

Construction and implementation strategy of quality management system for large-scale public building projects

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Abstract: As vital carriers of urban functions and image, large-scale public buildings' engineering quality not only determines their service life and safety but also directly impacts public welfare and urban development standards. However, quality management often faces significant challenges due to factors such as massive project scale, numerous stakeholders, extended construction cycles, and technical complexity. Based on an analysis of the current state and existing issues in quality management for large-scale public building projects, this paper proposes a framework for constructing a quality management system. It systematically elaborates on three aspects: the system framework, core elements, and key control points. To ensure the effective operation of the system, implementation strategies are proposed, including policy and regulation enforcement, personnel training and assessment, application of information technology, risk prevention and emergency management, as well as incentive and constraint mechanisms. Research indicates that a scientifically sound and comprehensive quality management system not only enhances construction quality and management standards but also promotes sustainable development within the construction industry.

1. Introduction

Large-scale public building projects constitute vital components of urban infrastructure and public service systems ^[1]. Their construction quality directly impacts public safety, functional performance, and the overall image of cities ^[2]. With rapid socioeconomic development and accelerated urbanization, the number and scale of large public building projects continue to grow, increasing construction complexity and technical demands ^[3]. However, during actual construction, factors such as numerous project participants, lengthy management chains, extended construction cycles, and complex environmental conditions often lead to quality issues, potentially triggering safety incidents and economic losses ^[4].

Against this backdrop, establishing a scientific, systematic, and highly operational quality management system has become a core requirement for ensuring the quality of large-scale public building projects ^[5]. Such a system must encompass full-process control from design and construction through completion and operation/maintenance, while emphasizing the coordinated operation of full participation, institutional norms, and technical measures ^[6]. Particularly in today's era of rapid digital and intelligent development, integrating information tools with engineering quality management represents a significant challenge facing the industry.

This paper focuses on large-scale public building projects, examining the current state of their quality management, approaches to system construction, and implementation strategies ^[7]. It aims to propose a feasible quality management framework and provide reference points for industry practice.

2. Current State and Challenges in Quality Management for Large-Scale Public Building Projects

China's accelerated urbanization has driven rapid growth in both the number and scale of large-scale public building projects, accompanied by continuous improvements in quality management standards. Many projects have adopted quality management systems like ISO 9001, establishing robust institutional frameworks and responsibility mechanisms. Some projects further leverage BIM technology, digital management platforms, and intelligent monitoring tools to achieve refined and

visualized quality control. Continuous policy regulations and technical standards from national and local governments provide institutional safeguards for quality control, keeping overall quality levels largely under control^[8]. Quality control objective function

$$Q = \sum_{i=1}^n w_i \cdot q_i \quad (1)$$

However, in actual construction, quality management for large-scale public building projects still faces a series of challenges and difficulties. While some projects have formally established quality management systems, they often lack effective implementation and dynamic improvement during execution, preventing the systems from functioning optimally. Since such projects typically involve multiple stakeholders—including designers, contractors, supervisors, and suppliers—collaboration and communication frequently encounter obstacles. Issues like unclear responsibility delineation and delayed information transmission frequently occur, undermining the effectiveness of quality control. During construction, particularly in complex processes, concealed works, and new technology applications, supervision becomes challenging. Inadequate quality traceability mechanisms can create hidden risks. The varying skill levels among construction personnel, coupled with insufficient systematic training and quality awareness among some frontline workers, further impacts quality management outcomes. While information and intelligent tools have been adopted in some projects, overall adoption remains low, with underutilized data and persistent information silos, showed in Figure 1 :

