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Research Paper

The Role of Quality 4.0 in Business Process Management: a Bibliometric Study

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Abstract. Quality 4.0 builds on the principles of Industry 4.0 to improve quality management. Integrating Quality 4.0 into Business Process Management (BPM) examines how digital technologies enhance process efficiency and innovation. The main research question is how Quality 4.0 can be aligned with existing BPM frameworks and how the digital transformation of traditional quality management techniques facilitates efficiency. A bibliometric analysis was conducted using the Scopus database, employing keyword analysis, link mining techniques, and network mapping to identify research trends and gaps. The results show the main directions of research on integrating Quality 4.0 and BPM and highlight implementation barriers such as organizational resistance and the need for strategic alignment. The study also suggests directions for future investigation, including the development of standardized frameworks for evaluating digital BPM outcomes and exploring emerging debates around human-centric, sustainable, and resilient approaches reflected in Industry 5.0 and Quality 5.0.

Keywords: Business Process Management, Quality 4.0; Quality Management, Business Process Reengineering

1. Introduction

Pursuing quality in products and services is a fundamental expectation that defines organizational value propositions across industries. While the interpretation of quality has evolved since the 1960s, its implementation and measurement mechanisms have undergone significant transformation in recent decades. The historical progression of Industrial Revolutions has shaped the trajectory of quality management. In the first Industrial Revolution, productivity and output volume preceded quality assurance and working conditions, whereas the 1980s introduced standardization, continuous improvement, and the integration of quality as a strategic approach. The establishment of industry standards reinforced quality management as a good business practice [1].

The fourth Industrial Revolution came with digital transformation, profoundly influencing how organizations manage and optimize their processes[2][3]. Quality 4.0, in concept, represents the integration of advanced digital technologies with traditional quality management principles[1][4][5]. This evolution enhances operational efficiency [6], process monitoring and control, and, more importantly, improves product quality, enabling organizations to remain competitive in dynamic and increasingly globalized markets [7][8][9]. At the same time, the reliance on data-intensive tools and

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automation introduces new challenges, including integration costs, workforce adaptation, and debates about the human-centric directions proposed by Industry 5.0 and Quality 5.0.

Business Process Management (BPM) is the foundational approach for optimizing organizational processes, focusing on aligning operations with strategic goals and improving overall performance [10]. Business Process Reengineering (BPR), a critical subset of BPM, emphasizes radical process redesign to improve productivity, efficiency, and innovation. Meanwhile, the rapid adoption of Quality 4.0 technologies presents new opportunities and challenges for BPM and BPR.

This paper investigates the role of Quality 4.0 in transforming BPM and BPR practices, exploring how digital tools can be integrated with established methodologies to address management challenges. Using a bibliometric analysis of literature indexed in Scopus, the study maps keyword trends, thematic clusters, and research gaps to examine how Quality 4.0 technologies intersect with BPM. The findings highlight both opportunities and barriers, offering actionable recommendations for organizations and providing a foundation for further research.

The paper follows the following structure: research objectives, literature review, methods and materials, results, discussion with managerial implications, and conclusions.

1.1. Research Objectives

The stud's main research question is: What is the role of Quality 4.0 in enhancing Business Process Management (BPM)? Specifically, the paper pursues the following objectives:

- To examine key trends in integrating Quality 4.0 within BPM and Business Process Reengineering (BPR), and to identify the digital tools and methodologies that facilitate this synergy.
- To address existing gaps and barriers in the adoption of Quality 4.0, including challenges related to organizational change, aligning digital technologies with workflows, and the skills required for effective integration.
- To provide actionable insights into how Quality 4.0 transforms BPM from a static framework into a data-driven, adaptive system, fostering continuous improvement and informed decision-making.

1.2. Quality 4.0 and Business Process Management

Quality 4.0 (Q4.0) represents a transformative shift in quality management, integrating cutting-edge digital technologies with well-established principles of operational excellence. With Quality 4.0, the quality profession must evolve. The new technologies enhance real-time monitoring and predictive analytics, overcoming traditional reactive approaches to quality management [11]. Unlike conventional methods focusing on conformance and defect reduction, Q4.0 fosters a proactive and interconnected ecosystem where quality assurance is embedded into business processes.

Integrating Q4.0 principles into organizational strategies has positively influenced digital transformation and sustainable excellence [12]. At the core of Q4.0 is agility, innovation, and resilience in business operations. Traditional quality management approaches, such as Total Quality Management (TQM) and Lean Management, emphasize continuous improvement through incremental changes. In

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contrast, Q4.0 enables transformative breakthroughs through automation, machine learning, and self-optimizing processes. One prominent example is predictive maintenance, which allows organizations to anticipate and resolve equipment failures before they occur, significantly reducing downtime and maintenance costs.

Additionally, integrating customer feedback through digital platforms ensures that products and services align with evolving market demands. Implementing Q4.0 can enhance competitive advantage by fostering innovation, improving decision-making, and differentiating market positions [4][12]. Moreover, green business process management, which integrates sustainability principles with process efficiency, further strengthens competitiveness through optimized resource utilization and reduced environmental impact.

Q4.0 also reshapes organizational culture by promoting cross-functional collaboration and data-driven decision-making. According to [5], the key benefit of Q4.0 is its ability to enhance transparency and real-time information sharing, enabling proactive quality management. The shift from manual, paper-based systems to automated digital platforms streamlines operations and improves traceability, accountability, and compliance with international standards (such as ISO 9001:2015). Furthermore, organizations use frameworks such as Accenture's Connected Quality and KPMG's Smart Quality to integrate digital quality assurance into business operations. As businesses must survive in competitive global markets, Q4.0 emerges as a critical enabler of sustainable growth and long-term excellence.

Business Process Management is a systematic approach to designing, executing, monitoring, and optimizing organizational processes to align with strategic objectives [1]. Focusing on end-to-end workflows in BPM ensures that business operations are efficient, consistent, and adaptable to changing market demands. Central to it is the emphasis on process standardization, resource optimization, and continuous improvement, which are critical for achieving operational excellence. Various frameworks, such as Lean BPM and Six Sigma, provide organizations with tools to identify inefficiencies, eliminate redundancies, and enhance overall productivity.

