Construction process optimisation and cost analysis in assembly building project management

Jun Yu

Anhui Poly Real Estate Development Co., Ltd., Hefei, Anhui, 230000, China

Keywords: Prefabricated construction; Construction process optimization; Project management; Cost analysis; BIM technology

Abstract: With the continuous transformation and upgrading of the construction industry in China, prefabricated construction has gradually become a green, low-carbon and efficient mode of building. However, in practical execution of the project, prefabricated construction involves several stages including component design, production, transportation, hoisting and on-site construction; so it often suffers from poor integration of various relevant processes (e. g., low management efficiency and difficult cost control). In this paper, construction process optimization and cost analysis are examined to investigate the characteristics of prefabricated building project management. It points to major problems including multi-layered construction organisation, challenging supply chain management and significant on-site supervision needs. It suggests process optimization approaches in three fronts—design-construction integration, supply chain and logistics management, as well organization of construction with on-site management underlining the importance of BIM technology and digital tools to improving collaborative efficiency. The cost structure of prefabricated construction is analyzed, and standardized design, production in scale and the whole detailed management process all are proposed as an approach for cost reduction and efficiency improvement. The new mode of optimized construction process in science has been proven to shorten project duration and improve quality as well as effectively reduce overall cost, thus providing management ideas and practical reference for the promotion of prefabricated construction.

1. Introduction

With the transformation of China's construction industry from extensive to intensive and green development, prefabricated buildings are currently emerged as one of the important directions for the development of the industry, which has also won widespread attention because it is considered an energy-efficient and environmentally friendly building model, with short construction period and controllable quality [1]. Prefabricated construction reshapes building methods with factory-made elements and rapid assembly on-site, in stark contrast to classic cast-in-place practices [2]. This approach is integrated into the national “dual carbon” strategic layout, and also takes industrialization and intelligent development in construction to a further level [3].

The practical application of prefabricated construction projects faces many management challenges [4]. On the one hand, prefabricated construction is a multi-stage process consisting of five stages from design, production to transportation, hoisting and installation. Delays or errors at any stage can break/ disrupt the entire progress leading to poor quality and schedule abnormalities on site [5]. Component standardization, on-site construction organization efficiency, and supply chain coordination directly affect the cost of construction [6]. The trade-off between cost reduction and the assurance of quality and safety is still a key issue in prefabricated construction management. This tension where optimising construction workflows and controlling costs become more at odds with each other becomes especially apparent in the large-scale implementation phases of a project.

Various aspects of prefabricated construction management have been studied in academic literature, such as the integration of BIM technology throughout lifecycle, supply chain optimization strategies, and smart construction methods among others. These have made various pain points in project management a bit more bearable! Nevertheless, existing research and practices remain incomplete in systems and management models needing improvement. The problem of how to construct a scientific

DOI: 10.25236/icacel.2025.179

and efficient construction process management system suitable for the characteristics of prefabricated buildings, and form a systematic transparency cost analysis control measures have become a common elegant topic; it is urgent to conduct further research.

This paper explores the characteristics and challenges of prefabricated building project management through "construction process optimization and cost analysis." The pathway should consist of: integrated design and construction; supply chain and logistics management; and construction organization and site management. The target cost control strategies are presented to give a reference for the high-quality development of prefabricated construction according to analyzing the characteristics of cost composition.

2. Characteristics and Challenges of Prefabricated Building Project Management

As a guideline for the transformation and upgrading of the construction industry in recent years, prefabricated construction is significantly different from traditional cast-in-situ [7]. An essential characteristic is the factory manufacturing of components and fast site assembly. This effectively shortens construction schedules, wet operation, as well as environmental pollution, and improves the controllability of building quality with regard to front-loaded fabrication processing and standardized construction workflows. But this "front-end dependency" model also creates management challenges. Components are so interdependent in design, production, transportation and delivery and a lot more that the aforementioned processes can not be separated from each other. Lack of design adherence or insufficient production control directly results in installation problems which could necessitate rework and lead to delays which increases project risks and costs. Total project cost decomposition

$$C_{total}=C_{design}+C_{production}+C_{transport}+C_{installation}+C_{management} \quad (1)$$

Prefabricated building management has more stakeholders and collaborative stages than traditional construction. The sharing of information and coordination of construction schedule among design firms, component factories, transportation companies, construction contractors and supervision agencies must be fully connected and kept online. If any one link in the chain is delayed, it can create bottlenecks that affect progress and quality across all links. Inadequate coordination of transportation and installation schedules can result in idle lifting equipment and labor, leading to additional costs [8]. Similarly, if such design information is not delivered timely, it can lead to component mismatches with the on-site structures which in turn leads to stoppage of construction. Because prefabricated construction management requires a higher level of end-to-end coordination and real-time control than traditional models;