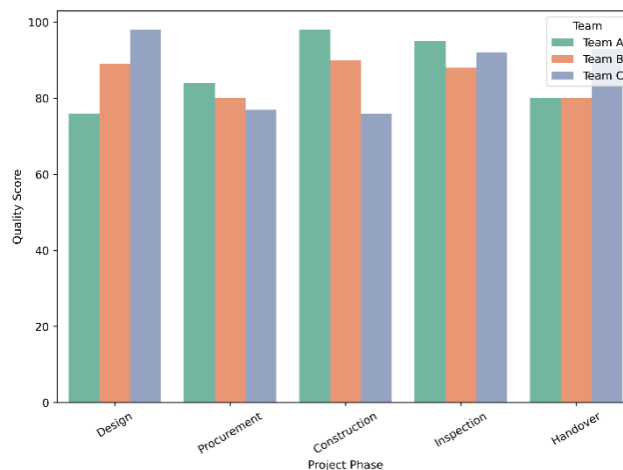


Figure 1 Quality scores across project phases

As project scale and complexity continue to increase, quality management for large-scale public buildings faces increasingly severe challenges. Super-high-rise buildings, large complexes, and landmark public facilities impose higher demands on construction techniques, material performance, and safety, driving a shift in quality management from traditional phased control to comprehensive, lifecycle-based oversight. The rise of green building and sustainable development concepts has introduced new quality dimensions—energy efficiency, environmental protection, and low-carbon construction—placing fresh pressures on existing management models. The rapid advancement of emerging technologies such as BIM, big data, IoT, and AI offers new tools and possibilities for quality management. However, their application remains exploratory, lacking unified standards and mature experience, with actual effectiveness yet to be fully validated. Establishing a scientific, efficient, and adaptable quality management system capable of responding to industry transformations has become a critical challenge for large-scale public building projects^[9].

3. Approach to Establishing a Quality Management System for Large-Scale Public Building Projects

The construction of a quality management system for large-scale public building projects must be grounded in the overall characteristics and management requirements of the project. It requires a

macro-level framework aligned with industry standards and development trends, while also defining core elements and operational mechanisms at the institutional, organizational, and technological levels. Furthermore, comprehensive control measures must be established for critical phases such as design, construction, and operation and maintenance. Only through the organic integration of top-level design, resource allocation, and process control can a scientific, systematic, and actionable quality management system be established, providing robust assurance for the high-quality construction of large-scale public building projects. Cost–quality trade-off model

$$C(Q)=C_0+\alpha Q^2 \quad (2)$$

3.1 Basic Framework of the Quality Management System

The construction of a quality management system first requires defining its guiding principles and overarching objectives. As complex systems engineering projects, large-scale public building projects must adhere to the fundamental principles of “full-process control, full participation, and continuous improvement” in quality management. Objectives should not only ensure that the physical quality of the project meets national standards and design requirements but also balance safety, functionality, economy, and sustainability to achieve a unified social and project benefit. Scientifically setting objectives provides directional guidance for system operation^[10].

In framework design, the quality management system should follow principles of systematization and standardization, forming a management structure that covers the entire project lifecycle. Typically based on the ISO 9001 quality management standard, it integrates the characteristics of the construction industry and relevant regulatory requirements to establish a comprehensive framework encompassing policies, standards, processes, and methodologies. This framework should coordinate relationships among multiple stakeholders—including designers, contractors, supervisors, suppliers, and owners—ensuring each phase has clear procedures and documented basis. Reliability function for structural components

$$R(t)=e^{-\lambda t} \quad (3)$$

Organizational structure is a core element within the system framework. Large-scale public building projects involve extensive scopes and numerous participants, necessitating a clear organizational structure and division of responsibilities. This should establish a multi-tiered quality management model led by the project owner, supervised by the supervision agency, executed by the construction unit, and supported by the design unit. Emphasis must be placed on implementing full accountability, where roles and responsibilities are clearly defined for all personnel—from management to frontline construction workers—ensuring quality management objectives are effectively communicated and executed at every level.

The fundamental framework of the quality management system must also incorporate dynamic management and continuous improvement mechanisms. Given the extended construction cycles of large-scale public building projects and the rapid evolution of external environments and technical conditions, new challenges inevitably arise during system operation. It is imperative to establish information feedback and improvement mechanisms, conducting regular evaluations and adjustments to the system's effectiveness to drive ongoing optimization of management standards. This not only enhances the system's adaptability and efficacy but also accumulates experience for subsequent projects, creating a virtuous cycle.

