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# The Evolution of Quality Management Towards Quality 5.0: A Maturity Model Perspective

**Agnieszka Czajkowska**[1*]

[1] Kielce University of Technology, al. Tysiąclecia Państwa Polskiego 7, Kielce, Poland
*Correspondence: czajkowska@o2.pl

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**Abstract**
Six main stages can be distinguished in the evolution of quality management concepts. Initially, attention focused on quality inspection and quality control, aimed at detecting errors and nonconformities in finished products. The next stage was quality assurance, which introduced preventive actions designed to eliminate defects during production processes. A major breakthrough occurred with the development of Total Quality Management (TQM), which expanded quality management to the entire organization and emphasized continuous improvement, employee involvement and customer orientation. More recently, the concept of Quality 4.0 has emerged, driven by digitalization, automation and the application of advanced technologies in quality management systems. The latest stage, Quality 5.0, integrates technological innovation with human-centric values such as ethics, sustainability and social responsibility. The aim of this study is to analyse the evolution of quality management concepts and to identify the relationships between successive approaches. The study is based on a structured literature review of scientific publications related to quality management development. As a result of the analysis, an Integrated Evolutionary Quality Management Model (IEQMM) is proposed, which conceptually links traditional quality management practices with digital transformation and human-centred sustainability principles. The findings highlight the complementary nature of successive quality paradigms and emphasize the importance of integrating technological capabilities with social and sustainability-oriented perspectives in modern quality management.

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## 1. Introduction

High quality brings increased productivity, reduced costs, and higher customer satisfaction, which, in turn, increases sales, profits, and the ability to survive in today's highly competitive market (Antonaras, 2010; Anderson et al. 1997). Numerous authors (Swamidass, 2000; Berawi, 2004, Czajkowska et al., 2023; Paixão et al., 2026), from various periods, point towards quality as a major factor in the competitiveness of enterprises (Griffin, 1998; Lynch, 2015). According to Slack, it is one of the five factors by which companies compete, alongside reliability, time, flexibility, and cost (Slack, 1995) According to Kaplan, it is one of the three most important factors, in addition to cost and time (Kaplan, 2001). The sheer number of definitions of quality is due to the rapid pace of change, mainly related to the increase in the wealth of society and new technologies. Quality management is rooted in the manufacturing industry, which has undergone significant changes over the past century, particularly with respect to the client's role. Moreover, new concepts and approaches related to quality management have been proposed over the years. Approaches to quality management have shifted from production to marketplace adaptation to a focus on customer expectations (Deming, 1986).

The evolution of quality management is of significant importance to management theory and business practice. The development of quality management, from quality inspection through TQM, Quality 4.0, to Quality 5.0, has had a significant impact on the shape of the contemporary world. For those reasons:

- Products have become more durable, safer, and more reliable. The quality of products and services directly translates into greater customer trust. Customers are more likely to return to companies that offer reliable, predictable, and tailored solutions.

- Services are better suited to the needs of customers. The evolution of quality management allows for satisfying the needs that are hidden, i.e., those of which the customers are not fully conscious (Yang, 2017).
- Eliminating waste generated by enterprises, streamlining processes, and creating innovation.

Quality and, consequently, quality management constitute an integral component of each company's strategy. The researchers emphasize that the implementation of quality management practices leads not only to improvements in quality but also to improvements in organizational performance (Yang, 2017; Al-Damen, 2017; Joiner, 2007; Carvalho et al., 2024). Honarpour (Honarpour, 2017) and Abdulkadir (F Abdulkadir, 2023) emphasize the increase in the productivity of employees in companies that implement quality management systems.

Quality management, in the context of business benefits, reduces costs, strengthens brands, fosters innovation, and contributes to organizational stability. Those factors, in turn, contribute to a higher standard of living, greater safety, lower costs for several goods, and an increased pace of technological development, all of which would not be possible without quality control. The development of Quality 4.0 and Quality 5.0 raises questions regarding the validity of previous concepts. Which elements remain crucial (e.g., standardization, applying processes) and which are transformed or eliminated?

Recent literature increasingly addresses the evolution of quality management in the context of digital transformation and Industry 4.0. Several studies analyse the relationship between traditional quality management approaches, such as Total Quality Management (TQM), and emerging concepts such as Quality 4.0, as well as the broader development of next generations of quality management (Liu et al., 2023; Ranjith Kumar et al., 2022). However, most studies focus on selected stages of this evolution, particularly the transition from TQM to Quality 4.0 or the technological dimension of digital transformation.

