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DIGITAL TWINS AS DATA-DRIVEN SUPPORT FOR PERFORMANCE MANAGEMENT IN THE EFQM MODEL: A COMPARATIVE AND THEORETICAL ANALYSIS

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***Keywords**: digital twins, EFQM model, performance management, radar logic*

Abstract: *Digital twins enable real-time monitoring, prediction, simulation, and optimization of physical assets and processes. however, their role in broader organizational performance management remains insufficiently defined. this paper examines how digital twin functionalities can provide data-driven support for performance management within the efqm model. a structured literature-based comparative analysis and qualitative content analysis were applied to studies addressing digital twins, efqm, quality 4.0, key performance indicators, and digital transformation. the findings indicate that digital twins can strongly support the efqm execution and results dimensions through operational monitoring, predictive analysis, and performance measurement, while scenario simulation can also inform direction. an integrative theoretical matrix connects digital twin functionalities with performance indicators, efqm dimensions, radar elements, and managerial decisions. the analysis concludes that digital twins can strengthen evidence-based assessment and continuous improvement but cannot independently evaluate leadership, organizational culture, or stakeholder perceptions.*

DIGITALNI BLIZANCI KAO PODRŠKA ZASNOVANA NA PODACIMA ZA UPRAVLJANJE PERFORMANSAMA U EFQM MODELU: KOMPARATIVNA I TEORIJSKA ANALIZA

***Ključne riječi*:** *digitalni blizanci, EFQM model, upravljanje performansama, RADAR logika*

Sažetak: *Digitalni blizanci omogućavaju praćenje u realnom vremenu, predviđanje, simulaciju i optimizaciju fizičkih resursa i procesa. Međutim, njihova uloga u širem kontekstu upravljanja organizacionim performansama još uvijek nije dovoljno jasno definisana. Ovaj rad ispituje na koji način funkcionalnosti digitalnih blizanaca mogu pružiti podršku zasnovanu na podacima za upravljanje performansama u okviru EFQM modela. Primijenjene su strukturisana komparativna analiza zasnovana na literaturi i kvalitativna analiza sadržaja studija koje se bave*

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digitalnim blizancima, EFQM modelom, kvalitetom 4.0, ključnim pokazateljima performansi i digitalnom transformacijom. Rezultati ukazuju na to da digitalni blizanci mogu značajno podržati dimenzije izvršenja i rezultata EFQM modela kroz operativno praćenje, prediktivnu analizu i mjerenje performansi, dok simulacija scenarija može doprinijeti i procesu usmjeravanja organizacije. Integrativna teorijska matrica povezuje funkcionalnosti digitalnih blizanaca sa pokazateljima performansi, dimenzijama EFQM modela, elementima RADAR logike i menadžerskim odlukama. Analiza pokazuje da digitalni blizanci mogu unaprijediti procjenu zasnovanu na dokazima i kontinuirano poboljšanje, ali ne mogu samostalno procjenjivati liderstvo, organizacionu kulturu niti percepcije zainteresovanih strana.

1. Introduction

Digital transformation has become increasingly important for organizations seeking to improve operational efficiency, quality, adaptability, and long-term competitiveness. Technologies associated with Industry 4.0 enable the collection and analysis of extensive operational data, but their implementation does not automatically result in improved organizational performance. Digital initiatives must be aligned with strategic objectives, performance indicators, and continuous improvement practices to produce sustainable benefits (Haimana & Severin, 2025).

Digital twins represent an important component of data-driven industrial environments. By maintaining a virtual representation of a physical asset, process, or system, a digital twin can support real-time monitoring, predictive analysis, scenario simulation, and process optimization. These capabilities can provide timely information about equipment condition, process deviations, resource consumption, quality, and expected future performance. Previous research has shown that integrating digital twins with established improvement approaches can enhance performance measurement and enable organizations to move from retrospective analysis toward predictive and adaptive decision-making (Mojumder, 2025).

The European Foundation for Quality Management (EFQM) Model provides a comprehensive framework for connecting organizational purpose and strategy with execution and achieved results (Fonseca, 2022). Previous studies have identified relationships between the EFQM Model, Industry 4.0, and Quality 4.0, emphasizing that EFQM can provide a strategic and technologically neutral perspective on digital transformation (Fonseca et al., 2021; Murthy et al., 2022). Other studies have demonstrated the use of EFQM criteria and key performance indicators for monitoring organizational improvement and sustainability performance (Martusewicz et al., 2025; Petrović et al., 2022; Petrović et al., 2023; Severin & Vlad, 2026). However, the specific role of digital twins within EFQM-based performance management remains insufficiently explained.

