




Fuzzy Modeling of the Impact of Total Quality Management Factors on the Performance of Construction Projects in Tehran with a Focus on Innovation and Continuous Improvement

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Abstract

The present study aims to evaluate and prioritize the impact of soft and hard factors of Total Quality Management (TQM) on the performance of construction projects, with an emphasis on the role of innovation and continuous improvement in Tehran. Given the complexity and multidimensional nature of construction projects, traditional quality management approaches are no longer sufficient to meet the increasing demands of this field, necessitating the adoption of scientific, systematic, and multi-criteria decision-making methods. Accordingly, this study employs the fuzzy TOPSIS method to analyze data collected from 30 managers, engineers, and experts involved in large-scale construction projects in the metropolitan area of Tehran. The main indicators include soft factors (leadership and management, organizational culture, participation and collaboration) and hard factors (monitoring and evaluation systems, resources and equipment, standardized processes) of Total Quality Management, as well as two performance components: innovation and continuous improvement. The findings indicate that soft TQM factors have a greater impact on project performance compared to hard factors. Specifically, the “leadership and management” component ranked first with the highest weight (0.813), whereas the “resources and equipment” component was ranked last. Furthermore, the mediating role of innovation and continuous improvement enhances the effect of TQM factors on project performance. By emphasizing the importance of human, organizational, and cultural factors alongside structural and technological mechanisms, this study provides practical solutions for improving the performance of construction projects and introduces new research avenues in the field of infrastructure project quality management.

Keywords: *Soft and Hard Factors, Total Quality Management, Performance, Construction Projects, Innovation, Fuzzy TOPSIS*

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1. Introduction

Construction projects are among the most complex organizational and technical systems in contemporary project-based industries because they require the coordinated integration of design, procurement, labor, materials, technologies, quality control mechanisms, stakeholder expectations, and regulatory requirements under conditions of uncertainty. In metropolitan contexts such as Tehran, the performance of construction projects is not

determined only by cost, time, and technical output, but also by the capacity of project organizations to institutionalize quality, reduce defects, improve stakeholder satisfaction, adopt modern construction technologies, and sustain continuous improvement across project life cycles. The growing scale and complexity of urban construction have made traditional quality assurance approaches insufficient, especially when project success depends on adaptive managerial capabilities, cross-functional coordination, evidence-based decision-making, and the systematic use of



innovation. Total Quality Management (TQM), as a comprehensive managerial philosophy, offers an integrated framework for improving project performance by aligning leadership, organizational culture, participation, standardized processes, monitoring systems, resources, and continuous improvement. In civil and construction projects, TQM is increasingly regarded as a key success factor because it links quality planning with managerial commitment, process discipline, customer-oriented performance, and organizational learning [1]. Therefore, examining the relative influence of soft and hard TQM factors on construction project performance is essential for identifying which managerial and technical dimensions deserve greater strategic attention.

The importance of quality-oriented management in construction has become more pronounced due to the rapid expansion of modern construction technologies, industrialized construction methods, digital tools, prefabrication, innovative materials, and sustainability-oriented infrastructure systems. Modern construction technologies are no longer peripheral technical options; rather, they are central mechanisms for enhancing productivity, resilience, precision, and long-term project value. Studies on the necessity of using modern technologies in construction emphasize their role in improving building resilience and responding to emerging environmental and operational risks [2]. Similarly, research on modern technologies in building materials and industrialized construction highlights the potential of technological transformation to improve execution quality, reduce waste, and increase efficiency in civil projects [3, 4]. In the context of national construction development, modern construction technologies have also been identified as necessary tools for improving large-scale housing and mass construction programs, where delays, quality defects, and resource inefficiencies can produce extensive social and economic consequences [5]. From this perspective, TQM and technological innovation should not be treated as separate domains; rather, quality management provides the organizational and procedural foundation through which modern technologies can generate measurable project performance outcomes.

The distinction between soft and hard TQM factors is particularly important in construction project environments. Soft TQM factors generally refer to human, cultural, and managerial dimensions such as leadership, organizational culture, employee participation, teamwork, communication, commitment, and learning orientation. Hard TQM factors

refer to more structural and technical dimensions such as process standardization, monitoring systems, measurement tools, documentation, resource allocation, equipment, and operational procedures. Although hard factors provide the formal infrastructure for quality control, soft factors often determine whether these systems are effectively implemented and continuously improved. In construction projects, leadership and management can create strategic direction, quality commitment, and accountability; organizational culture can shape behavioral norms and acceptance of quality practices; and participation and collaboration can improve problem-solving, reduce rework, and strengthen knowledge sharing. These dimensions are especially relevant in project-based industries where temporary organizations, subcontracting structures, fragmented responsibilities, and time pressure can weaken quality integration. Evidence from studies on Lean Six Sigma implementation in construction SMEs shows that managerial, organizational, and strategic barriers must be systematically prioritized to improve quality-oriented transformation [6]. Likewise, the use of fuzzy decision-making models for lean construction implementation demonstrates that barriers to quality and efficiency improvement are multidimensional and require structured prioritization rather than intuitive judgment [7].