This article discusses the evolution of the concept of quality and quality management over several decades. It characterizes the key concepts, with particular emphasis on Quality 4.0 and Quality 5.0, and discusses the related benefits. In addition, the paper proposes an integrated conceptual framework that highlights the continuity and complementarity of successive quality management paradigms.

While previous studies have analysed the transition from traditional quality management approaches to Quality 4.0 and discussed emerging Quality 5.0 perspectives, most of them focus on specific stages of this evolution. This indicates the need for integrative frameworks that connect traditional quality management foundations, digital transformation and human-centric sustainability principles within a coherent evolutionary perspective.

The aim of this article is to analyse the evolution of quality management concepts, present the relationships between successive approaches, and propose an Integrated Evolutionary Quality Management Model (IEQMM).

The research method involved an in-depth review of the subject's literature. The analysis covers scientific publications on quality management, models, and concepts. It analyses articles from peer-reviewed journals indexed in Scopus, Web of Science, and Emerald databases.

The selection of publications takes into account their timeliness, their importance for the development of quality management, and their close connection with the core issue under research. Despite extensive literature on individual quality management concepts, few studies integrate their evolutionary relationships within a single analytical framework. Existing research typically focuses on isolated stages such as TQM or Quality 4.0, leaving a gap in understanding their conceptual continuity and interaction. This study addresses this gap by proposing an integrated evolutionary model.

## 2. Methodology

This study adopts a structured narrative literature review approach to analyse the evolution of quality management concepts from traditional quality inspection to contemporary Quality 5.0 frameworks. The literature was collected from major scientific databases, including Scopus, Web of Science, and Emerald Insight, which index peer-reviewed journals in the fields of management, engineering, and quality science. Additional seminal works and foundational publications were included to ensure historical completeness of the analysis, particularly those that shaped early quality management theory and practice. Publications were identified using the databases Scopus, Web of Science and Emerald, which index peer-reviewed journals in the fields of management, engineering and quality science. The search was conducted using combinations of keywords such as "quality management", "Total Quality Management", "Quality 4.0", "Industry 4.0 and quality", "Quality 5.0", "evolution of quality management" and "digital transformation of quality". The review mainly covered publications from 1990–2024, while earlier classical works (e.g., Shewhart, Deming and Feigenbaum) were included where relevant to the historical development of quality management. The initial database search identified 56 records. After removing duplicates and screening titles and abstracts for relevance to the evolution of quality management and digital transformation of quality practices, 46 publications were selected for full-text analysis. The final sample consisted of 45 key publications, including peer-reviewed journal articles, academic books, conference papers and international standards. Only English-language publications were included to ensure comparability of sources. The selection criteria included relevance to the evolution of quality management concepts, theoretical or conceptual contribution, academic credibility of the publication source and citation influence within the field. Sources not directly related to quality management development, Industry 4.0/5.0 or digital transformation of quality practices were excluded. The selected literature was analysed using a thematic synthesis approach, focusing on identifying the key stages in the evolution of quality management concepts and the relationships between traditional quality management approaches, Quality

4.0 technologies and emerging Quality 5.0 perspectives. The results of this analysis formed the basis for developing the Integrated Evolutionary Quality Management Model (IEQMM).

## 3. From quality inspection to Quality 5.0

During the pioneering days of quality management, compliance and the importance of reducing variation in production processes were key features in defining quality (Shewhart, 1931; Oakland, 2014; Garvi, 1984). Subsequent definitions of quality were oriented towards customer satisfaction by meeting customer needs. Deming (Deming, 1986) clearly drew attention towards customer needs, defining that "quality should be oriented towards the current as well as future customer needs." A. V. Feigenbaum defined quality as the totality of the characteristics of a product or service in the sphere of marketing, design, production, and customer service, allowing the used products and services to meet the customer's expectations (Beckford, 1998). He assumed that quality is the totality of the characteristics of a product or service in relation to marketing, construction, manufacturing, and ancillary manufacturing processes that enable a product or service to meet customer expectations (Feigenbaum, 1991). The author of the "zero defects" principle, P. B. Crosby, defined quality as compliance with requirements. According to Crosby, quality is achieved by preventing defects rather than by assessing correct performance/manufacture (Więcek, 2007). In the ISO 9000:2001 standard, "quality means the degree to which a set of inherent properties meets the requirements" (PN-EN ISO 9000:2001). All quality definitions share a common core: quality means meeting customer requirements. Differences in the definition of quality across periods are related to the stages of development of quality assurance methods. In the 60s and 70s, they were limited solely to inspecting and correcting errors. In contrast, in the 80s and the 90s, they also included management related to preventing errors (identifying critical points, motivating the personnel, etc.). At the same time, global quality was introduced at last after the year 1999, meaning control over quality in all possible areas - quality management. This historical progression suggests that quality management has evolved not as a series of isolated concepts but as a cumulative paradigm in which each stage expands the scope and logic of its predecessors.

