

Systematic Innovation in Prefabricated Construction and Intelligent Building — Research on the Construction, Empirical Verification, and Industry Promotion of the DIIG Smart Construction System

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Abstract: To address the systemic challenges in the construction industry regarding efficiency, quality, safety, and sustainable development, this paper proposes and systematically elaborates on a smart construction technology system that deeply integrates digitalization, intelligence, industrialization, and greenification, namely the DIIG system, based on twenty-three years of engineering practice. This study first traces the three-stage evolution of the system from “special process breakthrough” to “system integration innovation” and ultimately to “industry empowerment paradigm”. Subsequently, it innovatively constructs a three-tier driving architecture model consisting of the “basic technology layer (foundation), system integration layer (guarantee), and frontier exploration layer (leadership)”, and details the core technical composition and innovation highlights of each layer. The system has been comprehensively validated in dozens of major projects covering six typical scenarios: national emergency response, super high-rise landmarks, international cultural tourism, ecologically sensitive areas, urban renewal, and complex public buildings. Empirical data analysis shows that applying the system can reduce the average project duration by 25%-40%, lower costs by 15%-30%, decrease construction waste by 45%-70%, and achieve zero accidents in major risk operations. The achievements of the system have been solidified through intellectual property rights achieved through national engineering awards, authorized invention patents, industry/local standards, and a series of academic papers. Finally, this paper discusses the future evolution path of the system towards the Internet of Construction Industry, human-machine collaborative construction, zero-carbon buildings, and collaborative ecosystem construction of industry, academia, and research. The research indicates that the DIIG system provides a logically consistent, comprehensively validated, and quantitatively beneficial integrated solution for the systematic transformation and upgrading of the construction industry.

Keywords: intelligent construction; prefabricated construction; DIIG system; construction industrialization; digital transformation; sustainable construction; systems engineering

1. Introduction

The global construction industry is deeply immersed in multiple pressures, including improving production efficiency, ensuring engineering quality, achieving low-carbon transformation, and addressing the shortage of skilled labor. Its traditional high-consumption, high-emission, and extensive development model has become unsustainable [1, 2]. Against this backdrop, construction industrialization represented by prefabricated buildings and intelligent construction centered around building information modeling, the Internet of Things, and artificial intelligence are widely regarded as dual engines driving profound changes in the industry [3, 4]. However, current industry practices generally suffer from core issues such as fragmented technological innovation, a disconnect between technology and management, and difficulties in scaling and promoting local achievements. There is a severe lack of a systematic technical framework and implementation paradigm that can integrate the entire process of design, production, construction, operation, and maintenance, and synergistically optimize multiple objectives such as “efficiency, quality, safety, greenness, and cost” [5].

To bridge the gap between theory and practice, this paper, based on a series of major complex engineering projects that the author has deeply participated in and presided over since 2005, systematically constructs and empirically validates a smart construction technology system named DIIG through a spiral research path of “practice-reflection-refinement-re-practice”. This study not only aims to elaborate on the generation logic, core architecture, and key technology clusters of the system, but also focuses on quantitatively revealing its comprehensive benefits through empirical data accumulated from major engineering projects covering multiple types and constraints. Furthermore, it delves into the potential impact of the system on promoting industry standard advancement, facilitating knowledge accumulation, and shaping the future technology ecosystem. The core contribution of this paper lies in providing a systematic transformation and upgrading solution for the construction industry, rooted in China’s rich engineering practices, supported by a complete methodology, and rigorously

validated across all scenarios.

2. From Practice to Paradigm: The Evolution Path of DIIG Technology System

The formation of the DIIG system is not a linear accumulation, but rather an evolution that has gone through three distinct and progressive stages, accompanied by the rapid development of China's construction industry and technological waves. It reflects a profound leap in cognition, from solving micro-technical problems to constructing a macro-industrial paradigm.

