Business process modeling and digital twins: a literature review

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Abstract. *Business process modeling is one of the most important steps in managing the lifecycle of a business process. Business process simulation using process simulation tools is a technique used to produce estimates of business process performance and cost structure. A digital twin of a business process is a virtual model used to replicate the behaviour of a real business process. The difference between a digital twin and a business process simulation is that the simulation does not require real-time data, while the digital twin relies on real-time data. This paper is about digital twins of business processes. The achievements of existing research in the field of business process simulation and digital twins are presented. In addition, the limitations of the existing research are investigated.*

Keywords. business process, business process modeling, digital twin, Internet of Things.

1 Introduction

This paper deals with the field of business processes and digital twins and their construction. A digital twin of a business process is a business process that is represented in terms of a virtual representation. The virtual representation of a real entity consists of a physical entity in the real world, a digital twin in program form, and data connecting the two aforementioned elements (TechTarget, 2023). According to Dumas (2021), a digital twin is a model of an object or system that, together with a set of data about events related to the object or system, allows accurate prediction of the performance of the physical object or system over time. The digital twin paradigm is specific to the importance of connecting the digital twin to real-world data sources from the environment and updating the state of the digital twin in real time. Digital twins are among the most important components of the recent Industry 4.0 revolution (Lugaresi & Matta, 2021). Creating digital twins and verifying their performance helps to understand user motivations and provides information and alternative options and suggestions in a form that supports decision-making by the various participants within the system (West et al., 2021). Examples of digital twins, among others, include a digital twin of the product, a digital twin of the production facility, a digital twin of the supply chain, Google Maps, which is a digital twin of the Earth's surface, etc. Modeling the business process and its digital twin includes all steps: from conception and engineering to service delivery, which means that real data about the business process and its activities are obtained as the business process unfolds. Unlike a simulation, a digital twin processes the collected data in real-time and intervenes in the real world through a specific actuator when needed. The advantages of a digital twin of a business process are: monitoring the state of business processes, timely response to unexpected events, shorter product development time, shorter product delivery time, faster product design optimization, product quality improvement, etc.

The purpose of this paper is to examine the results of previous research in the field of business process modeling, business process simulation, and digital twins.

This study aims to address the following research questions: Firstly, what are the identified limitations in previous research? Secondly, in light of these limitations, is there a viable approach to address them effectively?

The article is organized as follows; Chapter 2 explains the methodology used to conduct the study. Chapter 3 presents a literature review that highlights the results of existing research in the field of business process simulation and digital twins. The architecture of the process digital twin is proposed in Chapter 4. Chapter 5 presents the results of existing research in the field of business process modeling and Petri Nets. Chapter 6 identifies the limitations of the previous research. The paper ends with a conclusion in Chapter 7.

2 Methodology

For the purpose of this research, a literature review was conducted in the fields of business process simulation and digital twins. The literature search was conducted using Scopus and Web of Science databases and resulted in 25 scientific papers in total. Out of 25 papers, 12 were included in the in-depth analysis, which were directly related to the research field. The query used to search both databases was:

(("business process simulation" OR "simulation of business processes") AND "digital twin") ALL FIELDS

The search terms were "*simulation of business processes*" and "*digital twin*". All fields in the scientific databases were searched and the entire time period was considered. In this way, the search was not limited to a specific time period or to specific fields in which the research was published. The oldest research was from 2019 and the most recent was from 2023, indicating that this research field is still quite new. To support the research with additional knowledge on business process modeling, additional literature in the fields of simulation modeling and colored Petri nets was searched. The Scopus database was searched, and the search query was:

("business process modeling" AND "graph theory" AND "Coloured Petri net").

All fields of the database and the entire time period were searched. The search resulted in 38 articles, of which 6 were selected for in-depth analysis and deemed most relevant to the research. The following is an overview of the results of previous research.

3 Simulation of business processes and digital twins

This chapter presents the results of previous research in the fields of business process simulation and digital twins. Based on the analysis of the existing literature it will be determined whether there are limitations in the previous research.