Figure 1 Depicts the evolution of quality management from quality inspection and quality control to quality assurance, comprehensive quality management, and Quality 4.0 and Quality 5.0.

The Total Quality Management concept was a significant breakthrough in quality management (Dahlgaard-Park , 2011; Antony, J. et al. 2022). The basis for the idea should be sought in the early 40s of the last century (it became fully developed in the 80s-90s), owing to the collaboration of American scientists W.E. Deming (TQM is based on the so-called Deming cycle, among others) and J. Juran. TQM stands for Total Quality Management, i.e., "comprehensive quality management". TQM has led to the development of quality management methods, techniques, and tools. The concept of Total Quality Control was published in the early 60s. It combined multiple principles of achieving and experiencing from American-Japanese cooperation. The idea of quality management emerged in the United States at the turn of the 1970s and 1980s. Total Quality Management was adopted in the United States as an approach (some authors refer to it as a 'philosophy') that uses a set of quality methods, such as Six Sigma and Failure Mode and Effects Analysis. This indicates that TQM represents not merely a management method but a systemic shift from operational control toward organizational philosophy.

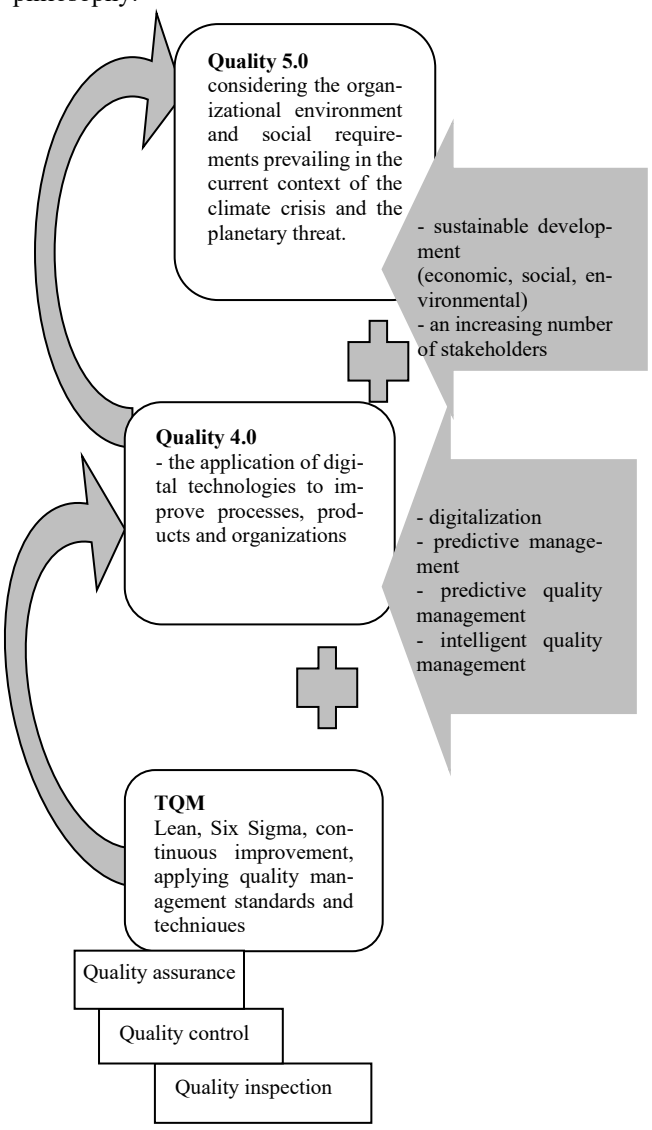


**Fig. 1.** Evolution of the quality management concept (own development)

Comprehensive quality management promotes the use of TQM methods by all employees in the organization (Kaur et al., 2019). Recent empirical evidence also confirms that TQM remains highly relevant for organizational performance, especially when combined with lean practices, which supports the view that newer quality paradigms extend rather than replace earlier quality management foundations (Thunyachairat

et al., 2024). The rapidly evolving technologies, processes, and practices currently transforming the production industry introduce the concepts of Quality 4.0 and Quality 5.0 into the quality management process.

