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BIBLIOMETRIC ANALYSIS OF DIGITAL TWIN DESIGN FOR SUSTAINABLE DEVELOPMENT AND COOPERATION BETWEEN INDUSTRIAL ENTERPRISES

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ABSTRACT

Designing digital twins of business processes as individual elements to establish cooperative links between enterprises represents a relevant and promising area of research. This approach directly contributes to sustainability goals by enhancing resource efficiency, fostering collaboration, and supporting data-driven decision-making. Bibliometric analysis enables the assessment of the current state of this field and the identification of key directions for its future development, including its alignment with sustainability policies. Notably, the study of designing digital twins of business processes remains underexplored, particularly from the perspective of cross-model design technology. This technology integrates digital twins of different business processes to facilitate real-time interaction and collaboration, optimizing industrial ecosystems for sustainable outcomes. The main objective of this article is to provide a systematic review of the literature on designing digital twins of business processes as individual elements to establish cooperative links between enterprises. The reviewed studies, sourced from Google Scholar, Scopus, and Web of Science, include publications in scientific journals and conference proceedings. Despite advancements, significant discussions and uncertainties persist regarding cross-model engineering technology, particularly concerning the integration platform for digital twins, knowledge schema, cross-model data exchange, and the collaboration framework, all of which have profound implications for sustainable industrial development.

Keywords: business process, cross-model design, sustainability, manufacturing efficiency, process optimization.

INTRODUCTION

Developing a digital twin of a business process involves creating a virtual model of a real business process to analyze, optimize, manage, and automate that process (Al-Sartawi et al., 2024; Eigner et al., 2021; Trauer et al., 2023). In recent years, digital twins have garnered significant attention due to their transformative potential across various industries, including manufacturing, healthcare, energy, journalism, and construction (Banshal et al., 2022; Murphy et al., 2020; V'yunenko et al., 2022; Zhao et al., 2022). The advancement of digital twin technology has unlocked new opportunities for industrial enterprises to establish cooperative relationships and enhance overall productivity (dos Santos et al., 2021; Javaid et al., 2023; Mascher, 2022). By providing a virtual replica of a physical system or process, digital twins facilitate real-time monitoring, modeling, and analysis of complex systems (Qi et al., 2018; Redeker et al., 2021; Ushasukhanya et al., 2024; Wang et al., 2021). This capability allows enterprises to identify bottlenecks, optimize processes, and predict potential failures, thus improving operational efficiency and resilience. Additionally, digital twins contribute to sustainability efforts by enabling resource-efficient operations and proactive risk management.

MATERIAL AND METHODS

This study aims to conduct a bibliometric analysis (Bakır et al., 2022; Borgohain et al., 2024; Donthu et al., 2021; Gouda and Tiwari, 2022; Rashed and Mutis, 2021; Tiwari, 2023) of the design of digital twins of business processes as discrete elements to establish cooperative links between enterprises. Such an approach not only addresses technical and operational challenges but also aligns with broader sustainability goals by fostering collaboration and optimizing resource utilization. The decomposition of a business process into its constituent elements is illustrated in Fig. 1.

Figure 1. Decomposition of business processes by their elements.

Cooperation arises through two main approaches: elements of spontaneous order and hierarchy. The interaction of digital twins of business processes corresponds to a hierarchical approach to cooperation. In this framework, firms are organized within a single group through the market, implementing a unified strategy (Cichon and Roßmann, 2018). Cooperation helps reduce transaction costs, as many transactions are conducted with partners within the group, with whom stable connections have been established via digital twins of business processes (Perez et al., 2021; Qi et al., 2018). Furthermore, as noted by Waclawek et al. (2023), cooperation facilitates the transfer of investments, technologies (including IT), and labor resources, as well as the implementation of joint IT projects and collaborative production activities. Joint coordination and optimization of business processes involve integrating multiple processes across various departments or organizations to achieve shared objectives. Digital twins play a critical role in this process by providing a common virtual platform for collaboration and optimization. Through the creation of a digital twin of a business process, stakeholders can model and analyze various scenarios, identify areas for improvement, and optimize processes in real time. The proposed cross-model engineering technology builds on the concept of digital twin interaction, integrating digital twins of different business processes to enable real-time collaboration and interaction between industrial enterprises. This technology entails the development of a platform that facilitates the interaction of digital twins across enterprises, promoting the seamless exchange of data, knowledge, and resources. The key components of the cross-model engineering technology are illustrated in Fig. 2.