In recent years, fuzzy multi-criteria decision-making methods have gained increasing relevance for construction management research because they allow researchers and practitioners to evaluate complex criteria under uncertainty, ambiguity, and subjective expert judgment. Construction project performance is rarely measured through fully objective and deterministic data; rather, it often depends on expert assessments of managerial effectiveness, readiness, quality practices, innovation capacity, resource adequacy, and process maturity. Fuzzy TOPSIS is especially useful in such contexts because it ranks alternatives based on their relative closeness to an ideal solution and distance from a negative ideal solution. This approach is compatible with construction decision environments in which linguistic judgments, uncertain information, and multiple criteria must be integrated into a coherent ranking framework. Recent studies have applied fuzzy TOPSIS and related hybrid fuzzy methods to prioritize Quality 4.0 dimensions, implementation readiness, construction satisfaction factors, and lean barriers [7-10]. These studies indicate that fuzzy decision models can improve managerial decision quality by transforming expert opinions into systematic rankings,

thereby supporting evidence-based prioritization in complex project and industrial settings.

Digitalization has also expanded the scope of quality management in construction. Digital technology enables real-time monitoring, data-driven inspection, Building Information Modeling integration, automated documentation, predictive analytics, defect tracking, and more transparent quality control procedures. A review of digital technology for quality management in construction emphasizes that digital tools can strengthen quality assurance, improve information flows, and create future research directions for more integrated project quality systems [11]. At the same time, Quality 4.0 research suggests that successful adoption requires more than digital infrastructure; it also depends on strategic prioritization, organizational readiness, process alignment, and cultural acceptance [8]. In industries moving toward Internet of Things readiness and smart operations, fuzzy TOPSIS has been used to rank implementation criteria, confirming that technological readiness depends on interconnected organizational, technical, and managerial criteria [9]. These findings are relevant to construction projects in Tehran because the performance benefits of innovation and digital tools are unlikely to emerge unless they are embedded within a broader TQM framework that aligns leadership, process control, culture, resources, and continuous improvement.

Innovation in construction is not limited to digital systems; it also includes new materials, construction methods, prefabricated technologies, bio-inspired components, recycled materials, and structural systems that enhance sustainability and resilience. Innovative construction material technologies have been introduced as essential contributors to sustainable and resilient civil infrastructure, particularly because infrastructure performance increasingly depends on durability, environmental responsibility, and long-term adaptability [12]. Research on transforming recycled glass waste into construction components demonstrates how material innovation can simultaneously address environmental concerns and create new construction products [13]. Similarly, high-performance bio-inspired prefabricated composites have been optimized for sustainable and resilient construction, showing the importance of integrating engineering innovation with performance objectives [14]. Structural and construction technology innovation is also evident in studies on frame-partitioned infill walls with sliding nodes and large openings, where new construction technologies are tested for improved technical performance

[15]. These developments show that innovation is a core performance driver in construction, but its effectiveness depends on organizational capacity to evaluate, adopt, standardize, and continuously improve the technologies used in projects.

The diffusion of construction technology innovation is itself a managerial challenge. Even when a technology has technical advantages, its adoption may be slowed by cost concerns, regulatory uncertainty, limited expertise, fragmented supply chains, resistance to change, or lack of managerial support. Research measuring factors that influence the diffusion of prefabricated construction technology innovation shows that technological diffusion is shaped by multiple organizational and environmental determinants [16]. Entrepreneurship-oriented studies in modern construction technologies also emphasize that innovation creates new opportunities for sustainable development when organizations are able to identify, evaluate, and operationalize these opportunities strategically [17]. In architectural and building contexts, modern construction technologies have been connected to improved design performance, daylight control, and architectural outcomes, indicating that innovation can influence both technical and experiential dimensions of the built environment [18, 19]. However, the diffusion and performance effects of these technologies require management systems that can ensure training, coordination, quality control, feedback loops, and continuous improvement. This reinforces the relevance of TQM as a managerial mechanism for converting technological potential into actual project performance.

