WiGeP-Position Paper: “Digital Twin”

Digital twins combine and expand the existing digital models in development with novel data streams of operational management of products, machines and services. Digital twins will change the product creation process substantially and enable new business and value creation models.

Research into the conceptual foundations, practical implementation and beneficial application of *digital twins* along the product life cycle is an essential interdisciplinary area of research at the Scientific Society for Product Development (WiGeP). This position paper summarizes the current findings and outlines seminal theses and expectations for future research activities and their industrial implementation. WiGeP deliberately takes a leading role in this context in order to decisively guide and shape the research and development activities around *digital twins* in accordance with the future orientation of Industry 4.0 in Germany, the associated innovations of the circular industry in Europe and the intensified global competitive situations in the environment of digital transformations in key industrial sectors.

INTRODUCTION & EXPLANATION

A *digital twin* is a digital representation of a product instance (real device, object, machine, service or intangible good) or an instance of a product-service system (a system consisting of product and associated service).

This digital representation includes selected features, states and behavior of the product instance or system. Similarly, different models, information and data are linked together within this digital representation during different life cycle phases (see [1] and [2]).

A *digital twin* can be derived from the *digital master* or generated from the real product instance. A *digital shadow*, on the other hand, can also contain data from a real product instance and can map information about its production and accordingly, a *digital shadow* is understood as a subset of a *digital twin.* The *digital twin,* therefore, contains links between the *digital master* and the *digital shadow.* The *digital master* contains the product geometry as well as behavioral models of this product or system. The *digital shadow* acts as an image of the operating, status or process data of the real product instance, also with regard to its manufacturing. A *digital twin* is able to capture and store, process and provide corresponding data of the associated product instance or even communicates bilaterally with the physical product instance [3]. It thus allows access to, for instance, production, assembly, measurement, operating, reconfiguration or maintenance and recycling data. This product-instance-specific data can either be managed directly via the *digital twin* or by accessing one of its subsets, *the digital shadow.*

A *digital twin* has its own life cycle, but this is related to the life cycle of the associated product instance. Instantiation will subsequently take place once the corresponding production approval, on the basis of the *master* or by entering data from the physically existing product instance or parts of it, has been made. This can, for example, occur at early stages of production, at the time of commissioning, or later for an active product instance (see Figure 1).

A *digital twin* can:

- be developed as part of a product or system and in conjunction with a *Digital Master* or
- be developed for an already existing product instance or parts thereof, or
- be adapted to specific application areas by configuration or parameterization.

A *digital twin* can be used, for instance, for the purpose of diagnosis and prognosis of the real product instance behavior, as well as for the protection of new product generations. Similarly, new business models for products, systems or product service systems could also be developed. *Digital twins* are used directly by product users, within a service provided by the product manufacturer or in a service offered by third parties. The capability to model intelligent technical products, product systems and complex product-service systems is a fundamental prerequisite for modern product development processes and thus a core component of future development competencies. It is precisely this ability that plays a central role in the development and use of *digital twins* throughout the entire product life cycle.

Traditionally, one of the key tasks of product development is to create a *digital master model* before product manufacturing or service delivery. With this *digital master* model developed at an early stage, which could also be referred to as the original model, a product service system could, for instance, be set up with a view to enhancing it for various areas of application.

So far, these have been digital-mathematical computer-internal product models with the aim of creating *digital prototypes*. The primary purpose is to define the functionality and to prove, secure and optimize it by calculation or simulation.

