ground contact and exposure to impact during shifting.

4. Regular inspections should be scheduled after every 10–15 reuse cycles for standard wall and deck panels, while beam and corner panels should be checked after every 8 to 10 cycles, which are more susceptible to deformation due to geometric complexity and handling stress.

5. De-shuttering operations should be carried out using designated lifting hooks and mechanical support equipment. Site instructions should clearly discourage manual dragging or dropping of panels during stripping.

Recommendations for Future Research:

This study is based on data from a single high-rise residential project in Gurugram, Haryana. Future research studies should broaden the scope by evaluating the aluminum formwork systems across several project sites in different cities of our country and climatic zones, including those regions that have high humidity, extreme temperature variation, or coastal exposure, which may affect panel degradation rates. Comparative studies between aluminum formwork and steel formwork systems under similar site conditions would also provide useful quantitative benchmarks. Additionally, a full life-cycle cost analysis that includes initial procurement, maintenance, repair, transportation, and recycling value at the end of service life gives strength to the economic case for aluminum formwork adoption in the Indian construction sector.

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■ Appendix A

Project Information

Project Name: Sobha International City

Location: Sector 109, Gurugram

Date of Observation: _____

Floor Number: _____

Observer Name: _____

1. Activity Details

Observation Item Details
Construction Stage ☐ Formwork Erection ☐ Reinforcement ☐
Concreting ☐ De-shuttering

Panel Type Observed ☐ Wall ☐ Slab ☐ Beam ☐ Corner

Work Area Room / Core / Slab / Wall Line

Start Time / End Time _____ / _____

2. Labor Deployment

Category Number of Workers

Skilled Labor _____

Semi-Skilled Labor _____

Helpers _____

Total Labor _____

3. Formwork Condition Check

Check Item	Yes / No	Remarks
Panels aligned properly	☐ Yes ☐ No	_____
Wall straightness checked	☐ Yes ☐ No	_____
De-shuttering oil applied	☐ Yes ☐ No	_____
Leakage control (timber support)	☐ Yes ☐ No	_____
Proper stacking of panels	☐ Yes ☐ No	_____

4. Damage / Repair Observation

Panel Type Damage Observed Action Taken

Wall Panel _____

Slab Panel _____

Beam Panel _____

5. Safety & Handling Practices

Proper lifting method used: ☐ Yes ☐ No

Rough handling noticed: ☐ Yes ☐ No

Storage yard condition: ☐ Good ☐ Average ☐ Poor

6. Cycle Time Notes

Planned activity for the day: _____

Actual progress observed: _____

Delay reason (if any): _____

7. Additional Remarks

■ Appendix B - Site Engineer/Supervisor Interview Questionnaire

Project: Aluminum Formwork Performance Study – High-Rise Residential Construction

Purpose: To collect practical insights from site engineers and supervisors regarding construction efficiency, reusability, handling practices, and on-site challenges.

General Information

1. Name of Engineer / Supervisor: _____

2. Role on Site: _____

3. Years of Experience in Formwork Systems: _____

4. Project Name / Tower: _____

5. Date of Interview: _____

Section A – Construction Efficiency

6. What is the typical floor cycle time observed using aluminum formwork?

7. What are the main reasons for delay during initial floors?

8. How does labor productivity change after repeated cycles?

9. What challenges are faced during erection and de-shuttering?

Section B – Reusability and Maintenance

10. What is the average reuse cycle achieved for wall, slab, and beam panels?

11. Which panel types require frequent repair or maintenance?

12. What are the common causes of panel damage on site?

13. How often are inspections carried out for aluminum panels?

Section C – Handling and Storage Practices

14. What procedures are followed during stripping and shifting of panels?

15. How aluminum panels stored after de-shuttering?

16. Are wooden battens or protective measures used during stacking?

o Approximate quantity: 2,000–2,500 panels per tower (indicative)

• Approximate Panel Weights:

o Standard Wall panels: Width 600mm, Height 2400mm-27 kg

o Standard Deck panels: Width 600mm, Height 1200mm-13.5 kg

4) Conventional Formwork Data

• Typical Floor Cycle Time:

o Aluminum formwork: 8–9 days per floor

o Conventional formwork: 12–15 days per floor

• Activity Sequence:

o Layout → Reinforcement fixing → Formwork erection → MEP Work → Supporting MS

• Change in Cycle Time with Progress:

o Initial floors showed longer cycle times due to learning effects

o Cycle time stabilized after 3–4 repetitions

5) Labor Data

• Number of Workers per Floor: 70–90 workers

• Skill Level Distribution:

o Skilled labor: approximately 25–30%

o Semi-skilled labor: approximately 70–75%

• Labor Requirement Across Cycles:

o Labor productivity improved progressively with repetition

o Dependence on skilled carpentry labor reduced after initial cycles

6) Reuse Cycle Records

• Number of Reuse Cycles Achieved: 200–250 cycles per aluminum panel

• Reuse Limits Followed on Site:

o Supplier-recommended Repetition limits

o Periodic inspection and quality control checks

• Variation in Reuse Between Panel Types:

o Standard panels exhibited higher repetition potential

o Beam and corner panels required earlier maintenance

7) Repair & Damage Records

• Frequency of Repairs: Minor repairs typically required after every 10–15 repetitions

