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DERLEME MAKALESİ / REVIEW ARTICLE

EVALUATION OF DIGITAL TWIN TECHNOLOGY

DİJİTAL İKİZ TEKNOLOJİSİNİN DEĞERLENDİRİLMESİ

Aliye Kübra ÜNAL[1]

Assoc. Prof. Dr. Aynur TORAMAN [2]

ABSTRACT

A digital twin is a digital representation of a physical entity that reproduces the data model, behavior, and communication with other physical entities. Digital twins act as a digital copy for the physical object or process they represent, providing near real-time monitoring and evaluation without being in close proximity. While most of its tangible applications are found mainly in industrial contexts, healthcare represents another relevant area where digital twins can have a major impact. The aim of this article is to give theoretical information about the definition, principles, roles, stakeholders and history of the digital twin concept. From this point of view, the articles in the field were examined and a review paper was created. It is also to create a comprehensive framework about digital twin applications in healthcare. After providing an overview of the application of digital twins in health services, the vision of this concept, which has recently found a place in research in Turkey, is discussed.

Keywords: Digital Twin, Health, Healthcare Management, Future in Health.

ÖZET

Dijital ikiz, fiziksel bir varlığın veri modelini, davranışını ve diğer fiziksel varlıklarla iletişimini yeniden üreten dijital bir temsilidir. Dijital ikizler, temsil ettikleri fiziksel nesne veya süreç için dijital bir kopya görevi görerek, yakın mesafede bulunmadan neredeyse gerçek zamanlı izleme ve değerlendirme sağlar. Somut uygulamalarının çoğu esas olarak endüstriyel bağlamda bulunsa da sağlık hizmetleri, dijital ikizlerin büyük bir etkiye sahip olabileceği başka bir ilgili alanı temsil eder. Bu makalenin amacı dijital ikiz konseptinin tanımı, ilkeleri, rolleri, paydaşları ve tarihçesi hakkında teorik bilgiler vermektir. Bu noktadan hareketle alandaki makaleler incelenmiş ve derleme bir çalışma oluşturulmuştur. Ayrıca sağlık hizmetlerinde dijital ikiz uygulamaları hakkında kapsamlı bir çerçeve oluşturmaktır. Dijital ikizlerin sağlık hizmetlerinde uygulanmasına genel bir bakış sağladıktan sonra, özellikle Türkiye'de nispeten araştırmalarda kendine yeni yeni yer bulan bu kavramın vizyonu masaya yatırılmıştır.

Anahtar Kelimeler: Dijital İkiz, Sağlık, Sağlık Yönetimi, Sağlığın Geleceği.

1. INTRODUCTION

The era of digital transformation witnessed these days is produce an huge effect in the industry and business sectors. The devastating effect of the digital transformation witnessed today has started to come to the fore more after the COVID-19, with the interruption of many operations

[1] Suleyman Demirel University, Social Sciences Institute, Health Management Doctoral Program, PhD Student, unal.kubra@hotmail.com.

[2] Suleyman Demirel University, Faculty of Economics and Administrative Sciences, Department of Health Management, aynurtoraman@sdu.edu.tr.

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in the industry and business sectors. After the COVID-19 that affected the world, it is obvious how successful those who adopted and started to implement a digital transformation strategy, from the sectors whose operations were interrupted, compared to those who did not adopt the digital transformation strategy and did not start to implement the digital transformation strategy (Fan et al., 2020, p. 7). Industries that have adapted to the digitally transformed business world have had the advantage of being connected, an indication that they are better at many things than others who have not survived. For instance, businesses that transform digitally are in touch with their employees everywhere and anytime, they maintain their business processes and reduce the effects of disruptions with improved customer experience, increased efficiency and profitabilitys (Fan & Mostafavi, 2019, p. 5).

The components of this digital transformation process are numerous and encompass all aspects of business units, from IT processes, automation and artificial intelligence to preparing the workforce for such a revolution. In his survey of successfully digitally converted businesses, Mckinsey listed the digital technologies, tools, and methods these organizations are using to achieve their goal of digitization (Manyika et al., 2011, p. 3). Prelusively, the deployment of traditional web and mobile technologies tops the list alongside cloud-based services that allow for the expansion of business resources and accessibility to employees and customers. The second is to integrate Internet of Things (IoT) technologies to collect data from any desired source, then use Big data architectures and analysis techniques to derive business decisions. In addition, the use of Artificial Intelligence (AI) and machine learning algorithms can improve the transformation process by predicting trends, detecting correlations and providing insights. A final resource is Augmented Reality (AR), which enriches the digitization process by providing an immersive experience for system users (Hamadache et al., 2016, p. 24).

