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E-mail: *architecturalsciences@gmail.com*

# Digitalisation of Quality Management Systems in Construction Industry: A Conceptual Exploration

Tayibe SEYMAN GÜRAY[1]*

**ORCID 1:** 0000-0001-5692-9669
[1] Fenerbahce University, Architecture and Design Faculty, Department of Int. Architecture and Env.Des., 34758, Istanbul, Türkiye.
** e-mail: tayibe.guray@fbu.edu.tr*

**Abstract**

*Although Quality Management Systems (QMS) play a critical role in ensuring consistency, performance, and sustainability in construction projects, traditional practices often fall short in addressing the sector's rapidly digitalizing and highly fragmented nature. Quality 4.0 emphasizes the value of emerging technologies, yet existing interpretations remain broad and do not fully reflect the operational realities of construction. This study reinterprets Quality 4.0 principles from a construction-specific perspective and examines how digital tools can be systematically integrated into core quality functions. Using a structured review of current literature and sectoral practices, the research develops an adaptive framework that links technological capabilities with inspection, documentation, communication, and continuous improvement processes.The results show that effective digital integration requires rethinking quality workflows through complexity, uncertainty, and non-linear project dynamics. The proposed framework offers a targeted approach to modernizing QMS and enhancing transparency, decision-making, and overall project performance in construction.*

***Keywords:*** *Digitalisation, Quality management systems, QMS, Construction projects, Quality 4.0.*

# İnşaat Endüstrisinde Kalite Yönetim Sistemlerinin Dijitalleşmesi: Kavramsal Bir Değerlendirme

**Öz**

*Her ne kadar Kalite Yönetim Sistemleri (KYS), inşaat projelerinde tutarlılığın, performansın ve sürdürülebilirliğin sağlanmasında kritik bir rol oynasa da, geleneksel uygulamalar sektörün hızla dijitalleşen ve oldukça parçalı yapısını karşılamakta yetersiz kalmaktadır. Quality 4.0 yaklaşımı yeni teknolojilerin değerini vurgulasa da, mevcut yorumlar geniş kapsamlı olup inşaat sektörünün operasyonel gerçekliklerini tam olarak yansıtmamaktadır. Bu çalışma, Kalite 4.0 ilkelerini inşaat odaklı bir bakış açısıyla yeniden yorumlamakta ve dijital araçların temel kalite fonksiyonlarına nasıl sistematik şekilde entegre edilebileceğini incelemektedir. Güncel literatür ve sektörel uygulamaların yapılandırılmış bir değerlendirmesi üzerinden, teknolojik yetkinlikleri denetim, dokümantasyon, iletişim ve sürekli iyileştirme süreçleriyle ilişkilendiren uyarlanabilir bir çerçeve geliştirilmiştir. Bulgular, dijital entegrasyonun etkin olabilmesi için kalite iş akışlarının karmaşıklık, belirsizlik ve doğrusal olmayan proje dinamikleri ışığında yeniden düşünülmesi gerektiğini göstermektedir. Önerilen çerçeve, KYS'nin modernizasyonuna katkı sağlamakta ve şeffaflığı, karar alma süreçlerini ve genel proje performansını artırmayı amaçlamaktadır.*

***Anahtar kelimeler:*** *Dijitalleşme, Kalite yönetim sistemleri, KYS, İnşaat projeleri, Kalite 4.0.*

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## 1. Introduction

Although Quality Management Systems (QMS) play a critical role in ensuring consistency, performance, and sustainability in construction projects, their effectiveness often depends on proper implementation across all project phases (Rumane, 2017; Sui Pheng & Hui Hong, 2005). Traditional QMS, typically aligned with ISO 9001 standards, rely on planned procedures, documentation, inspections, and corrective–preventive actions to ensure compliance and continuous improvement (Hoonakker et al., 2010; Jraisat et al., 2016). Despite their importance, these systems frequently face practical challenges, including fragmented information flow, inconsistent documentation, delayed reporting, and limited traceability, which can undermine both quality control and overall project outcomes.

