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SYSTEMATIC REVIEW

Digital twin modeling: A comparison of current approaches

[version 1; peer review: 1 approved, 1 approved with reservations, 2 not approved]

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Abstract

Background

The implementation of digital twins is of growing importance due to increasing interest. Various procedural models are used or are currently being developed in theory and practice. However, there is no generally accepted model. The aim of the present study is to record and analyze existing models and from the perspective of deriving development trends.

Method

In the first step, a systematic literature search is carried out; in the second step, the results are subjected to a comparative analysis.

Results

The study provides an overview of common process models for implementing Digital Twins. Fifteen approaches were selected for a detailed analysis. 1/3 are hybrid process models (i.e. a combination of several models), sequential and evolutionary models still dominate, and the phase length is between 5 – 10 phases. In other words, the majority of the existing process models analysed surprisingly follow a more sequential approach.

Discussion

Process models with a sequential character - with and without accompanying project management - dominate, but hybrid approaches are increasing in importance: (a) on the one hand as an integrated project management component, i.e. a combination of agile and classic project management, since these meet the digital twin requirements in terms of hardware (= rather classic approach),

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software (= more agile approach) and data management; (b) on the other hand, the merging or mutual supplementation of existing data science approaches - such as data mining with CRISP-DM - with the above project management approaches is to be expected.

Keywords
Digital Twin, Implementation, Modeling, Comparison



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Introduction

Companies in general and production companies in particular are affected by digitalization. You have to create products or services and hire digital talents (Sommer, 2023b) that meet the changing conditions. The term Industry 4.0 represents the upheaval, especially in the area of production. Another term is increasingly appearing in the context of the above discussion, that of the digital twin (Industry 4.0 and the Digital Twin, n.d.). Both terms express comprehensive challenges in the present and future, with DT representing a new facet - especially in the sense of medium-sized companies.

Industry 4.0. can be defined as follows: "Screws communicating with assembly robots, self-driving forklifts stocking high shelves with goods, intelligent machines coordinating independently-running production processes – people, machines, and products are directly connected with each other: the fourth industrial revolution has begun" (plattform-i40, n.d.). Different terms such as ".. smart manufacturing", digital transformation, and fourth industrial revolution" should not be included in the study as they contribute to confusion (Culot *et al.*, 2020). The implementation of Industry 4.0 can be seen, among other things, in the increase in digital processes in everyday production (Follath *et al.*, 2022). In other words, the fourth industrial revolution has broad consequences for companies, for example a manager from Autodesk Germany, a global technology provider for design and manufacturing, comes to the following conclusion:

> Until now, the technologies, platforms and skills required to implement and use the principles of Industry 4.0 have been reserved for those companies that had the necessary global presence to bear the costs of testing the relevant technologies. Now it's important to make this accessible to manufacturing companies of all kinds, regardless of size and budget. But as the world looks forward to this development, the continued triumph of technologies such as artificial intelligence (AI), IoT, analytics, robotics and 3D printing are already opening up new possibilities that suggest the dawn of another industrial revolution. (Lodhia, 2022)

Lodhia (2022), as Director of Autodesk Germany, refers in his assessment to the developing discussion about the topic of "Industry 5.0". In contrast to Industry 4.0, this new revolution can be defined as follows: "If Industry 4.0 is about digitally connecting machines to enable a seamless flow of data and the highest possible optimization, Industry 5.0 is believed to bring humans back into the game for collaboration and introduce the human touch to manufactured products while simultaneously focusing on sustainable manufacturing" (Raja Santhi & Muthuswamy, 2023). Core principles of Industry 5.0 are: (a) Human-centricity; (b) Sustainability; (c) Resilience (Industry 5.0, n.d.).

In addition to the term industrial revolution, the term digital twin is also repeatedly mentioned in the context of the digitalization of production. In principle, this is not a completely new concept, but rather a concept with rapidly growing interest (Qi *et al.*, 2021). From a scientific perspective, this concept can be defined as follows: "… digital twins have three main elements: a physical artifact, a digital counterpart, and the connection that binds the two together. The connection is the exchange of data, information, and knowledge between the physical and virtual counterparts, enabled by the development of advanced sensing .., internet of things .., high-speed networking, and advanced analytics ... technologies" (Sacks *et al.*, 2020). An alternative definition - from a practical perspective - is provided by SAP's definition approach: "A digital twin is a virtual model of a physical product, process, or service whereby sensors utilizing Industry 4.0 technologies (artificial intelligence, Internet of Things, and big data) provide real-time conditions, diagnostics, and predictions through data analysis. As many put it, it's the linkage between the physical and digital worlds" (SAP Digital Twin Archives, n.d.). In summary, it can be stated that the terminology shows a high level of coverage in theory and practice. Digital twins can be further subdivided based on the following criteria, among others: type, architecture and use case. Table 1 provides an overview (Verdouw *et al.*, 2021)

The following classification is particularly relevant for the production-related area: (a) Product Digital Twin; (b) Process

Table 1. Types of Digital Twins.

Types	Description
Imaginary Digital Twin	"A conceptual entity that depicts an object that does not yet exist in real-life"
Monitoring Digital Twin	"A digital representation of the actual state, behaviour and trajectory of a real-life physical object"
Predictive Digital Twin	"A digital projection of the future states and behaviour of physical objects using predictive analytics, such as statistical forecasting, simulation and machine learning methods"
Prescriptive Digital Twin	"A smart digital object that adds intelligence for recommending corrective and preventive actions on the real-life objects usually based on optimization algorithms and expert heuristics"
Autonomous Digital Twin	"Operates autonomously and fully controls the behaviour of real-life objects without on-site or remote intervention by humans"
Recollection Digital Twin	"Maintains the complete history of the physical object, which no longer exists in real-life"

Note. Based on Verdouw *et al.* (2021)

Digital Twins; (c) Operation Digital Twins (Bao *et al.*, 2019). The implementation is a challenge, especially for medium-sized companies. There are different approaches to the architecture, shown in Table 2:

In terms of use cases, the variety is also high. This ranges from the automotive sector, to production and smart cities, to healthcare (Singh *et al.*, 2022).

Based on the above, the question now arises as to what connection exists between Industry 4.0 / 5.0 and digital twins? Here we can again draw on the statements by Lodhia (2022), according to which the feasibility of Industry 5.0 exists, among other things, when the modern platforms and resources are able to communicate with each other and thus enable effective collaboration between humans and computers, which means means companies need to develop even further. In his view, manufacturing companies will be exposed to the following trends in the next decade, in which digital twins play a relevant role (Lodhia, 2022):

- Trend A "Product life cycle - planning and simulation": Feedback loops between the phases of production are assumed, which explains, among other things, the need for digital twins. Networked phases in production are expected that exchange information, learn and optimize. Industry 5.0 will produce systems that allow for dependencies and enable optimization in real time. In other words, product development is becoming faster and systems are becoming more complex.