One of the key strengths of BPM lies in its ability to bridge organizational silos and promote cross-functional collaboration. Studies illustrate that by mapping and analyzing workflows, BPM provides a holistic view of how various departments interact, enabling organizations to identify bottlenecks and implement solutions that enhance process flow. The data-driven nature of BPM further allows for informed decision-making, with performance metrics and key performance indicators (KPIs) serving as benchmarks for process improvement. These insights help organizations adapt to dynamic business environments while maintaining high levels of efficiency and customer satisfaction.

As organizations increasingly embrace digital transformation, BPM is evolving to incorporate advanced technologies that align with the principles of Q4.0. Digital tools such as robotic process automation (RPA), artificial intelligence, and process mining enhance BPM's ability to automate repetitive tasks, optimize resource allocation, and provide predictive insights. Furthermore, integrating BPM with Q4.0 technologies empowers organizations to transition from reactive to proactive management, where processes are continuously monitored and refined to meet strategic goals. This convergence highlights the critical role of BPM in enabling organizations to manage complex, globalized markets while driving innovation and maintaining their competitive edge.

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1.3. Conceptual Framework

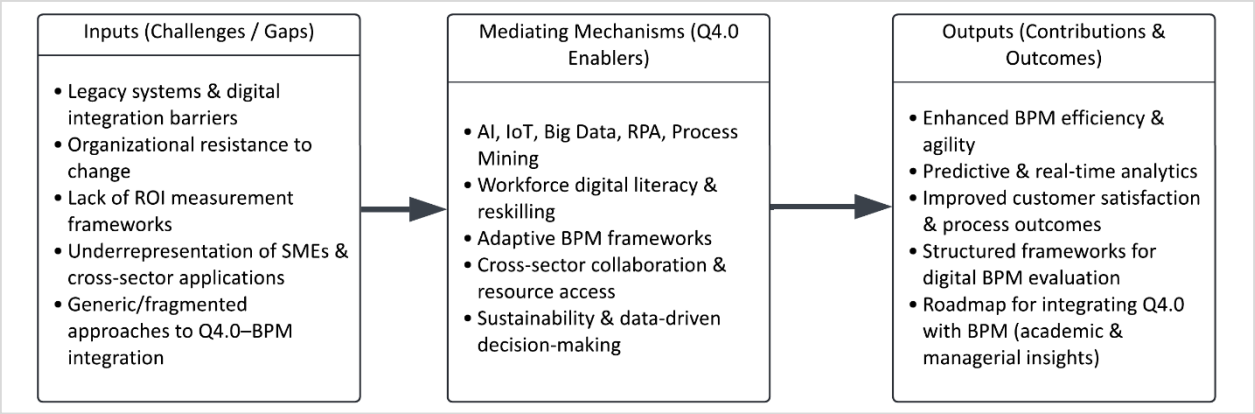

Figure 1. Conceptual framework for integrating Quality 4.0 and BPM
Source. Adapted from[11][10][14][15]

The conceptual framework in Figure 1 synthesizes the study's findings by linking the identified gaps in existing research with the enabling mechanisms of Quality 4.0 and the resulting outcomes for BPM. It illustrates how persistent challenges, such as legacy system integration, organizational resistance, and the absence of ROI measurement frameworks, can be addressed through digital enablers like AI, IoT, process mining, and workforce reskilling. These enablers, in turn, contribute to enhanced BPM efficiency, predictive and real-time analytics, and improved customer satisfaction. This study, through our bibliometric analysis, integrates both theoretical insights and managerial applications. Although published in 2016, study [14] remains fundamental in establishing the conceptual relationships between Quality 4.0 and BPM, and it provides an essential perspective on optimizing business processes.

Having established the relevance of Quality 4.0 as an extension of Industry 4.0 and its potential to reshape BPM, the following literature review synthesizes current perspectives, frameworks, and empirical findings.

2. Literature Review

Various studies highlight the close interlink between Quality 4.0 (Q4.0) and Business Process Management (BPM). Quality 4.0 builds on the principles of Industry 4.0, extending its digital technologies, such as AI, IoT, and big data analytics, into quality management practices to enhance efficiency, effectiveness, and innovation in business operations [16]. In this framework, BPM is identified as a critical technical factor[2], emphasizing the optimization and management of business processes to align with Industry 4.0 technologies and circular economy practices (CEP) [2][9][17][18] .

Technical Q4.0 practices, including BPM, Automatic Data Collection (ADC), and Technology Utilization (TU), play a pivotal role in driving organizational performance and sustainability **Hiba! A hivatkozási forrás nem található.**. Empirical studies using Structural Equation Modelling and Artificial Neural Network (ANN) techniques have demonstrated that technical Q4.0 practices, such as BPM, significantly influence the adoption of Industry 4.0 technologies and CEP, particularly in small- and medium-sized manufacturing enterprises (SMEs) [1]. Furthermore, technical Q4.0 practices mediate between social Q4.0 practices and outcomes like Industry 4.0 readiness and CEP, highlighting their importance in

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achieving long-term competitive advantages [1]. The ANN analysis further underscores the significance of BPM, ranking it among the key technical factors essential for the successful deployment of Industry 4.0 technologies and CEP [1].

Empirical evidence from developing countries shows that Quality 4.0 adoption is shaped by maturity levels across multiple organizational dimensions. Zulqarnain et al. [19] developed an implementation framework that identifies eleven critical factors influencing Q4.0 readiness in SMEs, underscoring the role of BPM as a mediator between digital tools and organizational performance.

These findings suggest that SMEs should prioritize social and technical Q4.0 practices, including BPM, to effectively succeed in digital transformation and promote sustainable manufacturing practices [1]. Thus, integrating BPM within the Q4.0 framework is not only a continuation of established quality principles but also a digitally enhanced extension of Industry 4.0, supporting process transformation, innovation, and sustainability.

