INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED21
16-20 AUGUST 2021, GOTHENBURG, SWEDEN

DIGITAL TWINS - DEFINITIONS, CLASSES AND BUSINESS SCENARIOS FOR DIFFERENT INDUSTRY SECTORS

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ABSTRACT

Over the recent years, several attempts were made to define the concept of the Digital Twin and to create a generic view for utilizing it within the industry. Still, many industry sectors are not able to transfer a generic definition into their product portfolio, as Digital Twins differ from each other to the same degree as physical products differ from each other. Hence, it is crucial to enlarge the definition towards a classification and business scenarios which enable sector specific views on the concept of the Digital Twin and help SME to utilize the concept towards their products. Future engineers will have to design physical products besides a digital counterpart and therefore have to identify interdependencies between these two products during the development. This paper discusses a generic definition of a Digital Twin that can be applied throughout different sectors as well as a classification for Digital Twins to enable the implementation of the concept on several maturity levels regarding the constraints of the product portfolio. In addition, these classes are viewed in different business scenarios and an outlook is given to further increase the usability of Digital Twins within new industry sectors.

Keywords: Digital Twin, Product-Service Systems (PSS), Business models and considerations, Systems Engineering (SE)

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Cite this article: Wilking, F., Schleich, B., Wartzack, S. (2021) 'Digital Twins - Definitions, Classes and Business Scenarios for Different Industry Sectors', in *Proceedings of the International Conference on Engineering Design (ICED21),* Gothenburg, Sweden, 16-20 August 2021. DOI:10.1017/pds.2021.129

1 INTRODUCTION

1.1 Motivation

Driven by the continuously increasing digitization of almost any area in the daily life, the increasing possibility of data acquisition, storage, transfer as well as assessment has led to a peak of expectations regarding the concept of “Digital Twins” (Gartner, 2018). In this context, the Digital Twin can be viewed as a crucial technology to enable future developments and progress in other areas. Consequently, over the recent years, several attempts were made to define this concept and to create a generic view to utilize it within the industry. However, many industry sectors are still not able to apply a generic definition on their product portfolio, as digital twins differ from each other to the same degree as physical products differ from each other. Hence, it is crucial to enlarge the definition towards a classification and business scenarios which enable sector specific views on the concept of the Digital Twin and help SME to utilize the concept towards their products. Motivated by this rising need, the authors of this paper have been working together with the German Research Association for Drive Technology (FVA e.V.) to identify these categories and scenarios. The association has the aim to create synergies within this industry sector. Its members are several German enterprises with diverse product portfolios which vary from simple roller bearings to complex turbine systems. This product variety shows that an implementation of a Digital Twin may be different for products of diverse complexity levels, e. g. through interfering with the physical structure. It also shows that the concept and usage of Digital Twins has been enlarged from its former classical users, e. g. the aerospace industry, towards small suppliers which try to utilize this concept for their environment and individual constraints. This accentuates the need of sector specific views on the concept of the Digital Twin as well as a thorough classification to enable a utilization for different sectors. Taking the different engineering capabilities of the enterprises into account, reveals the importance of a design focused approach which allows future engineers to adequately consider the dual or even bidirectional development, physically and digitally. Therefore, this paper discusses a generic definition of a Digital Twin that can be applied throughout different sectors as well as a classification for Digital Twins to enable the implementation of the concept on severe maturity levels regarding the constraints of the product portfolio. In addition, these classes are viewed in first different business scenarios and use cases to create a linkage between them and the classification. This supports the early analysis of the feasibility for different Digital Twin concepts and highlights possible obstacles appearing within this class. Finally, an outlook is given to further increase the usability of Digital Twins within new sectors.

1.2 Approach

To achieve this, associated key words within several definitions for Digital Twins are analysed and brought together to a generic definition. To enable a variety of application levels throughout several industry sectors the definition is subsequently enhanced by classes of digital twins. With these classes different business and application scenarios for the digital twin are identified. This ensures an economically driven view on the concept of the digital twin rather than a technology driven one. With this view, further obstacles towards a full integration of digital twins are discussed and an Outlook is given on which key areas still need to be focussed.