- Trend B "New Internet – networking of digital twins": Digital twins are, among other things, an expression of more comprehensive communication between systems and people or devices. It is assumed that a network will be created or required for this that operates in parallel to the existing Internet.

- Trend C "Collaboration – people and machines thanks to further developed AI": Machines are able to learn and work together with people. Artificial intelligence is currently experiencing high acceptance in the production sector. This form of intelligent and networked work promotes automation in production, which, among other things, increasingly enables the individualization of products.

- Trend D "Manufacturing-as-a-Service": Customers are increasingly being involved in production in such a way that they have products made to order. This can range from the color of the product to the dimensions. In other words, customers can, if necessary, send orders directly to production and thus trigger an order, virtually at the push of a button.

- Trend E "Adaptation and speed - tailor-made products": Short delivery times and the individualization of products are becoming increasingly important from the customer's perspective. This could have a significant impact on the systems and machines required, as well as the distribution or sale of the products to be produced. However, an important prerequisite for implementation is meeting the requirements in the Industry 4.0 environment. There are still relevant deficits in large and especially medium-sized companies.

Table 2. Selected Architectures and Frameworks.

Architecture / Framework	Year	Source
C2PS: A Digital Twin Architecture Reference Model for the Cloud-Based Cyber-Physical Systems	2017	(Alam & El Saddik, 2017)
An architecture of an Intelligent Digital Twin in a Cyber-Physical Production System	2019	(Talkhestani *et al.*, 2019)
Digital twin-driven product design framework	2019	(Tao *et al.*, 2019)
An application framework of digital twin and its case study	2019	(Zheng *et al.*, 2019)
Six-layer digital twin architecture	2020	(Redelinghuys *et al.*, 2020)
Generic Digital Twin Architecture for Industrial Energy Systems	2020	(Steindl *et al.*, 2020)
A digital-twin visualized architecture for Flexible Manufacturing System	2021	(Fan *et al.*, 2021)
A Distributed Digital Twin Architecture for Shop Floor Monitoring Based on Edge-Cloud Collaboration	2021	(Ouahabi *et al.*, 2021)
Digital Twin as a Service (DTaaS) in Industry 4.0: An Architecture Reference Model	2021	(Aheleroff *et al.*, 2021)
Use Case Scenarios for Digital Twin Implementation Based on ISO 23247	2021	(Shao, 2021)
Digital Twin—Cyber Replica of Physical Things: Architecture, Applications and Future Research Directions	2022	(Qian *et al.*, 2022)
A Novel Digital Twin Architecture with Similarity-Based Hybrid Modeling for Supporting Dependable Disaster Management Systems	2022	(Yun *et al.*, 2022)
The Development of a Digital Twin Framework for an Industrial Robotic Drilling Process	2022	(Farhadi *et al.*, 2022)

The explanations suggest that there could be a relevant connection between Industry 4.0 / 5.0 and digital twins, which is confirmed, among other things, by literature research (Lv, 2023, p. 1):

- "Equipment is the infrastructure of industrial scenarios, and the embedded intelligent upgrade for equipment is a Digital Twins primary condition"
- "Digital Twins can provide automated real-time process analysis between connected machines and data sources, speeding up error detection and correction"
- "Digital Twins can bring obvious efficiency improvements and cost reductions to industrial manufacturing"
- "Digital Twins reflects its potential application value and subsequent potential value in Industry 5.0 through the prospect"

The results make it clear that digital twins play or will play an important function in the context of Industry 4.0 and 5.0. Current studies come to the conclusion that, on the one hand, digital twins act as "enablers of cyber-physical systems to a product lifecycle data integration and processing platform" (Stjepandić *et al.*, 2022), but on the other hand their implementation in companies represents a challenge (Melesse *et al.*, 2020). In other words, there are extensive studies on potential areas of application, architecture and types of digital twins (Singh *et al.*, 2022); implementation in the sense of implementation as a project is obviously still a challenge. The authors Follath *et al.* (2022) to the realization that, on the one hand, the delimitation of the definitions of digital twins, especially in the areas of production and logistics, has not yet been sufficiently clarified and, on the other hand, there is still no generally accepted procedural model for implementation (Follath *et al.*, 2022). From this, the authors derive the following requirements for such a model: "The process model helps to classify which use cases a digital twin can be developed for, which steps must be taken during implementation, and provides an overview of the requirements and complexity during development" (Follath *et al.*, 2022). Scharch (2016) defines the term process model in the context of software development as "...form of a development scheme... (synonymous with process strategy, development approach)..." with the function of presenting the development process as a model.

Theoretical foundations

An important question in connection with digital twins and process models is whether they can be reduced to process models in the sense of software development. If you look at current publications, you will notice that the complexity of the digital twin also affects the complexity of the process models and their implementation. The real and virtual space of a digital twin requires not only an isolated process model for software development, but possibly additional process models with reference to the physical world as well as the data world. The challenge in this context is particularly the required interaction and management of the individual process models. The following Figure 1 uses a simple fictitious example to illustrate the different types of process models that could occur:

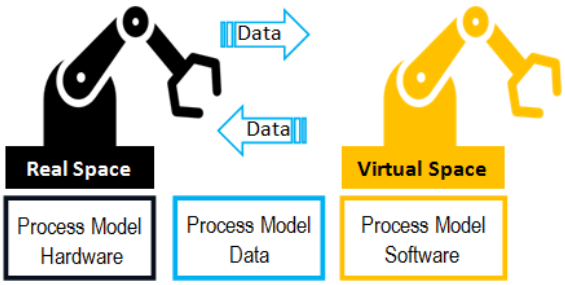

Figure 1. Interaction of the models. Note. Description if the interaction between the models, modified version according to Tao *et al.* (2019).

In practice, the challenge of handling these different types of process models is solved, among other things, via so-called program management or program manager (Null *et al.*, 2019), which is defined here as follows: "Program management combines several projects that are linked to one another are dependent. In this case, all projects serve to achieve an overarching goal. According to our definition, a program is, in short, a main project with many sub-projects" (Strasser & Schmidt-Sibeth, 2023). Consequently, on the one hand, the diversity of the relevant procedural models when implementing digital twins and, on the other hand, their handling via program management must be taken into account. As part of the work, a distinction will be made between four types of process models, which will be presented in the next chapter: (1) Process Model - Hardware; (2) Process Model - Data; (3) Process Model - Software; (4) Process Model – Various.

Process Models - Software

The software development life cycle (SDLC) deals with the creation of software and uses, among others, the following common process models: "… Incremental model, Prototype model, Spiral model, Iterative model, Waterfall model, V-model, RAD mode and Agile model… " (Kyeremeh, 2019).