Existing research predominantly examines digital twins as tools for operational improvement or considers EFQM within the broader context of Industry 4.0 and digital transformation. Therefore, there is a need to clarify how the information generated by digital twins can support performance assessment and continuous improvement within the EFQM Model. Accordingly, this paper addresses the following research question: How can digital twin functionalities provide data-driven support for performance management within the EFQM Model?

The objective of this paper is to analyze the relationships between digital twin functionalities, performance indicators, EFQM dimensions, and RADAR logic through a compara-

tive and theoretical analysis of the relevant literature. The main contribution is an integrative theoretical matrix that connects digital twin outputs with EFQM-based performance assessment and managerial decision-making while also identifying organizational areas that cannot be evaluated using digital twin data alone.

2. Research methodology

This study employed a structured literature-based comparative analysis and qualitative content analysis to examine the relationship between digital twin technology and performance management within the EFQM Model. The research was theoretical in nature and did not involve the development of a digital twin, collection of primary data, or empirical validation of the proposed relationships.

The core comparative sample consisted of six publications addressing complementary aspects of the research problem. The selected studies covered the integration of digital twins with operational improvement methods, the relationship between the EFQM Model and Industry 4.0, the application of EFQM in organizational transformation, Quality 4.0, key performance indicators, and digital frameworks for process improvement. The publications were selected according to their direct relevance to at least two of the following areas: digital twins, EFQM, performance management, Quality 4.0, and digital transformation. The purpose was not to conduct an exhaustive systematic review, but to compare representative approaches and identify the conceptual gap between technology-based performance monitoring and EFQM-based organizational assessment.

The analysis was conducted in three stages. First, each publication was examined according to its research objective, methodology, technological focus, use of performance indicators, principal contribution, and identified limitations. Second, the studies were compared to determine how they addressed digital technologies, operational performance, organizational excellence, and continuous improvement. Finally, the findings were synthesized to identify relationships between digital twin functionalities, generated information, performance indicators, EFQM dimensions, and RADAR elements.

Based on this synthesis, an integrative theoretical matrix was developed. The matrix does not modify the EFQM Model or propose a new digital twin architecture. Instead, it systematizes how digital twin outputs may provide evidence for EFQM-based performance assessment and managerial decision-making, while also identifying performance areas that require additional quantitative or qualitative information.

Digital twins and data-driven performance management

A digital twin can be described as a dynamic virtual representation of a physical asset, process, or system that is continuously updated using data from its physical counterpart (Grieves, 2023). Its operation depends on the integration of sensing devices, communication technologies, data-processing mechanisms, simulation models, and analytical tools. This connection allows the virtual representation to reflect changes in the physical system and provide information that can be used for monitoring, analysis, and decision-making. Unlike static digital models, digital twins are intended to capture system behaviour over time and support responses to changing operating conditions.

Petri et al. (2023) proposed a multilayer digital twin architecture for performance management in construction and industrial assets. The architecture integrates data acquisition, data management, virtual models, and user-oriented decision support. The digital twin can therefore support real-time monitoring, evaluate what-if scenarios, forecast future conditions, and identify operating strategies that improve efficiency, adaptability, and resilience. Although their application focuses on energy management in the built environment, the proposed logic is also relevant to industrial systems in which performance depends on the interaction of equipment, resources, environmental conditions, and operational decisions.

In industrial asset performance management, digital twins combine different models of equipment and processes to provide a more comprehensive representation of asset condition and behaviour. Yusupbekov et al. (2021) emphasized the use of physical, mathematical, and data-based models for evaluating industrial assets and supporting decisions concerning their operation. Relevant operational indicators may include availability, downtime, energy consumption, production rate, maintenance requirements, process stability, and asset efficiency.

However, data-driven performance management depends not only on the availability of operational indicators but also on the reliability of the digital twin that produces them. Psarommatis and May (2023) distinguished between the performance of the represented physical system and the performance of the digital twin itself. They proposed generic indicators covering the accuracy and accuracy variation of DT outputs, response time, and response time variation.

This distinction is important because inaccurate, slow, or inflexible digital twins may generate misleading information even when the selected operational indicators are appropriate. Consequently, digital twin-based performance management should combine system-level indicators with indicators describing the quality of the digital representation. Together, these measures provide a stronger basis for evidence-based decisions by linking the current and expected performance of physical assets with the accuracy, responsiveness, and adaptability of the analytical system used to evaluate them.

Performance Management in the EFQM Model

The EFQM Model is a comprehensive management framework used to assess organizational performance, guide transformation, and support sustainable value creation. Unlike performance management approaches based exclusively on financial or operational indicators, EFQM considers the relationships between organizational purpose, strategy, implementation practices, stakeholder expectations, and achieved results. Its non-prescriptive nature allows organizations to select methods, technologies, and indicators that correspond to their specific context while maintaining a common structure for assessment and continuous improvement (Fonseca et al., 2021; Martusewicz et al., 2024; Mutlu, 2025).