The authors Perez, Wassick & Grossmann (2022) conducted research on the application of digital twin and simulation in the supply chain. The authors propose a framework for creating a virtual replica of the business transaction process in the supply chain. The framework consists of three main components: (1) a system identification module used to model the business process in the supply chain, (2) a simulation module to create and run event simulations, and (3) an optimization module to optimize the business processes in the supply chain. The fundamental elements of the proposed digital twin were developed using the Julia programming language.

In the research (Romero et al., 2021), the authors mention the application of digital twin as one of the technologies that companies could use for effective adaptation in the integration of design, engineering, and production processes, using data collected by sensors and similar methods that can create parametric designs based on the business model process. As digital twins are created for more and more products today, advanced simulations and predictive models can be used to proactively identify and correct program and device performance.

Research (Dymitrowski & Mielcarek, 2021) has stated that digital twins can simulate any aspect of a company's operations. For example, digital twins can simulate the operation of a process or device (one or more) based on documentation to eliminate potential errors before a physical device is implemented or built.

The authors (Lugaresi & Matta, 2021) conduct a study using real-time factory data flow for online development of a simulation model of a production system. The authors investigate how model generation works online during the transition phase of establishing a production system. Within production planning and control applications, event simulation can be used as a digital twin of the production system.

Dumas (2021) deals in his work with process prediction through process interventions in real-time. More specifically, how to predict the values of the effects that occur when one or more processes are executed after an intervention in a business process. The research states that the digital twin of a business process has a potential application in the field of process optimization. The purpose of a digital twin of business processes is not so much to capture the business process as it is but to think about the effects of interventions, including interventions that have not been observed before. Research cites two ways to theoretically build a digital twin of a business process: by simulating system dynamics and by using machine learning methods.

Research (West et al., 2021) states that the digital twin adds value and support to the process of real-time operational decision making. Using the examples of 10 use cases, the authors show how digital twins help create value in the business process. Some of these use cases are: tunnel maintenance and repair, wood pattern cutting, factory operational planning and material flow, factory asset management, and server room temperature management and control. Ten use cases in which concepts of the digital twin were applied produced different outcomes. All of the digital twin development concepts were in the early stages, and the digital twins were not yet fully implemented and ready for use. Therefore, a limitation of the study is that the use cases were early concepts of digital twins and not fully developed digital twins, so they are considered only as a representation of extended use case concepts. The research is based on the assumption that in a business context, value is created when a decision is made and a certain action is performed in the system. According to the research results, the support of the digital twin in decision making can be seen at the operational, tactical, and strategic levels.

In their work, the authors (Sumereder & Woitsch, 2022) deal with digitization in the context of digital transformation, using the possibilities of a digital twin. The authors show which digitization principles/patterns are suitable for digital twin organizations and which principles/patterns are suitable for which organizational structure. The paper mentions the difference between a digital shadow and a digital twin. A digital shadow can be a hybrid version of a digital model and a twin, while a digital twin is characterized by automated data flows.

Research (Mallek-Daclin et al., 2022) indicates that the main goal of developing digital twins for a business process is to detect deviations that may appear during runtime. When deviations are detected, the digital twin suggests solutions to the users to help them make a decision, and this decision is considered the most optimal for the product development plan. The digital twin needs to retrieve data from the real system in real time to verify what is happening in the system and to determine what was predicted in the generated product development plan.

The authors (Park & van der Aalst, 2021) propose a framework for integrating the ERP system with business process simulation. The framework consists of three components: the ERP system, the simulation engine, and the transformation engine that converts commands into executions according to which the system updates the model. A simulation model represents reality in a simplified form and creates hypothetical instances of a business process, which enables the simulation of different scenarios. Successful implementation of digital twins of business processes using business process simulation depends on how accurately the simulation model represents reality.

