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

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Abstract: Observes that as significant carriers of urban functions and images, large-scale public buildings' engineering quality didn't only dominate its service life and comfort but also straightly impacted the pubic welfare and unique level of city developing. But quality management is a huge challenge due to factors like massive project size, numerous stakeholders, extended construction cycles, and technical complexity. By discussing the current situation and existing problems in terms of quality management in large-scale public building projects, this paper constructs a construction framework for the quality management system. It capitalizes on the framework of the system, its core elements and critical control points of it. Finally, to ensure that the system operates efficiently and orderly under practical conditions, implementation strategies are proposed from several aspects including policy and regulation enforcement, personnel training & assessment, information technology applicability, risk prevention & emergency management as well as incentive & constraint mechanisms. Studies show that a scientifically based and complete quality management system raises construction quality and management standards, as well as driving the sustainable development of the construction industry.

1. Introduction

Large-scale public building projects are essential parts of urban infrastructure and public service systems [1]. The quality of their construction directly affects public safety, functional performance, and cities' overall image [2]. As the socioeconomic development accelerates urbanization, many large public building projects have been completed, which increases construction complexity and technical difficulty [3]. Nevertheless, in the real construction process, quality problems can easily be caused by many participants of the project, long management chains, long construction cycles and complex environmental conditions [4].

Against this backdrop, buildinging a scientific, systematic and highly operational quality management system has become a core requirement for guaranteeing the quality of large-scale civil public building projects [5]. A system of this kind should include the control of the whole process, including design, construction, completion and operation/maintenance, with full participation, institutional norms (incentive mechanisms) and technical measures coordinated to promote [6]. Especially at the present stage of rapid digital and intelligent development, Information tools and engineering quality management integration is a major challenge for industry.

This study adds to the current state of quality management, system construction and implementation of large-scale public building projects [7]. The goal is to provide a practical quality management framework with points of reference for industry practice.

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

As China's urbanization speeded up, the number and scale of large-scale public buildings surged rapidly with constant improvement in quality management standards. Several projects also have adopted quality management systems as ISO 9001, establishing adequate institutional frameworks and accountability mechanisms. However, certain projects go beyond this by leveraging intelligent

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monitoring tools aligned with BIM technology and digital management platforms to attain refined quality control and visualization [8]. Continuous policy regulations and technical standards from national and local governments offer institutional safeguards for quality control, ensuring that the overall quality level remains within a relatively stable range. Quality control objective function

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

In reality, quality management as it specially applies to large-scale public building projects is still facing a set of challenges and difficulties. Although some projects have presented formal keys for quality management systems, very few manage to take a dynamic attitude where it is possible to promote continuous improvements during project execution, which leads them not to function in an ideal way. Because these projects typically include multiple stakeholders, including designers, contractors, supervisors and suppliers, collaboration and communication often hit the skids. Many obstacles such as lack of clarity regarding responsibilities and delayed communication of information occur, which hamper the effectiveness of quality control. It's difficult to hire supervision during construction, especially for complex processes, concealed work and new technology application. Weak quality traceability systems can lead to blind spots. The differentiation of skills among the construction personnel and a lack of systematic training and quality consciousness awareness in some first-line construction teams also affects the results of quality management. 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 :