2.1 Phase 1: Foundation Laying Period (2005-2015) - Special Process Breakthrough and Quality Standardization

This stage focuses on tackling global technical challenges in specific high-end engineering scenarios, with large complex spatial steel structures as a typical example. Using national landmark projects such as the National Stadium ("Bird's Nest") as a carrier, the core of research and practice is centered on welding processes for ultra-thick plates and low-alloy high-strength steels in harsh environments, precise installation of large-span irregular components, and deformation coordination control [6]. Through systematic process testing and parametric research, the principle of refined quality management, namely "process parameterization, operation standardization, and acceptance quantification," has been established. The outputs of this stage are represented by specialized technical papers such as "Low-temperature Welding Construction Technology for Building Steel Structures" and corporate construction methods [7], laying a solid foundation in process reliability and rigorous engineering culture genes for subsequent technological integration and innovation.

2.2 Phase II: Integration Period (2016-2019) - Systematic Fusion Innovation under EPC Mode

As the engineering general contracting model becomes mainstream, the focus of technological innovation shifts from "point" to "line" and "surface", emphasizing multi-disciplinary and whole-process collaboration. The Central Military Commission's 72002 project serves as a key milestone in this stage. Facing the triple strong constraints of "extreme construction period, highest confidentiality, and extreme quality", the project team pioneered an integrated solution of "whole-system prefabricated design + whole-process digital control". This solution successfully achieved a breakthrough result with a prefabrication rate of 92% and an overall construction period compression of 40% [8]. This practice not only verifies the great value of using BIM technology as a link to drive deep collaboration in design, procurement, and construction, but also marks a paradigm shift from relying on individual technological advantages to building an integrated capability of "technology-management-organization".

2.3 Phase III: Leading Period (2020-present) - DIIG System Construction and Industry Empowerment

Based on the profound practical accumulation and integrated experience in the early stage, this phase is dedicated to theoretical sublimation and systematic construction, explicitly proposing the DIIG smart construction system. This system has undergone rigorous verification of universality, robustness, and economy in six major projects with distinct characteristics, including the Qianhai MCC Technology Building (super high-rise), Universal Studios Beijing (complex irregular structure), Guangming Town Happy Countryside (ecologically sensitive area), Anju Weitang (urban renewal), and Songshan Lake Culture and Art District (complex geology). The system's achievements have been systematically solidified and outputted through top industry certifications such as the China Construction Engineering Luban Award, the National Quality Engineering Gold Award, and the Zhan Tianyou Hometown Cup Award, as well as through a series of invention patents, industry standards, and core journal papers [9, 10]. Its goal has been upgraded from ensuring the success of a single project to outputting reproducible and scalable industry-level technical paradigms and knowledge products.

3. DIIG system architecture model and core technology clusters

The DIIG system is a well-structured, internally and externally interconnected, and continuously evolving technological ecosystem. Its core architecture is a three-tier-driven pyramid model, as illustrated in Figure 1. The layers are tightly coupled through bidirectional data flow and value feedback, jointly supporting value creation throughout the entire project lifecycle.

3.1 Basic technology layer: the foundation of accuracy and efficiency

This layer aims to ensure ultimate precision and efficiency in the construction process from the source through underlying technological innovation, serving as the "cornerstone" of the system's operation.

(1) High-precision digital twin and intelligent deviation correction technology: A real-time closed-loop quality control

process has been established, encompassing “BIM forward design, 3D laser scanning for reverse verification, and automatic deviation correction by industrial robots.” In a high school project in Shenzhen, this technology has improved the installation accuracy of prefabricated concrete components from the industry average of $\pm 5\text{mm}$ to within $\pm 2\text{mm}$, achieving a one-time installation pass rate of up to 99.8%. The relevant technologies have been patented for cluster protection (e.g., ZL202320142776.1).

(2) Modular products and rapid assembly integration technology: By introducing the concepts of “product family” and “plug and play” from the manufacturing industry, a standardized residential unit module library and an integrated kitchen and bathroom system have been established. In the “Anju Weitang” urban renewal project, on-site rapid lifting and connection of a single integrated kitchen and bathroom unit within 4 hours were achieved, resulting in a 50% increase in overall design efficiency. This has led to the derivation of supporting corporate design guidelines and construction acceptance standards.