2 DIGITAL TWINS

Motivated by the aforementioned technical benefits and potentials of digital twins, many articles were published within the last years with the goal to define the concept of a Digital Twin. The concept was mentioned at first by Glaessgen and Stargel (2012), who are pointing out the necessity of digital twinning within complex technical systems, such as spacecrafts. Many other publications such as (Kritzinger *et al.*, 2018; Rosen *et al.*, 2015) tried to establish application specific definitions to describe explicit situations in which a Digital Twin is providing benefits, e. g. for production. Recent work has been done to achieve generic definitions and to create a common understanding of familiar terms for the Digital Twin, such as (Schleich *et al.*, 2017; Stark *et al.*, 2020; Ríos *et al.*, 2015; Grieves and Vickers, 2017). Moreover, more generic definitions have been proposed, e. g. by the International Academy for Production Engineering CIRP (Stark and Damerau, 2019) or the German Scientific Society of Product Development WiGeP (Stark et al., 2020). These define the Digital Twin as a digital representation of a physical product instance. This instance includes several properties and behaviours of the physical counterpart and connects them with data, information and models (Stark *et al.*, 2019). This describes the combination of a virtual domain with a physical domain. The Twin is built up by a Digital Master, which includes models to characterize the structure and behaviour of the physical counterpart, as well as by a Digital Shadow (Schuh *et al.*, 2018), in which real time data is stored and evaluated in combination with specific models of the Digital Master.

Beside these definitions, a plethora of papers aim at illustrating the potential application of digital twins for several purposes and tasks along the product life cycle, such as (Schleich *et al.*, 2019) and (Tao *et al.*, 2019b). In view of these different potential applications, still, many industry sectors are not able to apply a generic definition onto their product portfolio, as digital twins differ from each other to the same degree as physical products differ from each other. In addition, the implementation and application of a Digital Twin may be driven either by intrinsic motivations, such as developing new business fields, as well as by extrinsic requirements, as it was shown with related approaches, such as MBSE (Wilking et al., 2020).

3 DEFINITION & CLASSIFICATION OF DIGITAL TWINS

Reviewing the definitions of publications about Digital Twins within the last years, several properties and key words can be identified, which describe the concept. These publications vary from each other with different views, such as sector or technology specific ones. This hinders the clear definition of a generic and universal definition of the concept. Nevertheless, the following four key words appear regularly in the context of the Digital Twin:

- Physical Counterpart: The Digital Twin is viewed as the counterpart of a physical product (Hribernik *et al.*, 2013; Schleich *et al.*, 2017; Schroeder *et al.*, 2016) and is therefore distinguished from other terms like virtual prototypes which are used for simulations before the physical product is implemented.
- Connection: The Digital Twin analyses data which is received by the physical counterpart or other sources. It is therefore connected with sensors or sources like databases to receive the necessary data. Data can be but is not limited to sensor data or historic system data. (Schluse and Rossmann, 2016; Kuhn, 2017)
- Model Usage & Simulation: The Digital Twin is built up on models which are fed with the data it receives. Models within the Digital Twin concept are used to simulate scenarios (Gabor *et al.*, 2016) which are based on real time data (Tao *et al.*, 2019a; Lee *et al.*, 2013). With the output of these simulations predictions about future system behaviour can be given.
- Bidirectional Orientation: Digital Twins are not static. Real time data can be used to reach higher maturity levels of the model as they get more precise (Schleich *et al.*, 2017).

3.1 Definition

It can be argued, how relevant another definition of the Digital Twin is. However, none of the mentioned definitions combines the Digital Twin with derived business scenarios. This leads to a lack of understanding for enterprises which try to adopt the concept onto their product portfolio. The here mentioned definition should not be viewed as another definition but as an enhanced version which adds several dimensions for a detailed differentiation and a linkage with business scenarios. With the aforementioned key elements and the definitions viewed in Chapter 2, the following generic definition can be proposed to enable an application throughout several industry sectors:

The concept of the Digital Twin describes the connection of an existing, physical object with a virtual counterpart. This virtual counterpart consists several models, which describe the physical object and were created during the product development, e. g. system models, simulations, mathematical models, etc. and formed within this life cycle stage the so-called virtual prototype. Depending on various constraints, e. g. calculation speed, models have to be adapted towards the specific concept of the Digital Twin. With these models and real time as well as historic product data, received by sensors within the physical product, the Digital Twin analyses the current state and can make predictions about future behaviour. This analysis enables the creation of direct recommendations towards the user, e. g. through service notification, or directly towards the physical product, e. g. through optimization. This control circle enables the Digital Twin to adapt and enhance its own models by constantly increasing the maturity through current data. The optimal usage of the concept is achieved by the connection of

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multiple Digital Twins, an Aggregated Digital Twin. This connection allows the holistic view on the system.