The definition by Ebert (2014), the process models of software development can be divided into four model families (Ebert, 2014, as cited in Scharch, 2016):

- Sequential models are characterized by a separation into phases that are processed and completed one after the other in a top-down process. As part of this study, these models will include the classic "waterfall model with and without setbacks" (Scharch, 2016) and the "V-Shaped Model" as a variant of the waterfall model with integrated verification and validation of the product/order in relation to the fulfillment of customer requirements. In the "Parallel Model" the phases are processed in parallel, such as in simultaneous engineering (Scharch, 2016).
- Evolutionary models are used when the requirements are not precisely defined at the start of the project. In the context of this work, these include the "Spiral Model", which provides the option of planned jumps back to the individual phases of the classic waterfall

model (= recursive character) as well as the "Rational Unified Process" – RUP Model – with an iterative or incremental character (Scharch, 2016).

- Prototyping model (= creation of a usable preliminary version of the product), has the goal of carrying out an early evaluation or revision of a prototype in the interests of the customer (Scharch, 2016). This model is a subset of the Evolutionary Model.

- Agile Models have the ability to respond quickly to changes in the environment/customers. "SCRUM" as a model is based on phased planning (= sprint), whereby the theoretical basis is the agile framework according to the agile manifesto. "Extreme Programming" (XP) attempts to implement ideas in an early phase of the project via prototype (Scharch, 2016).

The above model families should be supplemented by the "hybrid model" as a further form of process models:

- Hybrid models are characterized by a combination of two or more models. What counts here are, among other things, combinations of traditional and agile approaches (Copola Azenha *et al.*, 2021)

Furthermore, another model family is to be introduced:

- Various models, which covers all models that cannot be assigned to the above model families

This results in an adaptation of the approach of Ebert (2014) regarding the characterization of process models (Ebert, 2014, as cited in Scharch, 2016), on the one hand in the sense of supplementing hybrid models and on the other hand in re-evaluating the areas of application of agile Models (= dashed line) that can be used especially in the area of "unstable conditions and high customer influence" as shown in Figure 2:

In total, six model families can be derived within the framework of this work: (1) Sequential Model; (2) Evolutionary Model; (3) prototyping model; (4) Agile Model; (5) Hybrid model; (6) Other models. If a specific process model is chosen for software development, the methods and tools are also

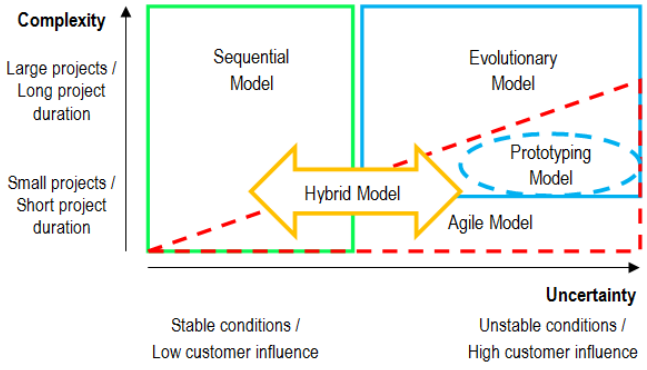

Figure 2. Overview – Process Models. Note. Modified overview according to Ebert (2014), cited in Scharch (2016).

defined (Scharch, 2016, p.6). In the context of this work, following this logic, we will always talk about process models with assigned methods and tools.

The question still arises as to whether there is a need for research regarding process models for software development for digital twins. This question can be answered positively, as various authors, including Follath *et al.* (2022), Schweigert-Recksiek *et al.* (2020), Johansson *et al.* (2022), Reinhart *et al.* (2019) and Wu *et al.* (2021) are working or have worked on the development of their own process models.

Process Models - Data

There are various procedural models with regard to data mining. These include, among others, the classic approaches (Rotondo & Quilligan, 2020):

- "Knowledge Discovery in Databases" (KDD)

- "Cross Industry Standard Process for Data Mining" (CRISP-DM) and its more agile data mining variant "ASUM-DM" (Angée *et al.*, 2018)

- "Sampling - Exploring - Modifying - Modeling - Assessing" (SEMMA)

These models have been supplemented by new or modified models, such as Microsoft's "Team Data Science Process" (TDSP), which can be defined as follows: ... "is a flexible, iterative data science methodology for the efficient delivery of predictive analytics solutions and intelligent applications" (Microsoft, 2023). Another procedural model is "DASC-PM", which is particularly concerned with the process of data science projects and the necessary skills (Schulz *et al.*, 2020).

Since the "data" and "software" process models partly follow similar principles, the above models should also be assigned to the following model families (Scharch, 2016): (1) Sequential Model; (2) Evolutionary Model; (3) prototyping model; (4) Agile Model; (5) Hybrid model; (6) Various approaches.

Process Models - Hardware

This process model is about process models that are required when implementing the digital twin with regard to production technology (e.g. the implementation of actuators or sensors). The following models can be used for this:

- "Lean Manufacturing", "Six Sigma" or "Lean Six Sigma" (= DMAIC cycle) as relevant models, even in the age of Industry 4.0 (Antony *et al.*, 2022)

- "Design for Six Sigma", if the focus is on a product (= less the process) as a digital twin (Psarommatis, 2021)

- "Business process management" (BPM) aims to map processes that are not physical in nature. These are used to digitally map the process in order to then show, for example, resource bottlenecks, incorrect process execution or other waste (BOC Group, 2023; GBTEC Software AG, 2023)

- "Total Quality Management" (Asana, n.d.)
- "Theory of Inventive Problem Solving" (TRIZ) as an innovation approach for technological products and processes (Li *et al.*, 2017; Sojka & Lepšík, 2020)
- "ISO – Standards" (ISO.Org, 2023)

Since the "hardware" and "software" process models also have similarities, the above models should also apply here: (1) Sequential Model; (2) Evolutionary Model; (3) prototyping model; (4) Agile Model; (5) Hybrid model; (6) Various approaches. Models that cannot be assigned to the above three model types are assigned here. The topic of model families is treated analogously to the other model types.

Research Question and Hypotheses

In summary, it can be stated that there are comprehensive studies (Singh *et al.*, 2021a) on types, areas of application (Singh *et al.*, 2022) and the architecture of digital twins, but the number of studies in relation is still limited to the methodical implementation of the implementation of digital twins in the sense of a step-by-step guide. This leads to questions, including which methods or tools should be suitable components of such a process model, e.g. data mining process methods (Rotondo & Quilligan, 2020), process improvement tools (Sojka & Lepšík, 2020) or hybrid approaches (Gemino *et al.*, 2021). Which methods or tools are currently used? What trends are emerging for the future?

Due to the complexity and diversity of the topic, there is a focus on process models for product or process digital twins in the sense of the Reference Architecture ISO 23247 (Shao, 2021) or comparable - ideally with a production reference - which are suitable for the implementation of digital twins are. The subject of research is therefore the question (RQ) about existing process models, their analysis or comparison as well as the derivation of ideas for modified process models:

> RQ1: What model approaches are the current process models for implementing digital twins based on?
>
> RQ2: What are the differences between the current process models for implementing digital twins?