Prefabricated building construction organization has special characteristics. On-site operations rely several construction machinery, lifting path, and components stacking sequence as the core of on-site manufacture only for lift and assembly large parts. Improper planning at the site layout stage, transportation routes and component storage management can result in working overlap between construction workers in confined areas, overcrowding on-site and machinery accident [9]. This precise demand for organization and scheduling puts forward higher requirements for the overall planning and on-site control ability of managers,showed in Figure 1 :

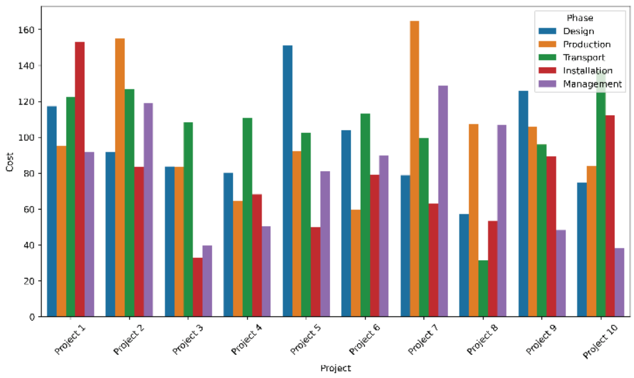

Figure 1 Cost composition by project phase

There are also many barriers in prefabricated construction for quality and safety management. The quality of the project is not only influenced by the construction methodologies on-site but also directly corresponds to the accuracy during manufacturing components. Dimensional tolerances in factory-built components can lead to difficulties assembling on site, putting the overall structural integrity at risk. Repeated high-altitude servicing of large-volume components exposes people to hazards significantly exceeding those in conventional construction. Since node connections and structural assemble are the key phases of the operation, any deviation from procedural directions may generate alarming safety risk [10]. As a result, quality and safety management should cover the entire lifecycle from the production of factory to construction on site.

Concerning costs, the development phase for prefabricated construction falls into a relatively high investment regime. Component strips must be produced in bulky factories, transportation equipment requires heavy machinery and hoisting. BIM technology and digital platforms, also needed to manage construction sites, add even more direct and indirect costs to projects. Inefficient construction workflows or resource allocation will put more pressure on cost control, which in turn slows the adoption rate and negatively impacts market competitiveness of prefabricated construction. Time–cost trade-off function

$$C(T)=C_0+\alpha \cdot \frac{1}{T} \quad (2)$$

At the management level, prefabricated construction is characterized by strong process front-loading, complex coordination requirements, meticulous organizational needs, prominent quality and safety risks, and significant cost control pressures. Those issues reflect the fact that prefabricated construction is different from conventional methods and raises new project management challenges. We should solve them by optimization of quite scientific construction process and systemic cost analysis.

3. Pathways and Strategies for Construction Process Optimization

Prefabricated construction projects are inherently complex and challenging, requiring a comprehensive and systemic approach for optimizing processes in these types of projects. This optimization is not a series of isolated improvements; it involves the entire life cycle from design, production, transport and installation through to post-construction management—a team sport across many players and interdependent phases. Only by means of effective cooperative mechanism and scientific management model can the quality, schedule and cost of prefabricated buildings be kept within the reasonable range. This can be achieved through three main methods that focus on optimization of the construction process: 1. Additionally, Generalize the recognition and thinking based on the practices in their respective field Strengthening pre-construction planning and information-sharing through integrated design-construction management; take BIM technology as the core to achieve full-process coordination. 2. Supply chain and logistics management optimization for smooth interlinking of component manufacturing, transport, and on-site installation to prevent time wastage and resource overdose. 3. Optimizing construction organization and site management to improve the rationality of process sequencing and on-site safety, thus achieving double improvement in construction efficiency as well as management benefits.