A critical requirement for integrating and deploying all these technologies in the digitization process is to have a reliable, high-performance, ultra-fast network connection using the latest network technologies. The network requirement is critical as it will enable the data transfer process from physical systems to cloud-hosted databases to be used for data analytics and to deploy artificial intelligence algorithms for predictions and insights. The network also interfaces physical systems via web or mobile platforms, allowing users to visualize real-time updates of physical systems. Additionally, through these interfaces it also allows users to control and trigger actions without being physically present within the physical system. This type of distribution is called Digital Twin (Castillo, 2016, p. 23).

The technology, which basically starts out with the aim of solving all kinds of human problems and changes our lives as it develops, also changes the structure of our problems as it is structured in the hands of human beings. The adequacy of the solutions found and the products put forward is questioned, and the problem evolves from finding a solution to finding the best and most rational solution. In this order, it gains great importance in order to make the future predictable, to minimize any possible problems and to reach the ideal. Digital Twin stands out precisely in this context (Jarrahi, 2018, p. 581).

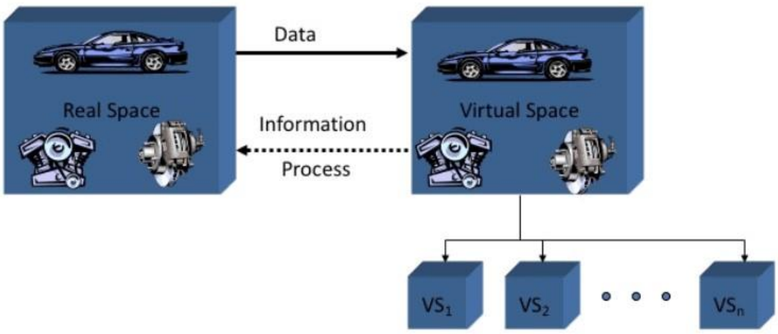
Digital Twin can be defined as the creation of a digital copy of any product, process or service without being physically exposed. Sensors integrated into a physical object collect real-time data about different factors of the object's performance. This data is transferred to a processing system and processed as input to the digital model. The created digital twin plays a role in understanding, analyzing, manipulating and optimizing the object. This means that by means of digital twins, the current performance of the object can be analyzed and predicted for the future, as well as the problems that will occur before starting production can be predicted and performance improvement can be made. In this way, both time and cost savings are achieved (Haag & Anderl, 2018, p. 65).

In this study, the concept of Digital Twin and what it represents are defined and explained in Chapter 2, then Chapter 3 includes some technologies that Digital Twins are commonly associated with in the digital transformation process. Chapter 4 has mentioned on the areas where Digital Twins are applied, and Chapter 5 details how the concept of digital twin is used in health care, which is one of these application areas. In Chapter 6, the advantages and disadvantages of the digital twin are mentioned. Finally, the article ends with a conclusion and an overview for future work in this area in Chapter 7.

2. HISTORY OF THE DIGITAL TWIN

The idea of Digital Twin technology was first mentioned in 1991 through David Gelernter's book "*Mirror Worlds*". Its application was first developed by Dr. Michael Grieves in 2002 for NASA's matching technology and the digital twin software concept was officially announced. Dr. Michael Grieves have stated that the history of the digital twin concept dates back to the University of Michigan's presentation to the industry in 2001 for the creation of a Product Lifecycle Management (PLM) center (Grieves and Vickers, 2017, p. 92). The visual of the presentation slide used in the presentation and created by Dr. Grieves is shown in Figure 1.

Figure 1. Conceptual Ideal for PLM



Resource: Dr. Michael Grieves, University of Michigan, Lurie Engineering Center, Dec 3, 2001.

While his slide is simply titled "The Conceptual Ideal for PLM" it is emphasized that it has all the elements of the digital twin outlined below. These elements can be listed as follows (Grieves, 2016, p. 4);

- Real Space,
- Virtual Space,
- Connection for data flow from real space to virtual space,
- Connection and virtual subspaces for information flow from virtual to real space.

John Vickers, working at NASA, introduced the concept of "*digital twin*" in 2010. NASA's digital twin concept was used to predict the lifespan of flying twins and to understand their ability to complete their mission. The Digital Twin has been defined by NASA as "*It is an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc. to reflect the lifetime of its flying twin. It is ultra-realistic and can take into account one or more important and interdependent vehicle systems* (Shafto et al., 2010, p. 3)."