Taking into account the research questions, the state of science and the focus on production-related use cases, the following hypotheses H can be derived:

> H1: The majority of the examined process models for implementing digital twins are based on sequential model families.
>
> H2: The majority of the examined process models for implementing digital twins are based on the phase model of classic project management.

Method

The study is based on a shortened systematic literature search according to Nordhausen and Hirt (2022), whereby search strings were not used. The following structure of the study was chosen (Nordhausen & Hirt, 2022), presented in Table 3:

The investigation is structured as follows:

> Step 1: Carrying out a literature search and analysis of the process models found with regard to the assignment to different model families, such as Sequential Model, Evolutionary Model, Prototyping Model, Agile Model or Hybrid Model
>
> Step 2: Comparative consideration of the process models in relation to the phases

Results

Carrying out Literature Research - Process Models

In order to derive different profiles for process models, the first step was to search for existing process models (PM), and the second step was to analyze the profile. The consideration was based on the following criteria: (a) name of the model; (b) brief description of the model; (c) assignment to the different types of process models (e.g. software); (d) Assignment of the process models to the defined "families", e.g. sequential models. It should be noted at this point that assumptions had to be made about family membership as the available

Table 3. Overview - Systematic Literature Search.

Step-by-Step Approach - Systematic Literature Research	Implementation of the Procedure - Systematic Literature Research
1. Establishing the research principle	A sensitive principle was chosen that allows as many hits as possible to the question.
2. Determination of search components	Digital twin, production, manufacturing, logistics
3. Establishing databases	DBIS, e-library, EZB, Scopus, Web of Science, Google Scholar, EBSCO, ProQuest, DOAJ, BASE
4. Determination of keywords	Project Management, Framework, Process Model, Design, Management, Planning, Implementation, Methodology, Practical Guide, Hands On, Method
5. Conducting the research	Implementation according to steps 1 – 4
6. Documentation of results	Implementation of the documentation

Note. Description of the research structure according to Nordhausen & Hirt (2022)

information was not always clear; (e) number of phases; (f) Mention of the title with reference to the source. The literature search provided the following results, summarised in Table 4:

Table 4. Overview – Selected Process Models.

Profil of the Process Model (PM)
Example I. • PM - Title: Digital Twin-Driven Product Design (DTPD) • PM - Description: A model with various methodologies/tools • PM - Type: Diverse – New approach • PM - Family: Sequential model – where the order can be changed and individual steps can take place in parallel (Tao *et al.*, 2019), which may indicate a "waterfall model or parallel model with few setbacks". • PM - Phases: 7x • PM - Source: **"**Digital Twin-Driven Product Design (DTPD) Framework" (Tao *et al.*, 2019)
Example II. • PM - Title: No title • PM - Description: A model with recommendations for the use of different models in the respective phases • PM - Type: Hard- and Software • PM - Family: Hybrid model approach - sequential model as a roadmap (= e.g. waterfall or parallel model with few setbacks), combined with evolutionary and agile models (e.g. SCRUM, Scaled Agile Framework - SAFe) in individual phases, e.g. in scaling (Reinhart *et al.*, 2019) • PM - Phases: 5x • PM - Source: **"**Digital twin - basics, fields of application and implementation strategies" (Reinhart *et al.*, 2019)
Example III. • PM - Title: No title • PM - Description: A model with some recommendations for methodologies / tools • PM - Type: Software • PM - Family: Sequential model with "Interdependence of Building steps" (Ariansyah *et al.*, 2020). It can probably be assumed that this is a "waterfall or parallel model with few setbacks". • PM - Phases: 8x • PM - Source: **"**Digital Twin Development: A Step by Step Guideline" (Ariansyah *et al.*, 2020)
Example IV. • PM - Title: DT Lifecycle • PM - Description: A model with detailed requirements for implementation • PM - Type: Hard- and Software • PM - Family: Presumably an evolutionary model with many regressions, including a prototyping model • PM - Phases: 10x • PM - Source: **"**A Requirements Driven Digital Twin Framework: Specification and Opportunities" (Moyne *et al.*, 2020)
Example V. • PM - Title: Integrated Five-Dimensional Framework & TRIZ Functional Model • PM - Description: Integrated model, insists on Five-Dimensional Framework and TRIZ • PM - Type: Hard- and Software • PM - Family: Hybrid model approach – sequential model (= five-dimensional framework) with elements of an evolutionary model (= various jumps back), combined with the TRIZ model • PM - Phases: 5x • PM - Source: **"**Conceptual digital twin modeling based on an integrated five dimensional framework and TRIZ function model" (Wu *et al.*, 2021)
Example VI. • PM - Title: The FA^{3}St Approach • PM - Description: A model with various methodologies/tools • PM - Type: Hard- and Software • PM - Family: Evolutionary model with many regressions; it is probably a "spiral model" or "prototyping model" • PM - Phases: 6x • PM - Source: "Methodology and Tools for Digital Twin Management - The FA3ST Approach" (Stojanovic *et al.*, 2021)

Profil of the Process Model (PM)
Example VII. • PM - Title: Five-Dimension Digital Twin Model • PM - Description: A model with various methodologies / tools, consisting of five dimensions for the implementation of a digital twin: Physical World - Virtual Model - Data Management - Services - Connections • PM - Type: Hard- and Software as well as Data • PM - Family: Sequential model • PM - Phases: 5x • PM - Source: "Enabling technologies and tools for digital twin" (Qi *et al.*, 2021)
Example VIII. • PM - Title: Digital Twin – ISO 23247 • PM - Description: A model with various methodologies/tools • PM - Type: Hard- and Software • PM - Family: Sequential model in the sense of a "waterfall model with few setbacks" • PM - Phases: 5x • PM - Source: "ISO 23247 Part 1 – 4, Software Development Life Cycle – Traditional" (Shao, 2021)
Example IX. • PM - Title: No title • PM - Description: A model with various sub-models • PM - Type: Hard- and Software as well as Data • PM - Family: Hybrid model approach - mix of sequential, evolutionary and agile models • PM - Phases: 5x • PM - Source: "Building Industrial Digital Twins: Design, develop, and deploy digital twin solutions for real-world industries using Azure Digital Twins" (Nath *et al.*, 2021)
Example X. • PM - Title: No title • PM - Description: A model based on the CRISP-DM approach • PM - Type: Data and Software • PM - Family: Evolutionary model with many possible regressions; it is probably a "spiral model" or "prototyping model" • PM - Phases: 6x • PM - Source: "A process model for the creation of digital twins for production and logistics" (Follath *et al.*, 2022)
Example XI. • PM - Title: No title • PM - Description: A model based on ISO 21500:2012 • PM - Type: Data and Software • PM - Family: Hybrid model approach - sequential model, based on a "waterfall model with rare regresses" or "parallel model" or evolutionary model in the sense of a "spiral model / prototyping model with many regresses" • PM - Phases: 5x • PM - Source: "D4.3 Digital Twin Supported Lean Project Planning, Control and Risk Management" (Johansson *et al.*, 2022)
Example XII. • PM - Title: No title • PM - Description: A model based on the CRISP-DM approach • PM - Type: Hardware and Data • PM - Family: Evolutionary model with many possible regressions; it is probably a "spiral model" or "prototyping model" • PM - Phases: 7x • PM - Source: "Process Model for the Data-driven Identification of Machine Function Usage for the Reduction of Machine Variants" (Wagenmann *et al.*, 2022)