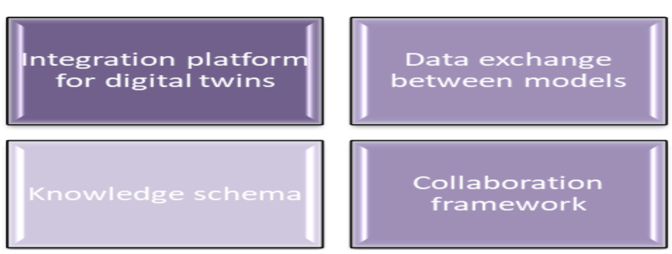

Figure 2. Key components of cross-model engineering technology.

Digital Twin Integration Platform: A cloud-based platform that enables the integration of digital twins from various enterprises, facilitating real-time collaboration and cooperation (Perez et al., 2022).
Cross-Model Data Exchange: A standardized data exchange protocol that ensures seamless data transfer between digital twins from different enterprises.
Knowledge Schema: A structured knowledge schema that captures relationships between different digital twins, enabling the identification of potential areas for collaboration and interaction.
Collaboration Framework: A framework that defines the rules and protocols for collaboration and interaction between industrial enterprises.
Based on the study (Anshari et al., 2022; Augustine, 2020; Cichon and Roßmann, 2018; Galli et al., 2019; Li and Li, 2024; Mascher, 2022; Melesse et al., 2020; Park et al., 2021), the analysis revealed several reasons for adopting digital twins in business processes across various industries:
Technological Limitations: It is not always feasible to deploy all necessary control and measuring devices or sensors, especially under extreme conditions where measuring parameters such as temperature or high pressure is impossible.
Enhanced Data Utilization: Connecting digital twins to embedded sensors allows for the collection and utilization of data for financial analysis and forecasting. This opens up opportunities for additional revenue streams, more accurate predictions, and optimized pricing strategies.
New Monetization Strategies: Industries such as agriculture, transportation, and intelligent commercial building management are exploring new monetization strategies based on the digital twin model (Meierhofer et al., 2021b). For instance, in the petrochemical sector, implementing digital twins during oil and gas production and processing can lead to tripling the raw material base, improving equipment efficiency by 20-30%, reducing unscheduled downtime by 15-20%, increasing oil recovery rates and volumes by 10%, and lowering the specific cost of oil production by 15%.
Another area of focus is the implementation of digital twins for equipment repair (Meierhofer et al., 2021b). This approach is applicable across industries and addresses key challenges, including enhancing the skills of personnel involved in equipment maintenance, providing interactive instructions for repair processes, ensuring strict adherence to repair protocols, and generating electronic reports.
The analysis of scientific papers (Kunath and Winkler, 2018; Meierhofer et al., 2021a; Sytov et al., 2021; Uhlemann et al., 2017) yielded the following conclusions.
There is a growing need to integrate systems and data from all production ecosystems. Creating a digital model encompassing the entire customer lifecycle or supply chain - including both first-tier suppliers and their suppliers—could provide companies with a meso-level view of their processes. However, this approach would require incorporating external entities into the digital ecosystems of internal processes.
Initially developed for the manufacturing industry by Mascher (2022), the concept of a digital twin has since evolved and expanded into other domains. Recent research includes contributions from Afanasiev, Grabchak, Loginov, and Mischeryakov (2021); Stjepandić, Sommer, and Stobrawa (2022); and Loaiza and Cloutier (2022).
Advances in information management and technology have enabled the application of digital twins in the financial sector. The ubiquitous digitalization of products and services into data, as demonstrated by researchers such as Fernando, Ganesh (2022), and Rocha et al. (2021), highlights the importance of this transformation.
Information-intensive industries leverage large volumes of data alongside tools such as artificial intelligence to optimize existing value chains (e.g., product design, service management). These efforts ultimately contribute to the development of comprehensive digital ecosystems (Lu et al., 2021; Meierhofer et al., 2021b).

