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Setting the Stage for Agents' Cooperation: Digital Twin Family as Framework for Systems Integration

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Abstract

Given present conditions of VUCA and BANI, production systems face frequent shifts in requirements, demanding efficient processing to maintain flexible. Production control, pivotal in such systems, navigates diverse target conflicts, requiring mutual representation of agent properties, targets, and conditions for joint optimization and self-reconfiguration. Dynamic representation of current information is essential, with Digital Twin technology showing promise. However, practical implementation often falters due to differing understandings and capabilities. Our work aims to propose a framework for designing and implementing specific, deliberate sets of networked Digital Twins, systematically analyzing existing concepts for integration, primarily through the Digital Twin Family approach.

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1. Introduction

Amid the ever-changing demands on industry, politics and society, which have been captured and explained over recent decades with the help of the terms of VUCA and BANI, manufacturing companies, too, have increasingly been confronted with a previously unknown extent of pressure and demand to flexibles' [1]. Over the course of time, this has been met with growing efforts towards automation. Current approaches are thereby characterized by concepts of decentralized, agent-based and self-organized system designs that use cooperative and emergent behavior of distributed entities in order to allow for both efficiency and adaptivity [2]. Digital integration is therefore considered a foundational prerequisite in that it serves as an enabling means to this end. In this respect, Digital Twins have been researched and developed as a promising application [3, 4].

However, despite their recognized and also demonstrated potential, their adoption in industry has remained as restricted as their employment in research efforts seeking to address complex endeavors [5]. Consequently, the actual technological

potential has not yet been fully exploited, which is related to various reasons. This includes, most notably, an often-foreshortened understanding of the technological core concept, which finds expression, for example, in a very limited equation of Digital Twins with visualizations [6]. In this context, relevant gaps in the knowledge and differentiation of the various forms of Digital Twins can often be observed, which is shown regularly, for example, in that only product twins are known. Last but not least, it is thereby to be observed that even substantial individual understandings regularly differ in relevant ways and do not share, for example, a commonly recognized, agreed and uniform foundation [7].

As a result, communication on Digital Twins is often curtailed and misleading, which in turn gives rise to limited and isolated implementations [8]. Finally, this contributes to purpose-oriented uses of Digital Twins often remaining absent, the use of the technology hardly being cost-effective and a retention towards the use of it manifesting which cannot do adequate justice to the potential actually associated with it.

Accordingly, to address this gap and leverage its inherent potential, is what drives our respective work. We believe that a

common basis of knowledge and action can provide essential support in designing holistically integrated solutions. It is therefore our motivation to offer a solid contribution to a streamlined communication.

Therefore, we aim to present a novel framework for the design and implementation of specific, deliberate and relevant sets of networked Digital Twins. In order to support collaborating partners from research as well as industry this is intended to be capable of conveying the concept of Digital Twin technology in an appropriate differentiation, to provide a common order, language and orientation and to be suitable to structure their development in a sound and practical manner. Considering the meaning of what we think for what we do we therefore draw on the benefits of employing a strong metaphor that unfolds its specific strengths in supporting comprehension and integration of knowledge, fostering orientation and systematization and strengthening the ability to act in handling the complex challenge on hand.

In accordance with this intention, we address the following questions:

- (1) What organizational logic can be proposed to promote understanding and differentiation of Digital Twins within the specific context of production?
- (2) How can we support the benefit-oriented design of suitable Digital Twins leveraging this foundation?
- (3) What inspiration can be used in order to motivate the effort of designing integrated Digital Twins?

To illustrate the development of our proposal, we organize our paper like this: Following the introduction we establish the relevant background in the field of Digital Twin integration, covering insights into its relevance, outlines of its key technological concept as well as a reality check that seeks to provide a concise impression of its current state of realization. After that, we describe the method we apply to work towards our goal. Our according findings are presented following this and subsequently being discussed afterwards. We conclude our work with a summary.

2. Theoretic Background

Whilst realizing systems integration using Digital Twins we introduce and highlight the relevant theoretical background in the following section.