With this definition a first conceptual structure of a Digital Twin and an implementation within its context can be given as shown in Figure 1. An explicit elaboration of such varies to the same degree as its physical counterpart varies from other products. On this generic level the beginning of a Digital Twin Life Cycle is shaped by a virtual prototype. This prototype contains several different kinds of models such as CAD, Simulation models, etc. Hence, the virtual prototype has to be adapted after the production of the physical twin to meet its specific requirements during the usage phase. Adaptions might be increasing or decreasing the level of detail of models to achieve shorter calculation times or more precise results. This can be caused by several impact factors, such as available storage. In addition, the virtual prototype has to be prepared to read the new data it is getting from the physical counterpart. Besides the technical implementation for this, e. g. through the internet of things (IoT), the Digital Twin requires further models. These further models enable the connection of received data with the actual location within the system or define the behaviour of the Digital Twin and necessary actions for predefined cases. This allows the translation of data and processed simulation results into direct recommendations and decision. These additions separate the Digital Twin from its predecessor, the virtual prototype. During the usage of the Digital Twin, data of the physical counterpart is stored. Relevant data is processed based on the existing models and other inputs, e. g. historic data. This data is processed and analysed, and the results are transferred into specific recommendations directly to the user or directly back into the physical system. The models are continuously updated to meet upcoming constraints or changes of the environment and optimize the results.

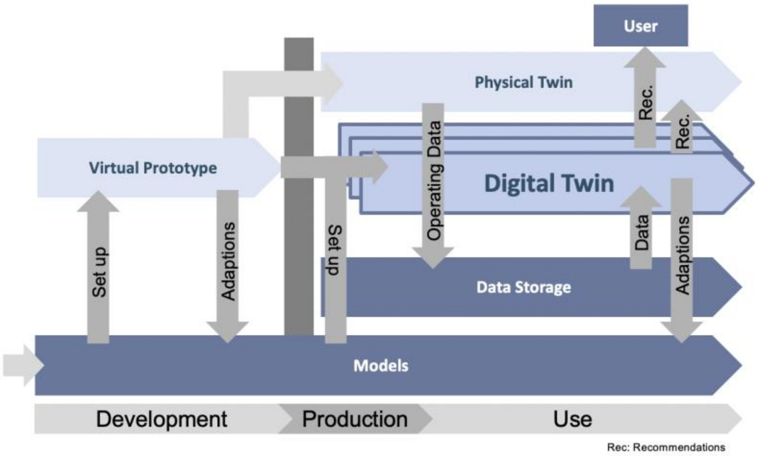

Figure 1: Conceptional structure of a Digital Twin

The here shown conceptual structure of a Digital Twin also highlights the usage of multiple Digital Twins. These aggregated Digital Twins indeed operate independently and fulfil their individual purpose. But their connection can create synergies as information can be received in a higher quality and is already processed. This prevents contrary recommendations of multiple Digital Twins as their results can be used as inputs for each other.

3.2 Classification

A major problem for many companies is the lack of a sufficient method to separate different classes of Digital Twins. Due to the inflation of different definitions of the term Digital Twin, it was an urgent demand from the industry to establish different dimensions which enable the users of Digital Twins to specify their concept. Therefore, an identification of these dimensions as well as a following classification of Digital Twins was mandatory.

3.2.1 Dimensions

Existing approaches to further classify are very detailed and describe close instances of Digital Twins, e. g. by focussing application specific scenarios. But especially the high heterogeneity of Digital Twins due to their variation of physical counterparts leads to a crucial difference. Hence, it is useful to identify categories for such a differentiation on a more generic level. Possible dimensions for this are the following four:

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- **Application:** Digital Twins are used for several different purposes. Some are used for the allocation and processing of data within the physical product. Others directly support the user and the decision-making process by giving specific recommendations or even act autonomously. This dimension describes the degree of autonomy for a Digital Twin. In no case it is a degree of maturity, as less autonomy might be more adequate in specific scenarios.
- **Data Model:** This dimension describes the status of occurring data. Some concepts require an immediate and continuous analysis of data to ensure the desired results, e. g. simulation models for autonomous driving. Other concepts require only an incremental reading and processing of data, e. g. the calculation and simulation of a component lifetime for maintenance and repair operations. Hence, the dimension of Data Models is crucial for the architecture of a Digital Twin, as it defines which models are used and which effort needs to be invested during the development phase of the Digital Twin and its physical counterpart.
- **Model Quality:** Digital Twins can be separated regarding the quality or fidelity of the used models. Some concepts can use less precise models if minor variations of the output do not have to be considered and further benefits such as a shorter runtime can be achieved, while others need an exact result. This dimension is heavily defined by external requirements for the Digital Twin concept. Especially during the product development this needs to be considered to prevent the parallel creation of models.
- **Real Time Capability:** Similar to the dimension of data models, this dimension describes the connection of the digital Twin. Physical and Digital Twin do not have to be connected locally but can be miles away from each other. Therefore, the transmission of data plays a crucial role for the development of Digital Twins. It directly impacts the development of its physical counterpart, as adaptions of its architecture might be required. On the contrary, if the Digital Twin is centralized, e.g. on a Server, the design of the concept needs to take into account adequate IoT-solutions.

These four dimensions can be used to separate different classes of Digital Twins from each other. However, to establish distinct classes, the field of application ensures a significant degree of differentiation. The field of application leads to the identification of three major classes of Digital Twins. Other publications already show that distinguishing Digital Twins in these fields is reasonable and leads to a common understanding of its differences (Kunath and Winkler, 2018). However, the other dimensions must be integrated, too, to ensure a detailed separation and enable the definition of sophisticated requirements.

3.2.2 Informational Digital Twin (IDT)

The first level of a Digital Twin describes a concept of information gathering. Data is collected from the physical counterpart and processed in a manner to provide useful information for the user. This simple version of a digital twin uses models to localize and analyse the data but does not give any recommendation towards the user for further actions. This low-level Digital Twin ensures a useful combination of data and brings them together. An example for this are force-displacement motions within servo drives for the production of washer barrels and its components, e. g. metal sheets. Sensors here combine the analysis of the provided force and combine it with the data about the displacement of the components. Only the combined data ensures that the required force is given by the necessary displacement to join together the single components and eliminate undesired jams within the production. This level of a Digital Twin only combines the two data sources and brings them together in a model. Further utilization of the results has to be conducted by the user. An implementation of such a Digital Twin is not shaped by a high effort. In fact, many of these Digital Twins are already an essential part of modern production facilities. New products need to be analysed towards their possibilities of integrating new sensors, since especially smaller parts could lack this ability. Therefore, the benefit of this implementation are comparable low interconnections within the system as well as a quick accessibility to data with marginal effort.

3.2.3 Supporting Digital Twin (SDT)

Unlike the IDT, the Supporting Digital Twin uses a variety of analysis and simulations to process the gathered data from the physical twin. In this class, data is not only provided to the user but is processed even further to identify additional information and support the user with the decision making based on the processed data. The SDT either provides this processed data directly to the user or, based on specific action models, derives direct recommendations of necessary actions. An example

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for such a class of Digital Twins is settled within the field of predictive maintenance. These Digital Twins utilize the received data and can analyse the remaining lifetime of several components. This insight achieved by the Digital Twin can be used to recommend maintenance and repair operations that are economically optimized. The implementation of this class requires, in addition to the IDT, a further analysis of the environment as well as predefined scenarios for which the Digital Twin is capable to give a reasonable recommendation and support the decision-making process. However, enterprises have to face a thorough analysis of these scenarios to ensure the advantages of a coordinated data analysis. Within this class, additional topics like data storage, model storage and model quality are becoming important to enable a punctual recommendation for the user.

3.2.4 Autonomous Digital Twin (ADT)

The third level describes an Autonomous Digital Twin. In addition to the SDT, this class of Digital Twins uses the provided recommendations for necessary actions to influence the behaviour of the physical product. The user might still be informed in this scenario. But the aim of ADT is to achieve a quick response to changing data of the physical twin, e. g. variations within a production facility. This ensures that valuable time is saved. The aforementioned example for the SDT can be enhanced towards an autonomous repair and maintenance system that automatically provides these actions. This class requires a complete analysis of the environment as well as a thorough development of derived actions for specific scenarios. Furthermore, it needs to be defined, how it reacts in situations which were not defined preliminarily. The implementation of such a Digital Twin is shaped by high technical efforts. It has a high interdependency with its environment and should be tested thoroughly to ensure a feasible implementation. Enterprises who desire this kind of Digital Twin for their products are confronted with a tremendous analysis of the system environment as well as the behaviour to ensure that the incoming data is processed in a coordinated manner and that the right guidance towards the physical product is given.