The term Quality 4.0 was first used in the American Quality Society's 2015 report (ASQ, 2015) in the context of referring to the TQM area for subsequent stages of industry development (Pereira & Romero, 2019) and the Quality 4.0 concept (ASQ, 2015). The features of Quality 4.0 include:

- digitalization of quality management,
- predictive quality management,
- mass personalization,
- intelligent quality management.

Its effects may include:

- improved customer satisfaction,
- improved product quality,
- improved operational efficiency.

Digitalisation has affected society and organizations at all levels. The effects range from the creation of new types of jobs to the use of digital tools to support daily activities. Digitalisation results in new competencies required to establish close cooperation with the IT Department (Ponsignon, et al., 2019) and new types of customer feedback channels. Quality 4.0 has significantly transformed existing quality management practices and has brought substantial benefits to the production industry (Ranjith Kumar et al., 2022; Liu et al., 2023, 2020). An increased use of new information technologies characterizes it. The technologies in question include big data analytics, the Internet of Things, cloud computing, additive manufacturing, artificial intelligence, and blockchain (Kagermann & Wahlster, 2022). Quality 4.0 is both a benefit and a challenge for each link in the production process: customers, employees, management, production, and information. Thus, Quality 4.0 should be interpreted as a transitional paradigm bridging traditional quality systems with data-driven intelligent management environments.

Authors (Fiałkowska-Filipek et al. 2023; Ranjith et al. 2022) indicated three dimensions of Q4.0 (Fig.2.): people, processes, technology; they include 11 elements denoting the key aspects of Q4.0: leadership, culture, compliance, management system, competences, collaboration, scalability, analytics, data, application development, connectivity (the connection between business information technology and operational technology).

The initial two dimensions (people and processes) constitute capacities (referred to as Capacities 4.0), which include real-time data management, interoperability, visualization, decentralization, agility, orientation toward services, integrated business processes, and sustainable growth. Business models based on I4.0 Technologies and 4.0 capabilities enable the meeting of customer and societal demands (Lasi, H., et al. 2014; Sony & Naik, 2020; Pereira & Romero, 2017). The application of digital technologies to improve processes, products, and organizations. While some models emphasize integrating quality management principles with new technologies, they neglect the urgent need to address deep social tensions and environmental issues.

These models do not cover the broader social and environmental aspects required for a holistic approach to quality management in the face of current challenges.

Although many studies analyse the technological dimension of Quality 4.0 and its links with traditional quality management approaches, fewer studies provide integrative frameworks combining technological, human and sustainability perspectives within one evolutionary model.

Quality 5.0 is closely related to the concept of Industry 5.0 and reflects a shift towards human-centric, sustainable and socially responsible approaches to quality management. Recent studies refer to this perspective as the next generation of quality management, extending traditional quality concepts to include social and sustainability dimensions (Fiałkowska-Filipek & Dobrowolska, 2023) Industry 5.0 aims to integrate human capabilities with advanced technologies, including artificial intelligence (AI), robotics, the Internet of Things (IoT), and augmented reality (AR). Modern research on quality management, from a sustainability perspective, highlights the need for a broader understanding of customer roles, while also considering the perspectives of other stakeholders. The increase in consumer awareness affects companies that strive to adapt to requirements to gain and sustain a competitive advantage. Integrating sustainability into TQM to maintain competitive advantage and improve productivity is necessary in the face of intense global competition (Zairi, 2002).

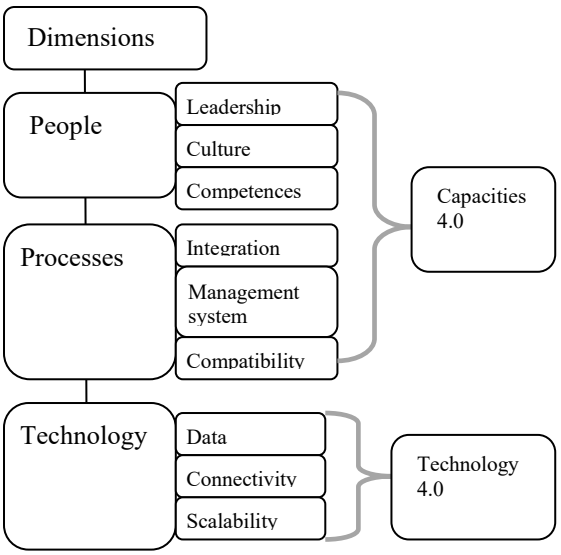


**Fig. 2.** Quality Model 4.0 (own elaboration based on Fiałkowska-Filipek et al. 2023; Ranjith et al., 2022)

Quality 5.0 requires a symbiotic relationship between humans and machines (Xu, X., et al. 2021; Grudkowska et al., 2022) where machines increase human capabilities, and not replace them. This human-centred interpretation is consistent with recent findings, which emphasize that Industry 5.0 should be understood not only through advanced technologies, but also through the crucial role of human competences, safe work environments and the broader social context of industrial transformation (Saniuk et al., 2024). This perspective confirms that contemporary quality management is no longer