2.1. Digital integration as foundation for designing advanced manufacturing systems

The manufacturing industry has undergone significant advancements in recent decades, resulting in increased complexity [9]. This complexity arises from various factors, including the growing automation, the introduction of Cyber-Physical Systems (CPS), the Internet of Things (IoT), and the escalating demands for flexibility and adaptability [10]. A manufacturing system comprises a multitude of interconnected components, including machinery, materials, human labor, information systems, and logistical processes [11]. These

components interact in diverse ways, leading to a dynamic and often unpredictable overall structure [1].

To address these challenges, numerous manufacturing companies are working towards realizing the vision of Industrie 4.0 [12]. This endeavor has increasingly resulted in the implementation of computer-assisted integrated systems [10]. Integrated systems are essential for managing the increasing complexity of modern manufacturing systems [9]. They seamlessly connect various components such as machinery, materials, labor, and information systems, resulting in more efficient and coordinated processes [13]. Through integration, redundant processes can be eliminated and resources optimally utilized, enhancing production efficiency and reducing operational costs [14]. Additionally, integrated systems enable consolidated data collection and analysis, providing comprehensive insights into production processes and supporting informed real-time decisions [15]. They offer flexibility and adaptability, allowing companies to respond more quickly to market changes and customer demands [16]. Finally, integrated systems improve quality assurance through continuous monitoring and documentation of all production steps, facilitating product traceability and compliance with quality standards [17].

Integrated systems optimize the value chain, improve coordination, and reduce inventory and lead times [18]. They enable the use of automation and artificial intelligence, increasing productivity and minimizing errors [11]. Additionally, they promote sustainability through optimized energy and material usage, enabling more environmentally friendly production. Finally, they enhance responsiveness to customer inquiries, increase customer satisfaction, and strengthen customer loyalty.

Despite their necessities and opportunities, the issue of integration has surfaced due to inflexible, hierarchical control structures whose complexity escalates rapidly with the scale of the systems [10]. The challenges associated with system integration can be viewed to some extent as motivation for the utilization of decentralized systems [2]. Decentralized systems circumvent this complexity by operating various systems and processes largely autonomously and independently [20]. Instead of relying on a centralized infrastructure, decentralized systems can use separate units or intersection points that communicate with each other but are less susceptible to comprehensive disruptions. Consequently, manufacturing systems should be conceptualized as loosely interconnected networks comprising communicating and collaborating agents.

In the realm of artificial intelligence and computer science, an agent is a self-directed system aimed at achieving specific goals [2]. The properties, goals and conditions of relevant system elements as agents must be mutually represented in order to enable joint optimization and self-organized reconfiguration [19]. A dynamic representation of ever current information is thereby fundamental. Digital Twin technology is a promising approach in this respect [20]. In the era of Industrie 4.0, the connection between Digital Twin technology and cooperated agents in decentralized systems serves as foundation for designing advanced manufacturing systems.

2.2. Digital Twin Technology

As a fundamental scientific definition, Digital Twins are recognized as virtual representations of physical objects, processes, or systems that capture and analyze real-time data about their state and behavior [3, 21]. These virtual models are continuously synchronized with their corresponding real-world objects to enable a precise mapping of the physical world [22]. Based on this foundation, Digital Twins provide the capability to simulate, monitor, and optimize complex systems, making them a central instrument for Industrie 4.0 and the Internet of Things (IoT) [20]. According to the fundamental definition, Digital Twins consist of three primary components: The digital master contains all relevant models from the planning phase of the considered physical or real world system. The Digital Shadow consists of data collected over the lifecycle of the represented system. The intelligent linkage of the digital master and shadow forms the third and central component of the Digital Twin [3, 21].