3.2.5 Combined Classification

This classification of Digital Twins allows an even more detailed view as the other dimensions can be added and create subclasses for a multidimensional categorization of the digital twin as shown in Figure 2. The general differentiation is achieved through a separation between the field of application e. g., as ADT. Within these field a further differentiation is conducted by viewing the three aforementioned dimensions. Furthermore, especially within the field of drive technology, it has been revealed that an additional separation mechanism is needed which classifies Digital Twins for components, e. g. a simple bearing roller, towards complex systems, e. g. turbine systems. This scheme allows to deepen these generic classes and create requirements for every single class to ensure an economic utilization of the concept. However, it has to be an important consideration in addition to these categories that Digital Twins vary significantly by viewing the product complexity. Therefore, this generic categorization has to be combined with a complexity view of the physical product, as it is already done within Systems Engineering. A first additional categorization could therefore distinguish between complex systems, subsystems and components, as these come along with further questions about the integration into other system environments. A complete categorization should therefore include these aspects shown in Figure 2.

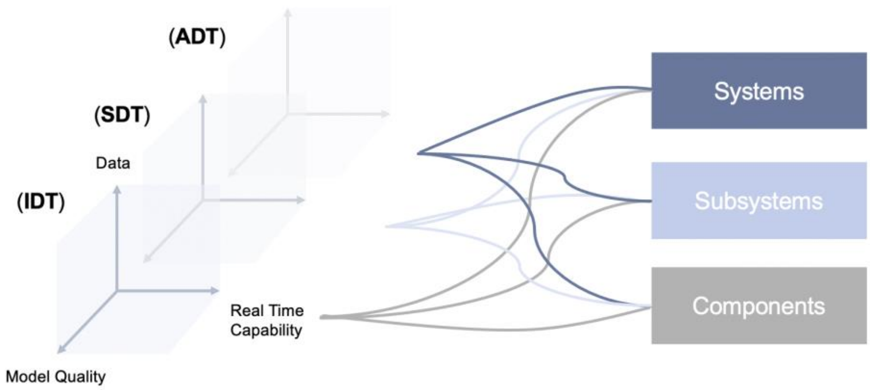

Figure 2: Generic classes and characteristics of Digital Twins

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4 APPLICATION SCENARIOS FOR DIGITAL TWINS

Several potentials such as the usage of the concept throughout the whole life cycle are often mentioned in the context of the Digital Twin. This does not necessarily mean that it is used in every single phase of that life cycle. The application scenarios show a combination of a technical implementability and the economical use. They emphasize that the Digital Twin does not go along with a complete digitization of the physical product but in the end rather results into an economic question. This is an essential step towards a successful implementation of the Digital Twin. Hence, the previous mentioned classification should not be viewed as maturity level in which reaching out the last level, the ADT, is desired. A composition of different classes is also possible and should be considered for the integration. Generally, three phases for the application of Digital Twins can be identified within the product life cycle: Beginning of Life (BoL), Middle of Life (MoL), End of Life (EoL). The Usage of Digital Twins is varying with these different phases and has different aims that can be transferred into main business scenarios afterwards.

4.1 Phases of a Digital Twin

4.1.1 Beginning of Life (BoL)

In this phase the potentials and use cases for the product development are focused. For example, a physical prototype can be equipped with additional sensors and a Digital Twin concept. Through this, the prototype can be analysed thoroughly, and data can be directly linked to specific system elements. This allows that physical prototypes can be tested and validated in early stages very precisely. These physical prototypes might even be equipped with sensors just for this specific testing purpose. This shows that a Digital Twin might not only be used for after sales services. Especially at the beginning of the life cycle during the analysis of prototypes an IDT might be the proper class of a Digital Twin. It ensures that relevant data can be collected but does not require significant changes of the physical product or other design efforts. The model quality is rather high in these phases to ensure an optimal analysis that is not heavily restricted by time.