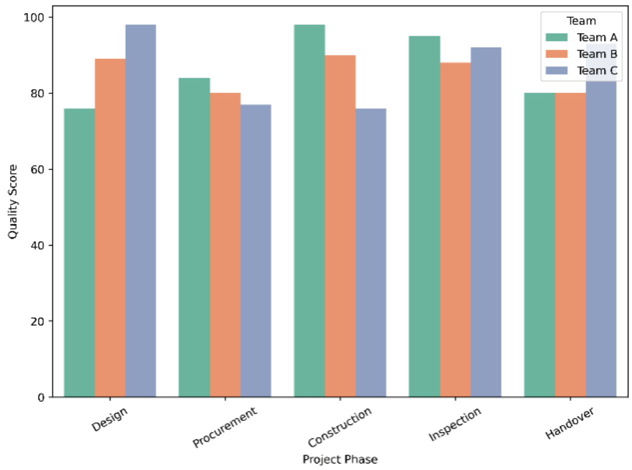

Figure 1 Quality scores across project phases

With the increasing scale and complexity of project, quality management of large-scale public buildings is facing increasingly severe challenges. Super high-rise buildings, large complexes and landmark public facilities have higher requirements for construction technology, material performance and safety. Quality management is evolving from traditional phased control to comprehensive lifecycle-based inspection and supervision. As the concepts of green construction and sustainable development continue to emerge, higher requirements have been imposed on traditional management models, including new quality dimensions such as energy-saving, environmental protection and low-carbon construction. However, the next-generation technologies such as BIM, big data, IoT and AI are advancing rapidly and provide new potential for quality management. But the application is still in an exploratory phase, with neither unified standards nor mature experience, and effectiveness has not been fully validated in reality. In recent years, it has become a major challenge for large public buildings to establish a scientific, efficient and adaptable quality management system that can respond to the changes of the era [9].

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

The overall characteristic and management requirements of large-scale public building project help to build a quality management system. It is necessary to build a macro-oriented framework for information in accordance with the industry's development trend and development standard, define its core components and operational mechanism at the institutional layer (e.g. law, public sector management), organizational layer (e.g. R&D organization, intermediary organizations) and technology layer (i.e., database, transaction platform). In addition, to critical phases including the design phase, construction phase and operation and maintenance phase thorough management measures should be put into place. It is not until the overall top-level design of quality management, resource allocation and process control organically integrated, so as to build scientific systematization and operability quality management system can provide strong guarantee for large-scale public building projects high-quality construction. Cost–quality trade-off model

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

3.1 Basic Framework of the Quality Management System

Defining its guiding principles and overarching objectives is the first step in building a quality management system. Liang1013] Large-scale public building projects are complex systems engineering projects that must follow the basic principle of “full-process control, full participation, and continuous improvement” in quality management. Objectives must be consistent with national quality standards, the physical quality of the project to meet design requirements as well as to achieve a common social benefit and project benefit in terms of safety; functionality, economy and sustainability. Targeting with scientific basis offers directional support for the system operation[10].

In the aspect of framework design, it shall develop a quality management system in accordance with principles of systematization and standardization, establishing a project life cycle management structure. At its origin based on the ISO 9001 quality management standard, it integrates construction industry characteristics and important secondary regulations uniquely to form a complete internal framework of policies, standards, processes, methodologies and so on. This framework should align relationships among multiple parties—including designers, contractors, supervisors, suppliers and owners—making sure that every phase has defined procedures and documented basis. Reliability function for structural components

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

This is one of the eight essential components in the system scaffolding that is organizational structure. Large-scale public building projects have wide scopes and a lot of participants, hence requiring us to use a clear organizational structure as well as division of labor. Thus, forming a multi-level quality management model catering to the project owner (the subject), the supervision agency (the overseer), construction unit (the executor) and design unit. The research also strongly emphasizes on a full accountability system implementation which establishes clear role and responsibility at every level—from management (contractors and owners) to the frontlines all managed under quality management aims which are effectively communicated clearly and adhered rigorously.

As well as this structure, the quality management system must also establish dynamic management and continuous improvement mechanisms. For large-scale public building projects that require a long construction cycle, the external environment and technical conditions continue evolving, thus innovative challenges naturally appear in the system operation stage. However, the systems check their effectiveness regularly and better upgrade management standards. Hence, it increases the versatility and efficiency of a system as well as improves experience for future projects creating harmony.