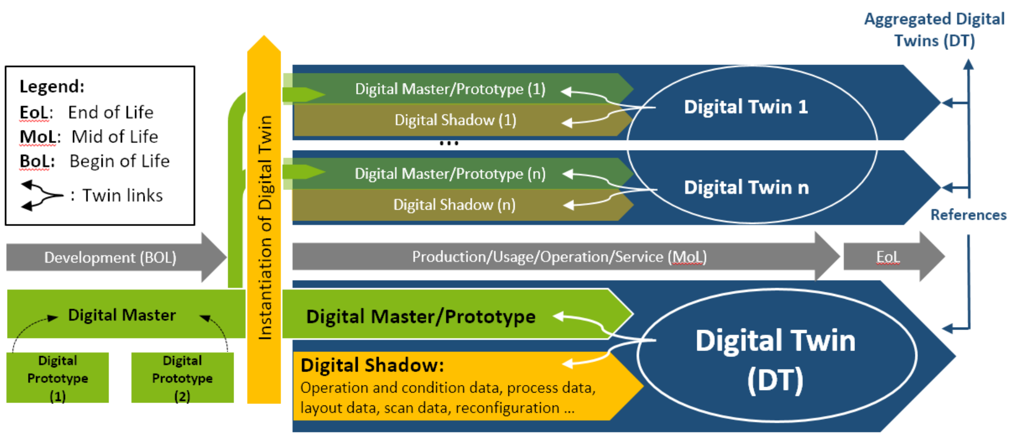

Figure 1: Definition of a digital twin in relation to a product (lower area) and a product instance (upper area) as well as to the digital master, digital prototype and digital shadow

Henceforth, the *digital twin* will play an important and expanded role in two ways:

1. For the development and specific design of the digital twins, existing digital representations must be expanded by further elements. These are, on the one hand, interface technologies, data transmission as well as networking and communication functionalities. On the other hand, capabilities are required to record, analyze, process and forward sensor data. This provides the basis for developing product-service systems with new service profiles.
2. From the already existing *digital twins*, the acquired know-how must be actively used in the sense of "Feedback to Design" (as part of an active knowledge return cycle). The *digital twin* is thereby used for the optimization of the current product as well as for the development of future generations of the product.

These major enhancements and changes in the environment of the *digital twin* justify the urgent need to have the Scientific Society for Product Development (WiGeP) position and explain the new and additional competences required for this. Based on this motivation, this paper examines the different types of *digital twins*, discusses the structure of *digital twins*, establishes the necessary expertise for the development of and with *digital twins* and outlines application scenarios for *digital twins*. Conclusively, recommendations for action are provided.

TYPES OF DIGITAL TWINS

Solution providers of digital systems, in particular, have been unable to make clear distinctions from the previous digital models of virtual product creation so far, with the result that industrial practice remains unclear as to the potential and forms of solutions offered by digital twins.

It is imperative to identify the different types of *digital twins*. A singular specification seems neither reasonable nor possible due to already existing divergent concepts. The instances of *digital twins* differ in a number of characteristics. The scheme shown in Figure , which is based on preliminary work by the authors ([4], [5]) and the analysis of the identified application cases, can serve to classify different concepts of the digital twin.

Application focus: The technical implementation of a *digital twin* is determined by the specification of the requirements and its objectives. The objectives can include not only information retrieval and analysis [6], but also decision support [7] up to the control of autonomous systems [5] or autonomous initiation and execution of operations.

The spectrum of applications in the life cycle phases of a technical system is enormous. A *digital twin* should represent the product instance as realistically as possible and thus be able to simulate its realistic behavior. Furthermore, the application domain and also the business model linked to the product influences the characteristics of a *digital twin*.

Model quality: A *digital twin* should be set up via the *digital master* right at the beginning of the product development phase and should be continuously further developed. Consistent model-based system development (*Model Based Systems Engineering*) through the networking of models enables to derive holistic statements in order to secure and optimize the functionality of a system during development. The *digital prototype* in development derived from the *digital master* can thus already be seen as a prerequisite for laying the foundations for a behavioral simulation of a *digital twin* in the use phase.

A *digital twin* must represent a product instance as realistically as possible for the respective addressed field of application. In this context, the term model quality defines how realistically a *digital twin* represents its physical product instance and what significance is associated with this in terms of scope, accuracy and applicability.

Considerable research is still needed to define the model quality of digital twins more precisely. Yet it is additionally necessary that compatible model quality levels and associated transformation methods are established in order to support the coarsening and refinement of digital twins and their adaptation to specific application contexts.