In the research (der Landwehr, Trott & von Viebahn, 2021), the authors propose a framework for providing structural guidance to practitioners and researchers working on evaluating the individual suitability of a computer simulation-based analysis approach and the adoption of a simulation study, particularly a digital twin. The proposed framework provides a holistic view of the benefits, opportunities, limitations, challenges, and characteristics of simulation in general, as well as simulation studies with a focus on digital twins. The authors' goal was to develop an applicable framework for simulation that represents the design artifact of the DSR (Design Science Research) method and addresses structural guidelines for the use of simulation studies and digital twins. The digital twin shows the continuous integration of physical and virtual space before and during system operation with permanent two-way data exchange. A simulation study and a digital twin require a significant amount of data and the ability to analyze the data. A digital twin can only achieve its full functionality if historical, current, and sensor data are integrated.

In research (Meierhofer et al., 2020), the concept of creating additional service value using a digital twin is elaborated. The goal is to design and project services based on the needs of customers, using the potential of the digital twin. The digital twin is based on a combination of data, analytics, and visualization insights to support decision making. Implementing a digital twin requires the development of various elements of simulation models at different levels of granularity, which are then combined. The authors propose a procedure for developing a digital twin that ranges from modeling ecosystem services to integrating technical resources.

In the research paper (Bocciarelli, D'Ambrogio & Panetti, 2023), the authors present a model-driven method for automated development of digital twins of real business processes. The proposed method uses data from IoT sensors to automatically reconfigure the simulation model so that the digital twin is continuously coherent and aligned with its real-world counterpart. The paper proposes a framework to support development and analysis based on simulation of business processes informed by the operation of IoT devices. The scientific contributions of the research lie in: (1) an IoT (Internet of Things) metamodel that provides a flexible and coherent description of the entities of the IoT system, which consists of network sensors; (2) a methodology that illustrates how the framework uses the UML language and BPMN to effectively support the development and analysis of IoT-aware business processes; (3) an architecture that describes the proposed framework in the context of its components and the capabilities it provides.

Table 1. Business features associated with the DT

Key insights into the business features associated with the digital twin (DT)	**Authors and Publication year**
Business process intervention.	Dumas, 2021.
Manufacturing system.	Lugaresi & Matta, 2021.
Decision-making, use case.	West et al., 2021.
Supply chain.	Perez, Wassick, & Grossmann, 2022.
Production management systems.	Romero et. al., 2021.
Business Model Innovation (BMI), literature analysis, empirical research conducted in companies.	Dymitrowski & Mielcarek, 2021.

Business process modeling, process discovering, product development plan.	Mallek-Daclin et al., 2022
Digital transformation.	Sumereder & Woitsch, 2022; der Landwehr, Trott & von Viebahn, 2021.
Ecosystems.	Sumereder & Woitsch, 2022; Meierhofer et al., 2020.
Simulation.	Park & van der Aalst, 2021; Landwehr, Trott & von Viebahn, 2021; Meierhofer et al., 2020; Bocciarelli,D'Ambrogio & Panetti, 2023.

Table 1 highlights the key aspects of business features that previous research has connected with the digital twin paradigm. Most of the previous research connects the usage of the digital twin to manufacturing systems, simulation, digital transformation, and ecosystems. It was also noted that authors of previous research emphasized the importance of the digital twin for operational decision making. Some authors have conducted research using use cases, which is considered a good way to demonstrate a proposed framework or methodology. Overall, the contribution of the digital twin in business can be seen in the context of business interventions, timely responses, product delivery, supply chain, and production systems.

4 The architecture of process digital twin

This chapter proposes the architecture of the process digital twin. The proposal is based on the literature (Bocciarelli, D'Ambrogio & Panetti, 2023) and Figure 1 shows the architecture of the process digital twin.