In recent years, the construction industry has been increasingly shaped by Industry 4.0, which integrates automation, data analytics, cloud computing, and smart sensing technologies into production and project management processes (Sawhney et al., 2020; PMI, 2021). Within this broader digital transformation, the concept of Quality 4.0 has emerged as a cross-industry paradigm that emphasizes enhanced connectivity, real-time data availability, integrated workflows, and evidence-based decision-making. Quality 4.0 provides a conceptual lens for understanding how digital technologies can reinforce traditional quality practices while introducing new capabilities such as predictive analytics and proactive monitoring (Marsden, 2019; Luo et al., 2022).

While Quality 4.0 is applicable across multiple sectors, the construction industry operationalizes this paradigm through domain-specific tools that embody its principles. Technologies such as Building Information Modeling (BIM), cloud-based document management systems, mobile inspection applications, Internet of Things (IoT) sensors, and digital dashboards exemplify how Quality 4.0 concepts are implemented in practice (Sacks et al., 2018; Sawhney et al., 2020; Araya-Santelices et al., 2025; Shaban et al., 2024; Ghosh & Karmakar, 2025). These tools support improved information consistency, traceability, collaboration, and decision-making, yet their deployment remains uneven across projects and organizations.

Despite growing attention, existing studies largely focus on individual technologies, specific project phases, or organizational contexts. There remains limited conceptual understanding of how commonly referenced digital technologies collectively align with core QMS activities in construction. Addressing this gap, the present study provides a conceptual exploration of digital QMS in construction, synthesizing literature on both traditional QMS functions and enabling technologies under the Quality 4.0 paradigm. By mapping digital tools to foundational quality processes, this work clarifies current developments in digitalized construction quality management and lays a foundation for future empirical and model-based research in this emerging field.

### 1.1. Challenges of Traditional QMS in Construction

Quality management in construction involves the structured processes and practices designed to ensure that project outcomes comply with standards, meet client requirements, and satisfy regulatory expectations (Rumane, 2017). Key components include planning, documentation, inspection, verification, corrective and preventive actions, and continuous improvement (Sui Pheng & Hui Hong, 2005; Hoonakker et al., 2010). Unlike manufacturing, construction projects are temporary, site-specific, and involve multiple stakeholders, leading to unique challenges such as variable site conditions, design–execution coordination issues, and diverse team interactions (Jraisat et al., 2016).

Traditional QMS in construction aim to ensure that projects meet client requirements, comply with standards, and satisfy regulatory expectations (Rumane, 2017). Core activities include planning, documentation, inspection, verification, corrective and preventive actions, and continuous improvement (Sui Pheng & Hui Hong, 2005; Hoonakker et al., 2010). However, the inherent characteristics of construction projects temporary nature, site-specific conditions, multiple stakeholders, and complex team interactions pose significant challenges for effective QMS implementation (Jraisat et al., 2016).

Key challenges of traditional QMS include;

- **Fragmented Information Flow:** Project information is often dispersed across teams and phases, leading to miscommunication, delays in decision-making, and inefficient coordination (Sacks et al., 2018; Sawhney et al., 2020; Marsden, 2019).
- **Inconsistent Documentation:** Reliance on manual record-keeping and paper-based processes increases the risk of errors, omissions, and duplication, undermining traceability and compliance (Ghosh & Karmakar, 2025; Araya-Santelices et al., 2025).
- **Delayed Reporting:** Slow feedback from inspections and quality checks often results in reactive rather than proactive quality control (PMI, 2021; Shaban et al., 2024).
- **Coordination Gaps:** Disconnects between design and execution teams can cause deviations from project specifications and design intent (Sui Pheng & Hui Hong, 2005; Sharma & Laishram, 2023).
- **Labor-Intensive Processes:** Traditional QMS heavily rely on human input for monitoring, verification, and reporting, which increases the potential for inefficiencies and oversight (Hoonakker et al., 2010; Luo et al., 2022).
- **Limited Real-Time Visibility:** Lack of immediate access to project data constrains timely interventions and evidence-based decision-making (Zaid et al., 2025; Marsden, 2019).

Organizational culture and predominantly reactive quality control practices further exacerbate these challenges (Sui Pheng & Hui Hong, 2005). Despite these limitations, traditional QMS remain foundational, establishing structured procedures for monitoring compliance and supporting incremental improvement throughout the project lifecycle (Rumane, 2017). Nevertheless, these inefficiencies highlight the need for digital solutions that enhance connectivity, traceability, and real-time decision-making in construction projects (Luo et al., 2022; Araya-Santelices et al., 2025).