There are several classifications of different Digital Twins to enable a clearer structuring and classification of the various applications and areas of use of Digital Twins. For Example, they can be divided into four different types, each of which has its own unique characteristics and advantages [5]. These are component, asset, system and process twins [23, 24]. In the production systems environment, a distinction is classically made between the factory twin, the product twin and the resource twin. The distinction of Digital Twins in lifecycle phases enables the specific modeling and optimization of the planning, production, usage, service, disassembling and recycling phases of a physical system [5]. Each phase utilizes different data and models to provide relevant insights and improvements [20]. Furthermore, a taxonomy has been developed for the field of Digital Twins that allows for the classification of the various definitions and concepts of Digital Twins [23]. The authors furthermore propose a set of archetypes for individual application [7].

Riedelsheimer et al. (2020) come to the conclusion that there are millions of possible manifestations of a Digital Twin. At the same time, the goals and definitions of the Digital Twin vary considerably depending on the area of application and usage scenario [5]. It even mentioned, that there is no common understanding of the term Digital Twin [25]. Therefore, descriptions and concepts that have been developed for a specific application cannot simply be transferred to new areas of application [20]. Individual visions must therefore be united.

To address these challenges, Stark et. al propose an 8-dimensional model to precise classification and targeted development of Digital Twins [21]. Subsequently, Riedelsheimer embed the 8-dimensional model into a generalized approach for the implementation of Digital Twins [5]. Furthermore, Haße et. al came up with design principles for shared Digital Twins to help practitioners design Digital Twins tailored for their inter-company use-cases [8].

2.3. Reality Check of Digital Twins

In research, there are a variety of activities and contributions focusing on research questions related to the integration of IoT

and real-time data, the utilization of artificial intelligence and machine learning, aspects of standardization and interoperability, as well as challenges regarding data quality and security in various application domains [26, 27].

However, current studies indicate that 65% of industry partners still have no plan for implementation, often due to a lack of knowledge, experienced staff, and tools [6]. The main reasons for a lack of implementation are no management decision, confusion about where to start, and a lack of understanding of the concept and its usefulness [6]. Furthermore, it is often unclear who within the company is responsible for the design and implementation of Digital Twins [5]. In summary, Dessault makes clear, that Digital Twin could either be a revolution or an impossible ambition, that can never truly be obtained [6].

In conclusion, Digital Twins are a transformative technology with a wide range of applications, whose potential is far from being fully realized. Current research is primarily focused on improving the accuracy, efficiency, and security of these systems to enhance their utility in real-world applications. This paper addresses a gap by not focusing on the technical aspects of the technology, but rather highlighting issues of design and technology transfer. The great variety of perspectives, understandings, and intentions shows that, particularly in the early phase, approaches to design are highly limited.

3. Method

In order to address the outlined gap through the provision of a framework that is suitable to guide and support the design and implementation of purposefully tailored and aligned Digital Twins, we respond to our according questions using the following set of methods.

First, to propose an organizational logic that is capable to promote the understanding and differentiation of Digital Twins within the specific context of production, we analyze existing approaches, differentiations and classifications as such as well as in terms of their respective shortcomings and strengths. For the purpose of utilizing them in the design of our proposal, we will then use our according findings to, on the one hand, extract exemplary aspects that are suitable for transfer as well as, on the other hand, identify gaps, limitations and potentials in order to address them accordingly. Thereby, we will support the conception of our framework with the help of a suitable metaphor that can convey key messages for a ready-to-use understanding of Digital Twin technology appropriately. Following this, our results are represented through the *Digital Twin Family* approach.

Second, seeking to support the benefit-oriented design of specific Digital Twins, we will provide a concrete tool to leverage this basis with a special consideration of practicability in industry. Based on a reflection of different approaches and the balancing of their weaknesses and strengths, we therefore opted for a canvas approach. In order to support the deliberate design purposefully customized Digital Twins, that can take on an infinite number of variations depending on the composition of their respective components, this demands a distinct method that is capable to provide orientation in precisely this respect.

A canvas can meet these requirements by contributing to making the complexity of design projects visible, systematizing design elements and indicating their relations. Its results can serve as a basis for decision-making and eventually strengthen commitment through documentation. The design of our concrete canvas will be based on the synthesis of the components of Digital Twins, from which we will derive its design areas as well as guiding questions.