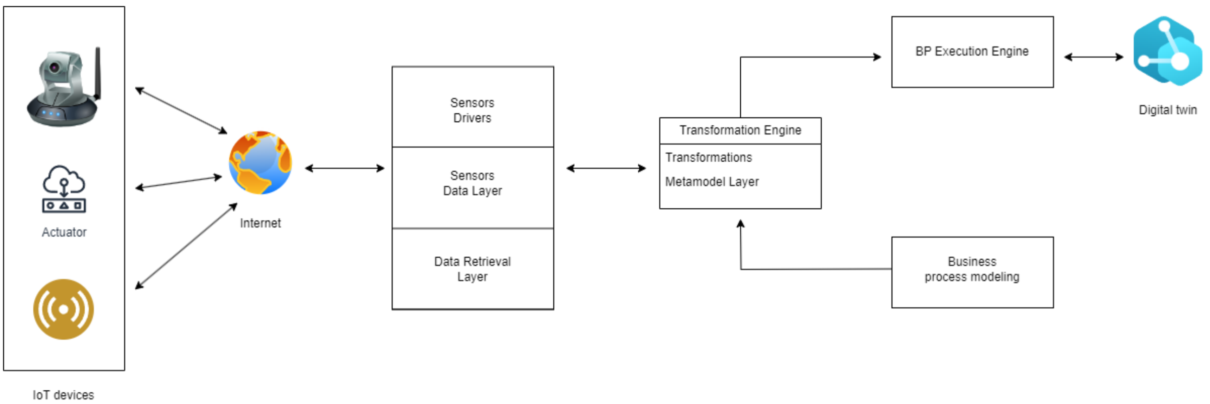

Figure 1. The architecture of process digital twin

The architecture of the process digital twin consists of IoT devices, Internet, Sensor Drivers, Sensors Data Layer, Data Retrieval Layer, Transformation Engine, Business process Execution Engine, Business process modeling, and digital twin model. Business process modeling provides a visual environment for specifying IoT-enabled business process and monitoring its execution. Business process Execution Engine executes the business process, and it is responsible for constructing the digital twin model and its maintenance. Transformation Engine implements the model-to-text transformations to produce an executable process description tailored to the adopted business process execution engine. It contains the transformation layer that provides model-to-text transformations, and the metamodel layer that provides an implementation of the IoT-BPMN metamodel. Sensors Drivers and Sensors Data Layer are the components “whose implementation is supported by the IoTBPMN-to-Sensor model-to-text transformation. Specifically, they provide the implementation of device-specific drivers and data models” (Bocciarelli, D'Ambrogio & Panetti, 2023). Data Retrieval Layer is responsible for updating the digital twin model with the data collected by the sensors that define the actual state of the real environment.

5 Business Process Modeling and Petri Nets

According to (Wang, Zhang & Shi, 2007), the goal of business process management is to improve and optimize existing business processes, and for this purpose, it works closely with other scientific methodologies. Petri nets methodology is used to model elements in a business process in which several participants are involved. Petri nets were invented by Carl Adam Petri in 1962. They have been widely used in the field of systems analysis and design for decades. “A Petri net in its basic form is called a place/transition net, or PTN, and is a directed bi-partite graph with nodes consisting of places (drawn as ellipses) and transitions (drawn as rectangles). The state of a Petri net is called a marking and consists of a distribution of tokens (drawn as black dots) positioned on the places. The execution of a Petri net (also called the ‘token game’) consists of occurrences of enabled transitions removing tokens from input places and adding tokens to output places, as described by integer arc weights, thereby changing the current state (marking) of the Petri net” (Jensen & Kristensen, 2009).

Petri nets can be used to analyze the structural and dynamical properties of the system through rigorous mathematical analysis and visualize computer simulations (ElMansouri et al., 2009). The authors (Yun & Zhang, 2011) state that flexible and hierarchical business processes cannot be well modeled using an "ordinary" Petri net due to its limited modeling capabilities. Considering the limitations of "ordinary" Petri nets, colored Petri nets with a hierarchical structure are proposed for modeling business processes. Colored Petri nets are an event modeling language that combines the capabilities of Petri nets with a high-level programming language (Mukhlash et al., 2018; ElMansouri et al., 2009). In colored Petri nets, each place has a type, and each token has a value (color) corresponding to the place type. The color is used to distinguish tokens (Mukhlash et al., 2018). Tokens contain data associated with them (ElMansouri et al., 2009). Since a business process can be divided into different levels of subprocesses, the model can also be divided into corresponding levels of subnets called pages. Models of colored Petri nets can be structured into pages (Yun & Zhang, 2011).