3.1 Integrated Design and Construction Management

Integrated design and construction management is the primary task of prefabricated building construction process optimization. In contemporary construction methodologies, particularly off-site construction assemblies (prefabricated structures), all the components need to be factory-prefabricated and brought together on site for assembly, unlike conventional design which operates quite independently from its construction. Therefore, the design phase needs to take production and installation feasibility into account from day one. Poor communication between design and construction teams can result in components not aligning with on-site conditions, resulting in knock-on effects of rework or delays, and quality issues. We need cross-disciplinary and cross-organizational mechanism to work closely together early in the project, so that design outputs are tightly aligned with construction needs (so that they do not waste time/money), this allows seamless transfer and sharing of information. Standardization effect on unit cost

$$C_{unit}=\frac{C_{fixed}}{Q}+C_{variable} \quad (3)$$

The building information modeling (BIM) technology is at the core of this process. The BIM platform not only supports modeling in three-dimensional visualization of the building components, but also parametric design that simulates component dimensions and joint detail as well as construction techniques. It allows them to catch and resolve conflicts before they might become an issue during the design phase. Doing so effectively decreases uncertainties at the construction site, while also significantly improving design versus construction alignment. Integrating BIM technology with construction schedules and cost budgets can also build a lifecycle information management platform for providing a scientific basis for subsequent production and installation.

Integrated management is also sublimated to unified and modular conception. The standardization of elements is vital for the economic sustainability and efficiency of prefabricated construction. Standardizing design and promoting modularization gives the potential to lower design complexity, production costs whilst improving interchangeability and applicability of components. Adopting standardized design reduces the error of on-site installation and enhances construction efficiency and safety. By working closely with design and construction teams early on in establishing standards and modular solutions, there is less rework during the design phase and more prescriptive drawings/plans going into the actual build. Cost performance index (CPI)

$$CPI=\frac{EV}{AC} \quad (4)$$

Integrated design-construction management needs a feedback loop. Unexpected events can also happen during the construction phase – for instance, alterations in site, design details to cater to constraints of construction methods or modifications towards supply of materials may be needed that could not have been planned ideally at the design stage. Integrated management is the need of the hour to facilitate issues arising on site to be reported back to the design team in real time and rectify any shortcomings through digital platforms for continuous and logical execution. Through this “closed-loop management,” design transforms from a deliverable into a dynamic, interactive process in synchronization with the construction practice and realizes scientific control in the whole life cycle.

3.2 Optimizing Supply Chain and Logistics Management

Supply chain and logistics strategies are essential for the successful implementation of prefabricated buildings. Because the production, transportation and installation of components is so closely interlinked, delays in any one stage can cause overall construction timelines to slip. Implemented such optimization in logistics management directly improves project efficiency,showed in Figure 2 :

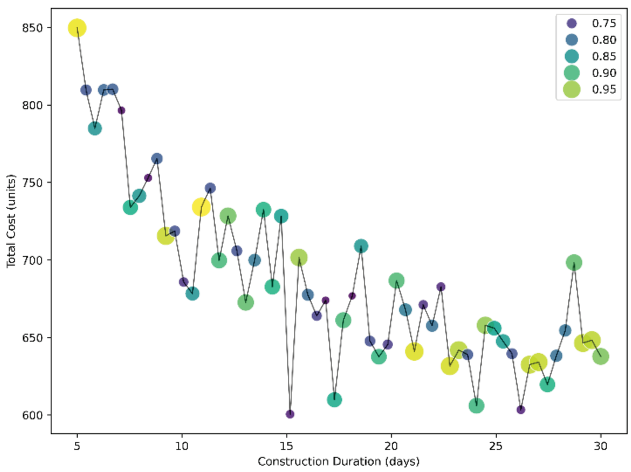

Figure 2 Time vs Cost trade-off with variance

Supply chain optimization must start with the component production phase. Prefabricated parts of prefabricated buildings are usually produced in specialized factories in a centralized process, where production sequences and quality directly affect processing on the building site. Smart production planning — in combination with on-demand production that aligns to actual site need — prevents the strain of storage from premature manufacturing as well as minimizes the waste of resources resulting from last-minute changes. This means production information must be frequently adjusted according to construction progress; hence components are delivered right on time that matches construction schedule.

Logistics and transportation are seen as both a focus point and an obstacle of prefabricated construction. A major challenge in road transportation is the limited potential - due to size, weight, transport vehicles and road conditions - of the loading components. If components are transported to a site at the wrong time, it can lead to site congestion or even disorderly storage of components. Crane or hoisting sequence undergo immediate installation upon arrival, minimizing footprint and secondary related handling—this is where logistics comes into place. The application of information platforms and the Internet of Things technology further supports real-time monitoring and scheduling for transport, enabling companies to improve coordination efficiency between transport and construction.

In this context, initiatives to improve supply chain and logistics management rely on information-sharing concepts. Component manufacturers, transport companies and construction firms should all communicate through a centralized data platform that gives the party in question real-time access to updates on demand fluctuations as well as progress. Cross-organizational collaboration mechanisms not only enable response times but also mitigate delays and losses due to information asymmetry. In the long run, integration of supply chain and logistics management through this collaborative model can establish a stable efficiency oriented industrial chain system, enabling widespread utilization of prefabricated construction.