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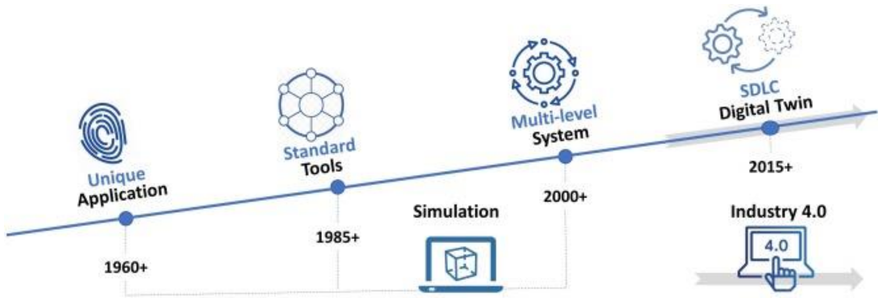
The concept of digital twin can be considered a relatively new concept. When the studies are examined, it can be said that some studies are actually simulation studies. The depth of the digital twin concept is still the subject of research. For this reason, there are studies examining how definitions have changed. Negri et al., (2017) stated that these definitions were used for the aviation sector between 2010 and 2013, the first studies for the manufacturing sector were put forward in 2013, and there were digital twin studies in 2015 that included a general product concept.

There are studies that improve this definition by adding other components to existing definitions. Grieves' definition of a digital twin is a 3-dimensional structure that describes the physical entity, the real model, and the data connection between them. Tao et al., (2018) added the concept of digital twin data and services to this structure and expanded it to a 5-dimensional structure in 2018. The digital twin data represents the asset that collects information from both the physical asset and the virtual asset. The structure that processes this data is called a service.

Coelho et al., (2021) added the decision support system to the digital twin components and expanded it to a 6-dimensional structure in 2021. In the study, it is mentioned that it is the first orientation to obtain the digital twin for in-house logistics (intralogistics) and focuses only on the visual system (simulation model) and decision support model. By using Simio software, the foundations of two different simulation-based decision support models that can be used for distribution channels and production areas have been established.

Digital Twin technology is considered to be one of the main 4th Industrial Revolution technologies. Like Microsoft, IBM, General Electric and Tesla etc. industry giants are developing digital twin technology and directing the 4th Industrial Revolution. This improvement is shown in Figure 2.

Figure 2. Advancement of the Digital Twin with Technological Advances



Resource: Harris (2020).

The basis of the health-related digital twin phenomenon is actually based on the approaches of Descartes and some other philosophers. Descartes was perhaps the first to ponder philosophically on the idea of such "*automata*" (Descartes, 1980, p. 32) and contemporary philosophy is in fact replete with twin-like creatures such as "*doppelgangers*" (Putnam, 1996, p. 35), "*zombies*" (Kirk, 2008, p. 82), and "*swamp-men*" (Donald, 1987, p. 447). This is proof that the idea of "*copying*" about human health is far from new. Although these philosophical approaches may seem interesting and different, they have also been stated to be controversial from time to time. They have been particularly criticized for being "*intuition pumps*" designed to trigger and direct individuals' intuition (Dennett, 2013, p. 320). But in the past, seemingly unlikely versions of digital twins have begun to materialize in healthcare. Recent work on the digital twin has strengthened the possibility of creating a dynamic (i.e. constantly updated) copy of the human body, or at least parts of the human body (Bagaria et al., 2020, p. 3; El

Saddik, 2018, p. 88; Jimenes et al., 2020, p. 90; Van Houten, 2018, p. 16). Especially after these researches in the field of health, interest in the concept of digital twins began to increase. But the digital twin is not a robot. Therefore, the health-related origin of the concept is based on that of Descartes. In this context, the phenomenon has been put forward as "*a system that somehow copies an individual, a part of an individual or a set of individuals*" (Descartes, 1980, p. 32). Based on this definition, it is seen that the digital twin has developed within the framework of the concept of "*digital model*", which is more common today in the field of health. As early as 1960, radiologists have started using rudimentary computational models of phantoms. Phantoms are objects employed in medicine or other fields to replicate the reaction of human tissue to certain processes (e.g., to radiation). The digitalization of phantoms resulted in digital phantoms. The digital phantom is in many ways the ancestor of the digital twin. In this context, it is seen that the first use of the term digital twin in health emerged in the field of medical imaging in 1994 (Renaudin et al., 1994, p. 580). As the definition above suggests, a digital twin is more than just a digital model. This difference is captured by the word "*living*" in the definition above which implies that a digital twin is connected to the real-life counterpart in a way a mere model is not (Kritzinger et al., 2018, p. 1019). The continuous adaptation of the twin to the real-life counterpart is helped by various technologies such as sensors, high-speed communication, cloud computing, artificial intelligence and many more (Raden, 2020, p. 15). The digital twin is therefore not one technology but a technological cocktail. In healthcare, the following fields are expected to be impacted by the advent of digital twins: personalized and precision medicine (Harris, 2020, p. 3), "*to build biologically detailed digital reconstructions*" of a brain or a heart, particular models for specific conditions such as brain aneurisms (Shugalo, 2019, p. 8), simulation models for operations and other interventions by using the "-omics": "*genomics, biomics, proteomics, or metabolomics, as well as physical markers, demographic, and lifestyle data over time of an individual*" (Raden, 2020, p. 24), drug discovery through in silico (organ-on-a-chip) clinical trials (Shugalo, 2019, p. 16).