3.2 System Elements and Core Content

Within the quality management system for large-scale public construction projects, institutional development serves as the most critical foundational element. A scientifically sound and comprehensive system provides the basis and standards for quality control across all project phases, encompassing quality accountability systems, technical specifications, inspection and acceptance protocols, and risk early-warning mechanisms. Establishing a robust institutional framework effectively standardizes diverse activities, mitigates arbitrary and uncertain management practices, and thereby ensures the controllability and stability of project quality, showed in Figure 2:

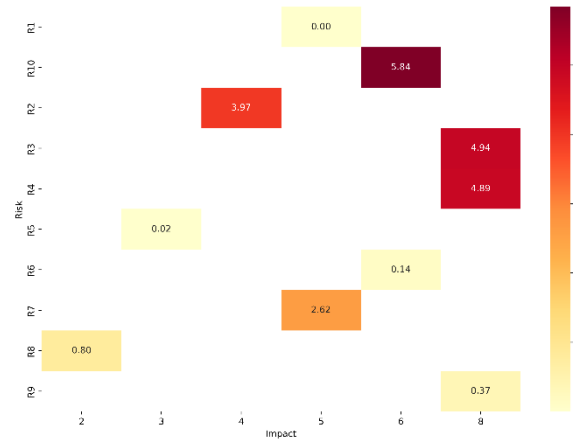


Figure 2 Risk vs Impact heatmap

Organizational support serves as the vital backbone for system operation. Quality management relies not only on systems and processes but also demands a robust organizational structure to guarantee execution. Projects typically establish dedicated quality management departments or task forces, clearly defining responsibilities and authorities for each management role to form a vertical chain of accountability from decision-making to execution. Emphasis on multi-party coordination ensures smooth communication and clear responsibilities among stakeholders—including owners, designers, contractors, and supervisors—to achieve synergistic quality management.

Technical support serves as the core driving force for effective system operation. With the advancement of information technology and intelligent solutions in the construction industry, technologies such as BIM, big data, IoT, and AI have become essential tools for engineering quality management. These technologies enable comprehensive data collection, real-time monitoring, and intelligent analysis throughout the construction process, providing scientific foundations for quality control. The application of advanced construction techniques and new materials also plays a positive role in enhancing engineering quality and controllability.

Quality culture and personnel competence are vital safeguards for the system's long-term effectiveness. While systems and technology provide external constraints and support, ultimate execution relies on people. Strengthening quality awareness among all personnel, enhancing the professional competence of managers and construction workers, and establishing a project culture centered on quality can boost the system's intrinsic motivation. Only by implementing training, assessment, and incentive mechanisms to assign quality responsibilities to every participant can the system be truly implemented and operate effectively.

3.3 Design of Key Control Points

The effectiveness of a quality management system for large-scale public building projects hinges on the effective control of key stages. Construction typically progresses through three core phases: design, construction, and operation/maintenance. Quality control across these phases is not only interdependent but also significantly determines the overall project standard. The design phase is the origin of quality formation. Defects or oversights in the design scheme cannot be fully remedied by subsequent construction, no matter how rigorous. Rigorous drawing reviews, design validation, and expert evaluations must ensure scientific and feasible designs. Integrating green, energy-efficient, and sustainable principles throughout the design process lays a solid foundation for project quality. Risk index model

$$RISK = \sum_{j=1}^m P_j \cdot I_j \quad (4)$$

Upon entering the construction phase, the focus of quality control shifts to process management. Construction sites often represent the most concentrated risks and the highest likelihood of issues arising. Therefore, control must be strengthened through standardized operations, rigorous process inspections, and concealed work acceptance. A dynamic monitoring mechanism should be established,

utilizing technologies such as sensors, drones, and BIM models to track construction quality in real time, enabling timely detection and correction of problems. Notably, the construction phase involves complex personnel and processes where negligence at any stage can compromise overall quality. Only through comprehensive, collaborative management across all processes and elements can stability and controllability be ensured during construction.

During the completion and operation phases, quality management centers on guaranteeing the building's functionality and long-term safety. Final acceptance serves not only to validate construction outcomes but also to assess the effectiveness of prior management. Systematic testing and evaluation are essential to confirm the building meets design and regulatory requirements. Quality management should not cease upon entering the operation and maintenance phase but extend throughout the building's entire lifecycle. Establishing mechanisms for operational monitoring and maintenance—continuously tracking structural safety, equipment performance, and usage environments—effectively extends the building's lifespan, reduces long-term repair costs, and facilitates the transition from “building well” to “using well.”

