# The Interactive Relationship between Digital Twin and Industrial Design Activities

**Prof. Nermin KAmel Elgedawy**

**Professor, Department of Industrial Design, Faculty of Applied Arts, Helwan University**

**Assist. Prof. Dr. Osama Ali Elsaid**

**Assistant Professor, Department of Industrial Design - Vice Dean for Postgraduate Studies and Research, Faculty of Applied Arts, Benha University**

**Assist. Lect. Asmaa Gamal Mohamed**

**Teaching assistant in the Department of Industrial Design - Faculty of Applied Arts - Benha University**

asmaa.elgazz@fapa.bu.edu.eg

## 1. Definition of the digital twin approach

- Digital twin as an integrated Multi physics, multiscale, probabilistic simulation of a complex product, which functions to mirror the life of its corresponding twin. Digital twin (DT) consists of three parts: physical product, virtual product, and the linkage between physical and virtual products.
- The Digital Twin is a set of virtual information constructs that fully describe a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level.
- The digital twin is as a real mapping of all components in the product life cycle using physical data, virtual data and interaction data between them.
- The approach consists of a dynamic virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning, and reasoning.
- The digital twin concept is the use of a digital copy of the physical system to perform real-time optimization.
- A digital twin is a digital replica of a living or non-living physical entity. By bridging the physical and the virtual world, data is transmitted seamlessly allowing the virtual entity to exist simultaneously with the physical entity.
- One can be observed while the theoretical research and analysis, all the definitions are focusing on the three components of the digital twin concept: the physical model, the digital model, and data transmission.

## 2. Process of building a functional digital twin

In general, it takes six steps to create a fully functional digital twin. It should be made explicit though, in practice, manufacturers may not strictly follow the sequence to build DTs. It is also possible that these steps can be conducted concurrently.

**Step (1): Build the virtual representation of the physical product:** The enabling technologies of this step are computer-aided design (CAD) and 3D modelling. Both are commonly used technologies in product design. The virtual product includes three aspects: elements, behaviors, and rules. At the level of elements, the virtual product model includes the

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geometric model and physical model of the product, user, and environment, etc. At the level of behaviors, the authors not only analyze the behavior of products and users, but also focus on the analysis of the product and user interaction generated by the behavior and modelling. At the rules level, it includes the evaluation, optimization and forecasting models established following the law of product operation.

**Step (2): Process data to facilitate design decision-making**

Data collected from various sources (i.e., from the physical product, and from the Internet) are analyzed, integrated and visualized. Firstly, data analytics is necessary to convert data into more concrete information that can be directly queried by designers for decision-making. Secondly, since product data are collected from diverse sources, data integration is useful for discovering the hidden patterns that cannot be uncovered based on a single data source. Thirdly, data visualization technologies are incorporated to present data in a more explicit fashion. Finally, advanced artificial intelligence techniques can be incorporated to enhance a DT's cognitive ability (e.g., reasoning, problem solving and knowledge representation), so that certain simple recommendations can be made automatically.

**Step (3): Simulate product behaviors in the virtual environment**

The enabling technologies of this step include simulation and virtual reality (VR). The former is used to simulate key functions and behaviors of the physical product in the virtual world. In the past, simulation technologies are widely used in product design. On the other hand, virtual reality (VR) technologies play the role of involving designers and even users to 'directly' interact with the virtual product in the simulated environment. Recently, VR technologies are increasingly employed to support virtual prototyping and product design. Many readily available VR hardware devices can be directly adopted for digital twin.

**Step (4): Command the physical product to perform recommended behaviors**

Based on the recommendations of DT, the physical product is equipped with a capability, by means of various actuators, to adaptively adjust its function, behavior and structure in the physical world. Sensors and actuators are the two technological backbones of a digital twin. The former plays the role in sensing the external world, whereas the latter plays the role in executing the desirable adjustments requested by DT. In practice, the commonly used actuators that are suitable for consumer products include, for example, hydraulic, pneumatic, electric, and mechanical actuators. In addition, augmented reality (AR) technologies can be used to reflect some parts of the virtual product back to the physical world. For example, AR enables end users to view the real-time state of their products. Recently, AR technologies are increasingly applied in the factory domain production engineering.