A further examination of the literature finds that integrating Q4.0 principles into BPM necessitates the adoption of a comprehensive suite of tools, methodologies, and frameworks that align digital technologies with process optimization goals [7]. Recent studies reinforce that BPM itself is evolving into adaptive, data-driven, and AI-enabled forms, which position it as a mediator between technology and organizational performance[19][20]. Technological tools play a pivotal role in this integration. IoT devices enable real-time data collection and monitoring, providing organizations with end-to-end visibility of their processes [13]. The authors further explain the significance of the Intelligent Internet of Things (IoT) as a critical design requirement for implementing Q4.0 in the electronics sector. Big data analytics uncovers inefficiencies and drives data-informed decision-making [21], while artificial intelligence (AI) and machine learning (ML) facilitate predictive modeling, anomaly detection, and autonomous decision-making. Additionally, cloud platforms foster scalability and seamless collaboration across geographically diverse teams, ensuring a globalized approach to process management.

Sectoral studies highlight the importance of context. Mittal et al.[22], analyzing the Indian furniture industry, found that organizational variables such as leadership support, employee training, and technological infrastructure significantly determine the effectiveness of Quality 4.0 initiatives in BPM integration.

Advanced process management methodologies complement these technologies. Lean BPM uses digital tools to minimize waste and increase workflow efficiency, while Agile BPM supports the dynamic adaptation of processes to changing business needs [23]. Q4.0 technologies enhance process improvement in manufacturing through real-time data analysis and automation. The integration of these technologies leads to significant reductions in repair rates and inspection times, ultimately driving efficiency and productivity [23].

Beyond sectoral insights, broader research demonstrates that BPM capabilities directly enhance sustainable digital transformation. Huy and Phuc [20] confirm that BPM fosters dynamic decision-making, enabling organizations to embed Q4.0 technologies in adaptive and sustainable process management. When integrated with Q4.0 technologies, such as AI-driven analytics, Six Sigma puts quality control and process improvement initiatives to a new level. These methodologies enable

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organizations to respond proactively to changing market demands while focusing on efficiency and quality.

Furthermore, established quality management frameworks are being redefined in Q4.0. The ISO 9001:2015 standard can be enhanced by incorporating automation, real-time monitoring, and customer feedback loops, ensuring continuous improvement and customer satisfaction. The EFQM Excellence Model, enriched with digital metrics, aligns organizational processes with leadership and innovation goals, emphasizing strategic alignment and continuous improvement.

Finally, cultural and organizational enablers are critical to the success of this integration. Effective change management strategies help address resistance and foster a digital-first mindset across all organizational levels. Concurrently, upskilling and training initiatives equip employees with the expertise to utilize Q4.0 tools within BPM frameworks effectively. These tools, methodologies, and frameworks provide a robust foundation for integrating Q4.0 into BPM, enabling organizations to achieve sustainable process excellence.

2.1. The Integration of BPM and Quality 4.0 in Addressing Global Management: Opportunities and Challenges

The convergence of Quality 4.0 and BPM represents a transformative shift in how organizations design, execute, and optimize their workflows. We see that organizations that embed Q4.0 principles into BPM can leverage the benefits of advanced digital technologies to create more agile, efficient, and resilient processes. This integration builds on traditional process management approaches but offers innovative ways to enhance operational excellence and address the demands of an increasingly complex business environment.

One of the most significant benefits of this integration is end-to-end process visibility. Incorporating tools like the Internet of Things (IoT), Big Data analytics, and cloud computing, organizations achieve real-time monitoring of their workflows[11][14]. This visibility allows for the seamless tracking of performance metrics, ensuring that potential bottlenecks or inefficiencies are identified and addressed promptly. Additionally, predictive analytics, a cornerstone of Q4.0, enables proactive improvements by forecasting potential quality issues before they escalate into acute problems. This shift from a reactive to a proactive process management approach significantly reduces downtime, enhances resource allocation, and improves overall process reliability.

The integration of Q4.0 and BPM also fosters enhanced collaboration across organizational silos. Digital tools such as collaborative platforms and process automation technologies streamline communication and enable cross-functional teams to work cohesively toward shared objectives. For example, data-sharing systems ensure quality metrics and insights are accessible to all relevant stakeholders, facilitating faster decision-making and alignment with strategic goals. Furthermore, this convergence supports continuous improvement in embedding feedback loops within processes, ensuring that lessons learned are systematically incorporated into future workflows.

In a globalized and competitive market, the synergy between Q4.0 and BPM provides organizations with a framework for innovation and adaptation. Aligning technological advancements with BPM methodologies provides organizations with a better chance of achieving digital transformation,

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remaining competitive, and meeting the evolving needs of customers and stakeholders. This integration positions organizations not only to achieve operational efficiency but also to sustain long-term growth and resilience.

However, despite the benefits, it is essential to note the challenges concerning the implementation of Q4.0 and BPM. Successful implementation of Q4.0 faces challenges, such as the low deployment success rate of projects based on Q4.0 [10][11][15]. The authors argue that continuous investment in AI and digital technologies is crucial for overcoming challenges and realizing the full potential of Q4.0 in BPM.

Integrating Business Process Management and Quality 4.0 provides innovative solutions to these challenges. In an era of rapid digitalization, organizations must deal with increasing operational complexity, heightened customer expectations, and stringent compliance requirements while maintaining competitiveness.

- Globalization and Operational Complexity

  As organizations expand their operations across multiple regions, managing processes efficiently while maintaining consistent quality standards becomes increasingly tricky. Q4.0 tools, such as advanced analytics and IoT-enabled monitoring, combined with BPM's structured and systematic frameworks, enable real-time coordination and decision-making across geographically dispersed operations. This ensures that global teams can maintain alignment with organizational goals and deliver uniform quality, even in complex supply chain networks. IoT devices enable continuous data collection and monitoring, providing organizations with comprehensive visibility into their processes. This capability is essential for real-time quality assurance and predictive maintenance, as seen in the pharmaceutical industry, where IoT enhances data accuracy and operational efficiency[7][13].

