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Digital Twin's Promising Future in Digital Transformation

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Abstract

Digital transformation is the process of using digital technologies to radically enhance the process, product, and service of companies and industries. One of the most promising tools for digital transformation is the digital twin; a physical entity's virtual replica that takes real-world data about a physical object or system as input and produces predictions or simulations through real-time reflection, interaction & convergence, and self-evolution. This paper gives a general overview on digital transformation with a particular focus towards digital twins. It specifically highlights the role of digital twins in the development, manufacturing, and utilization of products as well as in the ecosystem of smart cities.

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Introduction

Digital transformation is widely understood as the process of using technologies to radically enhance the performance of new or existing business processes, culture, and customer experiences to meet business fluctuations and market requirements. As a long-term initiative set to take over a 50% share of worldwide technology investment by 2023 [1], digital transformation is paving the path for business partners to adopt a streamlined workflow, IT leaders to secure their data, and employees to develop a more effective workforce. Additionally, a strong digital workplace can revolutionize any business making digital technology crucial for organizations to embrace in order to succeed.

Given the power of digital transformation, it is not difficult to see how it is connected to a company's survival or extinction. That is why it is described as the digital die-off reality [2]; a tremendous opportunity for those that embrace it and a death sentence for those that don't. However, success in these transformations can prove to be elusive. "Transformations are hard, and digital ones are harder [...] with less than a 30% success rate" according to McKinsey [3]. In 2019, despite $1.3 trillion invested in transformation initiatives, a staggering 70% hit roadblocks at companies like GE, Ford, and Procter & Gamble [4]. Lack of specific goals, the absence of clear strategy, inadequate risk management, insufficient resources and failing to focus on one of the most important elements – the customer experience - are some of the many reasons behind such companies' malfunctioned transformations. Despite the challenges, companies executing personalized employee communication platforms, adaptable workplaces, sentimental buying processes, and quantitative targets improved their stock prices and revenue in the long run. Well-known companies such as Microsoft, Hasbro, and NIKE showed a stock growth rate of 258%

within 5 years, 203% within 7 years, and 69% within 2 years respectively proving weighty improvements paid off, even if it was a risky road with many hiccups at the beginning [5].

Technological advancements have made the reimagining of many industries in the digital world possible. Data from a wide range of operational activities is now possible via the internet devices embedded in everyday objects; the Internet of Things (IoT) has become a powerful digital transformation tool. With 61% of enterprises showing some level of IoT maturity, data insight within digital business transformation is leading to high rates of success [6]. Artificial Intelligence (AI) is a vital tool as it helps analyze data, make decisions, and act on that data, often without involvement by humans. With an expected market of $125 billion by 2025 [5], AI is paving the path for innovative, efficient, and sustainable transformation. Not only does it enhance informed strategic digitization, but also enhances other essential digital transformation tools such as robotics, additive manufacturing, and augmented business. What's more, 5G promises to facilitate this further. With an approximate number of 1 billion 5G connections that will exist in 2023 [7], high speed and low latency will offer a more secure and efficient connectivity capability. This, with the acceleration of cloud and edge computing, will enable massive data transfers and bring digital transformation initiatives into high gear. Finally, high expectations are in place for digital twin technology, which is counted on as digital transformation's tool for replacing the physical world with the power of the virtual world. High-speed virtual simulation will help to reduce development time, production cost, and increase customer satisfaction. The digital twin market is estimated to grow from $3.8 billion in 2019 to $35.8 billion by 2025 at a compound annual growth rate (CAGR) of 37.8%. [8]. Gartner predicts half of all large industrial organizations will depend on a digital twin by 2021 [6].

Digital Twin – Definition and How it Works

A digital twin is a virtual imitation of an actual process, product, or service occurring in the real world. In other words, it is a model that takes real-world data about a physical object or system as inputs and produces as outputs predictions or simulations of how that physical object or system will be affected by those inputs. “At its optimum, any information that could be obtained from inspecting a physically manufactured product can be obtained from its digital twin”, suggested Grieves & Vickers [9].