3.2 System Elements and Core Content

Among all integral components that make up the quality management system for large-scale public construction projects, institutional development represents one of the most important underlying bases. The Foundation and Quality Control Requirements System: standards for quality control at every stage of the project — from establishing the basis and criteria for quality accountability systems, technical specifications, inspection and acceptance procedures to risk early warning mechanism. A well performing institutional framework creates a high level of standardization for various activities through the elimination of situational, and thereby ensures the controllability and stability of project quality,showed in Figure 2 :

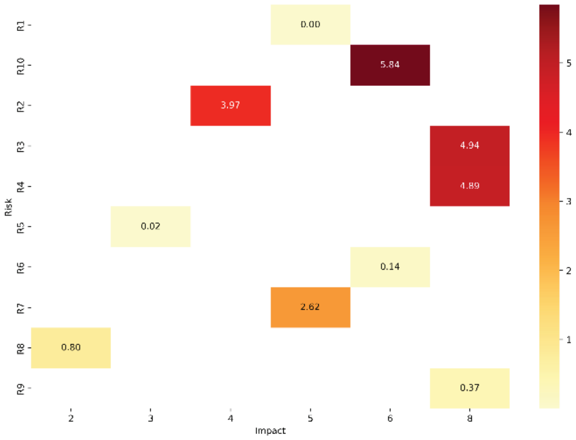

Figure 2 Risk vs Impact heatmap

Organizational support is the backbone for system operation. Quality management is not only about systems and processes; it also requires a solid organizational structure for execution. Projects generally create quality management departments or task forces, wherein the roles and responsibilities of each management level are well--defined to establish a clear vertical escalation of accountability from decision making downwards to execution. A focus on multi-party alignment provides smooth communication and clearly defined roles among all relevant stakeholders (owners, designers, contractors, supervisors) for achieving synergistic quality control.

Technical support is the most important driving force for system operation. In particular, technologies such as BIM, big data, IoT and AI have became the important tools to manage engineering quality with the popularization of informations model technology and intelligent solution in construction industry. Such technologies allow for extensive data collection, real-time monitoring and intelligent analysis during the entire construction period, laying a solid scientific foundation for quality control. There is a positive effect of the applied advanced construction technique and new material on engineering quality and controllability.

These are crucial safeguards of the system but their effectiveness over the long term depends on other pieces, particularly quality culture and personnel competence. While systems and technology provide the external constraints and support, execution lies ultimately with people. This can help improve the intrinsic motivation of the system, such as strengthening quality awareness among all personnel and enhancing the professional competence of managers and construction workers. In addition to this, creating a project culture centered on quality also acts in this direction. The system can only be truly implemented and effectively operated through training, assessment, and incentive mechanisms from the quality responsibility to each participant.

3.3 Design of Key Control Points

Effective control of the key stage is a decisive factor in the quality management system for large-scale public building objects. Generally, construction goes through three main phases—design, construction and operation/maintenance. Control of the quality on these arks is interdependent and plays a considerable role in determining the overall standard of the project. The foundation of quality formation comes from the design phase. No amount of subsequent construction, no matter how thorough, can fully make up for defects or oversights in the design scheme. Scientific and feasible designs must be ensured through rigorous drawing reviews, design validation, and expert evaluations. Green, energy-efficient and sustainable principles should form the core foundation of design process from the start to ensure a quality project. Risk index model

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

Once construction commences, quality control changes from product inspection to process control.

Construction sites are usually the densest in terms of risk and most prone to problems arising. So that control must be strengthened by standardized operation, strict process site, secret work acceptance. A hot monitoring mechanism should be established, using sensor-, drone- and BIM-based technology to monitor construction quality in continuous states to detect problems as soon as possible and correct them. Especially, the construction phase is a field with intricate personnel and processes such that lack of due diligence in any segment will affect end quality. As a result, the stability and controllability of construction can only be realized through comprehensive collaborative management throughout all processes and elements.

During completion and operational phases, quality management focuses on ensuring that the construction behaves according to expectations safely and reliably over its desired lifespan. Final Acceptance not only validates that outcomes of the construction but also evaluates whether previous management was effective or not. To ensure the building is in accordance with design and regulatory requirements, systematic testing and evaluation must be conducted. Quality control of the building does not stop at operation and maintenance but continues throughout its entire life cycle. Maintenance with operational monitoring and maintenance mechanisms—continuously tracking structural security, equipment functioning, and the environments of use—extends the building's life cycle, reduces long-run repair costs, and "building well" supplanted by "using well."