The model is organized into three dimensions: Direction, Execution, and Results. Direction addresses why the organization exists and what it intends to achieve. It includes Purpose, Vision and Strategy, as well as Organizational Culture and Leadership. Performance management within this dimension begins by defining strategic priorities, stakeholder expectations, desired outcomes, and the indicators used to evaluate their achievement.

Execution explains how the organization implements its purpose and strategy. It includes Engaging Stakeholders, Creating Sustainable Value, and Driving Performance and Transformation. This dimension connects strategic objectives with processes, resources, partnerships, improvement initiatives, and operational activities. Therefore, performance management is not limited to measuring final outcomes but also includes monitoring whether organizational approaches are appropriately implemented and adjusted. Martusewicz et al. (2025) demonstrated this relationship through an automotive case in which EFQM principles were connected with sustainability objectives, improvement initiatives, and measurable indicators concerning emissions, water consumption, and recycling.

Results address what the organization has achieved and intends to achieve in the future. The dimension covers Stakeholder Perceptions and Strategic and Operational Performance. Relevant indicators may include financial results, productivity, quality, resource consumption, environmental performance, customer-related outcomes, employee indicators, and progress toward strategic objectives. Severin and Vlad (2026) further demonstrated how key performance indicators can be associated with EFQM criteria, target values, assigned responsibilities, and improvement measures to provide a structured view of organizational progress.

EFQM performance management represents a continuous feedback process rather than a periodic comparison of achieved and planned values. Reliable quantitative indicators are important for assessing strategic and operational performance, while qualitative information remains necessary for evaluating leadership, organizational culture, stakeholder perceptions, and other human-centered aspects of organizational excellence.

Comparative analysis of related studies

The selected studies approach digital performance management from different technological and organizational perspectives. Some focus on the operational capabilities of digital twins, while others examine EFQM, Quality 4.0, sustainability, or broader digital transformation frameworks. Their comparison is presented in Table 1 according to research method, principal focus, treatment of digital twins and EFQM, and main contribution.

Literature source	***Approach***	***Main contribution***	***Limitation for this study***
Mojumder (2025)	Systematic review	Connects DTs with Lean Six Sigma and operational KPIs	Does not consider EFQM
Fonseca et al. (2021)	Literature and content analysis	Connects EFQM with Industry 4.0 and Quality 4.0	Does not examine DTs separately
Martusewicz et al. (2025)	Case study	Demonstrates measurable EFQM-supported sustainability results	DT is not implemented
Haimana and Severin (2025)	Conceptual analysis	Integrates EFQM with quality and risk management	Addresses digital transformation generally
Binci et al. (2024)	Bibliometric review	Identifies trends in Industry 4.0 and quality management	Does not develop an EFQM–DT relationship
Severin and Vlad (2026)	Framework and application	Connects KPIs, processes, and EFQM criteria	Application lacks DT simulation and prediction

Table 1 :*Comparative analysis of the selected studies (Authors)*

Mojumder (2025) links digital twins with Lean Six Sigma and operational performance but does not consider broader organizational criteria. Fonseca et al. (2021) connect EFQM with Industry 4.0, while Binci et al. (2024) identify digital twins as an emerging Quality 4.0 theme; however, neither study examines their specific role within EFQM. Martusewicz et al. (2025) demonstrate measurable EFQM-supported sustainability improvements, whereas Haimana and Severin (2025) integrate EFQM with quality and risk management in digital transformation.

Severin and Vlad (2026) connect EFQM criteria with KPIs through a digital application, but the application does not include the prediction, simulation, or optimization capabilities of a digital twin. Overall, previous studies address DT-based operational improvement, EFQM-enabled transformation, and KPI monitoring separately. They do not systematically connect digital twin outputs with EFQM dimensions and RADAR logic, which represents the research gap addressed in this paper.

3. Theoretical Integration of Digital Twins and the EFQM Model

Digital twins and the EFQM Model have complementary roles in performance management. A digital twin provides operational data, predictions, simulations, and optimization results, while EFQM provides the organizational context in which this information can be interpreted and connected with strategic objectives. The proposed integration therefore follows a data-to-decision process: data from a physical system update its digital representation; the digital twin analyzes current and expected performance; relevant outputs are translated into performance indicators; and these indicators provide evidence for EFQM assessment and improvement activities. The proposed integration process is presented in Figure 1.

Within the Direction dimension, digital twins can support strategic planning by forecasting future conditions, testing alternative scenarios, and estimating whether performance targets are achievable. For example, simulations may indicate the expected effects of changes in capacity, maintenance policies, energy use, or resource allocation. Their role is to provide analytical evidence for decisions established by organizational leadership.