- Customer Expectations and Personalization

  Modern customers demand high-quality products, services, and personalized experiences tailored to their unique preferences. Q4.0's customer data analytics capabilities provide insights into evolving consumer needs, while BPM optimizes the processes required to meet these demands efficiently. They enable organizations to deliver faster, more tailored responses to customer expectations, enhancing satisfaction and loyalty. Big data analytics helps businesses understand consumer behavior and preferences, allowing for targeted marketing campaigns and product development[25]. Companies use online interactions to gather data, that informs personalized services online and in physical stores.

- Compliance and Risk Management

  Managing risks effectively is a high priority in a globalized economy with varying regulatory environments. BPM frameworks ensure processes adhere to regulatory requirements by embedding compliance into workflows. At the same time, Q4.0 tools, such as predictive analytics and AI, proactively identify potential risks and ensure corrective measures are taken before disruptions occur. This synergy minimizes compliance failures, enhances risk mitigation, and provides organizational resilience. BPM frameworks streamline compliance by embedding regulatory requirements into operational processes, ensuring adherence throughout the organization[26]. Automated controls within BPM systems have strongly correlated with improved risk management metrics, such as fraud detection and regulatory reporting accuracy[27][28]. Despite the benefits, integrating advanced technologies like AI introduces challenges, including data privacy concerns and algorithmic bias, necessitating careful management [29].

DOI: 10.21791/IJEMS.2025.18

2.2. Importance of BPM-Quality 4.0 Integration for Process Efficiency and Innovation in Global Contexts

Q4.0 utilizes Industry 4.0 technologies to enhance BPM, improving process efficiency and reducing operational costs[4]. The authors further propose that data-driven decision-making using BPM frameworks incorporate data analytics to enable organizations to make informed decisions and optimize workflows and resource allocation[29]. The proposal supports this argument that Q4.0 promotes operational efficiency and innovation, particularly in adaptable and scalable global business environments.

- Enhanced Process Efficiency

  Q4.0 technologies, such as IoT, enable real-time data collection and monitoring, allowing organizations to optimize their processes continuously. When integrated with BPM, automation tools streamline workflows, reduce redundancies, and minimize human error. These advancements lead to cost reductions, improved resource allocation, and faster time to market for products and services.

- Agility and Innovation

  Q4.0's predictive capabilities, combined with BPM's flexibility, empower organizations to respond swiftly to market fluctuations, implement innovative ideas, and address emerging trends. Digital twins and simulation models allow organizations to experiment with process innovations in virtual environments without disrupting ongoing operations. This approach accelerates innovation while mitigating potential risks.

- Global Collaboration and Knowledge Sharing

  Cloud-based platforms and advanced BPM suites facilitate seamless collaboration among teams across different regions. Enabling the sharing of real-time insights and best practices, these tools foster a culture of continuous improvement. This global collaboration enhances organizational growth and ensures sustainability by promoting shared accountability and learning.

  The integration of BPM and Q4.0 thus represents a transformative force for addressing global management challenges, ensuring that organizations remain competitive, agile, and innovative.

Building on these theoretical and empirical foundations, the present study applies a bibliometric analysis to map the structure of research on Quality 4.0 and BPM.

3. Methods and Materials

3.1. Methods

The designed research process in Figure 2 follows a structured, ten-step methodology aimed at exploring the integration of Quality 4.0 into Business Process Management. It begins with defining the research purpose and identifying relevant academic sources (Steps 1–2). Literature is then collected and analyzed using bibliometric tools such as VOSviewer to uncover trends, citation networks, and keyword relationships (Steps 3–4). Bibliometric analysis is widely employed in recent Quality 4.0 and BPM studies to map research trends and intellectual structures[8][19].

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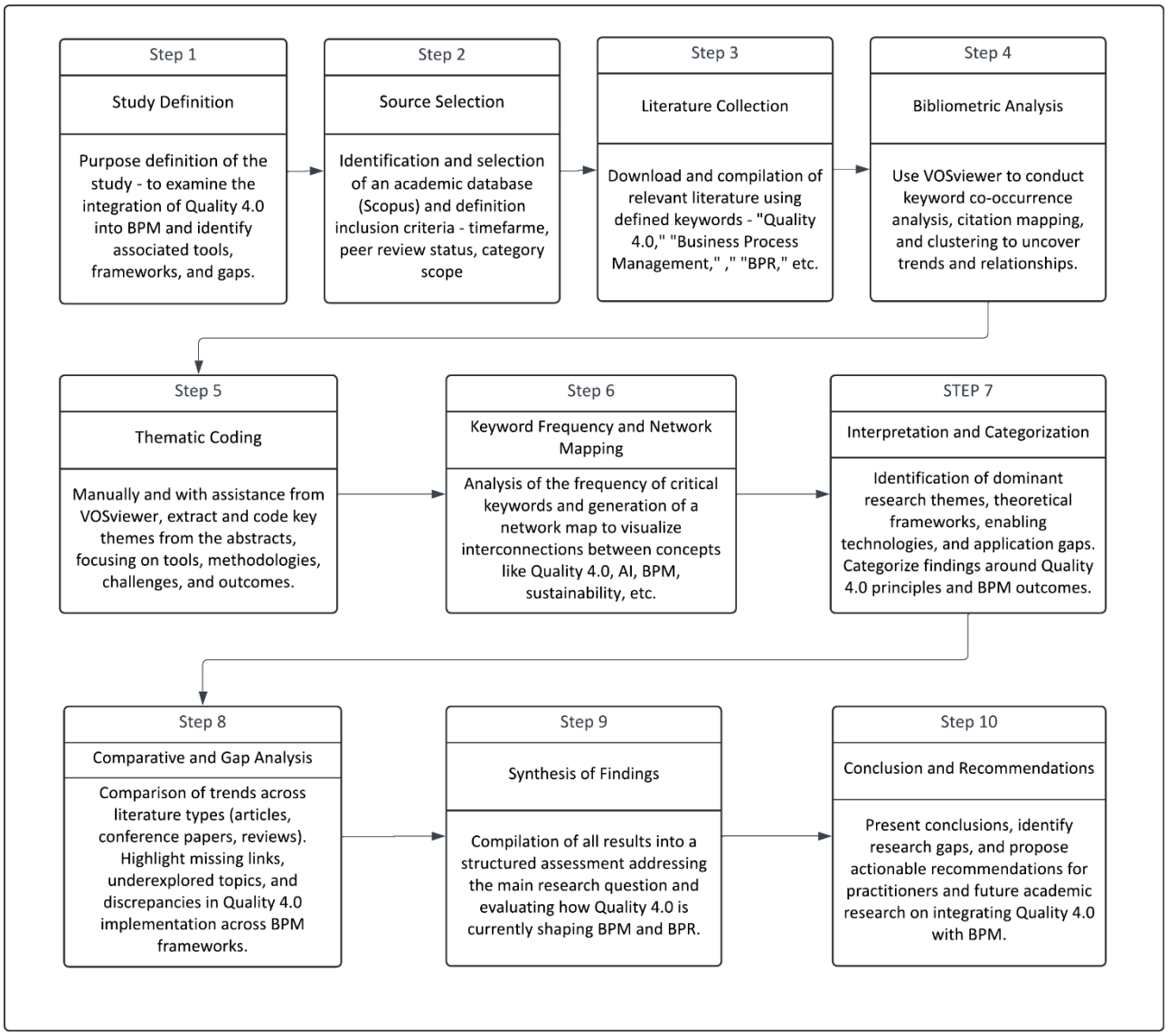