Methods
The research methodology was designed to provide a clear and systematic approach to collecting, analyzing, and synthesizing information related to the design of digital twins of business processes aimed at establishing cooperative links between industrial enterprises.
A literature review was conducted to identify inaccuracies and gaps in the study of the scientific problem of cross-model cooperation technology. The bibliographic analysis of existing works in this field was carried out in three stages (Farooq, 2023):

- Collecting relevant works: Identifying and compiling relevant literature.
- Filtering relevant works: Screening the collected works for relevance and quality.
- In-depth review and analysis: Conducting a detailed review and analysis of the selected works.

The search was performed using databases such as Google Scholar, Scopus, and Web of Science. Relevant keywords included:

- “business process digital twin design”
- “industrial cooperation”
- “finance digital twin”
- “HR digital twin”
- “project management digital twin”
- “inventory management digital twin”
- “design management digital twin”
- “sales management digital twin”
- “supply chain management digital twin”
- “service management digital twin”
- “business analytics digital twin”

As shown in Figure 3, most of the research in the field of digital twin design for establishing cooperative links focuses on management twins, cooperation, and business process design.

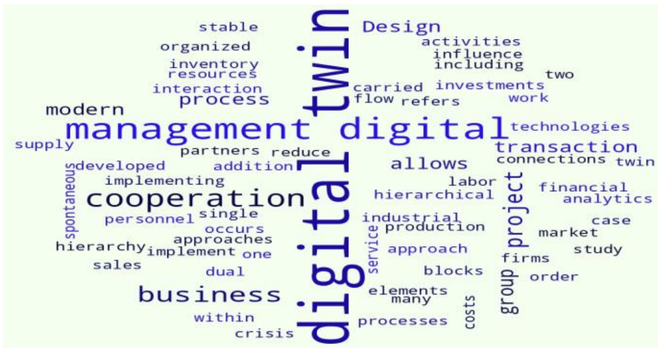

Figure 3. Bibliometric analysis of digital twin design for establishing cooperative relationships.

The search was restricted to articles published in English within the last five years. Relevant review and research articles were carefully selected for detailed analysis. Data related to the design of business processes using digital twins, aimed at establishing cooperation links between enterprises, were collected and systematically presented.

RESULT AND DISCUSSION

This review explores the research question of how digital twins of business processes are designed as integral components and serve to establish cooperative links between industrial enterprises. To address this issue, a conceptual framework is proposed that incorporates the following business process elements: production management, financial accounting and planning, sales management, inventory management, fixed asset management, supply management, service management, design management, logistics, project management, human resource management, and business analytics. The research conducted by Onaji, Tiwari, Soulatiantork, Song, and Tiwari (2022) highlights how the digital twin concept supports the realization of an integrated, flexible, and collaborative manufacturing environment—one of the objectives of the fourth industrial revolution. This work has significantly contributed to advancing the concept of digital twins and considering their role in fostering cooperation. However, the challenge of defining the cooperation structure of industrial enterprises using business process digital twins remains highly relevant.

The cooperation structure of industrial enterprises utilizing business process digital twins can be categorized as follows:

Horizontal Cooperation: Collaboration between different departments within an organization, such as manufacturing, logistics, and purchasing, to optimize business processes.

Vertical Cooperation: Collaboration between organizations within the supply chain, such as suppliers, manufacturers, and distributors, to optimize business processes.

Network Cooperation: Collaboration among multiple organizations across various industries to share best practices, knowledge, and resources.