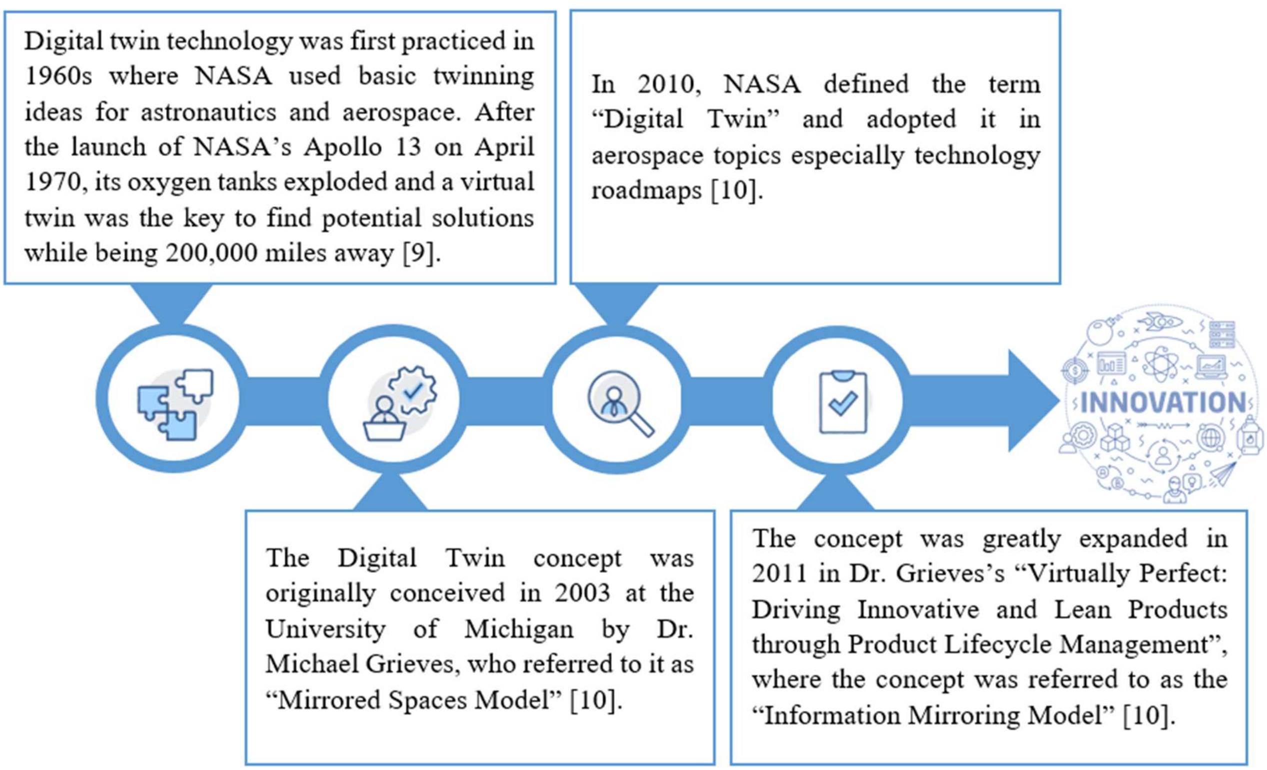

Figure 1: Digital Twin history and evolution

Currently, digital twin technology is based on three main aspects:

Real-Time Reflection

The virtual space is the real reflection of the physical space synchronized through incorporating sensors, simulation platforms, data analytics, and machine learning capabilities. Sensors are installed on physical objects to determine the objects' real-time phases and changes over time.

Iteratively collected data from physical sensors monitor the object's performance, operating conditions, and potential problems. Being comprehensive, it analyzes and aggregates both historical and real-time data resulting in a more credible convergence. The physical space and virtual space are not isolated in digital twin; smooth connection channels exist between the two spaces, made possible through the Internet of Things.

Iterative Interaction

Self-Evolution

Due to the closed-loop feedback and digital twin's intelligent factors, the virtual model undergoes continuous improvements without the need for human interaction. Based on the real-time data it is receiving, the physical-virtual environment provides necessary simulations for analysis and predictions.

Digital Twin and Product Lifecycle

As modern products become more complex and increasingly personalized, enterprises have challenges responding in a timely fashion to the market demand with guaranteed quality and competitive costs. Companies will be left behind if they do not adopt more adaptable and flexible processes. Digital information technologies, including digital twins, are being used to change how companies develop, manufacture, and provide on-going customer service.

Digital twins can be applied to the product lifecycle in 3 distinct phases:

1. ***Product Digital Twin***

Enterprises are using digital twins for the efficient design of new products. It provides a virtual-physical connection that lets companies analyze how a product performs under various conditions and make adjustments in the virtual world to ensure that the next physical product will perform exactly as planned in the field. Additionally, a digital twin is a mapping of the physical product and can make communication between clients and designers more transparent and faster. It can guide the improvement of the new product by making full use of customers' feedback and various problems that appeared in customers' usage of the previous generation. Siemens Healthineers, for example, developed a digital twin model of the human heart by which the system simulates the mechanical and electrical behavior of the heart, and applies machine learning techniques to create unique, patient-specific models based on medical imaging and electrocardiogram data [10].