Figure 2. Methods and research design process. Source: Own compilation

In Steps 5–7, thematic coding, keyword frequency analysis, and network mapping are used to extract dominant research themes and categorize them into frameworks, tools, and gaps associated with Quality 4.0 and BPM. Steps 8 and 9 involve comparative and gap analysis across different publication types and synthesizing findings that address the research question. Finally, conclusions and actionable recommendations are drawn for both practitioners and academics to support further integration and study of Quality 4.0 within BPM contexts.

3.2. Materials

Data was collected from the Scopus database, focusing on Q1-ranked publications in the subject area of Business, Management, and Accounting. This choice ensured methodological rigor and comparability across journals, although it also excluded potentially valuable interdisciplinary contributions, which is acknowledged as a limitation. The dataset included journal articles, conference papers, book chapters, and reviews, yielding an initial pool of 15,524 documents.

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The search process employed the following queries: "Quality 4.0" (TITLE-ABS-KEY), "Business Process Management" OR "BPM" (TITLE-ABS-KEY). Boolean operators were used to refine results, and the queries were applied within the defined subject category and Q1 journal filter. This process reduced the dataset to 2,077 documents more closely aligned with the study's focus.

A further narrowing was conducted to isolate studies explicitly linking Q4.0 and BPM, resulting in a final corpus of 98 core papers. Although 98 papers formed the basis of the bibliometric analysis, the references cited in this manuscript represent the most influential and thematically central contributions. Table 1 summarizes the narrowing process, and Figure 3 illustrates the distribution of document types.

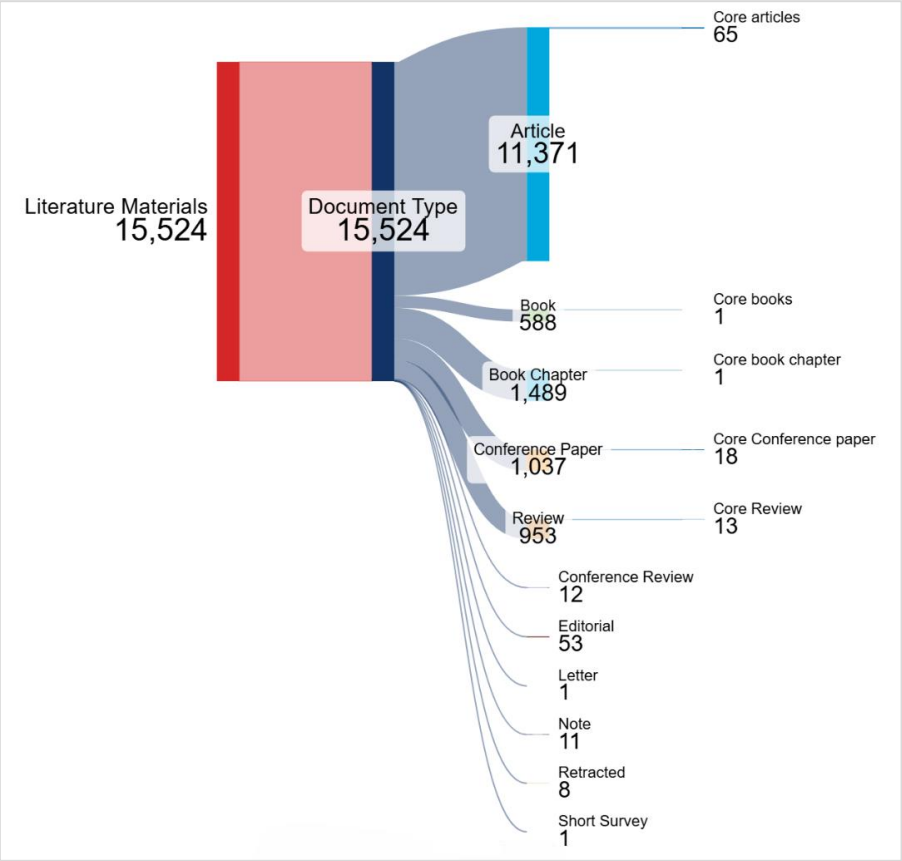

Figure 3. Document demographics

It is important to note that the high drop-off rate (as seen in Table 1) reflects the narrow specificity of the keywords and the decision to limit the corpus to Q1-ranked journals. While this ensured focus and quality, it may also have excluded relevant contributions from other subject categories (e.g., engineering, computer science, or interdisciplinary studies).