Quality control at critical junctures is not isolated but forms an interconnected, progressive chain. Only by tightly integrating design origins, construction processes, and operational maintenance support—supplemented by advanced technologies and scientific management methods—can a true full-lifecycle quality assurance system be established. This ensures large public buildings achieve optimal functionality, safety, and sustainability.

4. Implementation Strategies for Quality Management Systems in Large Public Building Projects

The scientific construction of a quality management system is merely a prerequisite for ensuring project quality. Its true effectiveness depends on practical implementation. The implementation of policies, regulations, and industry standards is the fundamental guarantee for the system's operation. Relevant government departments should continuously improve the regulatory framework, strictly enforce mandatory standards, and ensure the implementation of quality management measures through supervision, inspection, and incentive/penalty mechanisms. Construction entities and contractors should also proactively internalize these regulations and standards into their own management norms, establishing an execution framework at the institutional level that aligns with national policies. Process quality control using variance

$$\sigma^2 = \frac{1}{N} \sum_{k=1}^N (x_k - \mu)^2 \quad (5)$$

Talent development is a critical driver for system implementation. Large-scale public construction projects involve complex technologies and lengthy management chains, demanding high comprehensive competencies from both management and construction personnel. Establishing robust training and assessment mechanisms can continuously enhance professional capabilities and quality awareness, making full participation the practical foundation for system operation. Emphasis should be placed on attracting high-caliber specialists and multidisciplinary professionals to propel project management from experience-driven to knowledge- and data-driven approaches.

Technology application has become a vital enabler for enhancing implementation effectiveness. Technologies such as BIM, big data, IoT, and AI provide real-time, dynamic, and traceable data support for engineering quality management, facilitating precise control throughout the entire process. Establishing a unified information platform promotes data sharing among multiple stakeholders, breaking down data silos to enhance decision-making rationality and management transparency. The introduction of technological tools also enables automated monitoring and early warning systems on construction sites, significantly improving the efficiency of identifying and resolving quality issues.

The establishment of risk management and emergency response systems is also an indispensable component of the framework's implementation. Large-scale public construction projects often feature long cycles, substantial investments, and complex external environments, where various risk factors intertwine and compound. Only by embedding risk identification, assessment, and control mechanisms

into the system's operation can proactive prevention of potential issues be achieved. Developing scientifically sound contingency plans and establishing rapid response mechanisms can minimize losses during emergencies, ensuring project safety and quality stability. Lifecycle performance index

$$LPI = \frac{\int_0^T Q(t) dt}{T} \quad (6)$$

Incentive and constraint mechanisms are crucial for the system's long-term sustainability. Relying solely on regulations and oversight often fails to fully engage all personnel. Therefore, the system must incorporate scientific reward and penalty measures, closely aligning individual and organizational interests with quality objectives. By recognizing excellence and penalizing negligence, we not only boost personnel motivation but also gradually cultivate a project culture where “quality is a badge of honor and mistakes are a source of shame,” providing endogenous momentum for the system's sustainable implementation.

Implementing a quality management system for large-scale public building projects is a systematic endeavor. It requires external constraints through policies and standards, internal drivers from organizations and personnel, and the synergistic coordination of technological innovation and risk management. Only through the convergence of multifaceted measures can the quality management system truly transition from “paper” to “practice,” driving the overall enhancement of quality standards in large-scale public building projects.

5. Conclusion

Large-scale public building projects face significant quality management challenges due to their immense scale, complex structures, and numerous stakeholders. This paper analyzes the current situation and issues, proposes a framework for constructing a quality management system, and systematically elaborates on three dimensions: basic framework, core elements, and key processes. It further explores implementation strategies and discusses pathways and safeguards for practical application. A scientifically designed quality management system not only enhances overall project quality and safety but also promotes standardized and refined project management, driving the construction industry toward intelligent, green, and sustainable development.

With the rapid advancement of information technology and the deepening promotion of green building concepts, quality management for large-scale public building projects will increasingly trend toward intelligent and full-lifecycle approaches. Key research questions remain: how to better integrate advanced technologies with management models in practice, and how to achieve personalized and flexible management while maintaining standardization. Only through continuous optimization and refinement of the quality management system can the engineering quality of large public buildings be truly guaranteed, meeting the public's multifaceted demands for safety, functionality, and sustainability.

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