### 1.2. From Industry 4.0 to Quality 4.0

The limitations of traditional QMS have coincided with broader technological transformations across industries. Industry 4.0, characterized by the integration of automation, digitalization, data analytics, cloud computing, and smart sensing, has reshaped production, management, and operational processes in multiple sectors (Sawhney et al., 2020; PMI, 2021). Within this context, **Quality 4.0** has emerged as a cross-industry paradigm that leverages these technologies to enhance quality management practices.

Quality 4.0 emphasizes real-time data availability, connected and integrated workflows, predictive analytics, and evidence-based decision-making (Marsden, 2019; Luo et al., 2022). It transforms traditional quality management from reactive and documentation-heavy approaches into proactive, data-driven, and digitally enabled processes (Sacks et al., 2018; Zaid et al., 2025). Key enabling technologies include cloud platforms, IoT sensors, data dashboards, digital collaboration tools, and advanced analytics systems, which collectively facilitate traceability, transparency, and timely interventions (Sharma & Laishram, 2023; Shaban et al., 2024; Ghosh & Karmakar, 2025).

By conceptualizing quality management in the context of Industry 4.0, Quality 4.0 provides a framework for integrating digital tools with core quality processes, improving consistency, performance, and adaptability. This paradigm is applicable across industries, offering insights into how organizations can overcome the challenges associated with traditional QMS, including fragmented information flow, limited traceability, delayed reporting, and reactive decision-making (Araya-Santelices et al., 2025; Marsden, 2019).

## 2. Material and Method

This study adopts a conceptual research design to examine how widely discussed digital technologies relate to core QMS functions in construction. The material for the study consists of academic journal articles, books and recognised industry reports addressing traditional QMS practices, Industry 4.0 and Quality 4.0 concepts, and digital technologies applied in construction project environments. Particular

attention was given to literature published over the last decade, as recent studies increasingly explore the intersection of digitalisation and construction quality management (Figure 1).

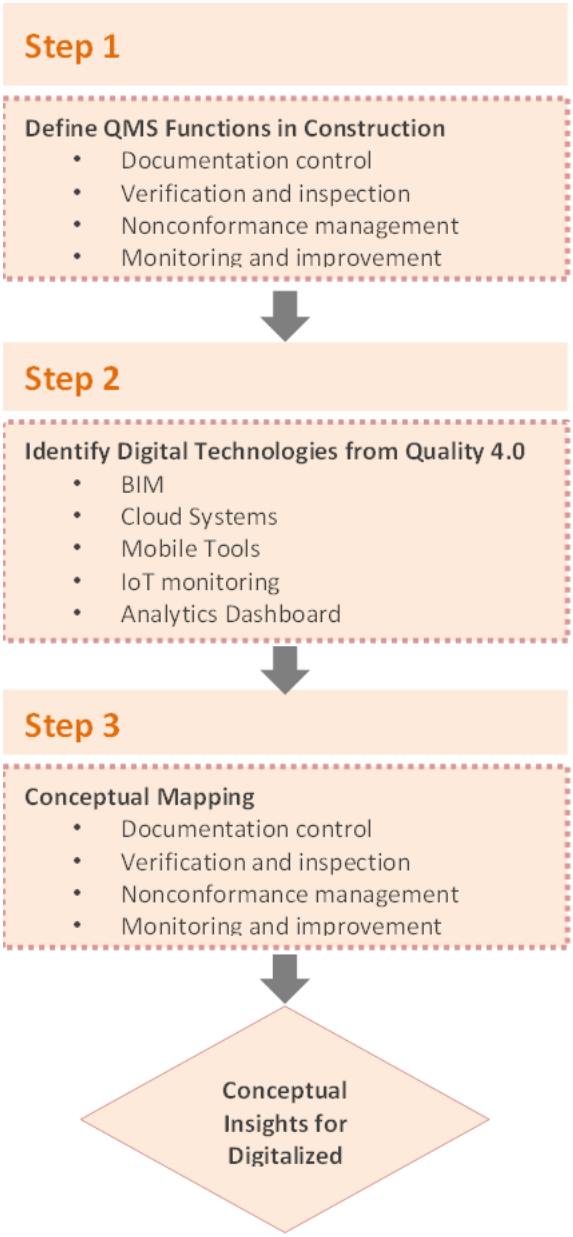



**Figure1.** Research workflow (Created by the author)

The technology categories considered in the analysis were informed by established Quality 4.0 literature, which identifies digital tools such as BIM, cloud-based document systems, digital collaboration platforms, mobile inspection applications, IoT monitoring devices and analytics dashboards as enablers of modern quality practices. These sources provided the conceptual basis for identifying relevant technologies in a systematic and literatüre grounded manner.