Continuous improvement is another central component of the relationship between TQM and construction project performance. In TQM logic, quality is not achieved through isolated inspection or end-stage control; rather, it is generated through ongoing learning, corrective action, standardization, participation, and feedback-based refinement. Construction projects often suffer from repeated errors, rework, communication gaps, and inconsistent documentation. Continuous improvement provides a mechanism for transforming project experience into organizational learning and for reducing the recurrence of quality failures across projects. In this regard, monitoring and evaluation systems, standardized processes, and work methods are important hard TQM factors because they provide the measurable structure through which improvement can be tracked. However, without leadership commitment and a culture that encourages participation,

learning, and innovation, formal systems may remain procedural rather than transformative. Studies connecting TQM with green performance and corporate social responsibility suggest that quality management can support broader organizational outcomes when it is linked to strategic responsibility, performance systems, and sustainability-oriented practices [20]. Therefore, in construction project management, continuous improvement should be considered both a performance outcome and a mediating mechanism through which TQM factors enhance project effectiveness.

The Tehran construction sector provides a significant context for examining these relationships. As a large metropolitan area with complex infrastructure demands, dense urban development, seismic vulnerability, resource constraints, and expanding construction needs, Tehran requires project management approaches that can improve quality, efficiency, resilience, and innovation simultaneously. The necessity of using modern construction technologies in building has been repeatedly emphasized in Iranian construction studies, particularly in relation to productivity, resilience, industrialization, and national development needs [2, 5, 21]. However, the mere availability of modern construction technologies does not guarantee improved performance. Project organizations must determine which quality management factors have the greatest influence and how innovation and continuous improvement reinforce that influence. Since construction project performance involves multiple interdependent criteria, fuzzy TOPSIS offers an appropriate methodological foundation for ranking soft and hard TQM factors based on expert judgment and uncertain decision conditions. This enables managers to move beyond general claims about the importance of quality and toward a more precise prioritization of the factors that most strongly affect project outcomes.

Despite the growing body of literature on TQM, modern construction technologies, quality improvement, and fuzzy decision-making, several gaps remain. First, many studies address technology adoption, digital quality management, lean implementation, or construction innovation separately, while fewer studies integrate these issues within a comprehensive TQM-based performance model. Second, although modern construction technologies have been studied in relation to resilience, materials, prefabrication, and sustainability, there is still a need to examine how managerial and organizational quality factors determine whether such innovations improve construction project

performance [12-15]. Third, while fuzzy TOPSIS has been increasingly applied in quality and construction management, its use for prioritizing soft and hard TQM factors with explicit attention to innovation and continuous improvement remains limited [6, 8, 10]. Finally, in the context of Tehran construction projects, a practical ranking of TQM factors can help project managers, engineers, and policymakers identify whether human and cultural factors or technical and structural mechanisms deserve greater emphasis in quality improvement strategies. Addressing this gap is both theoretically meaningful and practically necessary for improving the performance of urban construction projects.

Accordingly, the aim of this study is to use the Fuzzy TOPSIS method to evaluate and prioritize the effects of soft and hard Total Quality Management factors on the performance of construction projects in Tehran, with a specific focus on the roles of innovation and continuous improvement.

2. Methodology

This study is applied in terms of objective and employs a mixed-methods (qualitative–quantitative) approach in terms of nature and methodology. In the qualitative phase, indicators related to the research variables were extracted through a systematic review of prior studies and scholarly articles. In the quantitative phase, these indicators were ranked and analyzed using the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) method (Patil & Kant, 2014). The statistical population consists of project managers, engineers, and professionals in the construction industry in Tehran who are actively involved in various construction projects. These participants include senior managers, project managers, site engineers, and other technical and managerial experts who play key roles in construction projects in Tehran.

3. Findings and Results

In this section, the inferential findings of the study are presented based on the research questions and hypotheses. The primary question concerns the prioritization of the impact of soft and hard Total Quality Management (TQM) factors on the performance of construction projects based on the role of innovation and continuous improvement. Additionally, the relative importance of each criterion is determined using the Fuzzy TOPSIS method.