4.1.2 Middle of Life (MoL)

The second phase takes place during the usage phase of the product. In this phase aspects like continuous analysis are focused. Especially maintenance, repair and overhaul are a central benefit of a Digital Twin in this phase. It enables the predictive maintenance as actual data of the physical product can be analysed and simulated. This allows the prediction of the further lifetime expectation of individual components. These insights provide access to an early recognition of necessary maintenance operations and support the optimization of these. An example for this is offshore wind turbines (s. Figure 3). The restricted accessibility results into pricey maintenance operations. Therefore, it is crucial to plan these operations thoroughly and keep the amount of them as low as possible. Through the benefit of predictive maintenance, the Digital Twin is able to ensure just-in-time operations and conduct them only in necessary cases. For this business scenario the second (SDT) or third (ADT) class is highly recommended, as in many scenarios a human will not be capable anymore to process the incoming data by himself but needs the support of computer simulations or even predefined actions.

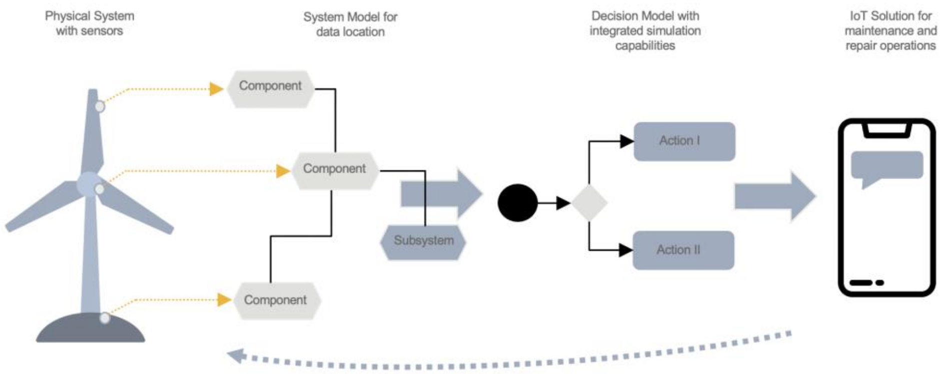

Figure 3: Example for a Digital Twin in MoL

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4.1.3 End of Life (EoL)

At the end of the product life cycle a continuous assessment is required to evaluate a continued use of the product, e. g. for aircrafts. The Digital Twin is able to directly connect received data from components, such as the degree of efficiency, and to calculate the overall benefits by adding other data and mathematical models. It supports the decision about the future of the product and prevents an early disposal or an uneconomical continued use.

4.2 Business Scenarios

These three dimensions can be translated into three generic business scenarios for the usage of Digital Twins. Especially this clear definition of possible scenarios enables enterprises to apply a suitable concept on their own constraints and product portfolio. The project revealed that many enterprises associate the Digital Twin with production optimization. In fact, the three generic business scenarios offer a much broader potential:

- **Establishment of Service Offers:** The aforementioned use of Digital Twins for predictive maintenance allows enterprises to establish services besides the conventional sales of their products. They can now use the untapped data lying within their physical products.
- **Digital Products:** It is a common phrase how urgent the digitization for enterprises is. Whenever it is not possible to provide service offers, e. g. if the data has to stay with the customer, the Digital Twin can be sold as a digital product besides the physical one. This turns conventional engineering enterprises more and more into digital enterprises. Especially SME will face a significant challenge with this as this requires an enhancement of their digital capabilities.
- **Continuous Improvement:** If the sale of a digital product or the establishment of services are not possible, which is mainly the case in consumer markets, the Digital Twin can be used to continuously improve the quality of the product. Data generated by the physical product can be analysed and directly linked to components of the product.

Nevertheless, these three business scenarios are not mandatory, as the implementation of a Digital Twin should be mainly an economically oriented question besides the technological possibilities. The focus on the utilization predominantly for SME seems reasonable as they lack specific capabilities for such a process. To ensure the integration of these mentioned use cases, the creation and standardization of Digital Twins must be further discussed.

5 FURTHER DISCUSSION

The variety of definitions published within the last years shows that the concept of the Digital Twin is still a topic in current discussions of research. It is therefore crucial to establish a definition that is separating the Digital Twin from other terms like the virtual prototype. This will help enterprises to precisely use the concept and guarantee a common understanding within supply chains. In fact, many components of a Digital Twin are already existing as sensors, models and IoT solutions are established factors of a modern product development. The obstacle that prevents a further push of the Digital Twin is the lack of a framework that combines the single components of a Digital Twin, as seen in Figure 4. This framework needs to meet the requirement of a universal application. While sensors can be made for specific purposes, the whole software development that is required for a Digital Twin has to be as adaptable and universal as possible to ensure a wide diversity of possible scenarios.