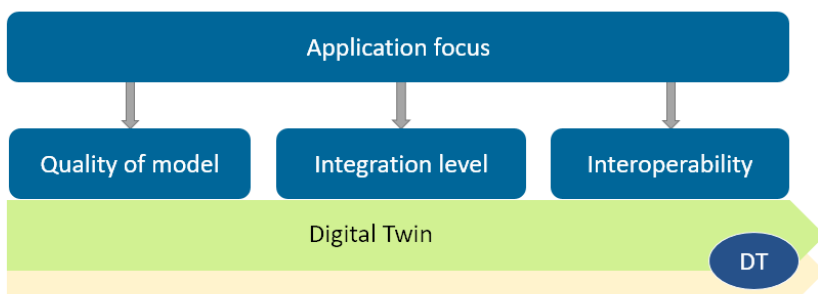

Figure 2: Characteristics of digital twins to distinguish between different types

Integration level / Interoperability: Digital twins are also characterized by their integration and interoperability capabilities. Integration is based on the aggregation of several digital twins and can be expressed by integration levels. Integration levels can include, for example, the functional or self-sufficient state of a product in the field, the systemic interaction of the product with its environment, the representation of a manufacturing component, a manufacturing machine, a production line, a production plant or a production location. Interoperability means that the individual digital twins are compatible with each other and communicate with each other. In addition, the interaction of *digital twins* is the subject of current and future research activities.

EXPERTISE REQUIRED FOR THE DEVELOPMENT OF DIGITAL TWINS

The information needed for the development of a *digital twin* is derived from the *digital master*, i.e. specific models from different disciplines of product development have to be mastered. Additional skills regarding economic efficiency and legal constraints as well as profound knowledge of information and communication technology and data science are also essential. The high complexity of the cause-and-effect relationships within a physical product places considerable demands on the skills required to develop *digital twins*. In the future, the specification, modelling and implementation of *digital twins* will become an integral part of product development as well as a new field of application for existing physical "products" to which a digital twin must be added.

The development of *digital twins* requires

- System expertise and
- Methodological expertise.

Systems expertise is understood as the ability to recognize, describe and model a complex realm of reality in its structure and behavior as a system [13].
Methodological expertise is required to use the specific structural and behavioral models of *digital twins*. Model integration and interoperability enable the integration of operational data for use in *digital twins*.

Thus, a *digital twin* can be operated with basic methodological knowledge. By interpreting aggregated data from digital twins, findings can be used for the further development of subsequent product generations. It is also necessary to establish the following professional qualifications for the representation of digital twins:

- To be able to build standardized technology stacks such as REST API, microservices and dynamic data formats
- To be able to develop semantic contextualization in the field of data analytics and artificial intelligence.

DIGITAL TWIN APPLICATION SCOPE

The understanding of *digital twins*, which can map and predict the state and behavior of the physical product from different perspectives, is the key factor for the development of new application potentials of *digital twins* along the product life cycle.

Furthermore, *digital twins* are increasingly getting into the core of new product service systems and business models, such as so-called "pay-per-use" business models, for which, in addition to the provision of a service by a machine, knowledge of its condition is crucial for sustainable success. In the following, different degrees of complexity of the implementation of digital twins are considered.

The continuous observation of the behavior of a real product using its *digital twin* enables the detection of behavioral anomalies and the initiation of reactive measures. One example is the real-time wear or error detection during remote monitoring, especially when the products are difficult to access. This also enables the use of a product service system, e.g. through consumption-dependent subsequent delivery of auxiliary materials. For both the machine manufacturer and the operator, this results in cost savings, since service technician assignments can be better planned or do not have to be carried out at all, and remote maintenance or repair can be carried out by technicians on site.
In case the *digital twin*, in addition to condition monitoring, has the ability to diagnose or forecast, i.e. to interpret current data from the field or, based on this, to predict future product behavior, then active measures can be enabled. This includes maintenance demand forecasting and preventive maintenance, which can also be planned efficiently and effectively over distance. It is also possible to expand the service portfolio of a product-service system by integrating further forecasting models, for instance in the field of car sharing, when a temperature-dependent preconditioning of the interior climate can be started when a user requests a service, especially for electric vehicles.