solely technology-driven but increasingly human-centred and sustainability-oriented. This broader orientation is consistent with recent research indicating a transition from traditional CSR logic toward ESG-based responsibility, where ethics, transparency and sustainability become measurable and strategically integrated elements of organizational development (Rosak-Szyrocka, 2025). Four key issues related to shaping quality (Fig. 3.) they invariably concern the customers' requirements and satisfying their needs (Teece, 2010; Nahavandi, S., 2019) the requirements of the company and the care for its interests, as well as sustainable development (Porter, 2006), the environment changing at the fastest pace in history encourages to analyse the quality of our products and services constantly.

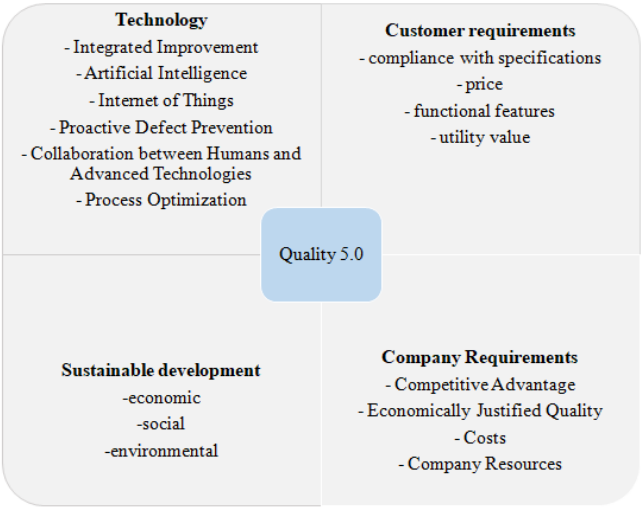


**Fig. 3.** Main components of Quality 5.0

Apart from the benefits, there are also challenges, such as the greater responsibility associated with operating machines. The evolution of industrial solutions requires an increase in employees' competencies, enabling them to interact with these solutions for the common good. The challenge is also to reconcile the pursuit of quality and customer satisfaction with the pursuit of sustainable development.

Overall, the literature indicates that quality management evolution follows a trajectory from inspection-based control to integrated, intelligent, and human-centric systems, which justifies the need for a unified evolutionary framework such as the model proposed in this study.

The proposed Integrated Evolutionary Quality Management Model (IEQMM) complements existing studies by presenting a holistic conceptual framework integrating traditional quality management approaches with the technological perspective of Quality 4.0 and the human-centric and sustainability-oriented perspective of Quality 5.0.

## 4. Benefits of the most recent quality concepts

New technologies and related innovations have a fundamental impact on each participant in the production process – customer, employee, managers, production, and information. The benefits are presented in Table 1.

**Table 1.** Benefits of Quality 4.0 and 5.0

| Participants | Benefits |
|---|---|
| Customer | • customers have control over what they purchase<br>• the number of purchased products<br>• the ability to change orders at any time during production at no additional cost<br>• products tailored to the needs of customers<br>• higher expectations of customers regarding quality<br>• access to product information and technical details<br>• products are more personalized |
| Employee | • overseeing the work performed by machines<br>• a more coordinated position (employees have the competencies to make decisions and solve problems)<br>• It allows employees to engage in the quality management process through the use of digital technologies and analytics, which can increase employee engagement and motivation.<br>• the use of advanced interfaces (e.g., virtual reality and augmented reality) to facilitate human-machine interaction and to allow for better quality management |
| Management | • intelligent quality management (intelligent machines, sensors)<br>• integrated production system<br>• applying analytics to predict quality issues and maintenance requirements,<br>• improving competitiveness through real-time quality monitoring and management,<br>• increased efficiency of the quality management process. |
| Production | • Fewer NOKs (non-compliant products)<br>• Minor or the lack of quality differences<br>• Reduced number of standstills<br>• Timely repairs are possible due to machine status signals<br>• digital technologies,<br>• advanced analyses,<br>• real-time data analysis,<br>• predictive maintenance,<br>• artificial intelligence,<br>• increased efficiency,<br>• reduced costs,<br>• immediate correction of quality issues,<br>• utilization of cutting-edge technologies - IoT, cloud computing, big data, and artificial intelligence (AI) |
| Information | • Fast and efficient collection and processing of data collected from multiple sources<br>• designers can anticipate usage and maintenance requirements<br>• It allows for the identification and correction of issues related to quality in real time, which can reduce the costs of reprocessing and warranty |

The benefits presented above demonstrate that the evolution of quality management concepts increasingly combines technological innovation with human-centered and sustainability-oriented approaches.