3.2 System integration layer: Collaboration and security assurance

This layer focuses on reconstructing project management processes through digital platforms and intelligent monitoring methods, achieving efficient collaboration across multiple disciplines, and establishing an inherently safe proactive prevention system.

(1) BIM-based whole-process collaborative management platform: A digital collaborative platform that integrates “bi-directional association between WBS (Work Breakdown Structure) and model components” and “automatic detection and early warning of professional interface conflicts” has been developed. This platform enables dynamic linkage and visual control of design changes, material procurement, and construction progress. Application results show that the platform can improve cross-professional collaboration efficiency by about 25% and reduce engineering changes caused by information errors and omissions by up to 40%.

(2) Intelligent monitoring and active safety assurance system: Integrating multiple innovative technologies: 1) “Panel scaffolding + steel bracket” combined support system, used for ultra-high formwork support, achieving a balance between mechanical performance and construction efficiency; 2) IoT-based multi-parameter intelligent monitoring and early warning system for deep foundation pits, providing real-time sensing and trend prediction of displacement, stress, water level, etc.; 3) Real-time monitoring and anti-collision system for large component hoisting trajectory, integrating Beidou/GNSS high-precision positioning. In complex working conditions of projects such as Songshan Lake and Qianhai, it has achieved “zero accidents” in the construction of deep and large foundation pits and ultra-high formwork support, with a system early warning accuracy rate of 100%.

3.3 Frontier Exploration Layer: Leading the Way in Green and Intelligence

This level represents the development direction of the system, dedicated to exploring the deep integration of the construction industry with cutting-edge technology and sustainable development concepts, and defining future construction models.

(1) Deep integration of industrialization and intelligent equipment: In the ultra-high-rise project of the Qianhai Zhongye Technology Building, the innovative application of the rapid assembly core tube system of “concrete-filled steel tubular columns + steel truss floor support plates” achieved an assembly rate of 85% for the main structure. The self-developed “eccentric lock with sub-aperture” aluminum alloy formwork system has achieved a turnover of more than 300 times for a single set of formwork, and the efficiency of on-site formwork construction has been increased by three times.

(2) Integration of green construction and full-life cycle carbon emission reduction technology: The system integrates various green technologies such as building-integrated photovoltaics, intelligent sprinkler maintenance, prefabricated ecological slope protection, slurry recycling treatment, and hydraulic physical model testing. In projects located in ecologically sensitive areas like the Happy Countryside in Guangming Town, the disturbance to the original soil and water environment caused by construction activities is minimized through refined simulation and maximized prefabricated construction. The system has achieved an average reduction of 45%-70% in construction waste across its application projects, and the estimated full-life cycle carbon emission reduction based on the production, transportation, construction, and energy consumption savings of building materials exceeds 35%. Several projects have been awarded LEED Gold certification or China Green Building Three-Star certification.

4. Full-scenario empirical research and comprehensive benefit analysis

4.1 Multi-level project verification matrix

To rigorously verify the wide applicability, technical robustness, and economic rationality of the DIIG system, this

study applies it to six major engineering projects with distinct characteristics, forming a complete empirical research matrix, as shown in Table 1.

Table 1. Verification Matrix of DIIG Technology System for Full-Scenario Applications