Third, in order to encourage the effort that is involved with designing integrated Digital Twins, we will showcase a production-specific range of achievable added values against the background of a selection of current industry concerning issues. Thereby, to provide an impression of the variety of possible design purposes, the differing types and numbers of Digital Twins required and their respective distribution and localization across life cycle phases and representation levels, we will formulate condensed success stories and accompany them with concise visualizations.

4. Results

In line with our research questions, our findings are presented in three areas in this section. First, the framework of the *Digital Twin Family* is presented as an organizational logic to promote understanding and differentiation of Digital Twins with special emphasis on a manufacturing context. Second, we introduce the Digital Twin Canvas as a design framework for a purpose-oriented development of Digital Twins. Third, we provide three visually supported success stories to highlight selected benefits of the application of integrated Digital Twins as a motivational resource for according design efforts.

4.1. Digital Twin Family – a technology portrait

As already presented in the theoretical background, there are already a large number of distinctions between Digital Twins. In practice, the differentiation between different life cycle phases is particularly important. As such, it should be retained as an essential descriptive feature for classification, but not as a superordinate descriptive element, since ideally every twin would go through all the phases. In contrast, the distinction according to levels appears to be less unsuitable, as this should not be a relevant descriptive feature when the levels of the

automation pyramid are resolved. A further distinction takes into account, among other things, the types of twins. However, terms such as asset twin or system twin are sometimes so vague that the names of Digital Twins are not always understood in the same way, which can lead to misunderstandings and confusion. One of the reasons for this is the complexity and diversity of the applications and the different perspectives and requirements of the various specialist disciplines. In manufacturing companies, this sometimes leads to neologisms such as a digital robot twin or a design twin, that are not related to a commonly recognized classification. It is therefore essential to give the digital twins specific names. Above all, this is necessary to enhance mutual understanding and streamline communication, further to appropriately express the distinct capabilities and tasks of the different components of a production system, and last but not least to provide a production specific language that finds acceptance in application by conveying a domain-specific meaning.

Therefore, the framework of the *Digital Twin Family* has been developed taking into account both, scientific design recommendations and industry specific experiences. It refers to the creation of digital representations or models of real objects, processes or systems and their interconnection within a respective production system. In the context of families of Digital Twins, different entities or components are linked together to enable integrated solutions in complex systems or organizations. These Digital Twins can include both physical and virtual elements and are used to improve the understanding, analysis, optimization and reconfiguration of the real system. The concept of Digital Twin families is tailored for use in production and logistics, able to cover components of all system levels and applicable throughout all life cycle phases.

We present the concept of a *Digital Twin Family* for manufacturing systems in Figure 1. For a general summary, the following twin types of the *Digital Twin Family* framework are introduced:

- The *digital factory twin* is a virtual representation of a physical building. This digital copy contains comprehensive information about the structure, equipment, systems and surroundings of the real building.