• Common Types of Damage:

o Edge bending and deformation

• Main Causes of Damage:

o Improper handling during stripping and shifting

o Concrete leakage due to inadequate sealing

o Improper stacking and storage practices

8) Material Wastage Data

■ Response from the interview

1) Project Information - Sobha International City

• Project Name: Sobha International City

• City / State: Gurugram, Haryana, India

• Type of Building: High-rise residential development

• Number of Floors: Typically, G+20 to G+30 (varies by individual tower)

• Typical Floor Area: Approximately 3,000–3,500 m² per typical floor

2) Structural Drawings

• Typical Floor Structural Drawings:

o Reinforced concrete shear walls (internal and external)

o Reinforced concrete slabs (typical thickness 150–200 mm)

o Integrated/concealed beams where applicable

• Structural System Adopted:

o RCC shear wall-slab structural system

• Drawings Used for Formwork Planning:

o Structural Drawings

o Architectural Drawings

o MEP Drawings

3) Aluminum Formwork Layout & Panel Details

• Aluminum Formwork Layout Drawings:

o Wall panel layouts (internal and external)

o Slab soffit and deck layouts

o Beam side and soffit panel layouts

o Prop and deck support layouts

• Panel Schedule:

o Panel types: Wall panels, deck panels, beam panels, corner panels, kicker panels, Closing panels

o Standard Wall panel size: Width 600 mm; height 2400mm

● Quantity of Scrap Aluminum Generated:- It depends on the Next project.

● Handling and Storage Practices:

- Designated storage yards
- Panels stacked with wooden battens for separation and protection.

● Disposal / Recycling Method:

- Scrap aluminum sold to authorized recyclers or returned to vendors

9) Quality & Finish Observations

● Surface Finish Achieved: Smooth and uniform concrete surface

● Plastering / Remedial Work Requirement:

- Plastering eliminated
- Only putty required

● Quality-Related Site Observations:

- Improved dimensional accuracy and verticality
- Reduced rework and construction defects

10) Site Photographs

11) Cost Data (Indicative)

● Approximate Formwork Cost: ₹10,500–11,500 per m² (initial investment)

● Repair / Replacement Cost: Approximately 3–5% of total formwork cost over project lifecycle

● Labor Cost Difference: 20–25% reduction compared to conventional formwork

12) Supervisor Insights

● Ease of Use: High after initial training period

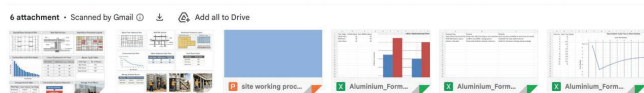
● Speed of Construction: Significantly improved due to repetitive and standardized operations

● Training Requirements: Approximately 7–10 days for workforce familiarization

● Practical Challenges:

- High initial capital investment
- Requirement for strict sequencing and coordination
- Changes in drawings cannot be made once the shell plan is approved

13) Other Construction Techniques / Conventional Formwork



■ Appendix C

Fresh Concrete Pressure on Formwork

$$P = \gamma \times h$$

Where:

P = pressure on formwork (kN/m²)

γ = unit weight of fresh concrete (≈ 24 kN/m³)

h = height of concrete (m)

This formula calculates wall pressure to prevent bending, leakage, and failure of aluminum wall panels. Reference: M.K. Hurd Concrete Formwork, ACI 347 Guide to Formwork for Concrete.

Pouring Rate and Temperature Effect

$$P = C \times R \times T$$

Explanation: This calculation helps control the increase in pressure caused by fast pouring and temperature changes, so that panels are not suddenly overloaded. Reference: ACI 347R Formwork for Concrete.

2.5.3. Load on Props:

$$W = A \times t \times \gamma$$

Explanation: This calculation is used to check the load coming on props so that slab collapse and excessive settlement during concreting can be avoided. Reference: IS 14687 Falsework and Formwork Code.

2.5.4. Spacing of Props:

Explanation: Proper spacing in props is important to give support to the slab during concreting. If the spacing is more, extra deflection may occur, and if it is too little, then unnecessary material and cost are added. Reference: IS 14687 - Falsework and Formwork Code, M.K. Hurd³ Concrete Formwork.

2.5.5. Bending Stress in Aluminum Panels:

$$\sigma = M / Z$$

Explanation: This check is important to make sure that aluminum panels do not bend permanently during concreting. By controlling the bending stress, the shape of the panels is maintained, and the same panels can be reused many times. Reference: Eurocode 9 Design of Aluminum Structures.

2.5.6. Deflection Limit:

$$\delta = (5wL^4) / 384EI$$

Explanation: Controls surface finish quality and prevents uneven walls and honeycombing.

Reference: IS 456,⁹ M.K. Hurd.³

2.5.7. Safe De-Shuttering Time:

$$ft \geq 0.7 f_{ck}$$

Explanation: Ensures concrete gains sufficient strength before stripping to avoid cracks and collapse. Reference: IS 456:2000

2.5.8. Productivity Calculation :

$$\text{productivity} = (\text{floor area}) / (\text{cycle time} \times \text{labour floor area})$$

Explanation: Measures construction speed and labor efficiency per floor cycle. Reference: IJRESM, IJARET.