## 5. Proposed conceptual model: „Integrated Evolutionary Quality Management Model (IEQMM)

It must be emphasized that Quality 5.0 does not substitute the earlier concepts, but instead integrates and expands upon them. In practice, all previous approaches remain necessary, as they form the foundation for constructing new philosophies of quality.

The model covers four basic elements:

- The foundation that constitutes traditional approaches to quality: TQM, Lean, Six Sigma, ISO Standards.
- Quality 4.0 or modern technologies: AI, IoT, Big Data, cloud. They enable automation, prediction, and real-time quality monitoring.
- Quality 5.0 focuses on the integration of people and machines, emphasizing the value of the human factor in production processes and the importance of sustainable development.
- The interaction of the elements mentioned above ensures innovation, Flexibility of Processes, and Customer Satisfaction.

Quality 3.0 means stable processes, repeatability, error elimination, and a culture of continuous improvement.

In this context, Quality 3.0 can be associated with the maturity of Total Quality Management and continuous improvement approaches, emphasizing process stability, repeatability, error reduction and the development of an organizational culture of continuous improvement (Dahlgaard-Park, 2011; Yang, 2017).

In the IEQMM framework, the layers are causally related: technological capabilities of Quality 4.0 enhance operational effectiveness, while the human-centric and sustainability-oriented perspective of Quality 5.0 provides the strategic and societal context for their responsible application.

The elements of the IEQMM model are interconnected through a set of dependencies: foundational quality management practices provide process stability, digital technologies enhance analytical and operational capabilities, while human-centric and sustainability-oriented practices shape strategic direction and stakeholder expectations. Figure included in Appendix A presents the conceptual structure of the proposed IEQMM framework.

The key elements of the IEQMM conceptual framework, together with their definitions, supporting literature and example indicators, are presented in Table included in Appendix B.

In contrast to previous conceptual frameworks that focus mainly on the technological aspects of Quality 4.0 or the sustainability perspective of Quality 5.0, the proposed IEQMM model integrates these dimensions with traditional quality management foundations within a single evolutionary framework.

It serves as the framework for Quality 4.0 and Quality 5.0, which do not replace the “obsolete”, but rather add technology, ethics, ecology, and social responsibility. Quality 5.0 does not abandon Kaizen; Lean only introduces a social aspect to it. Quality 5.0 is closely related to Quality 4.0 and its associated technologies, including IoT, AI, Big Data, and others

Organizational culture and leadership are key elements that must be considered. They decide on the adaptation of new tools and the integration of quality processes. Organizational culture and leadership are critical to quality because leaders shape culture through their vision, communication, and behaviour, whereas a positive culture facilitates engagement, motivation, and continuous improvement. Leadership and organizational culture act as enabling factors that facilitate the effective implementation of Quality 4.0 and Quality 5.0 principles, translating technological and human-centric capabilities into organizational performance outcomes.

A high-quality culture, supported by conscious leaders, focuses on customers, processes, employee engagement, and data-driven decision-making, thereby leading to better results. Appendix C contains selected counterparts of the characteristic aspects of the 5.0 concept of quality management as related to previous concepts.

The proposed Integrated Evolutionary Quality Management Model (IEQMM) conceptualizes the evolution of quality management as a layered system in which successive paradigms extend rather than replace earlier approaches. The foundational layer includes traditional quality management practices such as TQM, Lean, Six Sigma and ISO-based management systems, which ensure process stability and organizational learning. The second layer reflects the technological transformation associated with Quality 4.0, characterized by the use of digital technologies such as artificial intelligence, big data analytics, IoT and cloud computing to enable predictive and data-driven quality management. The third layer represents Quality 5.0, which extends the technological paradigm by incorporating human-centric values, sustainability and social responsibility into quality management practices. In this perspective, Quality 5.0 integrates technological capabilities with ethical, environmental and social considerations, aligning quality management with broader societal expectations.

## 6. Discussion

The findings of this study highlight that the evolution of quality management is not a sequence of isolated paradigms but rather a cumulative and integrative process in which successive concepts expand earlier approaches instead of replacing them. The analysis confirms that traditional quality foundations such as standardization, process control, and continuous improvement remain essential even in technologically advanced frameworks such as Quality 4.0 and Quality 5.0. This continuity indicates that modern quality paradigms should be interpreted as extensions rather than disruptions of classical management principles.