Type	**Total**	**Core Set**
Article	11,371	65
Conference Paper	1,037	18
Review	953	13
Book/Chapter	2,077	2
Total	15524	98

Table 1. Comparative table on the study's narrowing process

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The articles constitute the largest category, with 65 papers, highlighting that journal articles are the predominant source of scholarly contributions. Conference Papers account for 18 papers, suggesting that a significant portion of research has been presented at academic and professional conferences. The study also notes that review papers comprise 13, indicating that systematic reviews and literature syntheses have been conducted on the available knowledge.

Book chapters and books are minimally represented, with only two entries combined, suggesting that monographic literature is not a significant material with possible gaps for discussing the intersection of Q4.0 and BPM.

To gain a deeper understanding of the data, a network analysis was conducted on the 98 papers to identify tools, methodologies, and frameworks through thematic analysis, keyword frequency analysis, and network mapping, uncovering trends and gaps. Using VosSoftware, the study analyzed the keywords that link Q4.0 to business processes, as shown in Figure 3. The high drop-off rates reflect a selective filtering process, ensuring strong alignment with the study's specific focus.

The methodological process generated a core dataset of 98 studies, the analysis of which provides insights into research themes, keyword clusters, and emerging gaps presented in the following results.

4. Results and discussion

4.1. Results

Figure 4 presents a network analysis visualization of keyword relationships within 98 research papers on Q4.0 and business processes, created using VOSviewer software. The network structure highlights key concepts, tools, methodologies, and frameworks related to Q4.0, revealing clusters of interconnected themes based on keyword frequency and co-occurrence. The largest node in the network is "Quality 4.0," indicating its dominant role in the analyzed literature. Numerous links extend from "Quality 4.0" to other concepts, demonstrating its strong interconnection with various business process management methodologies, tools, and frameworks.

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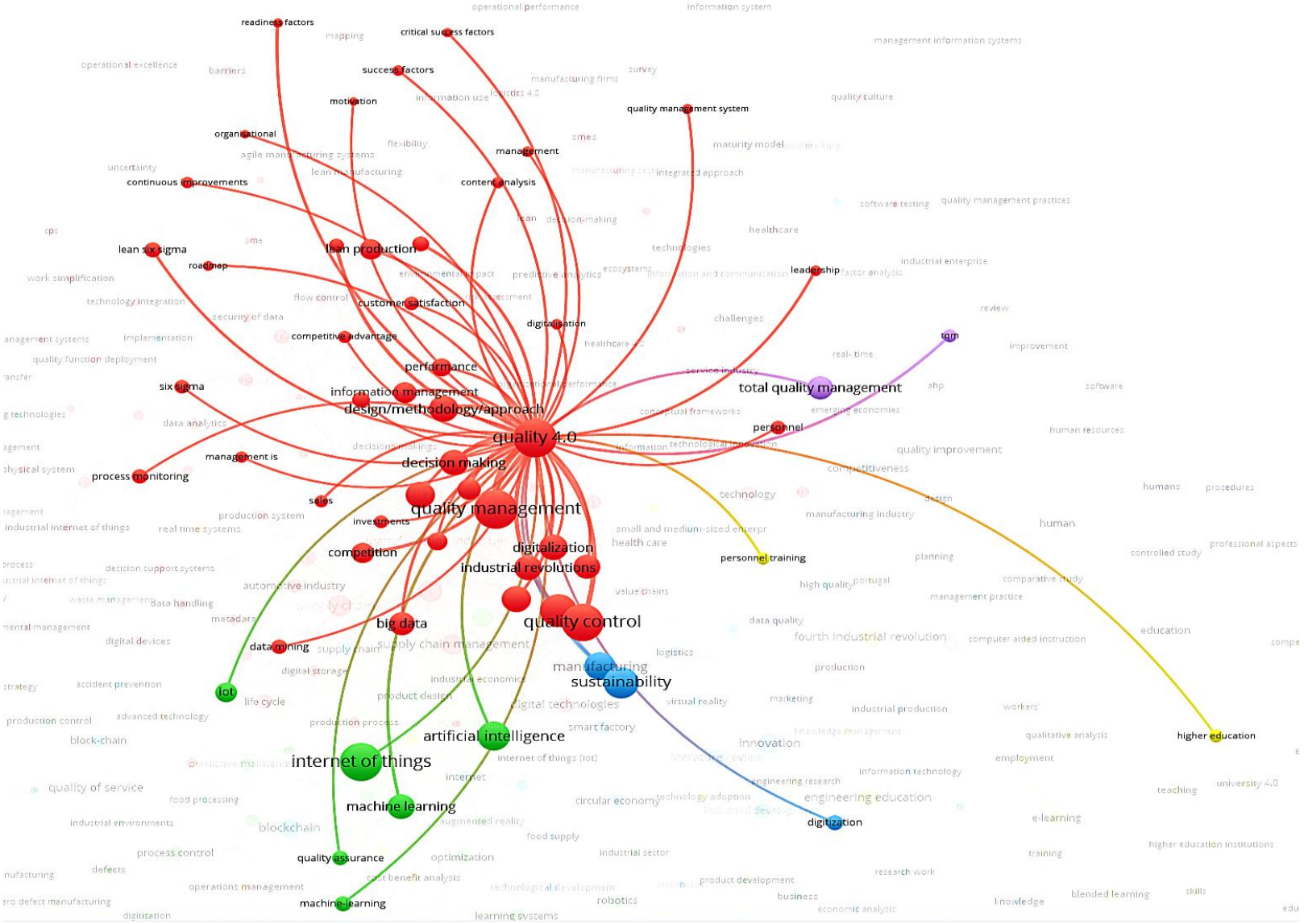

Figure 4. Network analysis of Quality 4.0 to business processes. VOS Viewer. Data source: Scopus.

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The red cluster represents the core quality management approaches. This cluster focuses on Q4.0, quality management, quality control, and decision-making.