Figure illustrates the flow of information using a demonstrator for the test bench of an aircraft landing gear. The sensors of the demonstrator enable the behavior analysis in the digital twin and, for example, the development of control strategies to control disturbances during the landing process.

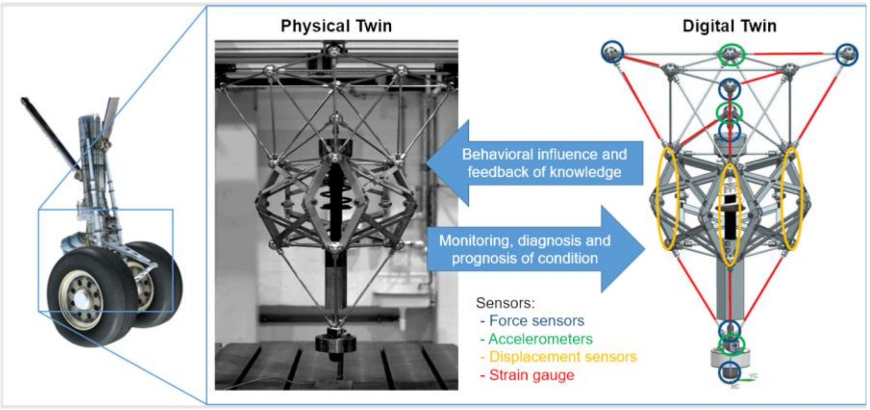

Figure 3: Demonstrator for experimental behavior analysis of an aircraft landing gear with sensor technology for coupling to the digital twin [14, 15]

The recognition and feedback of usage and behavioral scenarios of the real product via the *digital twin* into the product development enables the concrete definition of functional properties, beyond the acquisition of pure load data for dimensioning. Use and behavior of the real product in the use phase are important information for the development of similar products and for the determination of the requirements for the next product generation and for the estimation of the properties of the coming product generation life cycle. The knowledge return cycle at the demonstrator in Figure enables the revision of structural components and coupling elements with the goal of a lighter and at the same time more robust design.

Given the above features, the *digital twin* is an approach for the development and operation of sustainable systems. On the one hand, the status recognition and prognosis of the real product instance can be applied at the end of the use phase to make evidence-based decisions about its further use or reuse. On the other hand, based on the behavioral simulation conducted by the *digital twin*, it is possible to investigate more environmentally friendly, sustainable operating strategies for the real product instance.

A solid estimate of the efforts that will be necessary to initially implement *digital twins*, to represent them efficiently and to operate them permanently cannot be made at present. The reasons for this are diverse and, according to the following considerations, demand a broad and intensive examination as part of subsequent research:

- Differentiation between the *digital twin of a product instance* and the *digital twin of an entire product family*
- Type of *twin effect* between the *digital master* or *digital prototype* and the *digital data stream of the digital shadow* (see [1], [2])
- Aimed at explicit linking persistence or semantically implicit linking forms between digital shadow and digital master or prototype.

SUMMARY AND OUTLOOK

By presenting this position paper, the Scientific Society for Product Development (WiGeP) has acknowledged the portfolio of solutions for *digital twins* and the resulting expertise requirements as centrally important and pioneering. The understanding of the structure and the possible types of implementation of digital twins will be crucial for decision makers as well as for operatively active development and industrial engineers of companies in charge of products and services of technical systems. By this means, they will be able to offer and implement new and increasingly digital value creation solutions effectively in the future.

WiGeP, as the leading scientific society for product development, has aimed at conducting targeted research into the expertise and solutions around *digital twins*, to provide training concepts and to actively support companies in the introduction and implementation of *digital twins*. To achieve the skill-set to develop, maintain and integrate *digital twins* into technical systems it will be decisive to research and step-by-step establish new development capabilities in industry with regard to system and model based engineering (*MBSE, Model based Systems Engineering*) and the future methods and techniques of *Advanced Systems Engineering (ASE)*.

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