Project type Category	Representative Project	Core Validated Capabilities	Key Quantitative Outcomes and Industry Impact
National Emergency Project	Central Military Commission 72002 Project	Rapid, high-quality, and confidential construction and system integration capabilities under extreme multiple constraints	The construction period has been shortened by 40%, resulting in cost savings of approximately 30 million yuan; the technical system has been incorporated into the “Technical Guidelines for Prefabricated Construction of National Defense Projects”
Super-tall Landmark	Qianhai Zhongye Technology Building	Industrialized and intelligent construction of super high-rise buildings and green technology integration capabilities	The assembly rate of the main structure is 85%; it has obtained the three-star certification for green buildings in Shenzhen and the Quality Structural Engineering Award
International Cultural Tourism Benchmark	Universal Studios Beijing, Lot 6	The ability to control and achieve millimeter-level precision in complex and irregular structures and artistic designs	It has won the China Construction Engineering Luban Award and the National Quality Engineering Gold Award; the installation accuracy of key parts is controlled within $\pm 2\text{mm}$
Ecologically Sensitive Project	Guangming Town Happy Countryside	Flood control evaluation, ecological protection, and coordination capability for complex lifting operations within the ecological red line for water-related projects	Innovatively applying Beidou monitoring and hydraulic models, it successfully passed the review conducted by the Provincial Water Resources Department in one attempt; thus, an eco-friendly construction method was formed
Urban Renewal Project	Anju Weitang Renovation Project	Sustainable renewal model for high-density built-up areas featuring low cost, low disturbance, and rapid revitalization	Reduce construction waste by 55% and shorten the construction period by 30%; establish a reproducible paradigm of old building renovation technology
Complex Cultural Public Building	Songshan Lake Culture and Art District	Comprehensive safety control capability for deep and large foundation pits, high formwork support, and multi-disciplinary prefabricated technology under complex geological conditions	The deformation control of deep foundation pits is $\leq 25\text{mm}$, and there have been no accidents in high-formwork construction; it has won the “Zhan Tianyou Hometown Cup Award” in Guangdong Province

4.2 Quantitative comparative analysis of comprehensive benefits

Through horizontal and vertical data statistics and comparative analysis of a series of projects applying the DIIG system in the past five years, its comprehensive benefits are significant, as shown in Table 2. Compared with industry benchmarks or traditional construction methods, this system demonstrates systematic advantages in core performance dimensions.

Table 2. Quantitative analysis of comprehensive benefits of DIIG system application projects

Evaluation Dimension	Key Performance Indicator (KPI)	Average Performance in DIIG Projects	Industry Benchmark/ Traditional Method	Improvement
Economy & Efficiency	Project Duration Compression Rate	25% ~ 40%	Baseline 0%	Significantly Reduced
	Overall Cost Reduction Rate	15% ~ 30%	Baseline 0%	Significantly Reduced
	First-time Acceptance Rate	> 98.5%	Industry average ~90-95%	Increased by 3-8.5%
Quality & Precision	Prefabricated Component Installation Accuracy	$\leq \pm 2\text{mm}$	Industry common $\pm 5\text{mm}$	Accuracy Improved by 60%
Resources & Environment	Construction Waste Reduction Rate	45% ~ 70%	Routine items (reference values)	Substantially Reduced
	Material recycling rate	> 80%	Industry average (lower)	Significantly Increased
	Estimated Life-cycle Carbon Reduction	> 35%	Benchmark building	Significant Contribution
Safety	Number of Major Safety Incidents	0%	Industry target <0.1%	Zero Incident
	Major Risk Control (e.g., Deep Excavation)	Early warning accuracy rate: 100%, deformation meets the standard	High-risk operations in the industry	Effectively Controlled

5. Industry contribution, knowledge accumulation, and influence

5.1 Promote standard setting and industrial technological progress

The practical achievements of the DIIG system have transcended the scope of individual projects and been transformed into public knowledge products that drive industry progress. Its key technologies and management experiences have been incorporated into national industry standards/guidelines such as the “Technical Guidelines for Prefabricated Construction in Defense Engineering” and the “Fire Protection Technical Standards for Emergency Prefabricated Buildings” (T/CECS 1258-2023) [11], and have provided core practical cases and data support for local standards such as the “Technical Standards for Prefabricated Decoration of Affordable Housing in Shenzhen”. In the field of ecological environmental protection, relevant river-related engineering construction technologies and ecological slope protection methods have also been included in provincial technical guidelines, achieving a leap from enterprise practice to industry standards.

5.2 Establishing an independent intellectual property system

A structured cluster of independent intellectual property rights has been formed around the core of the system. As the first inventor, I have obtained a total of 9 national authorized patents (including 2 invention patents), covering key aspects such as collaborative design methods, intelligent construction equipment, and active safety protection. At the same time, I have presided over the preparation of 10 major engineering technical reports, including the “Fire Protection Technical Scheme for Prefabricated Box Houses” and the “Special Scheme for Curtain Wall Engineering of Super High-Rise Buildings”, all of which have passed the review of provincial and ministerial-level authoritative experts and have been promoted and applied as templates in similar projects.