Profil of the Process Model (PM)
Example XIII. • PM - Title: Small-Scale Digital Twin Implementation Framework • PM - Description: A model with various methodologies/tools • PM - Type: Hardware and Data • PM - Family: Sequential model, based on a "waterfall model or parallel model with rare jumps" • PM - Phases: 7x • PM - Source: "Proposing a Small-Scale Digital Twin Implementation Framework for Manufacturing from a Systems Perspective" (Loaiza *et al.*, 2023)
Example XIV. • PM - Title: No title • PM - Description: A model with various technologies or methodologies/tools • PM - Type: Hardware and Data • PM - Family: Sequential model, based on a "waterfall model or parallel model with rare jumps" • PM - Phases: 5x • PM - Source: "Digital Twin: Technology Evolution Stages and Implementation Layers with Technology Elements" (Jeong *et al.*, 2022)
Example XV. • PM - Title: No title • PM - Description: A model with various methodologies/tools • PM - Type: Hard- and Software • PM - Family: Hybrid model approach - Based on a sequential model (= "waterfall model with rare regresses" or "parallel model") or evolutionary model in the sense of a "spiral model / prototyping model with many regresses" • PM - Phases: 7x • PM - Source: "Advancing digital twin implementation: a toolbox for modelling and simulation" (Singh *et al.*, 2021b)

Note. Description of 15x selected Process Models

The above list of selected process models does not claim to be complete, but it does provide initial results with regard to the methods or tools used: (a) The process models often consist of a combination of several models; (b) The majority of procedure models for hardware and software are presented; (c) sequential and evolutionary models with more or fewer regressions or their combination dominate; (d) The number of phases ranges from 5 – 10 phases; (e) The models are generally not older than 4 years; (f) The boundary between architecture and process model is partially undefined; (g) Project management approaches are partly integrated into the process model.

The following Table 5 provides an overview of the assignment of the process models to model families and in particular the role of the hybrid process models, although it must be pointed out again that in some cases clear information regarding the assignment was missing and therefore certain assumptions had to be made.

Overall, it can be stated that the hybrid process models in the narrower sense (= agile with traditional) or broader sense (= non-agile with traditional) make up around 1/3 of all models. This result is interesting in that it confirms a trend that is also visible in the comparison between agile and classic project management (Pepino *et al.*, 2021). In other words, for complex tasks with many people or partners involved and customer requirements that are generally difficult to predict, as is typically the case for the implementation of digital twins, hybrid approaches seem to be an important option.

Comparative Consideration - Process Models

In the second step, the above process models were examined in detail in relation to the process steps, i.e. the individual process steps were presented and examined according to patterns.

To summarise, the following main finding - based on Table 6a to Table 6e - were obtained: For examples II, III, IV, VI, IX, X, XI and XII, phases were discovered that can be found in a similar form in almost all the examples analysed. These phases included:

- Define / Initiating Phase: This phase includes necessary project preparations and measures for the project start, such as goal definition or situation analysis. Here, the above examples mostly show clear similarities, visible from the terms used, such as "define, preparation, identify, operational understanding, initiating or situation analysis".

- Design / Development / Planning Phase: Almost all examples are also characterized by the fact that they go through a design or development phase or both, recognizable by the terms "design, development, modeling, planning".

- Use / Scaling / Implementation Phase: Some models explicitly refer to the implementation phase.

- Controlling / Review or Validation Phase: The majority of models go through this phase, which can be recognized

Table 5. Overview - Assignment of the different models.

Process Model	Model Families according to Ebert (2014)				Hybrid Model
	Sequential Model	Evolutionary*) Model	Agile Model	Other Models	
Example I.	▲				NO
Example II.	●	●	●		YES
Example III.	▲				NO
Example IV.		▲			NO
Example V.	●	●		●	YES
Example VI.		▲			NO
Example VII.	▲				NO
Example VIII.	▲				NO
Example IX.	●	●	●		YES
Example X.		▲			NO
Example XI.	●	●			YES
Example XII.		▲			NO
Example XIII.	▲				NO
Example XIV.	▲				NO
Example XV.	●	●			YES
TOTAL	**11x**	**9x**	**2x**	**1x**	**5x**

Legend: *) incl. Prototyping Model; ▲ Single Model; ● Hybrid Model

Note. Assignment of different models according to the approach of Ebert (2014)

Table 6a. Overview – Process Steps of each selected model.

Example I.	Example II.	Example III.
Step 1: Create Virtual Product	Step 1: Preparation (Vison/Team/Approach/Ressources)	Step 1: Define the requirements
Step 2: Analyze, Integrate and visualize data	Step 2: Design (Understanding/Idea/Prototyp/Validation)	Step 2: Develop the information flow
Step 3: Simulate behaviours	Step 3: Review (Business Plan/ Decision)	Step 3: Build the virtual representation
Step 4: Control behaviours	Step 4: Scaling (Traditional / Agiles Project Management)	Step 4: Develop the data exchange system
Step 5: Communicate with virtual product	Step 5: Controlling (Monitoring / Learning)	Step 5: Carry out analysis
Step 6: Measure data		Step 6: Develop actions
Step 7: Use of the framework of digital twin-driven product design (DTPD) for design activities		Step 7: Verify
		Step 8: Validate
Source: (Tao *et al.*, 2019)	Source: (Reinhart *et al.*, 2019)	Source: (Moyne *et al.*, 2020)

Table 6b. Overview – Process Steps of each selected Model.

Example IV.	Example V.	Example VI.
Step 1: Envision	Step 1: "Perform a function analysis to identify and decompose the digital twin's functions"	Step 1: Identify
Step 2: Design	Step 2: "Classify functions into corresponding modules of the five-dimensional framework"	Step 2: Model
Step 3: Develop	Step 3: "Construct the expanded TRIZ function model of the PE as the basis for the conceptual model"	Step 3: Develop (Configure/Deploy/Verify)
Step 4: Verify	Step 4: "The VE completes the data analysis to generate corresponding instructions and optimize the PE's operation"	Step 4: Share
Step 5: Validate	Step 5: "Embody users in the conceptual model"	Step 5: Use
Step 6: Deploy		Step 6: Validate
Step 7: Use		
Step 8: Evaluate	Source: (Wu *et al.*, 2021)	Source: (Stojanovic *et al.*, 2021)
Step 9: Maintain		
Step 10: Tune / Rebuild		
Source: (Moyne *et al.*, 2020)		

Table 6c. Overview – Process Steps of each selected Model.