The strongest connection is found in Execution. Real-time monitoring can support process control, while diagnostic functions can identify deviations and their possible causes. Predictive analytics can estimate failures or performance deterioration, and simulation can test improvement alternatives before their physical implementation. These capabilities support the EFQM emphasis on creating sustainable value and driving performance and transformation.

Within Results, digital twins can continuously provide operational indicators such as availability, downtime, cycle time, energy consumption, production rate, process stability, and asset efficiency. Nevertheless, indicators describing stakeholder perceptions, employee satisfaction, leadership, culture, or reputation require additional qualitative and organizational data.

Digital twin outputs can also support RADAR logic. Desired results determine which indicators the digital twin should monitor. Simulation helps evaluate alternative approaches, while real-time data support the monitoring of their deployment. Because EFQM de-

cisions depend on the quality of available evidence, the accuracy, response time, and flexibility of the digital twin should also be evaluated (Psarommatis & May, 2023).

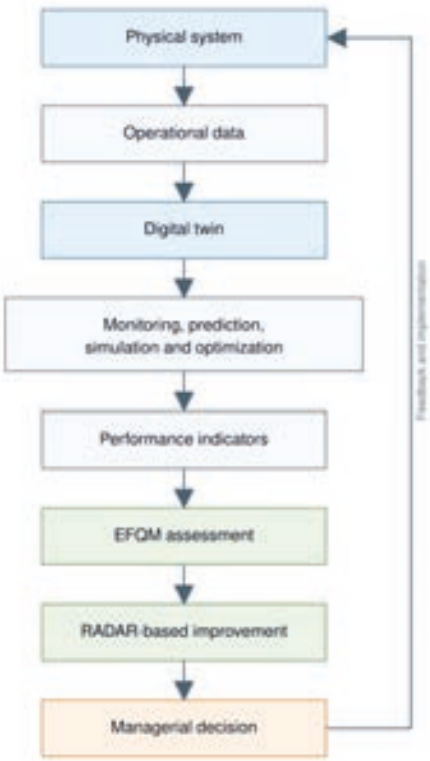

Figure 1: Proposed Integration Process Between Digital Twins and EFQM-Based Performance Management

The relationships between digital twin functionalities, performance indicators, EFQM dimensions, RADAR elements, and supported managerial decisions are summarized in Table 2.

DT functionality	**Example KPI**	**EFQM dimension**	**RADAR element**	**Supported decision**
Real-time monitoring	Availability, downtime, OEE	Execution, Results	Deployment, Assessment	Corrective action
Diagnosis	Defect rate, process variation	Execution	Assessment	Root-cause removal
Prediction	Failure risk, expected downtime	Direction, Results	Results, Assessment	Preventive action

Scenario simulation	Capacity, cycle time, energy use	Direction, Execution	Approach, Refinement	Scenario selection
Optimization	Productivity, efficiency, resource use	Execution	Refinement	Parameter adjustment
DT evaluation	Accuracy, response time, DT-flex	Execution	Assessment	Validation of DT evidence

*Table 2***:** *Theoretical integration of digital twin functionalities and EFQM performance management*

4. Discussion

The proposed integration indicates that digital twins can strengthen EFQM-based performance management by expanding the evidence available for organizational assessment. Their principal contribution lies in replacing exclusively retrospective reporting with continuous monitoring, prediction, and simulation. This allows organizations not only to evaluate achieved performance but also to estimate future conditions and compare possible improvement actions before implementing them in the physical system.

The strongest relationship is identified within the Execution and Results dimensions. Digital twins can directly support process monitoring, resource optimization, predictive maintenance, operational transformation, and the measurement of strategic and operational results. Their contribution to Direction is more limited but still relevant, as forecasts and scenario simulations can support target setting, capacity planning, and the evaluation of strategic alternatives. However, digital twins cannot define organizational purpose, values, leadership priorities, or stakeholder expectations.

The reliability of the integration depends on data quality and the performance of the digital twin itself. Inaccurate sensor data, incomplete system representation, delayed processing, or insufficient model flexibility may lead to unreliable indicators and inappropriate decisions. Therefore, DT accuracy, response time, and flexibility should be evaluated together with the operational performance indicators derived from the physical system.

The analysis also confirms that digital twin data cannot cover the entire EFQM assessment. Operational measures such as downtime, productivity, quality, energy use, and asset efficiency can be monitored directly, whereas organizational culture, employee satisfaction, leadership effectiveness, reputation, and stakeholder perceptions require additional qualitative and organizational information. Digital twin outputs should consequently complement, rather than replace, existing EFQM assessment methods.

The principal limitation of this study is its theoretical nature and the restricted number of publications included in the comparative analysis. The proposed relationships have not been validated within an organization. Future research should therefore examine the integration through industrial case studies, expert evaluation, and longitudinal analysis of EFQM indicators before and after digital twin implementation.

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