The green cluster focuses on digital transformation technologies that link Q4.0 to the Internet of Things (IoT), Artificial Intelligence (AI), machine learning, and blockchain technology.

The yellow cluster represents training and workforce adaptation with keywords such as "personnel training" and "higher education," distinctly linking the processes to Quality 4.0 and TQM. There is an increasing emphasis on developing skills and competencies required for Q4.0 adoption in organizations and academic institutions.

The blue cluster points to innovation and sustainability in business processes, where sustainability and digitalization appear as major themes, which point to a growing interest. Sustainability is a key consideration that cannot be ignored. The network emphasizes sustainability and green business process management as an emerging priority, reflecting the alignment of Q4.0 with environmental, social, and governance (ESG) objectives. For example, to comply with regulations, social and environmental concerns have led governments and institutions to enforce sustainability reporting rules[6].

Researchers recognize the importance of automation and intelligent systems in improving business process quality. Keywords such as "customer satisfaction," "performance," "competitiveness," and "design methodology" indicate a research focus on improving business outcomes through digital quality strategies. The connections suggest that intelligent, data-driven quality control systems and automation emerge as fundamental enablers of Q4.0. The presence of big data and process monitoring indicates a shift from reactive quality control to predictive and real-time analytics.

Lastly, the connection between engineering education, innovation, and Q4.0 suggests that academia plays a crucial role in advancing research and implementation strategies. These results provide a foundation for deeper discussion on how Quality 4.0 can enhance BPM, both in terms of conceptual development and practical application.

4.2. Discussion

The study's central research question was the role of Quality 4.0 in enhancing Business Process Management. Having looked at the 98 papers, the findings indicate that Quality 4.0 can be effectively aligned with existing BPM frameworks by embedding digital tools such as AI, IoT, and process mining into established methodologies like Lean, Six Sigma, and TQM. This integration transforms BPM from a static, workflow-driven model into a dynamic, data-driven system capable of real-time adaptation. The digital transformation of traditional quality techniques therefore facilitates efficiency by enabling predictive analytics, faster decision-making, and continuous process improvement. The detailed analysis of the 98 papers further illustrates how these alignments and transformations manifest in practice, with recurring themes and patterns that can be grouped into the following key findings:

- The integration of technology and quality management stands out. Various authors agree that Quality 4.0 emphasizes the integration of advanced technologies such as AI, Big Data, and IoT into quality management practices. This integration enhances BPM by enabling real-time data analysis and decision-making, improving efficiency and effectiveness.

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- Secondly, there is a shift towards data-driven decision-making. Leveraging Quality 4.0 enables organizations to utilize data analytics to understand customer needs better and improve process performance. This data-driven approach supports BPM by facilitating informed decisions that enhance process outcomes and customer satisfaction.
- Further, there is an emphasis on continuous improvement, where Quality 4.0 fosters a culture of continuous improvement within organizations. Utilizing digital tools and methodologies, organizations identify inefficiencies in their processes and swiftly implement corrective actions, enhancing BPM as supported by empirical studies demonstrating that Quality 4.0 adoption enhances BPM agility and resilience[22][30][22].
- Regarding collaboration and communication, the adoption of Quality 4.0 encourages collaboration across departments through shared digital platforms. This improved communication streamlines BPM by ensuring all stakeholders are aligned and informed about process changes and quality standards.
- The papers note that Quality 4.0 shifts the focus towards customer requirements and expectations. Organizations enhance their service delivery and product quality by aligning BPM with customer needs, increasing customer satisfaction and loyalty.
- Lastly, the papers explore frameworks such as Total Quality Management for digital transformation. Similarly, the growing focus on Quality 4.0 provides a structured framework for organizations to transition into digital environments. This framework aids BPM by outlining the necessary capabilities and stages for successful digital transformation, ensuring that quality management is integrated into all business processes.

Identified Gaps in Previous Research	**Contributions of This Study**
Fragmented treatment of Quality 4.0 (Q4.0) technologies and BPM frameworks, often studied in isolation.	Provides an integrated bibliographic analysis that connects Q4.0 technologies (AI, IoT, RPA, process mining) with BPM practices, showing how digital transformation reshapes process management.
Lack of systematic quantification of research attention across Q4.0–BPM domains.	Applies bibliometric methods to perform keyword weighting and thematic clustering, offering measurable insights into the relative focus areas of academia and industry.
Limited focus on practical challenges such as organizational resistance, skill gaps, and legacy systems in BPM transformation.	Highlights these challenges explicitly through thematic analysis, linking them to underrepresented areas in research and offering actionable recommendations for stakeholders.
Insufficient frameworks to evaluate the return on investment (ROI) and measurable outcomes of digital BPM initiatives.	Proposes directions for developing standardized ROI assessment methodologies.
Underrepresentation of SMEs and cross-sectoral contexts in the digital BPM discourse.	Identifies SMEs and non-manufacturing sectors as gaps in the literature and suggests future research to extend the applicability of Q4.0–BPM frameworks beyond large enterprises.

Table 2: Identified gaps and the study's contribution

Previous studies on Business Process Management (BPM) and Quality 4.0 (Q4.0) have essentially treated these domains in isolation, often focusing on either technological advancements or process

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frameworks without exploring their integration. Similarly, while the role of digital transformation has been widely acknowledged, systematic efforts to quantify research attention, synthesize challenges, and provide measurable insights remain limited.

Table 2 presents a comparison of these gaps with the contributions of this paper. The bibliometric method applied in this study quantifies thematic attention in Q4.0–BPM research, providing a data-driven overview of where academic and industrial focus has been concentrated. Beyond synthesis, it identifies practical challenges, such as organizational resistance and skill gaps, that are underexplored in existing research, while also proposing future directions, particularly the development of ROI measurement frameworks and the inclusion of SMEs in the discourse. This dual emphasis on theoretical integration and practical relevance stresses the unique contribution of this study and places it as a bridge between academic exploration and managerial application.

Lastly, a comparative overview of the conventional QM, Quality 4.0, BPM, and enhancement features is presented in Table 3.