Example VII.	Example VIII.	Example IX.
Step 1: Tools for cognizing & controlling physical world	Step 1: "Select standards & technologies for data collection"	Step 1: Pre-Project
Step 2: Tools for digital twin modeling	Step 2: "Select standards & technologies for data control"	Step 2: Project Scoping
Step 3: Tools for digital twin data management	Step 3: "Select standards & technologies for communication between DCDCE and CE"	Step 3: Project Design / Development
Step 4: Tools for digital twin service applications	Step 4: "Select standards & technologies for digital representation"	Step 4: Project Validation
Step 5: Tools for connections in digital twin	Step 5: "Select standards & technologies for for communication between digital twins and users"	Step 5: Project Scaling
Source: (Qi *et al.*, 2021)	Source: (Shao, 2021)	Source: (Nath *et al.*, 2021)

Table 6d. Overview – Process Steps of each selected Model.

Example X.	Example XI.	Example XII.
Step 1: Operational understanding	Step 1: Initiating	Step 1: Situation Analysis
Step 2: System understanding	Step 2: Planning	Step 2: Problem Containment
Step 3: System preparation	Step 3: Implementing	Step 3: Alternative Solutions
Step 4: Modeling	Step 4: Controlling	Step 4: Selection of Solutions
Step 5: Evaluation	Step 5: Closing	Step 5: Consequences Analysis
Step 6: Application		Step 6: Make Decision and Realization
		Step 7: Recapitulate and Learn
Source: (Follath *et al.*, 2022)	Source: (Johansson *et al.*, 2022)	Source: (Wagenmann *et al.*, 2022)

Table 6e. Overview – Process Steps of each selected Model.

Example XIII.	Example XIV.	Example XV.
Step 1: "Define what processes, products, or system to twin in the virtual space"	Step 1: "Digital virtualization: digital representation and objectification process"	Step 1: "Cross-integration of multiple models to accurately simulate dynamic behaviors of a physical twin"
Step 2: "Install perception devices such as sensors, actuators, tags, and readers in the physical layer"	Step 2: "Digital twin synchronization: real-time mutual synchronization between real-world and virtual-world components"	Step 2: "Execution of DT model in "what-if" scenarios to facilitate forecasting, maintenance and risk assessment"
Step 3: "Create a database management system that give access to different type of databases"	Step 3: "Modeling and simulation: analyzing and predicting the real world"	Step 3: "Evolution of DT model over time, along with the physical twin"
Step 4: "Enable a digital thread that connects different types of data, devices, and systems"	Step 4: "Federated digital twin: interworking for mutual federation and collaboration between digital twins"	Step 4: "Reduction of model computation time and maintenance of model complexity"
Step 5: "Install a digital twin software that shows digital twin models and data and enables user's operation"	Step 5: "Intelligent digital twin services: Managing digital twin service lifecycle"	Step 5: "Integration and control of real-time data"
Step 6: "Create digital twin models with their properties in the DT software"		Step 6: "Calculation level of uncertainty in computed results and acquired data"
Step 7: "Enable digital twin functionalities such as feeding data to DT models"		Step 7: "Validation and verification (V & V) of DT model"
Source: (Loaiza *et al.*, 2023)	Source: (Jeong *et al.*, 2022)	Source: (Singh *et al.*, 2021b)

by the terms "Controlling, Review, Validation, Validate, Evaluation".

- Closing / Lessons Leaned Phase: In the majority of models, the permanent implementation of the developed digital twin including lessons learned - combined with the completion of the project - also takes place in this phase. This can be seen in the terms "closing, maintain, application, recapitulate and learn".

The five phases mentioned above in Table 7 represent a kind of intersection for the above examples II, III, IV, VI, IX, X, XI and XII. What is striking about these phases is that they can be found in a similar form in the Principles of Project Management, i.e. classic project management (Wysocki, 2007).

Although no pattern could be identified in the phases for Examples V., VII. and VIII., the similarity in terms of the procedure was striking. In these examples, the focus of consideration was on the use of suitable tools/technologies for the respective phases.

Examples I., XIII., XIV. and XV. could not be assigned to any of the above groups. What is characteristic of this group is that they describe the step-by-step implementation process, detached from a project management approach.

Discussion

Hypothesis Testing

If you look at the examined process models for digital twins, the following conclusions can be drawn from the hypotheses:

- Hypothesis 1 was based on the assumption that sequential procedural models predominate. The results show that different model families are used. Sequential models represent the largest proportion of models (= sum of single and hybrid models), followed by evolutionary models. Hybrid model approaches as mixed forms appear in 1/3 of the models. Overall, Hypothesis 1 can therefore be confirmed.
- Hypothesis 2 dealt with the question of whether the phase model of classic project management can be found in the majority of the process models examined. In this regard, it can be stated that in 8 of 15 models a large proportion of the relevant phases were actually recognizable, in the remaining 7 models this was negative, i.e. here too only a brief confirmation of hypothesis 2. For the 7 deviating models it can be seen that whose process models are either strongly oriented towards the implementation of the architecture of digital twins or on the connection between the process model and the tools/methods that can be used. In other words, the project management approach is not an essential part of the latter models.

Implications

The results allow the following conclusions to be drawn in practice:

(a) The examined process models for digital twins were mostly based on the phases of classic project management, some with a sequential character, which does not necessarily do justice to the complex challenges; (b) Evolutionary process models

Table 7. Comparison of the Approaches – Implementation Process vs Project Management.

Process Model	According to Wysocki (2007)	5 Phases - Intersection
Phase 1	Defining	Define / Initiating
Phase 2	Planning	Design / Develop / Planning
Phase 3	Launching	Use / Scaling / Implementation
Phase 4	Monitoring and Controlling	Controlling / Review / Validation
Phase 5	Closing	Closing / Lessons Leaned

Note: Similarities between classic Project Management and the analysed Process Model Approaches

are a useful extension of the sequential model approach, but should be supplemented by agile project management with the appropriate method kit (e.g. Scurm, SAFe), since digital twin projects are usually larger projects with many project participants that require a supporting project management methodology. Evolutionary process models alone - without a suitable method kit - are not enough here; (c) Hybrid project management approaches as part of the process model - in the sense of combining classic and agile project management - could represent a useful addition, as these approaches offer more flexibility in terms of the requirements for the individual implementation steps. Agile approaches are often preferred in programming, whereas classic project management approaches still dominate in technology. Both areas are usually the subject of the development of digital twins, which suggests a compromise; (d) Hybrid models are not only reduced to agile and traditional approaches, the combination of other process models, such as the CRISP-DM approach for data management with a Lean Six Sigma approach for project management, could also seem sensible (Schäfer *et al.*, 2018). The same applies to the combination of innovation approaches such as TRIZ with a process model for digital twins (Sojka & Lepšík, 2020); (e) Various process models lack the project management approach, e.g. Examples I., XIII., XIV. and XV. offer a flowchart - often based on the architecture of the digital twin - for the implementation of the digital twin. Such approaches should – if necessary and sensible – be supplemented by a project management approach; (f) Other process models, such as Examples V., VII. and VIII., focus on providing a toolbox that provides suitable tools and methodologies. These approaches are helpful because they already provide tools but should also be complemented by a project management approach; (g) Artificial intelligence approaches are still underused, although simple tools to support them are already available (Sommer, 2023a).