**Step (5): Establish real-time, two-way, and secure connections between physical and virtual products**

The connections are enabled using a number of technologies, such as network communication, cloud computing and network security. Firstly, networking technologies enable the product to send its ongoing data to the 'cloud' to power the virtual product. The feasible networking technologies for consumer products include, for example, Bluetooth, QR code, barcode, Wi-Fi, Z-Wave, etc. Secondly, cloud computing enables the virtual product to be developed, deployed, and maintained completely in the ‘cloud’, so that it can be conveniently accessed by both designers and users from anywhere with an Internet access. Lastly, since product data are directly and indirectly concerning user-product interactions, it is critical to guarantee the security of connections. Considering the Internet of Things, much effort has been devoted to connecting the physical and virtual product, which can be adapted for the DT research.

**Step (6): Collect all kinds of product-related data from various sources**

There are three types of product-related data that should be processed by DT. For ordinary products, physical product data is usually divided into product data, environmental data, customer data and interactive data. Product data contains customer comments, viewing and download records. Interactive data consist of user-product-environment interaction, such as stress, vibration, etc... Using the sensor technology and IoT technology can collect some of the above data in real time, and analyze from the product manual, web page customer browsing records, download records, evaluation feedback, etc., can obtain the rest of the data. The collected data are fed to Step (1) to close the loop towards building more functional virtual product.

## 3. The design process considering the dominance of the idea of the digital twin of products:

A digital twin model of a product can continuously collect data for the entire product lifecycle stages such as design, manufacturing, production, quality inspection, and maintenance. etc… Therefore, the digital twin model can manage, track, and maintain the product by sensing, storing and presenting the data of the entire product lifecycle; The role of the digital twin in the data-driven product design process is as follows:

- **Communication between the digital twin and the designer (Users’ Needs Analysis):**

There is a reciprocal interaction between the product and the user, since the digital twin is a real-time digital representation of the physical product, it can interact directly with the end user and provide real-time product status information and timely suggestions for usage, maintenance and development services, such as (Avatar product) (an avatar is a representation of digital product for interaction with the end user on Facebook), as well as information available on the Internet for building User Profiles, whereby a user profile can be considered as the digital representation of a particular user in the digital world**.**

- The digital twin increases the designer’s understanding of the user and his requirements, as data related to the user is collected from various e-commerce, social, and research platforms on the Internet (such as vital activities and personal habits), and data is collected directly from various smart devices (such as smartphone and smart watches, and smart coffee machines) through the Internet of Things, as the associated information is used to improve the personalization of the product with the ability to adapt and offer and propose new functions and features of the product by analyzing users’ reviews on electronic platforms.
- The digital twin guides the designer to formulate the functional requirements realistically, where the functions that can all be detected by sensors and analyzed by the digital twin can be represented by basic information such as the number of times of use, the duration of use each time, the number of users, etc…

- The digital twin provides designers with information about capability where capability refers to the potential functions of a product that the user performs in the real world where information can be collected directly based on user behaviors from many smart products or through virtual reality technologies.
- The digital twin illustrates the different design constraints of a product because the digital twin is directed by product lifecycle management, being able to aggregate design constraints imposed by all relevant stakeholders, some examples of constraints include weight, size, budget, schedule, manufacturability, environmental standards, safety, etc…
- A digital twin designed to identify variations and problems of product parameters differences (ex. weight, speed, force, pressure, temperature, lighting, power, etc.).
- The Digital Twin identifies and simulates product-related uncertainties in the physical world that can impact product performance, function, behavior, and structure at different stages throughout the product lifecycle and simulates them in the digital world, so that more robust design solutions can be created and virtually validated.
- The digital twin identifies the different complexities associated with the product; There are four types of complexity resulting from design decisions, namely, real complexity, imaginary complexity, assemblage complexity, and periodic complexity. Possibly real complexity; in contrast if there are complications only by a limited number of users all the time, it is likely to be fictitious complexity).
- The digital twin integrates contextual information into the creation of the design, some contextual information such as time (when the product is used), location (where the product is used), how (activities of the product required to be performed), who (which user profile) and environmental conditions (such as temperature, light, sound, humidity); By comparing the hypothetical and the physical contexts, the designer can further understand the ideal and real contexts in which the product is used, to improve the product's adaptability.

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