The review also demonstrates that digital transformation has significantly reshaped quality management by introducing predictive analytics, automation, real-time monitoring, and intelligent decision-support systems. However, the emergence of Quality 5.0 suggests that technological sophistication alone is insufficient. Contemporary quality management increasingly requires the integration of ethical, social, and environmental considerations, emphasizing human–technology collaboration, sustainability, and stakeholder value. This shift reflects a broader transformation in management theory from efficiency-driven logic toward responsible and human-centered organizational models.

Another important insight concerns the multidimensional nature of quality. Earlier frameworks focused primarily on product conformity and defect reduction, whereas contemporary approaches conceptualize quality as a systemic construct encompassing organizational culture, leadership, technological infrastructure, and stakeholder relationships. This broader perspective supports the need for integrative models such as the proposed IEQMM, which synthesizes technological, managerial, and humanistic dimensions within a unified framework.

From a theoretical standpoint, the study contributes to quality management literature by clarifying conceptual linkages among historical and contemporary paradigms and by proposing a structured evolutionary interpretation of their relationships. From a practical perspective, the findings suggest that organizations should avoid treating new quality concepts as substitutes for existing systems. Instead, they should adopt layered implementation strategies that build upon established practices while incorporating digital and sustainability-oriented innovations.

Finally, the analysis indicates that future research should move beyond descriptive examinations of quality concepts toward empirical validation of integrative frameworks. Testing the proposed model across industries, organizational sizes, and technological maturity levels would provide valuable insights into its applicability and generalizability. Such studies would help determine whether integrative approaches truly enhance organizational performance, resilience, and long-term competitiveness.

## 7. Summary and conclusion

This study has several limitations. First, it is based on a literature review and does not include empirical validation of the proposed model. Second, the analysis focuses primarily on conceptual sources rather than empirical investigations. Future research should therefore test the IEQMM model across industries, organizational contexts and geographical regions in order to verify its applicability and robustness.

The study contributes to the literature by proposing the Integrated Evolutionary Quality Management Model (IEQMM), which conceptualizes the evolution of quality management as an integrated framework linking traditional quality management practices with digital transformation and human-centric sustainability principles. By combining the technological capabilities associated with Quality 4.0 and the human-centric perspective of Quality 5.0 within a single conceptual structure, the model provides a comprehensive perspective on the future development of quality management.

The analysis demonstrates that quality management concepts have evolved continuously in response to technological progress, global market dynamics and rising societal expectations. This evolution reflects a shift from narrow product-oriented definitions of quality toward broader perspectives that integrate sustainability, stakeholder value and social responsibility. Contemporary approaches, particularly Quality 5.0, highlight the importance of balancing technological advancement with human-centered and ethical considerations.

The findings indicate that all historical stages of quality management remain relevant foundations for current and future developments. Rather than replacing earlier concepts, new paradigms extend and integrate them, creating more comprehensive and adaptive quality frameworks. Organizations that adopt such integrative approaches may achieve improved operational efficiency, stronger competitiveness and greater stakeholder trust.

At the same time, the transition toward advanced quality paradigms introduces new challenges, including the need for higher employee competencies, responsible technology adoption and awareness of potential social and ethical risks. Addressing these challenges will be essential for ensuring that the next stages of quality management development contribute not only to organizational performance but also to broader societal well-being.

The results of this study may be particularly useful for managers, quality professionals and researchers, as the proposed IEQMM framework helps integrate traditional quality management practices with emerging digital and sustainability-oriented approaches.