5.3 Promote academic exchanges and talent echelon construction

As the first author, I have published 6 academic papers in domestic core journals such as “China Construction Metal Structure” and “Construction Technology”, systematically summarizing the technical principles, management innovations, and theoretical considerations at various stages [6, 7, 8]. By establishing internal innovation studios, organizing industry technology seminars, and implementing a “mentor-apprentice” system in major projects, I have systematically cultivated a group of composite technical backbones proficient in digital design, intelligent construction, and project management, achieving the explicitization and sustainable inheritance of tacit knowledge.

6. Conclusion, Discussion, and Future Outlook

6.1 Research Conclusion

Through long-term, iterative engineering practice and systematic theoretical refinement, this study successfully constructs and empirically validates the DIIG smart construction technology system. The main conclusions are as follows:

(1) The effectiveness of the system has been verified across all scenarios: The DIIG system is an effective system framework that has undergone rigorous testing in six major typical scenarios of national-level emergency response, super high-rise buildings, complex cultural tourism, and other major engineering projects. It is capable of systematically addressing complex challenges in the construction industry related to multi-objective optimization, including efficiency, quality, safety, greenness, and cost.

(2) The comprehensive benefits are significant and quantifiable: empirical data indicates that applying this system can yield significant and quantifiable improvements in core dimensions such as construction duration, cost, resource consumption, and safety performance (as shown in Table 2), possessing clear economic, social, and environmental values.

(3) Possessing industry-level scalability: The system has achieved solidification of achievements and knowledge spillover through multiple channels such as top engineering awards, authorized invention patents, industry/local standards, and academic papers, forming a logically complete, reproducible, and scalable industry-level technical paradigm with significant potential for industrial empowerment.

6.2 Discussion

The underlying logic of the success of the DIIG system lies in its systematic thinking and engineering philosophy that permeates throughout. It does not pursue isolated breakthroughs in individual technologies to the extreme, but emphasizes the deep integration and collaborative evolution of the four dimensions of digitalization, intelligentization, industrialization, and greenification. It reveals that modern complex engineering construction is shifting from competition based on “technology application” to higher-level competition based on “system construction” and “ecological integration”. At the same time, this system is rooted in the large-scale, highly complex, and rapidly iterative construction environment of China’s

specific development stage. Its experience holds significant reference value for the global construction industry, especially for emerging economies facing similar challenges of transformation and upgrading. However, its promotion and application also require adaptive innovation in combination with localized policy environments, industrial foundations, and market conditions.

6.3 Future Outlook

In response to the accelerated breakthroughs in artificial intelligence, Internet of Things, and robotics technologies, as well as the urgent global goal of “carbon neutrality”, the DIIG system will continue to evolve dynamically:

(1) Platformization and Ecologization: Evolving towards an open collaborative platform based on the Internet plus of the construction industry, integrating upstream and downstream data of the industrial chain, and utilizing big data and artificial intelligence algorithms to achieve networked intelligent collaboration and decision optimization across all elements and throughout the entire process.

(2) Autonomous construction and human-machine integration: Deeply integrate intelligent equipment such as construction robots, 3D printing, and unmanned construction machinery to overcome the automation bottlenecks in traditional labor-intensive processes such as main structure construction and interior fine decoration, and move towards a “less-manned, unmanned” smart construction site.

(3) Carbon neutrality leadership and performance-driven: Develop high-performance near-zero energy consumption/zero carbon building envelope systems, building-integrated photovoltaic and smart energy management systems, and establish a building material carbon footprint database and design tools covering the entire life cycle, leading the industry towards deep decarbonization.

(4) Collaborative innovation ecosystem co-construction of industry, academia, research, and application: Actively build or integrate into interdisciplinary and cross-field innovation consortia, promote the rapid engineering transformation of cutting-edge basic research results in materials science, information science, mechanical engineering, and other fields in the construction scenario, and jointly address long-tail technical challenges and systemic challenges faced by the industry.

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