2. Production Digital Twin

Digital twin technology can be used in production from the input of raw materials to the output of finished products. A production digital twin can be part of an overall smart manufacturing facility and help validate how well a manufacturing process will work by using a Digital Twin Shop-floor (DTSS) before anything goes into production. The DTSS uses product digital twins of all the manufacturing equipment to further optimize the production methodology.

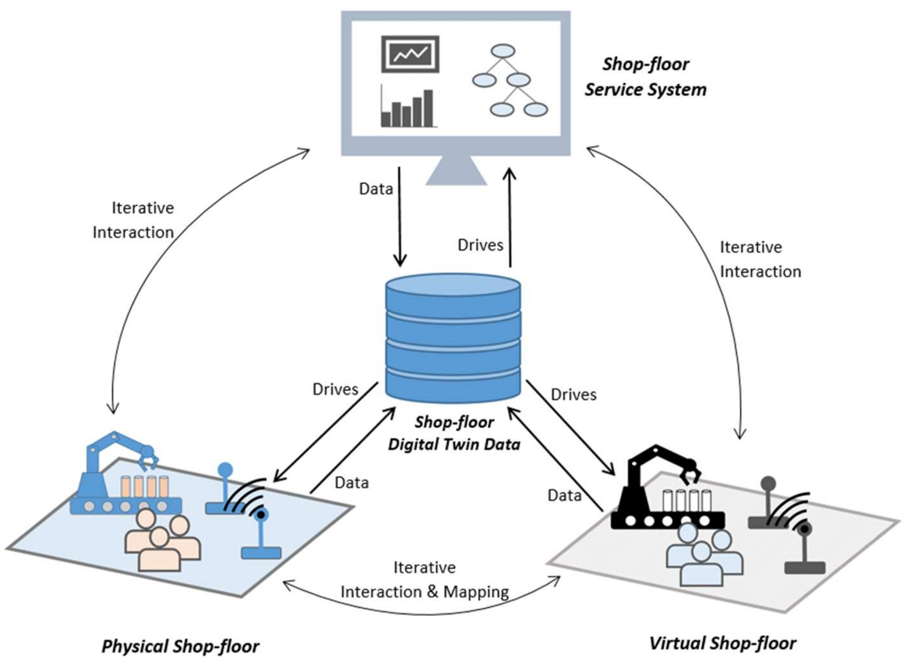

Figure 2: Digital Twin Shop-floor

As seen in Figure 2, the DTSS consists of four components: (1) Physical Shop-floor (PS) representing the actual assets and equipment, (2) Virtual Shop-floor (VS) with the virtual imitation of PS, (3) Shop-floor Service System (SSS) a computer program configured to iteratively interact with and connect both PS and VS, and (4) Shop-floor Digital Twin Data (SDTD) where monitored data, analyzed data, algorithms, results, and predictions are stored.

Industry 4.0, the fourth revolution in manufacturing, signifies the transformation of legacy sites into promising autonomous manufacturing facilities driven by consistency, flexibility, and efficiency [11]. This is accomplished by the rising of digital industrial technologies that gather and analyze data across machines. Digital twin technology is rapidly being adopted across various use cases in industrial fields as its enhancements are consistent with technologies important for Industry 4.0, as shown in Figure 3 below.