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## Appendix

### Appendix A

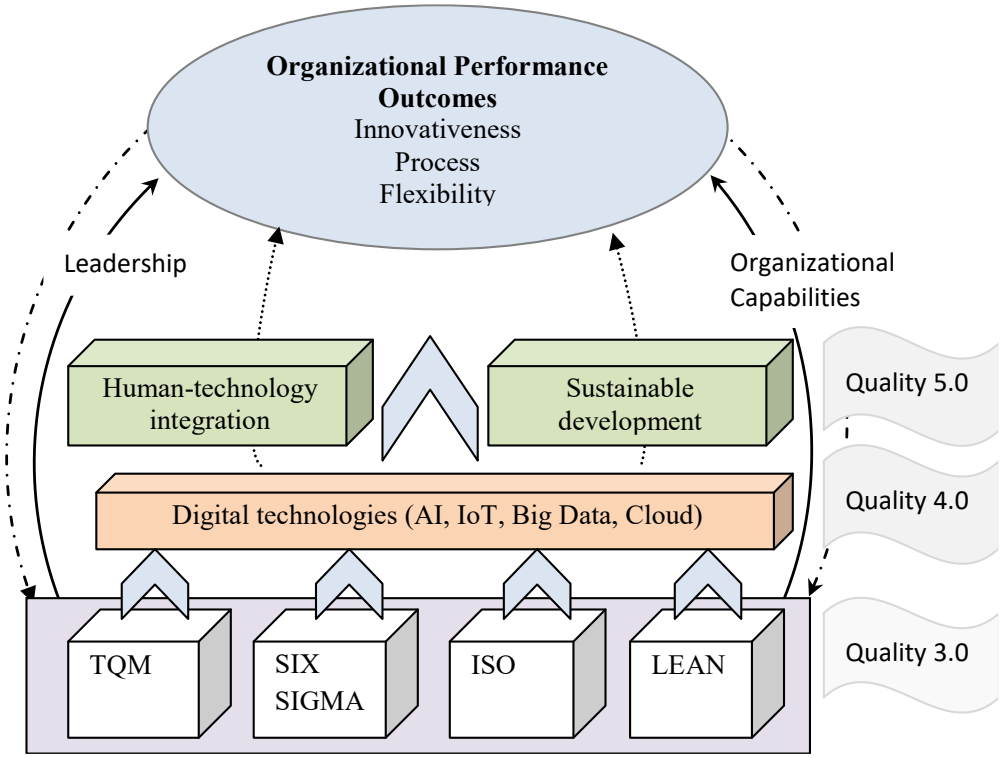


**Fig. 4.** Integrated Evolutionary Quality Management Model (IEQMM)

### Appendix B

**Table 2.** Elements of the IEQMM conceptual model

| Model element | Definition | Literature basis | Example indicators |
|---|---|---|---|
| Foundational QM practices | Traditional quality management systems ensuring process stability and continuous improvement | Dahlgaard-Park 2011; Yang 2017 | defect rate, process capability, cycle time |
| Digital quality capabilities (Quality 4.0) | Use of digital technologies to support data-driven quality management | Ranjith Kumar et al. 2022; Sony & Naik, 2020 | predictive maintenance accuracy, real-time quality monitoring |
| Human-centric and sustainability practices (Quality 5.0) | Integration of social responsibility, human-machine collaboration and sustainability into quality management | Fiałkowska-Filipek & Dobrowolska 2023 | employee engagement, ESG indicators, stakeholder satisfaction |
| Governance and leadership | Organizational culture and leadership enabling integration of quality paradigms | Dahlgaard-Park 2011 | leadership commitment, quality culture maturity |

**Appendix C**

**Table 3.** Selected counterparts of the characteristic aspects of the 5.0 concept of quality management as related to previous concepts

| | Earlier concepts | Quality 5.0 |
|---|---|---|
| **Total Quality Management** | Orientation towards the customer | • AI-based personalisation,<br>• considering social, emotional, and ethical needs |
| | Continuous improvement | • data analysis in continuous improvement, predictive actions |
| | People and their competencies | • development of digital competences,<br>• protection of the mental well-being of employees |
| **Six sigma** | Statistical control of processes | • machine learning<br>• big data<br>• predictive reliability models<br>• automatic process regulation |
| | Analysis of the causes of variability | |
| | Process stability and risk management | ISO standards structures provide the framework for implementing new technologies in a controlled manner |
| **ISO standards** | ISO 45001 Occupational Health and Safety | Mandatory for the implementation of robots and AI |
| | ISO 26000 Social Responsibility | Technology supports humans instead of replacing them. |
| | Standards:<br>ISO/IEC 27001 – Information Security<br>ISO 20000 - IT Service Management<br>ISO/IEC 38500 ICT Governance | They ensure the effective use of AI, Big Data, and IoT without compromising data integrity.<br>It allows for the integration of technology with humans. |
| | ISO 14001- Environmental Management | Ensure compliance of technological implementations with the principles of sustainable development. |
| **LEAN** | Workplace standardization | • intelligent standardization,<br>• standards are automatically updated |
| | Value Stream Mapping | • digital twins<br>• real-time monitoring,<br>• predictive mapping |
| | Muda elimination | • eliminating wastefulness with AI and IoT,<br>• detecting patterns leading to failure,<br>• other losses related to digitization, such as data duplication and elimination |
| **Quality 4.0** | Focus on technology:<br>• Internet of Things (IoT)<br>• Big Data<br>• artificial intelligence<br>• automation | Extension of technology 4.0 to include ethics, ecology, and sustainable development. |