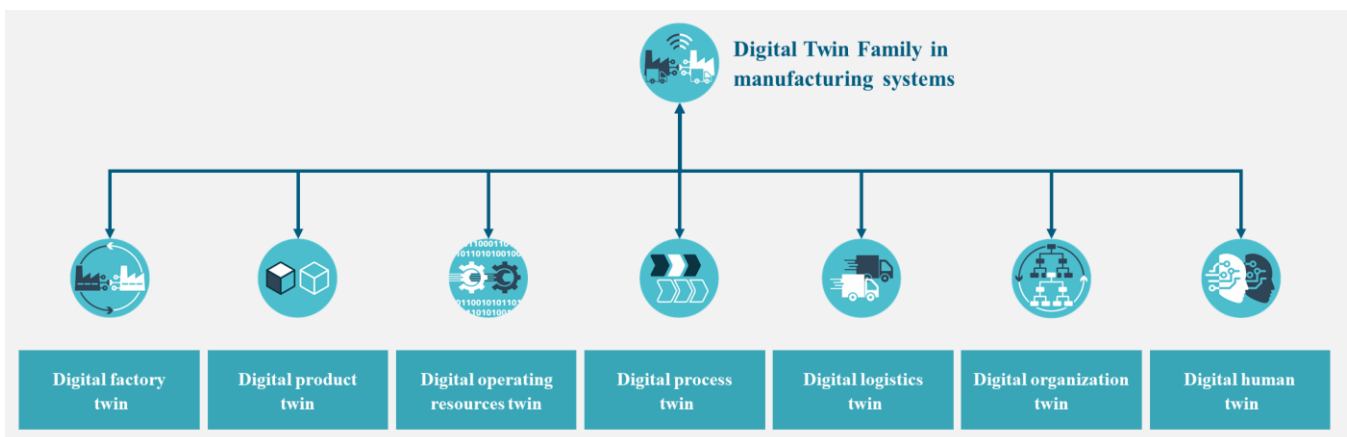


Figure 1: Digital Twin Family in manufacturing systems

- The *digital product twin* is a virtual representation of a physical product that contains all the relevant information and features of the real object.
- The *digital operating resource twin* is a virtual representation of a physical resource and relates to all the goods required in a company for the manufacturing of a product.
- The *digital process twin* is a virtual representation of a real process that takes place in a company or organization and is understood as the digitized production memory.
- The *digital logistics twin* is a virtual representation of a physical logistics system or supply chain. This digital copy contains comprehensive information about the structure, processes, flows of goods and data as well as the performance of the real logistics system.
- The *digital organizational twin* is a virtual representation of an organization that includes all essential structures, processes, resources, procedures and relationships within the organization.
- The *digital human twin* refers to a virtual representation of a person. It includes information for identification and contains characteristics on constitution, disposition, qualification and adaptation.

In order to specify the suggested twin types with regards to economic, benefit-related and technological design aspects, that are not being covered in the family approach, we accompany this initial proposal with a design framework for their development that is presented below.

4.2. Digital Twin Canvas – a design framework

Building a Digital Twin requires a methodical approach that ensures that all relevant aspects are taken into account and the desired goals are achieved. Existing approaches to designing Digital Twins, as described in the theoretical background, already address this to some extent. They offer a systematic approach and a method as a clear and comprehensible

framework for solving problems. Step-by-step processes systematically guide users through all the important aspects of a Digital Twin. Furthermore, these methods promote commitment and communication within the team and provide a good framework for interdisciplinary collaboration. One shortcoming, however, is that these methods often have weaknesses in terms of processing and visualization in order to better understand the relationships between the design elements and their interaction. Another important requirement is the consideration of target group-oriented preparation in order to address the aspect of an often-lacking management decision as a hurdle to implementation in the area of manufacturing.

To suitably meet these requirements, we chose the approach of a canvas, which integrates own particular strength with positive characteristics of further candidate methods. As such, it helps to structure complexity, guides the systematic exploration of possible solutions within a clearly formulated set of design tasks and processes and represents respective decisions and results in clear and concise manner.

Inspired by the Business Model Canvas approach, the structure of a *Digital Twin Canvas* is presented below. This is intended to serve as a visual tool to present the structure of Digital Twins in a clear and understandable way and to enable a holistic view of Digital Twins through its simple handling. The canvas is used to classify all decisive technical, organizational and economic features and characteristics and prepare them in terms of conceptual requirements. The visual nature of a canvas is also intended to promote creative thinking and improve shared understanding and interdisciplinary collaboration. By focusing on the essentials, the canvas also serves as a strategic planning tool to support well-founded strategic management decisions. In summary, we consider the canvas to be a superior solution because it recognizes complexity, provides guidance through the process, allows the systematization of design elements and provides decision support through management-oriented documentation. We present the *Digital Twin Canvas* in Figure 2.