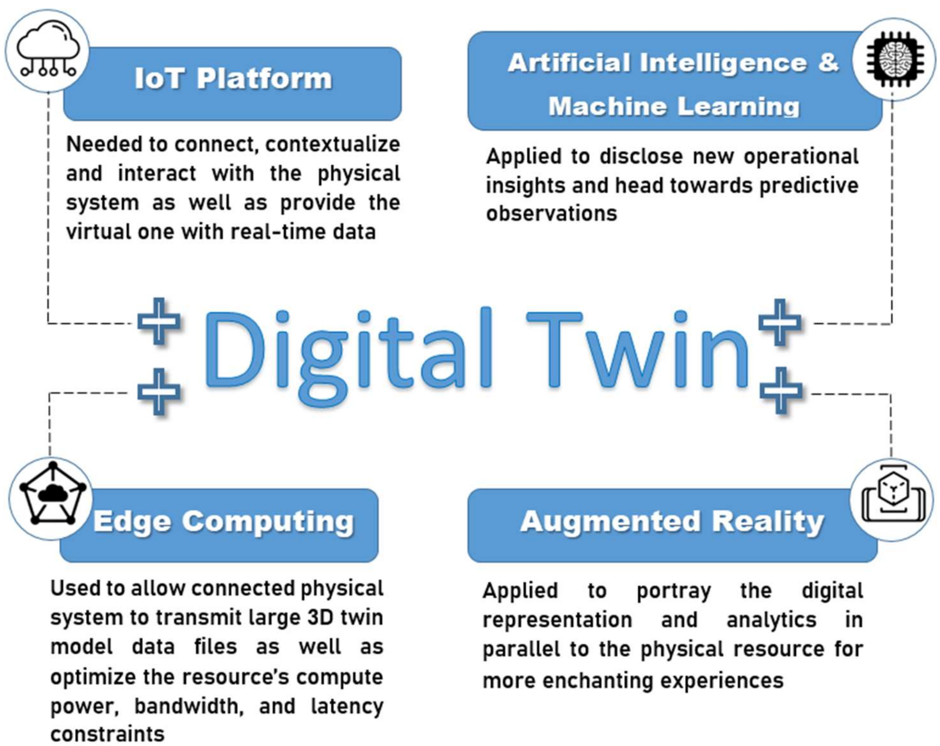

Figure 3: Industry 4.0 Technologies Contributions

3. Service Digital Twin

The digital twin for product service captures, analyzes, and acts on usage data to provide actionable insight for informed decision making. It refers to the phases after-sale including real-time product operation state and maintainability. This helps gain insight to improve virtual models and enhance the product and production of digital twins while the physical product is still in use.

Digital Twins in Use: Automotive Industry

The revolutionary digital twin technology has changed the dynamics of the automotive industry. The digital twin of the product comprises the entire car, its software, mechanics, electronics, and physical behavior. The product digital twin can optimize the driving performance of a car, airflow & heat development, and material behavior. Using the production digital twin, each step of the manufacturing is simulated in order to identify problems and optimize the factory floor before producing real parts. The service digital twin can look at consumer usage and satisfaction data (for example, reliability both pre and post-warranty period) and map it back to the product design and manufacturing processes for ongoing improvement.

With the advantages of increased fuel efficiency and greenhouse gas (GHG) emission reduction, electric vehicles (EVs) have been taking an increasingly greater share of the private and commercial automobile market. By introducing a mobility model with a digital twin, EV's behavior and interaction simulations can study the efficiency and quality of the charging stations and EVs from both the supply and demand-side. The digital twin EV is modeled with the same physical and electrical profiles and traffic characteristics as the real-world EV in terms of mobility pattern, travel demand, energy consumption, and supply. Through tracking a series of driving operations, such as steering, accelerating, and braking, the digital twin EVs can be matched to consume exactly the same energy as the real-world EVs. Consequently, this method offers a realistic and reasonable moving trajectory analysis of EVs while enhancing the charging scheduling algorithms and charging station position deployments.

Digital Twins in Use: Smart Cities

Digital twins of cities have recently attracted attention as a useful virtual platform that captures changes to the physical environment in the city and all associated activities and movements. This became possible due to sensors, Unmanned Aerial Vehicles (UAVs), satellites, and mobile networks that monitor real-time data a smart city uses to achieve smart real estate, transportation, construction, building, home, parking, and other infrastructure facilities as seen in Figure 4.