3.3 Improvements in Construction Organization and Site Management

In prefabricated construction workflows, the on-site organization and management play as interlock between front-end design task, components manufacturing operation, and logistics transportation. Without such skills, manpower performance directly impacts general construction quality and adherence to the project schedule. In recent years, prefabricated projects require fewer operational phases on site compared to traditional construction, while they heavily rely on organizational coordination and scheduling during lifting of components, assembly and joint detailing. Small mistakes in these areas can cause construction delays, or safety incidents. Thus, improving construction organization and site management is essential for development of constructivism.

Construction management is all about rigorous planning focused on hoisting operations. Being that most prefabricated elements are heavy and large in dimensions, hoisting sequences and stacking spots on-site with transport routes need to be scientifically elaborated to enable a mass production-related workflow on-site. However, through rational process scheduling, reasonable division of construction sections, and flow or parallel work modes, the duration can be extraordinarily shortened while effectively reducing waiting time. At the same time, BIM-based construction simulations can facilitate preemptive warnings for conflicts in lifting paths and spatial occupancy problems, allowing optimization changes before actual construction to evade turmoil on site.

Second, dual control of quality and safety must be given top priority in on-site management. Joint connections are the most critical quality control points in prefabricated buildings; mishandling at these building joints directly endangers structural stability and durability. Thus, standardized construction methods shall be strictly implemented on the site, along with rigorous quality inspections and process supervision. Moreover, the hoisting of voluminous components has a higher risk and demand for improper safety management systems with intelligent monitoring tools that reduces hazards. Real-time tracking of hoisting activities through sensors and video surveillance, for example, allows prompt detection and resolution of anomalies to ensure construction safety. Process optimization objective function

$$P=\frac{Q_{installed}}{T_{work}} \quad (5)$$

Information technology and intelligent solutions, like improving organization at construction sites. At the same time, it is possible to control everything on-site in real time through a construction site information platform, improving utilization rates of personnel, machinery and materials as well as management transparency. The use of drone inspections, IoT monitoring devices, and intelligent construction equipment not only improves the management accuracy but also provides data support for dynamic optimization in the course of construction. The application of this information- and intelligence-oriented management model facilitates the construction efficiency and management quality of prefabricated buildings, which is conducive to refining the entire process from project implementation to operation.

4. Cost Analysis and Control Measures for Prefabricated Buildings

The cost system of prefabricated structures is markedly different from that of traditional construction, focusing mainly on design improvement, processing of prefabricated components, transportation and lifting, and on-site construction and management. BIM technology is applied at the design phase which requires more fine-tuning, thus relatively higher investment. However, the impact of rational design is on later rework mitigation which pays off across the entire product lifecycle. Investing in a factory, molding, and quality inspection for precast components. Unit costs are high, especially for the initial promotion phase, as no economies of scale exist. At the same time, transportation and hoisting for larger components should never be ignored as how roads, Distance transport, and machinery rents can quickly unblock your money in marginal cost. On the other hand, in terms of on-site construction and management, wet activities have decreased, while demands are increasing for construction organization and information management, safety control; corresponding increases in management costs have also occurred.

On the cost control side, lean design is seen as central to a lower bottom line. Encouraging standardized and modular designs could reduce the number of non-standard components, which in turn will help reduce design complexity and production difficulty. At the same time, utilizing BIM technology for deep integration between design and construction not only allows simulation of the construction process in advance to find problems, but also links schedule plans and cost budgets based on them to create a quantifiable basis for decision-making. By optimizing ahead of time based on information technology, it is possible to effectively avoid rework and additional expenses in the later stage, thus achieving wharf cost control at the source. Productivity of installation work

$$P=\frac{Q_{installed}}{T_{work}} \quad (6)$$

Scale and refining processes yield costs in component production and transportation. Production needs assembly-line operations and standardized component manufacturing to take full advantage of economies of scale and reduce unit costs. At the same time, having “production on demand” prevents wasting of stock and storage location. Batching and lifting sequences for “arrival-to-installation” transport and hoisting needs to be a highly structured process, with minimal secondary handling/tags and no temporary storage. IoT and intelligent dispatch systems that allow for real-time monitoring help improve transportation efficiency while reducing risk.