Table 1. Abbreviations of Sub-Criteria

Criterion	Symbol	Category
Participation and Collaboration	A1	Soft TQM Factors
Leadership and Management	A2	Soft TQM Factors
Organizational Culture	A3	Soft TQM Factors
Monitoring and Evaluation Systems	A4	Hard TQM Factors
Resources and Equipment	A5	Hard TQM Factors
Standardized Processes and Work Methods	A6	Hard TQM Factors
Project Performance Based on Innovation	C1	Project Performance
Project Performance Based on Continuous Improvement	C2	Project Performance

In this study, the Fuzzy TOPSIS method is employed for prioritizing the criteria. The methodological steps are adapted from Patil and Kant (2014).

Step 1: Construction of the Fuzzy Decision Matrix

Assume the decision matrix is defined as:

$$X = [x_{ij}]_{m \times n}$$

where each column represents a criterion and each row represents an alternative. The element x_{ij} denotes the performance value of alternative i under criterion j . These values are expressed as triangular fuzzy numbers:

$$\tilde{x}_{ij} = (l_{ij}, m_{ij}, u_{ij})$$

Table 2. Linguistic Variables and Corresponding Fuzzy Numbers

Symbol	Importance Level	Fuzzy Number
VP	Very Poor	(0, 0, 1)
P	Poor	(0, 1, 3)
MP	Medium Poor	(1, 3, 5)
F	Fair	(3, 5, 7)
MG	Medium Good	(5, 7, 9)
G	Good	(7, 9, 10)
VG	Very Good	(9, 10, 10)

Inputs required include criteria weights w_j and the type of criteria (benefit or cost).

Step 2: Normalization of the Decision Matrix

For benefit criteria:

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^*}, \frac{m_{ij}}{u_j^*}, \frac{u_{ij}}{u_j^*} \right)$$

For cost criteria:

$$\tilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}} \right)$$

Step 3: Weighted Normalized Matrix

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times w_j$$

Step 4: Determination of Ideal Solutions

$$A^+ = (\max v_{ij}), A^- = (\min v_{ij})$$

Step 5: Distance Calculation

Distances are computed using Euclidean distance:

$$d_i^+ = \sqrt{\sum (v_{ij} - v_j^+)^2}, d_i^- = \sqrt{\sum (v_{ij} - v_j^-)^2}$$

Step 6: Closeness Coefficient

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-}$$

Step 7: Ranking

Alternatives are ranked based on descending values of CC_i .

The collected survey data were aggregated using the arithmetic mean to facilitate group decision-making.

Table 3. Fuzzy Decision Matrix

Alternative	C1 (Fuzzy)	C2 (Fuzzy)
A1	(1, 4.6, 9)	(3, 6.2, 9)

A2	(3, 5.8, 9)	(5, 8.8, 10)
A3	(3, 6.2, 9)	(1, 8, 10)
A4	(3, 5, 7)	(7, 9.2, 10)
A5	(3, 5, 7)	(1, 8, 10)
A6	(1, 4.6, 7)	(1, 6.6, 10)

Table 4. Normalized Fuzzy Decision Matrix

Alternative	C1	C2
A1	(0.111, 0.511, 1)	(0.333, 0.689, 1)
A2	(0.333, 0.644, 1)	(0.5, 0.88, 1)
A3	(0.333, 0.689, 1)	(0.1, 0.8, 1)
A4	(0.429, 0.556, 0.778)	(0.778, 1.022, 1.111)
A5	(0.333, 0.556, 0.778)	(0.1, 0.8, 1)
A6	(0.111, 0.511, 0.778)	(0.1, 0.66, 1)

Table 5. Weighted Normalized Matrix

Alternative	C1	C2
A1	(0.116, 0.334, 0.413)	(0.166, 0.263, 0.255)
A2	(0.339, 0.427, 0.413)	(0.249, 0.356, 0.255)
A3	(0.339, 0.459, 0.413)	(0.049, 0.292, 0.255)
A4	(0.421, 0.364, 0.327)	(0.388, 0.352, 0.285)
A5	(0.331, 0.363, 0.324)	(0.049, 0.275, 0.255)
A6	(0.110, 0.334, 0.324)	(0.049, 0.227, 0.255)

Table 6. Positive and Negative Ideal Solutions

Type	C1	C2
Positive Ideal (A ⁺)	(0.451, 0.451, 0.451)	(0.303, 0.303, 0.303)
Negative Ideal (A ⁻)	(0.110, 0.110, 0.110)	(0.049, 0.049, 0.049)

Table 7. Distances from Ideal Solutions

Alternative	S ⁺	S ⁻
A1	0.301	0.392
A2	0.116	0.502
A3	0.222	0.469
A4	0.431	0.668
A5	0.489	0.516
A6	0.333	0.378