Limitation

However, the results of the study also show that the development of models is not yet complete and that the process models presented therefore only reflect the current interim status of development. It should also be noted that process models and project management approaches of the authors analysed were sometimes - consciously or unconsciously - combined with each other, which may lead to a lack of clarity in the results of this study. Further investigations are required in order to analyse the dynamic further development of the process models and to eliminate possible inaccuracies.

Conclusion and outlook

The fifteen process models examined document, on the one hand, that the implementation of digital twins based on suitable process models is an important topic in practice, but on the other hand, the discussion is still open about what such a process model looks like. With increasing interest in digital twins, the need for suitable process models is expected to grow steadily. Process models with a sequential character - with and without accompanying project management - dominate, but hybrid approaches are increasing in importance: (a) on the one hand as an integrated project management component, i.e. a combination of agile and classic project management, since these meet the digital twin requirements in terms of hardware (= rather classic approach), software (= more agile approach) and data management; (b) on the other hand as a combination of different models, such as CRISP-DM approach for data management with a lean approach for implementation in production.

The focus of further investigation should be the collection of empirical data regarding the success of the various model approaches in practice.

Data availability

Underlying data

All data underlying the results are available as part of the article and no additional source data are required.

Reporting guidelines

Figshare: PRISMA checklist for '*Digital twin modeling: A comparison of current approaches*', https://doi.org/10.6084/m9.figshare.24530518.v1 (Sommer, 2023c).

Data are available under the terms of the Creative Commons Attribution 4.0 International license (CC-BY 4.0).

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Summary: The report offers a summary of the many process models that are commonly used for the implementation of digital twins.

Recommendations with "Acceptance for indexing":

1. I feel the introduction section can be further elaborated with newer works with limitations and challenges. Also, I recommend some related research work:
   - A, Niaz MU *et al.* (2021[1]).
   - MU, Shoukat *et al.* (2021[2]).
   - Shoukat *et al.* (2023[3]).
2. It's better to use abbreviations for repeated words, such as digital twin (DT).

3 .For easy understanding, use more pictures.

References

1. A, Niaz MU, Shoukat Y, Jia S, et al.: Autonomous Driving Test Method Based on Digital Twin: A Survey. *https://ieeexplore.ieee.org/document/9628341*. 2021. Publisher Full Text
2. MU, Shoukat S, Yu S, Shi Y, et al.: Evaluate the Connected Autonomous Vehicles Infrastructure using Digital Twin Model Based on Cyber-Physical Combination of Intelligent Network. *https://ieeexplore.ieee.org/document/9661190*. 2021. Publisher Full Text
3. Shoukat M, Yan L, Zhang J, Cheng Y, et al.: Smart home for enhanced healthcare: exploring human machine interface oriented digital twin model. *Multimedia Tools and Applications*. 2023; **83** (11): 31297-31315 Publisher Full Text

Are the rationale for, and objectives of, the Systematic Review clearly stated?

Yes

Are sufficient details of the methods and analysis provided to allow replication by others?

Yes

Is the statistical analysis and its interpretation appropriate?
Yes

Are the conclusions drawn adequately supported by the results presented in the review?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Digital twin, autonomous vehicle, and brain computer interface.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 08 May 2024

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Yu Zheng
Institute of Intelligent Manufacturing and Information Engineering, Shanghai Jiao Tong University, Shanghai, China

This paper compares current approaches to digital twin modeling, emphasizing the increasing importance of digital twins in various industries. It conducts a systematic literature review to analyze existing models, highlighting common process models and their characteristics. The discussion explores the dominance of sequential process models and the emerging significance of hybrid approaches. The study also addresses the connection between digital twins and Industry 4.0/5.0, outlining key trends and challenges. Overall, it provides valuable insights into the landscape of digital twin implementation and identifies areas for future research and development.

Suggestions：

1. The abstract lacks specific details about the comparative analysis methodology and findings. Provide more information on the criteria used for selecting and comparing the models, as well as the key findings of the analysis.
2. The introduction provides a comprehensive overview of Industry 4.0/5.0 and digital twins, but it could be more concise. Streamline the introduction by focusing on essential concepts and omitting redundant information.
3. Terminology such as "Industry 5.0" and "digital twin" is defined but could benefit from clearer contextualization. Provide more contextual examples or case studies to illustrate the practical implications of these concepts in various industries.
4. The discussion on process models lacks depth in addressing potential challenges and limitations. Expand the discussion to include critical analysis of the strengths and

weaknesses of different process models, considering factors such as scalability, adaptability, and resource requirements.

5. The classification of process models could be presented more systematically to enhance clarity. Organize the classification of process models into a structured framework, possibly using tables or diagrams to illustrate the relationships between different model families.
6. The section on theoretical foundations could benefit from clearer delineation of the linkages between digital twins and existing process models. Provide more explicit explanations of how different types of process models apply to the development and implementation of digital twins, with concrete examples or case studies.
7. The discussion on process models for hardware implementation is relatively brief compared to other sections. Expand the coverage of hardware-related process models, considering their importance in enabling the physical instantiation of digital twins in manufacturing and other domains.
8. The paper could discuss the implications of digital twin modeling for specific industries or applications in more detail. Include case studies or examples illustrating how different process models are applied in real-world scenarios across diverse industry sectors.
9. The conclusion could provide a more nuanced synthesis of the key insights and implications derived from the comparative analysis. Summarize the main findings of the study and offer recommendations for future research directions or practical implementation strategies based on these findings.
10. The paper could benefit from a clearer delineation of its contribution to the existing literature on digital twin modeling. Explicitly state the novelty or unique insights offered by the study in comparison to previous research in the field, highlighting its contributions to advancing theoretical understanding or practical applications of digital twins.
11. Ensure consistency between the abstract and conclusion by harmonizing the messaging and emphasizing the same core insights and recommendations.
12. The paper could explore the implications of emerging technologies (e.g., AI, IoT) on digital twin modeling in more detail. Discuss how advancements in AI, IoT, and other technologies are shaping the evolution of digital twin modeling approaches, including their potential to address existing challenges or enable new capabilities.
13. The discussion on the challenges of implementing digital twins could be expanded to encompass broader issues such as data security, privacy, and interoperability. Broaden the scope of the discussion to include a more comprehensive analysis of the technical, organizational, and regulatory challenges associated with digital twin implementation, with insights into potential mitigation strategies.
14. The paper should clarify the specific research questions or objectives guiding the comparative analysis of digital twin modeling approaches. Explicitly state the research questions or objectives at the outset of the paper to provide readers with a clear understanding of the study's purpose and scope.
15. The paper could incorporate more critical reflections on the implications of digital twin modeling for socio-economic factors such as job displacement and inequality. Consider integrating a broader socio-economic perspective into the discussion to address potential implications of digital twin adoption for employment patterns, skill requirements, and societal equity.
16. The methodology section lacks detail on how the literature search and comparative analysis were conducted. Including specific search criteria and analysis methods would enhance the rigor of the study.