The methodological approach consisted of three steps as illustrated in Figure 1. First, core QMS functions in construction such as documentation control, design and work verification, inspection, nonconformance management, monitoring and continuous improvement were identified based on established QMS literature and ISO 9001 principles. Second, literature relating to digitalisation, Industry 4.0 and Quality 4.0 was reviewed to determine commonly cited technologies and their documented applications in construction quality contexts. Third, insights from these two bodies of literature were synthesised to conceptually map how selected digital technologies support or enhance fundamental QMS activities.

As a conceptual study, this approach does not involve empirical data collection or model development. Instead, it aims to consolidate fragmented knowledge and provide an integrated perspective that may guide future empirical investigations into digitalised quality management in construction projects.

## 3. Findings and Discussion

The findings of this study provide a conceptual synthesis of how commonly referenced digital technologies support core QMS functions in construction. Drawing on both traditional QMS principles (Sui Pheng & Hui Hong, 2005) and the enabling technologies highlighted in the Quality 4.0 domain (Marsden, 2019; Luo et al., 2022) , the analysis demonstrates that digitalisation enhances established quality activities by improving information consistency, coordination, traceability, and decision-making across project phases. To clarify these relationships, Table 1 presents a conceptual mapping between core QMS functions and Quality 4.0 enabled digital technologies. The table highlights six key QMS areas documentation control, design and work verification, inspection, nonconformance and CAPA management, monitoring and measurement, and continuous improvement and aligns each with relevant digital tools, including BIM, cloud-based document management, mobile inspection applications, IoT sensors, and analytics dashboards.

**Table 1.** Digital technologies commonly associated with Quality 4.0 and their relationship to core QMS functions in construction projects.

| QMS Function | Traditional Purpose (ISO 9001 Context) | Supporting Digital Technologies (Quality 4.0 Enablers) | Key Contributions / Improvements |
|---|---|---|---|
| **Documentation Control** | Maintain, update, and trace project records | Cloud-based document management platforms | Real-time access |
| | | BIM document modules | Version control |
| | | Digital collaboration platforms | Improved traceability |
| | | | Reduced fragmentation |
| **Design & Work Verification** | Verify conformity of design and site work | BIM | Early clash detection |
| | | BIM–GIS workflows | Improved design communication |
| | | Model-based coordination tools | Enhanced consistency between design and site |
| **Inspection & Site Quality Control** | Conduct scheduled and unscheduled quality inspections | Mobile inspection apps | Faster reporting |
| | | Field management platforms | Digital checklists |
| | | Reality capture tools (photogrammetry, 360°) | Photo-enabled evidence |
| | | | Consistency in inspections |
| **Nonconformance & CAPA Management** | Identify, report, and resolve deviations | Digital issue-tracking systems | Faster identification |
| | | Cloud-based NCR/CAPA workflows | Digital audit trail |
| | | Mobile NCR reporting tools | Transparent corrective actions |
| **Monitoring & Measurement** | Collect and evaluate process or product data | • IoT monitoring devices | Real-time data |
| | | Environmental sensors | Evidence-based decision making |
| | | Analytics dashboards | Continuous monitoring |
| **Performance Evaluation & Improvement** | Evaluate quality performance and improve processes | Data analytics platforms | Trend analysis |
| | | Integrated digital QMS | Feedback loops |
| | | Lessons-learned systems | Supports continuous improvement |

To make the conceptual contribution explicit, Table 1 does not merely list digital tools, but systematically maps Quality 4.0 enabled technologies to core QMS functions. This mapping clarifies how digitalisation operationally supports established quality management activities rather than

treating technologies as standalone innovations. By aligning each QMS function with specific digital enablers and their corresponding contributions, Table 1 provides an analytical lens for interpreting the role of Quality 4.0 in addressing key contributions.