There still remain very important cost control measures in terms of scientific work sequencing and development of the digital platform during construction and management phases. By dividing construction sections rationally and conducting parallel operations, the project duration is shortened and rent management cost of equipment are reduced. Implementing a robust cost monitoring system allows for real-time tracking of labor, machinery, and materials which optimizes resource utilization while reducing waste. At the same time, the introduction of intelligent construction equipment, drone inspection and sensor monitoring can improve management precision and safety level as well as reduce incremental costs caused by quality problems or safety accidents. As these measures are gradually implemented in real projects, the cost structure of prefabricated construction will be continuously optimized, and its economic benefit and market competitiveness will continue to be improved.

5. Conclusion and Outlook

Prefabricated construction is one of the important ways to modernize China's construction industry, and it has unique advantages in promoting energy conservation and emission reduction, improving construction efficiency, and ensuring project quality. But in comparison to traditional construction model, it has clear characteristics including high process advancement, complex inter-process coordination and specialized organization of theme construction as well as concentrated quality and safety risk, high cost control pressure. This paper addresses this issue by recommending an optimization approach based on a systematic analysis of prefabricated construction process and cost structure with a specific focus on three areas namely: integrated design and construction management, supply chain, and logistics optimization; improvement in the construction organization and site management. It also goes into more detail on certain cost control measures. The research shows that scientific planning at all stages and careful management at all levels can effectively improve the efficiency of prefabricated construction and reduce unnecessary costs, so as to achieve the best combination of project quality, schedule and economic benefits.

In the future, as building industrialization and intelligence are further deepened, prefabricated construction will be more widely used. The integration of these emerging technologies—namely BIM, big data, IoT and AI would enable a more synergized design-production-transportation-construction work process with dynamic optimization and intelligent control at all stages. In parallel, with the maturity of the industrial chain and the appearance of economies of scale; production and construction costs will decrease gradually, it creates conditions for economic crisis and competitiveness. The green building and the low-carbon development goals will become a policy driver for prefabricated construction, as well as one of the market drivers in more sectors in which prefabrication will play increasingly important roles in urban development and sustainable growth.

However, continuous promotion of prefabricated construction includes not only the innovation of technology and management but also rely on policy-driven, industrial collaborative development and characteristics talent cultivation. Continue to explore and summarize the optimization of construction technology processes and cost control through continuous pursuit, prefabricated construction will become a key path for promoting transformation upgrading and further green development in China's construction industry future.

References

[1] Pich M T, Loch C H, Meyer A D .On Uncertainty, Ambiguity, and Complexity in Project Management[J].Management Science, 2002, 48(8):1008-1023.DOI:10.1287/mnsc.48.8.1008.163.

[2] Mota C M D M, Almeida A T D .A multicriteria decision model for assigning priority classes to activities in project management[J].Annals of Operations Research, 2012, 199(OCT.):361-372.DOI:10.1007/s10479-011-0853-z.

[3] Lova A, Tormos P .Analysis of Scheduling Schemes and Heuristic Rules Performance in Resource-Constrained Multiproject Scheduling[J].Annals of Operations Research, 2001, 102(1-4):263-286. DOI:10.1023/A:1010966401888.

[4] Tormos P, Lova A .A Competitive Heuristic Solution Technique for Resource-Constrained Project Scheduling[J]. Annals of Operations Research, 2001, 102(1-4):65-81. DOI:10.1023/A:1010997814183.

[5] Xu G, Papageorgiou L G .A Construction-Based Approach to Process Plant Layout Using Mixed-Integer Optimization[J].Industrial & Engineering Chemistry Research, 2007, 46(1):351-358. DOI:10.1021/ie060843k.

[6] Krivonozhko V E, Utkin O B, Volodin A V,et al.Constructions of economic functions and calculations of marginal rates in DEA using parametric optimization methods[J].Journal of the

Operational Research Society, 2004, 55(10):1049-1058.DOI:10.1057/palgrave.jors.2601759.

[7] Tormos P, Lova A .An efficient multi-pass heuristic for project scheduling with constrained resources[J]. International Journal of Production Research, 2003, 41(5):1071-1086. DOI:10.1080/0020754021000033904.

[8] Buyst E, Loyen R .Presentation of the research project 'Rotterdam and Antwerp: A century and a half of seaport competition in the Rhine-Scheldt-Meuse Delta (1860-2000)'[J].Environmental Modelling & Software, 2004, 26(1):83-91.DOI:10.1016/j.envsoft.2010.03.034.

[9] Fox J, Bell D, Edmond G,et al.A practical tool for low-carbon road design and construction[J]. Transport, 2011, 164(3):165-179.DOI:10.1680/tran.2011.164.3.165.

[10] Liang, Lou Y .Grouping decomposition under constraints for design/build life cycle in project delivery system[J].International Journal of Technology Management, 2009, 48(2):168-187(20). DOI:10.1504/IJTM.2009.024914.