Are the rationale for, and objectives of, the Systematic Review clearly stated?
No

Are sufficient details of the methods and analysis provided to allow replication by others?
Partly

Is the statistical analysis and its interpretation appropriate?
Partly

Are the conclusions drawn adequately supported by the results presented in the review?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Digital twin, LLM, Data mining

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Reviewer Report 07 May 2024

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Marco Picone
Universita degli Studi di Modena e Reggio Emilia, Modena, Emilia-Romagna, Italy

The submitted research is appealing and interesting with a good timing and associated to a relevant topic for the community.

However according to me there are some main issues that should be addressed the author:

- There are sections that represent the core of the contribution that are quite small and where the discussion can be extended significantly. For example: Method, and Discussion while on the other hand the Introduction seems quite long with different subsection. According to me a reshape, re-organisation and extension of the paper in required

- Even if the author considered several interesting references, there are some relevant contribution from Roberto Minerva, Paolo Bellavista, Andreas Wortmann that I believe might be definitely relevant in the discussion. For example there have been different contribution related to Digital Twin Modeling and also Software Engineering that can be relevant to be mentioned in this work.

- Furthermore, activities coming from Standardization Bodies and Consortium such as ETSI, ISO and the Digital Twin Consortium are worth of investigation and detailed mentioning in the work

Are the rationale for, and objectives of, the Systematic Review clearly stated?
Yes

Are sufficient details of the methods and analysis provided to allow replication by others?
Partly

Is the statistical analysis and its interpretation appropriate?
Not applicable

Are the conclusions drawn adequately supported by the results presented in the review?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Digital Twins, Internet of Things, Distributed Systems

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 03 May 2024

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Daniella Tola
Aalborg University, Aalborg, Denmark

From my understanding, the study has chosen 15 different papers which use a methodology to develop Digital Twins (DTs), and categorizes these models into hybrid (consisting of at least two different models types) or one of the models types: sequential, evolutionary, agile, and other models. The importance of choosing these specific categories is not clearly detailed, but merely introduced by refering to a single book.
I believe the research is interesting, however, there are multiple areas in which I believe this research must be improved before it can be approved as a scientifically peer-reviewed article.

Major issues:
- Greatly reduce the number of text that is directly copy-pasted from other articles (even though they are cited).

- The hypotheses of the study seem a bit forced, and with no evidence or reasoning of why these specific hypotheses have been chosen.

- Maybe I missed this while reading, but I can't seem to find the reason why it was relevant to choose papers that have between 5-10 phases. Why is this specific number of phases interesting to look at?

- The limitations should also explain that the number of articles studied (15) is a constraint itself. And also add more detail on how these specific articles were chosen, maybe it is clear for others, but I didn't feel convinced when reading this article.

Minor issues:
- There is no reason to have such a long introduction that explains Industry 4.0 and 5.0 in detail. I believe the readers would benefit more from an explanation of what exactly a DT is and what is the difference between a process model and procedural model (as you mention both in the abstract).

- I would personally use a more well-accepted definition of a DT; e.g., the one by Michael Grieves or the one defined in the ISO 23247 on DTs.
The definition of a digital twin in the context of manufacturing from ISO 23247-1 definition 3.2.3 is: *"fit for purpose digital representation of an observable manufacturing element with synchronization between the element and its digital representation*." The definition you provided is from an article I hadn't ran into yet.

Minor details on writing:

Abstract
Background
Although I do think it is implicit, I would probably add that these are procedural models for developing DTs. And maybe also specify exactly which part of a DT, i.e., just the model of the system (assuming it's a system).

When you say 'model', do you mean a 'replica' of a system, or a methodology?
I think this should be made clear.

'The present study': I would probably just call it 'this study' to avoid any confusion.

'.. from the perspective of deriving..': replace with 'derive' - makes the sentence concise

Method
As a reader I would probably be interested in how many papers/books/etc were read and analyzed, and if you followed a specific process for analysis.

Results
In the Background you write 'procedure models' and now you write 'process models'. Is there are difference in this case, or are you talking about the same thing?

'Fifteen approaches were selected..': If there is room, it may make sense to briefly explain why these specific approaches were selected.

'5-10 phases': What is a phase defined as? The reader does not know what this is yet.

The last sentence '... analysed surprisingly follow...': Why is this a surprise?

Discussion
The last sentence is a bit confusing. I'm not entirely sure what you are trying to say.

... such as data mining with CRISP-DM: maybe put this in parentheses as well, if you think it is necessary to include in the abstract, and consider introducing what CRISP-DM is.

Introduction
Table 1: These are directly copy-pasted from the Verdouw 2021 paper, which focuses on smart farming. I honestly do not think it is the most relevant paper, or DT types to introduce in this study. You only mention the "Imaginary Digital Twin" and "Recollection Digital Twin" once in the whole paper. So consider if these should be left out. Furthermore, I think if you want to introduce them, then you should rephrase the description of the DTs, instead of copy-pasting, or make it more clear that these are directly taken from Verdouw and not just write "based on Verdouw 2021".

Trend D:
From my understanding, please correct me if I am wrong, manufacturing as a service is still being heavily researched and not yet ready to use in the industry, so to avoid any misinterpretations, may write "customers will be able to"

Table 2:
This is just a list of papers. The reader can try finding them and reading them, but what knowledge does it contribute with in this article?

Sentence under Figure 1
"Program management combines several projects that are linked to one another are dependent" is confusing and needs to be rephrased.

Figure 2
I think the "(=dashed line)" should be written in the figure text and not in the main text.

Method
First sentence: "...whereby search strings were not used": What was used then? How did you find the papers?

Table 3: "A sensitive principle..." What principle?

Are the rationale for, and objectives of, the Systematic Review clearly stated?
No

Are sufficient details of the methods and analysis provided to allow replication by others?

Partly

Is the statistical analysis and its interpretation appropriate?
Partly

Are the conclusions drawn adequately supported by the results presented in the review?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Digital Twins, Robotics, Manufacturing, Configuration, 3d visualization

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.