Petri nets are widely used to simulate and evaluate the execution of different types of processes and are very effective (Cartelli, Di Modica & Tomarchio, 2015). In research (Ou-Yang & Lin, 2008), a framework is developed to analyze the feasibility of the BPMN business model under Petri net conditions. The goal is to bridge the gap between BPMN and Petri nets so that the developed business model can be transferred to the Petri net model. The result is that the constructed BPMN business model can be interpreted by business people and its feasibility can be simulated and analyzed by experts who understand Petri nets. The authors propose an approach to bridge the gap between the BPMN business model and Petri nets through the use of XML. XML is a recognized standard for integrating various technologies in a Web-based environment (Ou-Yang & Lin, 2008).

In (Mukhlash et al., 2018), the business process of production systems was analyzed using colored Petri nets. First, the researchers collected data from the event log and created a model of Petri nets. Then, they analyzed the model to check compliance, availability, and bottlenecks. After that, they converted the model into colored Petri nets. In the end, they made a conclusion about the business process based on the results of the analysis and simulation.

6 Limitations of the existing research

In their research, the authors (Bocciarelli, D’Ambrogio & Panetti, 2023) state that their methodology makes no assumptions about the availability of IoT BPMN modeling tools. There is no information in the research about data collection by network sensors. In addition, most of the previous research does not address the feedback that the digital twin sends back to the reactor to change the performance of the activity when unexpected events occur. Therefore, the question is how the digital twin communicates with external devices and whether it even sends feedback message about the performance of business processes to make a decision in real-time.

The study (Perez, Wassick & Grossmann, 2022) states that digital twin models were generated using historical data from databases and updated in real-time using live process data. The study does not explain exactly how the digital twin models are updated using "live process data", and questions arise about the data content, where it comes from, and how it is communicated to the digital twin. Also, if the digital twin model is generated based on historical data, is that data still “real-time” at the time of go-live?

In studies (Lugaresi & Matta, 2021; Park & van der Aalst, 2021), the concept of the digital twin is equated with simulation, which is not quite correct, because a digital twin is not a simulation, since its implementation requires more advanced conditions and its creation is more complex. The simulated business process model does not require real-time data, and the business process simulation is not updated in real-time but is executed in order to observe the past behavior of the business process without indicating possible changes. A digital twin uses data in real-time, updates its performance in real-time using data it reads from external devices and sensors, and is a more advanced form of digital twin when machine learning is incorporated into its implementation. The idea of machine learning is that the digital twin model is updated according to the amount of data collected during its execution and forms a dataset on which artificial intelligence (AI) can be trained, enabling it to communicate with the digital twin in terms of adjusting execution based on its behavioral patterns.

Upon comprehensive evaluation of the existing literature, it became apparent that the research conducted thus far does not sufficiently encompass the structural transition to the digital twin.

7 Conclusion

A digital twin is a tool that supports decision making by translating possible options into a business context and helping to identify the consequences of different decisions. A process digital twin is a virtual representation or replica of a physical industrial process or system. It combines real-time data, advanced analytics, and simulation models to mimic and simulate the behavior of the actual process. Process digital twin captures and models the process's behavior, dynamics, and characteristics. The concept of process digital twins is revolutionizing the way industrial processes are monitored, controlled, and optimized. Organizations can gain valuable insights, improve efficiency, and make informed decisions to drive operational excellence by creating virtual replicas that closely mirror physical processes.

It is a matter of when to create a process digital twin because limitations can arise if a process digital twin is created too early in terms of insufficient or incomplete data. It is important to enrich the business process with a digital twin and execute it in real time. This allows for more realistic modeling of reality, and the non-deterministic behavior of the system can be made more adaptive. This paper presents the results of previous research in the field of business processes, digital twins, and colored Petri nets. A process digital twin architecture is also proposed, and the limitations of previous research are identified.

Acknowledgment

This work is supported by the Croatian Science Foundation under the project IP-2019-04-4864.

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