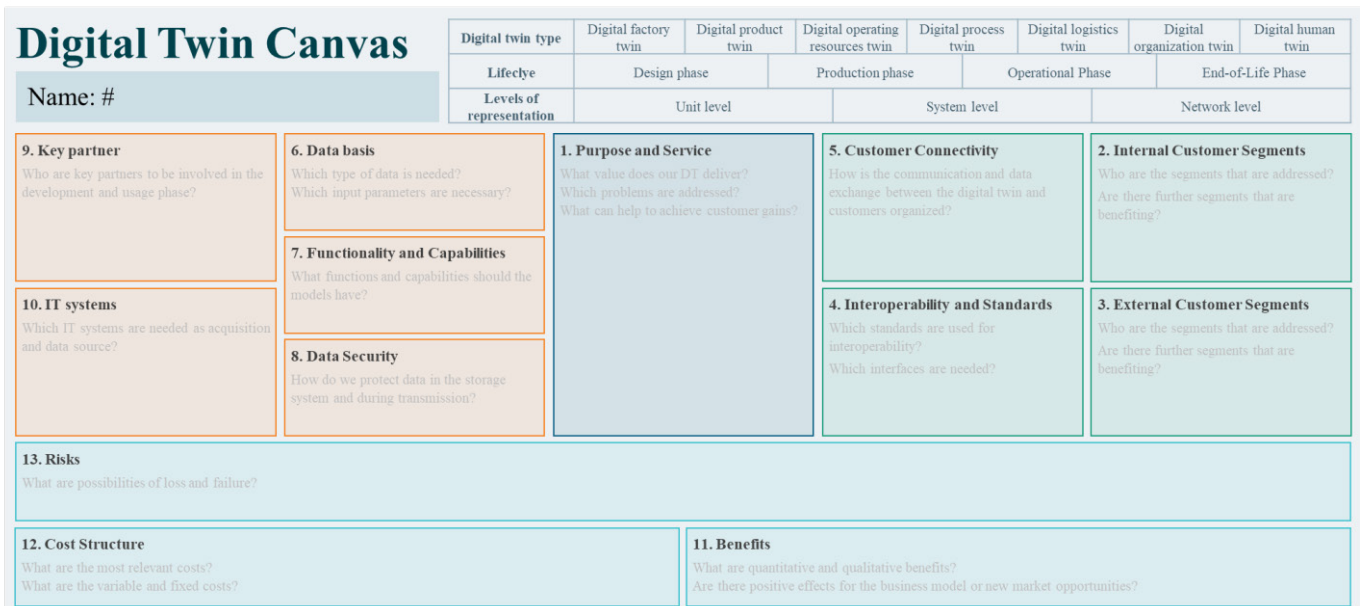


Figure 2: Digital Twin Canvas

Synthesizing relevant questions from development and utilization, the *Digital Twin Canvas* we suppose is organized in four major categories, each of which is subdivided into corresponding elements that themselves are again supported with respective guiding questions. In this way, it covers the key design areas of purpose and service, customer orientation and access, modelling and development as well as finance and valuation in their holistic relationship. In an ideal-typical approach, this enables the purpose-based elaboration of appropriate Digital Twin designs following the numbering in the illustration, whilst also allowing other approaches according to any given development occasion.

4.3. Better together – success stories of Digital Twin Families

Finally, to motivate and illustrate the aspired added values of integrated Digital Twin designs, we herewith provide three selected examples that are presented as production specific success stories.

(i) Self-organized production control

Production planning and control systems are subject to constant change and various change drivers, which makes continuous adaptability necessary due to disruptions, delivery bottlenecks or different customer requirements, for example. The integration of Digital Twins of operating resources, products, processes, human and factory (Figure 3) can significantly increase the performance of existing systems. Existing tools and control approaches are reaching the limits of their capabilities, particularly due to the assumption that energy and personnel resources are permanently available. In the future, intelligent orchestration of the various Digital Twins will make it possible to carry out optimizations and reconfigurations during the process and make autonomous adjustments to the production system and its control. Necessary aspects of agile production control are the evaluation of flexibility and efficiency potentials, for which a consistent *Digital Twin Family* is essential as a basis for feasibility, potential and cost estimates.