In documentation control, as illustrated in Table 1, cloud-based platforms, BIM-enabled documentation modules, and digital collaboration tools mitigate longstanding challenges of fragmented or outdated records (Hoonakker et al., 2010). They enhance version control, provide real-time accessibility, and improve traceability, directly addressing weaknesses of traditional paper-based systems (Ghosh & Karmakar, 2025; Shaban et al., 2024).

For design and work verification Table 1 shows BIM and BIM-GIS workflows offer structured environments for model-based coordination and early discrepancy detection (Sacks et.al., 2018). These tools improve design interpretation, reduce errors during handover, and enhance alignment between design and site activities, contributing to lower rework and more reliable outcomes (Sharma & Laishram,2023).

Inspection and site quality control benefit from mobile inspection tools and reality-capture Technologies (Table 1). Digital checklists, photo evidence, and automated timestamps support more consistent, transparent, and timely inspections, resolving issues of delayed reporting and inconsistent field documentation (Marshdan, 2019).

In terms of nonconformance and CAPA management (Table 1) , digital issue-tracking systems and cloud-based NCR workflows enable faster identification, assignment, and resolution of deviations. They provide a clear audit trail and facilitate coordinated corrective actions, which are essential for effective QMS implementation (Gosh&Karmakar, 2025; Zaid et al., 2025).

For monitoring and measurement, IoT sensors, environmental monitoring devices, and dashboards provide real-time data, enabling evidence-based decision-making and proactive responses to quality deviations. This transition from reactive to data-driven monitoring exemplifies a major improvement over conventional practices (Luo et al., 2022).

Finally, digital tools contribute to continuous improvement by enabling data aggregation, trend analysis, and integration of lessons learned. Analytics dashboards and reporting platforms support monitoring long-term performance and establishing structured feedback loops, reinforcing ISO 9001 principles of learning and improvement (Rumane, 2017).

Overall, the conceptual mapping shows that digitalisation complements rather than replaces traditional QMS practices. It serves as an integrative framework that link traditional QMS with Quality 4.0 capabilities. Quality 4.0 technologies address persistent gaps such as fragmented documentation, limited visibility, and slow information flow while introducing new capabilities around connectivity, automation, and real-time data. Their effectiveness, however, depends on organisational readiness, interoperability, and alignment with established procedures, echoing broader observations in the literature on digital adoption challenges (Sharma & Laishram; PMI, 2021).

Although this conceptual synthesis provides valuable insights, it is subject to limitations. The study is based solely on published literature and does not include empirical data from construction projects, limiting assessment of practical implementation challenges. It also does not account for variations across project types, organisational structures, or levels of technological maturity. Future empirical research is needed to validate, refine, and contextualise the conceptual linkages presented here.

**4. Conclusion and Suggestions**

This study provided a conceptual exploration of the potential of Quality 4.0 technologies to enhance construction quality management by addressing the limitations inherent in traditional QMS. By mapping core quality management functions to digital tools including BIM, cloud-based document systems, mobile inspection applications, IoT sensors, and analytics dashboards the study offers a framework for understanding how digitalisation can support more integrated, data-driven approaches to quality assurance.

The analysis underscores that digital tools are not a replacement for established QMS procedures but serve to augment them. Their adoption can foster proactive monitoring, structured feedback loops, and continuous improvement processes, creating opportunities for organisations to move from reactive to anticipatory quality management. This shift has implications not only for compliance and performance but also for improving collaboration across project teams and enhancing accountability. Additionally, investigating the integration of emerging tools and analytics with existing quality practices can provide further insights into optimising digital quality management in construction projects.

While the conceptual framework establishes a foundation, practical implementation and organisational readiness remain critical factors in realizing the benefits of digitalised QMS. Future empirical research could build on this framework by examining real world project applications through case studies, surveys, or longitudinal analyses, focusing on how digital tools are integrated into existing QMS workflows. In particular, empirical studies may investigate technology adoption maturity, organisational capabilities, interoperability challenges, and the measurable impacts of Quality 4.0 enabled QMS on project performance, resource efficiency, and stakeholder engagement. Such research would further contextualise and validate the conceptual relationships identified in this study.

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The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study.

**Author Contribution and Conflict of Interest Disclosure Information**

The article was written by a single author. There is no conflict of interest.

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