Table 8. Closeness Coefficient and Ranking

Criterion	Symbol	CCi	Weight	Rank
Participation and Collaboration	A1	CC1	0.565	4
Leadership and Management	A2	CC2	0.813	1
Organizational Culture	A3	CC3	0.678	2
Monitoring and Evaluation Systems	A4	CC4	0.608	3
Resources and Equipment	A5	CC5	0.513	6
Standardized Processes	A6	CC6	0.532	5

The results indicate that the “Leadership and Management” criterion (A2), with a weight of 0.813, ranks first, followed by “Organizational Culture” (A3) with a weight of 0.678, both belonging to soft TQM factors. “Monitoring and Evaluation Systems” (A4), a hard TQM factor, ranks third with a weight of 0.608. “Participation and Collaboration” (A1) ranks fourth with a weight of 0.565.

“Standardized Processes and Work Methods” (A6) ranks fifth with a weight of 0.532, while “Resources and Equipment” (A5) ranks last with a weight of 0.513 in influencing construction project performance based on innovation and continuous improvement.

4. Discussion and Conclusion

The findings of this study provide a structured prioritization of Total Quality Management (TQM) factors influencing the performance of construction projects in Tehran, with particular emphasis on the mediating roles of innovation and continuous improvement. The results clearly indicate that soft TQM factors exert a stronger influence on project performance compared to hard factors. Specifically, leadership and management (A2) emerged as the most influential factor, followed by organizational culture (A3), while participation and collaboration (A1) also demonstrated a significant contribution. Among hard factors, monitoring and evaluation systems (A4) ranked higher than standardized processes (A6) and resources and equipment (A5), with the latter occupying the lowest position. These findings suggest that while structural and technical mechanisms remain important, the human, managerial, and cultural dimensions of quality management are more decisive in enhancing project performance under conditions of uncertainty and complexity.

The prominence of leadership and management as the most critical factor is consistent with the theoretical foundations of TQM, where top management commitment is considered the cornerstone of successful quality implementation. Effective leadership not only establishes strategic direction but also facilitates resource allocation, motivates employees, and fosters a culture of continuous improvement. In construction projects, which often involve fragmented organizational structures and multiple stakeholders, leadership plays a crucial role in aligning diverse actors toward shared quality objectives. This finding aligns with prior research emphasizing that TQM serves as a key driver of success in civil projects when leadership commitment is present and actively enforced [1]. Furthermore, studies on Lean Six Sigma implementation in construction SMEs have highlighted leadership-related barriers as primary determinants of success or failure, reinforcing the importance of managerial engagement in quality initiatives [6]. Similarly, integrated fuzzy decision-making models have demonstrated that strategic and managerial factors often rank higher than technical ones when prioritizing quality improvement dimensions [8].

Organizational culture, as the second-ranked factor, also plays a pivotal role in shaping project outcomes. A culture that promotes quality awareness, accountability, learning, and collaboration can significantly enhance the effectiveness of both soft and hard TQM practices. In construction

environments, where errors and rework can have substantial cost and time implications, a supportive culture encourages proactive problem-solving and reduces resistance to change. This finding is consistent with research linking TQM with broader organizational outcomes such as green performance and corporate social responsibility, where cultural alignment is essential for achieving sustainable performance improvements [20]. Moreover, the integration of digital quality management systems requires cultural readiness and acceptance, as technological tools alone cannot ensure improved outcomes without corresponding behavioral adaptation [11]. Therefore, organizational culture functions as a critical enabler that amplifies the impact of both innovation and continuous improvement processes.

Participation and collaboration, ranked fourth, further reinforce the importance of human-centered factors in construction project performance. Collaborative practices enhance information sharing, coordination, and collective problem-solving, which are essential in complex project environments characterized by interdependencies and uncertainties. This result is supported by studies indicating that barriers to lean construction implementation often stem from insufficient collaboration and stakeholder engagement, highlighting the need for participatory approaches in quality management [7]. Additionally, in contexts where modern construction technologies are introduced, effective collaboration becomes even more critical, as successful implementation requires coordination among designers, engineers, contractors, and technology providers [5]. Thus, participation and collaboration not only improve immediate project performance but also facilitate the integration of innovative practices.

Among hard factors, monitoring and evaluation systems achieved the highest rank, underscoring their role in providing measurable feedback and supporting continuous improvement. These systems enable organizations to track performance, identify deviations, and implement corrective actions systematically. The importance of such systems is consistent with research on digital quality management, which emphasizes the role of data-driven monitoring and real-time evaluation in enhancing construction quality [11]. However, the lower ranking of standardized processes and work methods suggests that formalization alone is insufficient without supportive managerial and cultural conditions. While standardized processes are necessary for consistency and efficiency, their effectiveness depends on proper implementation, continuous updating, and alignment with project-specific requirements.