Figure 3: Agile production control – involved Digital Twins

(ii) Integrated, robust value creation network

The aim of an integrated view of the system is also to link different levels. Due to their different polarizations and objectives, the interactions between the plant level, the operations management level and the supply chain level are sometimes unmanageable. Understanding these interactions is

aided by understanding the individual sub-target systems of the Digital Twins of operating resources, processes, products and logistics (Figure 4). Based on these distributed Digital Twins, it is possible to implement an integrative data model for dynamic condition assessment. On this basis, the design and development of robustness control loops enables the dynamic control of the overall system and thus the strengthening of system-oriented optimization, configuration or recovery, not only on an individual target basis.

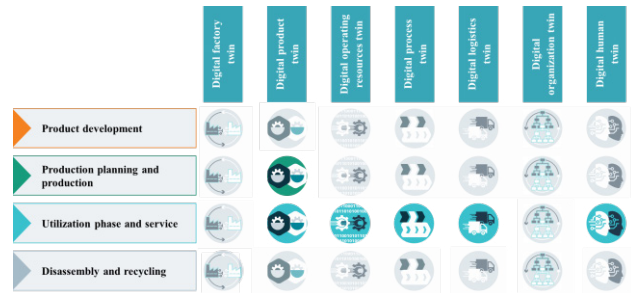


Figure 4: Integrated, robust value creation network – involved digital Twins

(iii) Rapid industrialization of new products

The industrialization of new products is also a complex use case and a much-discussed approach that can benefit from the integration of Digital Twins of product, factory and operating resources (Figure 5), especially when considering the different life phases. The use of the individual twins already offers different advantages. In addition, there are use cases in which the various forms of the Digital Twin must be considered in combination in order to develop their potential along the entire process. Modularization creates a superordinate model and reduces the complexity and manageability of the information. This allows the entire production system to be viewed holistically and optimized. By avoiding the consideration of isolated areas, interactions and emerging problems can be identified and addressed at an early stage. Furthermore, integration provides a comprehensive database on which well-founded investment and planning decisions can be made.



Figure 5: Rapid industrialization of new products – involved Digital Twins

Especially for systems that are subject to permanent change, there is potential for autonomous optimization and reconfiguration of the system based on current system states. This makes it possible to tap into new productivity potential in decision-making, control and reconfiguration processes.

5. Discussion

For the purpose of addressing a current situation in which the technological potential of Digital Twins cannot yet be considered thoroughly exploited, our paper presents three approaches that can contribute to addressing this gap with a particular emphasis on causative factors that can often already be localized in the early attempts of adopting this technology.

With this including, at its very basis, an often-misleading communication which finds its roots in inconsistent uses of terms, vague understandings of technology core concepts and limited knowledge of the variety of technology specifications, we introduced the framework of the *Digital Twin Family*, which provides parties involved in implementing Digital Twins with a tailored classification, using production-specific language and practical definitions. Whilst acknowledging that dealing with the given diversity of terms, definitions and classifications represents a challenge in itself, it thus aims to contribute to promoting an effective communication. Therefore, the approach is supported by the use of a strong metaphor that makes the abstract concept discussable and thus designable with a familiar image. Although a comprehensively standardized understanding of Digital Twin technology is thereby hardly realistic, we so wish to help find shared definitions that can serve in the context of their dedicated use case.

Since, further, digital twins best unfold their rich potential in interaction with each other, according considerations are pivotal in early stages of their design. Ensuring goal-orientated planning from the start has thereby shown to be of utmost importance in order to successfully design performant integrated systems. In order to support this challenge, we introduced the Digital Twin Canvas. Serving as a heuristic frame of reference, it can unfold the potential to derive harmonized development strategies from the early development phase. In this way, it helps to ensure the vital integration and connectivity of Digital Twins, to support companies as a quality standard in the realization of holistic and far-sighted solutions and, finally, to promote the success of a Digital Twin implementation in that phase of the project in which the costs of implementing changes are still the lowest. In doing so, it ultimately actively reflects the basic premise of early planning decisions setting the frame for the strategic impact to follow.