Quality control at crucial times is not standalone but an interwoven progressive chain. A true full-lifecycle quality assurance system can only be formed through the organic combination of design origin, construction process and operational maintenance support, supported by advanced technologies and management methods. Ensuring the best possible functionality, safety and sustainability of large public buildings.

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

A scientific quality management system is only the basis of realizing project quality. How well it works in practice remains to be seen. Policies, regulations and industry specifications: it is the basic guarantee of the system operation. Moreover, the relevant government departments continuously improve regulatory system, strictly enforce enforced standards and ensure quality management measures are implemented through supervision/inspection/incentive mechanism and penalty mechanism. And for construction entities and contractors, it is also necessary to take the initiative to dig through these regulations and standards in advance internally, turning them into normative management norms that should be implemented within the enterprise organization. Process quality control using variance

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

A key driving force for implementing systems. Large-scale public construction projects have complex technologies and long management chains, requiring high comprehensive competencies for both management and construction personnel. And the establishment of full training and assessment mechanism can continuously enhance the professional quality of organ staff, so that the awareness of quality is permeated into every work, making full participation as a operational foundation for the entire system. Accumulate knowledge and experience in attracting highly qualified specialists with a range of specialties to advance project management methods from an empirical approach to one based on modern knowledge and data.

There has emerged an indispensable enabler of implementation effectiveness through the application of technology. Technologies like BIM and big data, IoT, AI can supply the real-time, dynamic as well as traceable data support for engineering quality management to realize accurate control in each process. This unified information platform helps share data among multiple stakeholders, so breaking the data silos can enhance the rationality of decision-making and transparency in management. In addition, technological tools can convey real-time information to construction sites which supports automated monitoring and early warning systems for problems at the site that are critical in improving efficiency of identifying quality issues and solving them.

To implement this framework, the establishment of risk management and emergency response systems is the another essential component. Large-scale public construction projects have long periods and high investment, with a complex external environment, where various risks are intertwined and compounded. Proactive prevention of potential problems is only possible by integrating risk identification, assessment and response mechanisms into the operation of the system. Science-driven contingency planning and rapid response strategies will minimize loss during crises, project safety, and quality will remain stable. Lifecycle performance index

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

Mechanisms of incentives and constraints as the long-term sustainability of the system. When relying only on regulations and oversight, we miss out, as not all personnel are fully engaged and on-board in achieving our objectives. Hence, the system should be infused with measures of reward and penalization based on science as closely aligning individual and organizational interests to quality goals. Through both commendation and condemnation, we inspire the personnel motivation necessary to return this project intermediate benefit to resources; a gradual formation of the endogeny project culture that will be able to make “high quality is a medal, mistake access will be also other shame”, slow pacing power for sustainable implementation ensure from system body.

Implementing a quality management system for large public buildings: A systematic approach It calls for both external constrains from policies and standards, internal incentives in form of organizations and personnel, as well the coordinated synergy between technology innovation system and risk management. The paper — practice transformation of the quality management system through the integrated implementation of multidimensional dimensions, to promote large public buildings engineering construction projects overall quality improvement.

5. Conclusion

The scale, complexity and number of stakeholders involved in large-scale public building projects have compounded the quality management challenges they face. This paper studies the current situation and existing problems, puts forward a framework for the construction of quality management system with in-depth analysis from three aspects: basic framework, core elements and key processes. It goes into implementation strategies and offers pathways and safeguards for practical application. This facilitates the implementation of smart green and sustainable development in the construction industry by standardizing and optimizing project types through a scientifically designed quality management system, improving the overall project quality and safety.

As information technology continues to evolve rapidly and the concept of green buildings is further promoted, quality management of large-scale public building engineering projects will gradually begin to integrate intelligent and whole-process management methods. There are some questions to be answered: How do we integrate advanced technology with the management model in practice, and how can we manage (providing personalization and flexibility) without sacrificing standardization? Therefore, this also makes continuous improvement and optimization of the quality management system, to truly guarantee sustainable engineering quality, meet the public's multi-dimensional needs for safety, function and other requirements.

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