Dimension	**Conventional QM**	**Quality 4.0**	**BPM**	**Enhancement Features (via Q4.0 in BPM)**
Focus	Product/service quality	Digital quality + analytics	Process alignment & optimization	Data-driven, adaptive, real-time BPM
Tools/Methods	TQM, Lean, Six Sigma	AI, IoT, Big Data, RPA	Process modeling, reengineering	Predictive analytics, process mining
Approach	Reactive, compliance-based	Proactive, predictive, integrated	Strategic & operational alignment	Continuous improvement, agility
Outcomes	Defect reduction, compliance	Digital innovation, customer experience	Efficiency, effectiveness	Competitiveness, sustainability

Table 3: Conventional QM, Quality 4.0, BPM, and fnhancement features in BPM

The comparative overview demonstrates how conventional quality management, Quality 4.0, and BPM intersect yet differ in focus, tools, and approaches. Highlighting the enhancement features introduced when Q4.0 is integrated into BPM, the Table 3 illustrates the shift from reactive, compliance-based practices to proactive, data-driven, and adaptive process management.

4.2.1. Managerial Implications

The findings of this study have several direct implications for managers seeking to integrate Quality 4.0 into BPM practices:

- Adopt integrated digital strategies: Managers should align BPM initiatives with digital technologies (AI, IoT, automation) to achieve measurable improvements in efficiency and customer experience.
- Invest in workforce reskilling: Continuous training in digital tools and analytics is necessary to reduce resistance and enhance employee adaptability.

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- Measure ROI systematically: Organizations must develop structured approaches for evaluating the impact of digital transformation projects to ensure long-term value creation.

For instance, we examine case examples where Hungarian organizations provide concrete illustrations of these implications in action. OTP Bank and Erste implemented automated self-service ticketing stations across their branches, streamlining customer flow and reducing line-up times, and as a result, freeing staff for higher-value tasks and demonstrating enhanced service efficiency through process automation.

Meanwhile, retailers such as Lidl and Inter-spar across Eastern Europe specifically within Hungary are deploying self-checkout systems to expedite customer transactions and reduce labor costs. For example, in Hungary, Lidl [31] alone had over 1,137 self-checkouts as of January 2025, reflecting an increasing significance in improving operational throughput and customer satisfaction. These measures exemplify how Quality 4.0 technologies, when aligned with BPM, yield tangible improvements in process management and user experience.

4.2.2. Challenges and Limitations.

While the benefits of Quality 4.0 for BPM are widely recognized, several drawbacks and challenges are also evident. Many organizations face difficulties in aligning legacy systems with new digital tools, creating cost and integration burdens. Resistance to change, particularly among employees unaccustomed to digital workflows, often slows implementation. Additionally, the heavy reliance on advanced data analytics and AI introduces concerns around data security, privacy, and ethical governance.

From a strategic perspective, Q4.0 adoption is uneven: large firms tend to lead the transformation, while SMEs encounter resource constraints that hinder participation. Moreover, the rapid pace of technological innovation has sparked debates around the next phase of development, such as Industry 5.0 and Quality 5.0, which emphasize human-centricity, sustainability, and resilience beyond purely technological optimization. Current BPM literature does not yet address these shifts, so it remains an open question how future process management frameworks will evolve.

Concerns regarding integration costs, workforce reskilling, and digital ethics are well-documented in recent reviews, which argue for frameworks that balance technological progress with sustainability and human-centric approaches [3][32].

We note that both the advantages and the limitations underscore the dual reality of Q4.0 in BPM: it is both a transformative enabler of efficiency and innovation, and a source of new challenges that require further theoretical and practical attention.

These results provide a foundation for deeper discussion on how Quality 4.0 can enhance BPM, both in terms of conceptual development and practical application.

Conclusions

This study has explored the role of Quality 4.0 in enhancing Business Process Management, emphasizing how digital transformation redefines traditional quality practices. Through an extensive review of 98

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research papers, we identified key trends, methodologies, and frameworks shaping the integration of Q4.0 into BPM and BPR.

Our findings indicate that Q4.0 does not replace traditional quality management methods (such as Lean, Six Sigma, and Total Quality Management) but enhances them with digital capabilities. Advanced technologies, such as AI, Big Data, and IoT have enabled organizations to shift from reactive to predictive and real-time analytics, thereby improving process efficiency, decision-making, and competitiveness.

Furthermore, the study highlights the increasing role of data-driven decision-making, sustainability, and workforce adaptation in the adoption of Q4.0. Organizations leveraging digital tools can improve customer satisfaction, collaboration, and continuous improvement, all of which are essential to an effective BPM strategy. However, challenges remain, particularly in implementation barriers, organizational change, and developing structured frameworks for integrating Q4.0 into BPM.

In addition to synthesizing existing work, this study contributes novel insights by systematically mapping research attention through bibliometric analysis, identifying underexplored themes such as return on investment (ROI) measurement, SME adoption, and cross-sector integration. Furthermore, it highlights the increasing role of data-driven decision-making, sustainability, and workforce adaptation in Q4.0 adoption. Organizations leveraging digital tools can improve customer satisfaction, collaboration, and continuous improvement, all of which are essential to an effective BPM strategy.

Future research should address these challenges, particularly in developing methodologies that align Q4.0 with existing BPM practices. Additionally, future studies could explore the roles of leadership, employee engagement, and regulatory considerations in shaping the future of digitalized quality management. Emerging discussions on Industry 5.0 and Quality 5.0 also warrant attention, as they highlight the need for more human-centric, sustainable, and resilient approaches that may further redefine BPM in the years ahead[9][20][21].

For managers, the findings suggest that digital transformation initiatives in BPM should be pursued not as isolated technology adoptions but as integrated strategies that combine process redesign, workforce reskilling, and cultural change. Equally, organizations should prioritize measurable outcomes such as improved efficiency, resilience, and customer value creation, to ensure that Quality 4.0 investments yield clear business benefits.

Conflicts of Interests

The authors declare no conflict of interest.

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