Finally, since limited and isolated implementations are not to do adequate justice to the actual potential of Digital Twin technology, we provided three success stories in order to illustrate the benefits of integrated Digital Twin applications. Representing an opportunity to learn from a model they are intended to utilize the value of good and relatable examples as this can help to eventually shape clearer understandings, use them associatively as a source of inspiration and apply them, finally, to a company's own questions. As a result, integrated Digital Twin design not only contributes to leveraging the technology's potential in achieving intended corporate objectives, but also helps to pave the way for the realization of advanced manufacturing systems.

While important steps for overcoming the gaps could thus be taken, a number of limitations nonetheless remains. Above

all, the value of the methods presented stands and falls with their profound application. Accordingly, it is best being accompanied with precise recommendations for use, distinct models of procedure as well as, ideally, a thorough moderation, that can effectively navigate the complexity of integrated Digital Twin design by translating, reflecting and integrating the various perspectives involved. Furthermore, the realization of Digital Twins is of relevant dependency of a systems general digital maturity level, meaning an implementation to appear more demanding the fewer prerequisites are met. In the future, interface-compliant design of Digital Twins will form the basis for utilizing advanced analytics, ensuring a high degree of real-time interoperability. This also enables the provision of data for cross-company exchange to leverage network effects. It will be crucial to determine to what extent Digital Twins can be automatically generated and/or configured through self-description or libraries. This will also be necessary to ensure the quality standards of the twins for operation. This is likely to be a decisive quality feature to keep the *Digital Twin Family* interoperable and robust, and to expand it prospectively. Finally, it remains to be acknowledged that while successes in design and implementation are relevant results, continuous upkeep and actualization are required in order to ensure that the potential created does not dissipate.

For those involved in realizing integrated Digital Twin designs, the following implications are thereby derived. For practitioners, the approaches we propose are intended to provide application-oriented support in processes of designing Digital Twins, to make transdisciplinary cooperation more effective and efficient as well as to strengthen user sovereignty in recognition of their primary ownership. Regarding research, we come to emphasize a responsibility that must not be limited exclusively to technical advances, but should rather be complemented by providing methodical support for respective implementation matters. Regarding this, we would thereby like to point out that the development and introduction of distributed Digital Twins is a challenging task for many companies that is regularly associated with a high and unpredictable implementation effort. Additional methods for systematizing, shortening and improving planning and implementation are therefore of great importance.

With according respect to this, we henceforth aim to contribute to this by formulating concise recommendations for utilizing our contributions, underpinning our approaches with a substantial body of methods as well as by promoting industry-specific standardization initiatives regarding Digital Twin design in a joint and mutual engagement of research and practice.

6. Conclusion

In summary, this contribution has introduced the *Digital Twin Family* approach, which is accompanied by a systematic design framework and an illustration of the benefits of integrated Digital Twin design efforts. Above all, it thereby represents a definitional accomplishment, supporting not only to achieve communicative alignment but also to enhance purpose-orientation in processes of utilizing Digital Twins.

Additionally, as outlined in the introduction of our work, the final objective of Industrie 4.0 is to realize self-organizing in production and logistics, driven by the major goal of making systems more responsive, adaptable and reconfigurable.

In this vision, cyber-physical systems are quintessential in that they consolidate systems statuses and environmental conditions as input for manufacturing control.

Taking both strengths from Digital Twins and self-organizing production into account, their coupling appears to be necessary to facilitate data-driven autonomous negotiation and simulation-based adaptive optimization not only in the manufacturing system but also in the supply chain level.

Against this backdrop, besides being of utmost importance in leveraging the technology's potential to achieve intended corporate objectives, integrated approaches related to Digital Twins hold even greater significance in that they set stage for agents' cooperation as a prerequisite for self-organization.

However, for this to succeed in the future, planning must be re-recognized in its far-reaching meaning in the future: Not only does it encompass organization, but above all innovation.

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