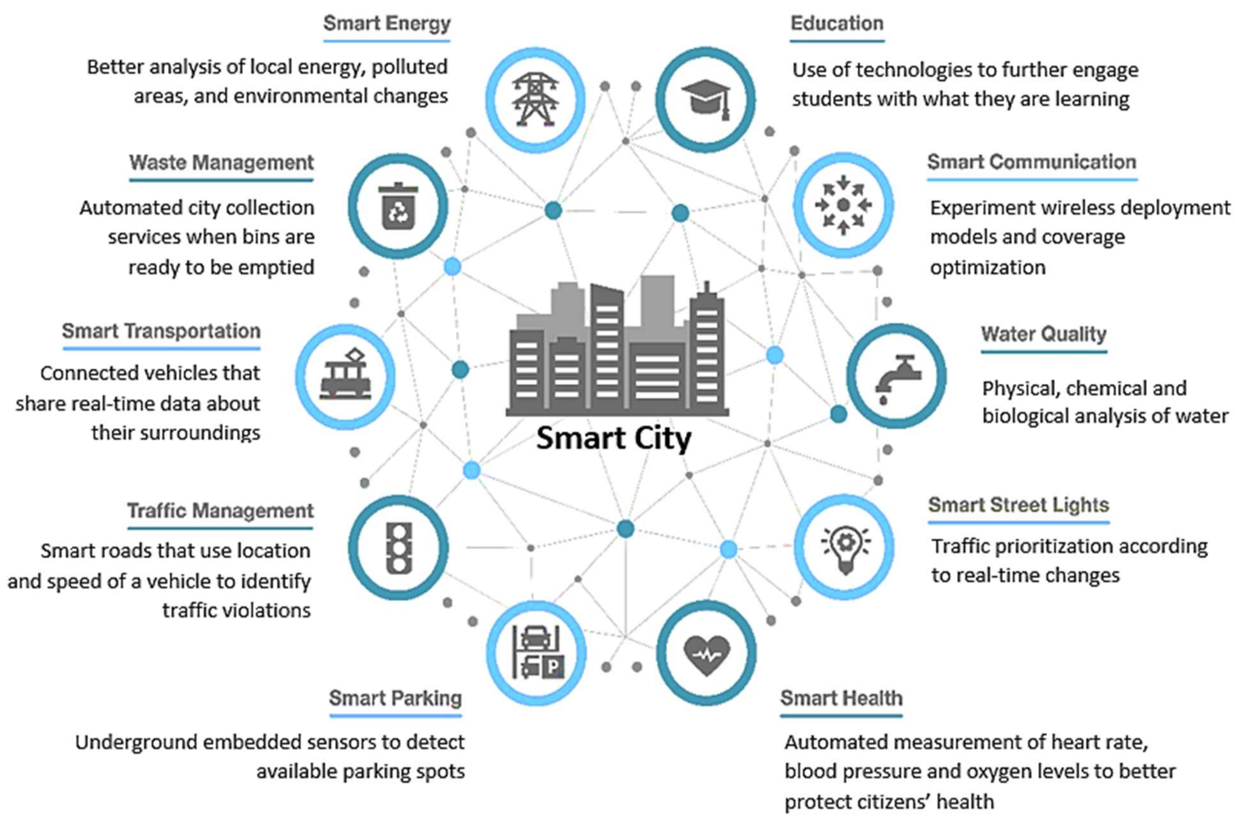

Figure 4: Benefits of Smart Cities

In November 2014, Singapore invested $73 million in its smart city initiative under the name Smart Nation; a smart city that strives to provide sustainable communities through using digital technologies [12]. Singapore created a plan for national digital infrastructure, society, and government wherein every company must increase its digitization efforts with assistance from the Government Technology Agency. Transportation management is based on historical data and real-time passenger analysis to make automatic adjustments based on demand levels. “We are doing a traffic simulation and instead of looking at two-dimensional dots, we are looking at virtual cars or trucks or taxis,” said Ronnie Lee, deputy director of Singapore’s Geospatial Specialist Office [12]. The next potential step for Singapore could be integrating and sharing city data through a collaborative effort involving 50 companies for cost savings and further efficiencies in scaling. [13].

Conclusion

Marshall McLuhan famously observed, “First we build the tools, then they build us,” reflecting the fundamental shift and impact digital twin technology has on the scope of engineering as it widens the scale of human imagination. The product lifecycle and smart cities are just two examples of domains that are already being greatly impacted by digital twins. Implementation of digital twin technology as part of an overall digital transformation of an enterprise can be powerful given the impact on productivity, operational efficiency, and customer satisfaction. In the future, digital twin technology will be continuing to be applied to even more industries, catapulting businesses into their next level of digital transformation, where the physical and virtual assets will no longer be distinct.

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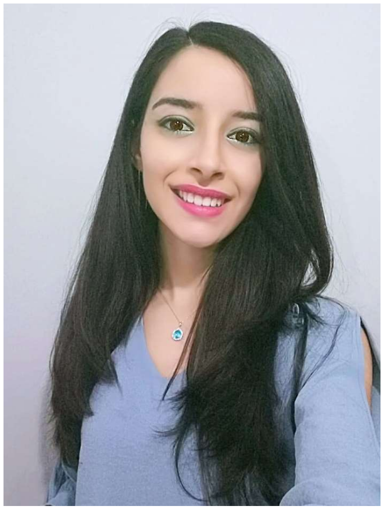

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