The industrial collaboration model is structured around the following components:
Digital Twin Platform: A shared virtual platform that enables real-time collaboration and optimization of business processes.
Data Integration: The integration of data from diverse sources, including sensors, ERP systems, and CRM systems, to provide a unified view of the business process.
Analytics and Modeling: Real-time analytics and modeling of business processes to identify areas for improvement and optimize processes.
Collaboration Tools: Tools such as chatbots, video conferencing, and project management software to facilitate communication and collaboration among stakeholders.
The benefits of collaboratively coordinating and optimizing business processes using digital twins include:
Increased Efficiency: Real-time optimization of business processes leads to greater efficiency and cost reduction.
Enhanced Collaboration: Digital twins facilitate seamless collaboration among stakeholders, resulting in better decision-making and improved outcomes.
Increased Agility: Digital twins enable rapid modeling and analysis of various scenarios, allowing organizations to respond quickly to changing market conditions.

The proposed approach for identifying potential links between individual business process activities in mesoeconomic systems involves the following steps:
Activity Mapping: Identifying and mapping individual activities or business functions within a business process.
Dependency Analysis: Analyzing the dependencies between activities, including input-output relationships, resource allocation, and information flows.
Network Analysis: Representing activities and their dependencies as a network to identify clusters, nodes, and bridges.
Link Identification: Identifying potential links between activities based on their dependencies, proximity, and similarity.

The proposed approach categorizes links between individual activities into three types:
Operational Links: Connections between activities that are operationally dependent, such as input-output relationships.
Information Links: Connections involving the exchange of information, such as data sharing or communication.
Resource Links: Connections involving the sharing of resources, such as personnel, equipment, or facilities.
Liezina et al. (2020) presented a comprehensive literature review on digital twins in the supply chain. Three years later, researchers such as W.S. Lam, W.H. Lam, P.F. Lee (2023), Garcia-Buendia, Moyano-Fuentes, Maqueira-Marín, Cobo (2021), Groher, Riss (2023), and Abouzid, Saidi (2023) explored sustainable supply chain management across various domains, including production, design, logistics, procurement, management information systems, quality assurance, safety, social responsibility, financial management, structural management, and advertising.
A notable contribution by Abouzid and Saidi (2023) was the introduction of a new conceptual method for implementing digital twin technology in supply chain processes. However, the issue of relationships in digital twins of supply business processes remains underexplored. Researchers such as Barykin et al. (2021) have also left this area insufficiently addressed.
Focal companies, managing their supply chains through business processes, aim to establish relationships between supply chain entities to effectively track and control the links among participants. This approach ensures seamless coordination and optimization within the supply chain.
Managed links refer to the connections between the business processes of the focal company and the most critical entities that the company prioritizes for integration and management.
Unmanaged links are connections established between the business processes of entities that the focal company fully trusts or whose processes cannot be controlled due to resource limitations.
Tracked links are connections established between the business processes of supply chain participants that do not have direct contact with the business processes of the focal company. These links are particularly significant for maintaining the integrity of the network structure. Tracked links are essential and require continuous monitoring to ensure the system's efficiency and reliability.

CONCLUSIONS

In conclusion, collaborative coordination and optimization of business processes using digital twins offer a promising approach to enhancing the efficiency and effectiveness of industrial enterprises. This study reviewed research published in scientific journals and conference proceedings, drawing from knowledge bases such as Google Scholar, Scopus, and Web of Science. It was observed that significant discussions and uncertainties remain in the field of cross-model design technology, particularly concerning the digital twin integration platform, knowledge schema, data exchange between models, and collaboration structure. Beyond the aspects of designing digital twins of business processes discussed in this paper, we believe that defining the structure and model of collaboration for industrial enterprises is essential. The reviewed works did not fully address the complexity of business processes in mesoeconomic systems, which consist of intricate networks of activities or business functions performed by various stakeholders, including organizations, institutions, and individuals. These activities are often fragmented, and their interdependencies are not always apparent. A lack of visibility into these interdependencies can result in inefficiencies, bottlenecks, and suboptimal performance. We see significant potential for future research in developing a methodology for industrial cooperation based on the cross-model interaction of digital twins of business processes. Furthermore, bibliometric analysis of the literature highlights a promising direction for advancing engineering technology that leverages cross-model interaction of digital twins to establish cooperative links between industrial enterprises, particularly in mitigating risks associated with reduced economic security.

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