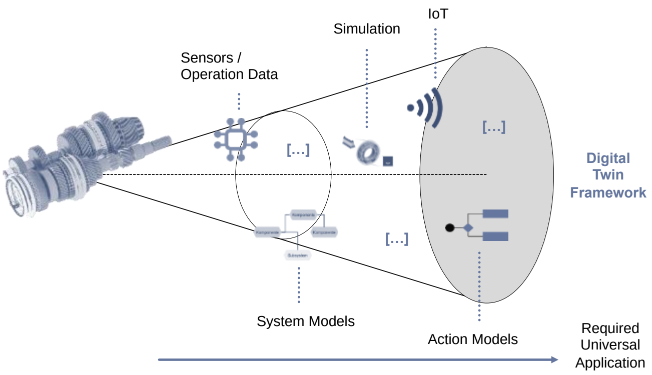

Figure 4: Key elements of Digital Twins towards a coherent framework

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Software vendors will have to meet this gap of frameworks by focusing the high additional efforts for SME. These will be confronted with an integration of development efforts of digital products and even further with the interdependencies with the physical product. This will make it impossible to develop individual concepts as they simply lack the development capabilities for these. It is therefore essential, to establish a further standardization of elements within the concept and introduce open exchange formats. They can guarantee that business models are technologically enabled, and the concept can be enhanced towards user specific needs which would be prevented by a limitation through a closed framework. These exchange formats will therefore have to meet three basic requirements:

- Readability: It is essential that models and connected elements of the Digital Twin can be read by tools. This means that either open formats are supported, as XML, or widely spread industry standards are used.
- Content: In addition to the readability the content of the exchanged data must follow specific standards to enable a common understanding of the data. Examples for this can be specific standards for the data construction.
- Extensibility: The Digital Twin describes a highly heterogeneous field of application. The possibility to integrate extensions that enable the integration of user specific adaptions of the concept are therefore crucial to ensure a widely spread acceptance.

6 SUMMARY & OUTLOOK

This paper has contributed towards the enhancement of the Digital Twin concept. Classical definitions were lacking a further classification of the Digital Twins which was introduced in this paper by defining different levels and dimensions. These can be used by enterprises that are struggling with finding a suitable Digital Twin concept for themselves. Overall, it contributes to the compensation of additional effort and provides support for the utilization of the concept in new product categories such as simple products. It gives first overview of possible business scenarios and shows different economical motivations for the use of it. Nevertheless, it has been identified that the usage of Digital Twins especially in these areas is still shaped by obstacles. Besides the economic questions and the identification of individual benefits of the concept a thorough analysis of technological possibilities has to be made.

These obstacles lead to the identification of several research tasks that have to be viewed within the next years to achieve a full integration of a Digital Twin concept within the industry. The development of these varies as much as the development of the physical counterpart varies. A Digital Twin for a simple roller bearing varies drastically from a complex system, e. g. a spacecraft. Therefore, a sufficient methodology has to be created that is capable of these differences and takes the interdependencies of this bidirectional development, physically and digitally, into account. Especially a focus on the system architecture during the development has to be set as the Digital Twin might influence this significantly by requiring additional sensors or components within the system. Enterprises that did not initiate this enlargement of their design capabilities will face a substantial challenge within the next decade and might lose their competitiveness. In addition, the motivation for model creation has to change. In current development areas it is viewed as a tool to test and validate the physical product. In future scenarios the model creation will become part of the product and has to be integrated in a suitable manner into the methodology. Approaches like MB(S)E already point into the right direction, where models are a key element. However, these approaches are still focused on complex technical systems. First changes in the usage of MBSE were identified, as more and more non-conventional users and their supply chains adopted this approach. These additional challenges coming along with it can be transferred to an integration of Digital Twins in these sectors, too. The answer to these challenges will be a main research topic for the future that has to be elaborated in accordance with technological possibilities and the economical feasibility.

ACKNOWLEDGMENTS

The Authors would like to thank the German Research Association for Drive Technology (FVA e.V.) for funding the trend study FVA 889 I “Digital Twin”.

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https://doi.org/10.1017/pds.2021.129 Published online by Cambridge University Press