The lowest ranking of resources and equipment indicates that the mere availability of physical assets does not guarantee improved project performance. This finding challenges traditional assumptions that prioritize material and technological inputs over managerial and organizational capabilities. Although modern construction technologies and advanced equipment are essential for enhancing productivity and resilience, their impact is contingent upon effective management and integration within organizational processes. Studies on modern construction technologies have consistently highlighted their potential benefits, including improved resilience, sustainability, and efficiency [2-4]. However, the current findings suggest that without strong leadership, culture, and collaboration, these technologies may not achieve their full potential. This interpretation is further supported by research on the diffusion of construction technology innovation, which identifies organizational and managerial factors as key determinants of successful adoption [16].

The mediating roles of innovation and continuous improvement provide additional insight into the mechanisms through which TQM factors influence project performance. Innovation enhances the ability of construction projects to adopt new materials, methods, and technologies, thereby improving efficiency, sustainability, and resilience. Research on innovative construction materials and technologies has demonstrated their capacity to transform infrastructure performance and address environmental challenges [12, 14]. Similarly, studies on recycled materials and advanced structural systems highlight the potential of innovation to create new value in construction processes [13, 15]. However, the effectiveness of innovation depends on the organizational context in which it is implemented. TQM provides the framework for integrating innovation into project processes, ensuring that new technologies are evaluated, standardized, and continuously improved.

Continuous improvement, on the other hand, ensures that quality enhancement is an ongoing process rather than a one-time effort. By systematically identifying and addressing performance gaps, continuous improvement contributes to long-term project success and organizational learning. This aligns with research emphasizing the role of TQM in fostering sustainable development and entrepreneurship opportunities in modern construction technologies [17]. Furthermore, the integration of continuous improvement with monitoring systems and standardized processes creates a feedback loop that enhances overall project performance. In this context, innovation and continuous improvement act

as complementary mechanisms that amplify the impact of both soft and hard TQM factors.

The combined interpretation of these findings suggests that construction project performance is primarily driven by managerial and organizational capabilities, which enable the effective utilization of technical resources and the successful implementation of innovation. This perspective is consistent with broader trends in construction management research, which emphasize the integration of quality management, technological innovation, and organizational learning as key determinants of project success. In the Tehran context, where construction projects face unique challenges related to urban density, regulatory complexity, and resource constraints, the prioritization of soft TQM factors provides valuable guidance for improving project outcomes. By focusing on leadership, culture, and collaboration, project managers can create conditions that support innovation and continuous improvement, ultimately enhancing performance across multiple dimensions.

One limitation of this study is the relatively small sample size of experts, which may affect the generalizability of the findings. Although the participants were selected from experienced professionals in the construction industry, a larger and more diverse sample could provide a more comprehensive representation of perspectives. Additionally, the study relies on subjective judgments expressed through linguistic variables, which, despite being processed using fuzzy logic, may still introduce bias. The focus on construction projects in Tehran also limits the applicability of the results to other geographical or industrial contexts. Furthermore, the cross-sectional nature of the data does not capture dynamic changes in TQM implementation over time.

Future studies could expand the sample size and include participants from different regions or countries to enhance the generalizability of the findings. Longitudinal research designs may also be employed to examine how the impact of TQM factors evolves over time. Additionally, integrating other multi-criteria decision-making methods or hybrid models could provide deeper insights into the relationships among variables. Future research may also explore the interaction effects between digital transformation, Industry 4.0 technologies, and TQM practices in construction projects. Investigating the role of external factors such as regulatory frameworks, market conditions, and stakeholder pressures could further enrich the analysis.

From a practical perspective, construction project managers should prioritize the development of strong leadership capabilities and foster an organizational culture

that supports quality, innovation, and collaboration. Investment in training programs and knowledge-sharing initiatives can enhance employee participation and improve overall project performance. Organizations should also strengthen their monitoring and evaluation systems to support continuous improvement while ensuring that standardized processes remain flexible and adaptable. Although resources and equipment are necessary, their effective utilization depends on managerial competence and organizational alignment. Therefore, a balanced approach that integrates soft and hard TQM factors is essential for achieving sustainable improvements in construction project performance.

Authors' Contributions

Authors equally contributed to this article.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

All procedures performed in this study were under the ethical standards.

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