3. CORE TECHNOLOGIES RELATED TO DIGITAL TWIN

A Digital Twin can be defined as a digital model of a physical system and its ongoing processes deployed via a data link that allows the physical system to be converted into a virtual one while maintaining a high level of synchronization between them. However, there are some common misconceptions about Digital twins (Table 1). These common digital twin misconceptions include digital twins, 2D/3D modelling, system simulation, validation computation, digital prototyping etc., due to closely related technologies such as (Boschert & Rosen, 2016, p. 62). For example, when looking at simulation studies, a virtual version of a product or system is seen. The point that distinguishes the concept of digital twin from the concept of simulation is that there is data and an information flow as a result of processing this data between the physical and virtual system. Here we are talking about a real-time data stream (Van Dijk, 2020, p. 15).

Similarly, Fuller et al., (2020) of highlighted the fundamental difference between digital twins and digital models/shadows of systems regarding the nature and direction of data flow between physical and virtual systems. In digital twins, data flow is automatic and is integrated in both directions between physical and digital systems to synchronize the digital object with the current state of the physical and also send control information to it. The entire data cycle is integrated. This is also highlighted in Grieves (2016) and Tao et al., (2018) where the fundamental element of digital twins is defined as the link between digital and physical systems carrying data and control information between them. A digital twin with these data can provide all necessary information about the physical system in real time, making it the most suitable target for digital twins.

Table 1. Misconceptions About Digital Twin

Term	Definations and Differences
Digital shadow	A digital shadow contains a physically existing product and its virtual twin, but it has only a unidirectional data connection from the physical entity to its virtual representative, meaning the virtual twin only digitally reflects the physical product.
Digital modelling	Modelling is the essential aspect of a digital twin but is not an alternative term to represent digital twin as a whole. There are bi-directional data connections between the physical product and its virtual twin; however, the data is exchanged manually, meaning the virtual twin represents a certain status of the physical product with the manually controlled process of synthesis.
Digital thread	The digital thread represents the continuous lifetime digital/traceable record of a physical product, starting from its innovation and designing stage to the end of its lifespan, and it plays an important role in the digitalisation process and functions as the enablers of interdisciplinary information exchange. Also, the digital thread is healthcare data, including real-time data detected from medical and wearable devices or external factors, simulation data from digital models, historical health data and electronic health records (EHRs) from healthcare institutions, and service data from platforms that enable the communication between the physical and virtual objects and spaces.
Simulation	Simulation refers to the important imitating functionality of digital twin technology from the virtual twin’s perspective, and simulation indicates a broader range of models; it is an essential aspect of the digital twin rather than an alternative term representing digital twin, as it does not consider the real-time data exchange in between the physically existing object.
Fidelity model/Simulation	Fidelity refers to the level of imitation state of a simulation model compared with the physical product it is reproducing. It is common to find terms like high/low/core/multi fidelity model/simulation, which describe different fidelity levels or considerations while building up the simulation model. It is also frequently found that researchers use high fidelity or even ultrahigh fidelity to describe the common feature of the digital twin considering its real-time dynamic data exchange between the physical object and virtual twin.
Cyber twin	Some researchers referred to cyber twin and digital twin interchangeably as a result of understanding “cyber” as another alternative term for “digital”. It is also common to see terms like cyber digital twin, cyber twin simulation, cyber-physical system, and so on. The key aspect the cyber twin or cyber-physical system would like to address is a network (internet architecture), closely related to the advancements and implementations of IoE (Internet of Everything). It is also common to mix the cyber twin or cyber-physical system network architecture with a digital thread.
Device shadow	It is common to find research on device shadow in areas of cloud computing platforms and the Internet of Things (IoT). Device shadow highlights the virtual representation of the physically existing object; in brief, it refers to the service of maintaining a copy of information extracted from the physical object, which is connected to IoT.

Resource: Jones et al., (2020); Liu et al., (2021); Sepasgozar (2021); Singh et al., (2021); Zhang et al., (2022).

Without a thorough understanding of the digital twin and its associated technologies, it is common to be confused with one of the core technologies, and often the elements or steps of the digital twin are confused with the digital twin itself. The dynamic, real-time and bidirectional data link characteristics of the digital twin are the keys to distinguishing the digital twin, but are also the most common source of misconceptions.

4. SCOPE OF APPLICATION IN DIGITAL TWIN

Digital twin technology operates in various fields such as space technologies, automotive, aviation, healthcare, construction and utilities. For example, real-time monitoring of the services of underground structures in cities and controlling their infrastructure are among the uses of digital twins. The rapidly expanding digital twin market guarantees that it will gain acceleration in the global market in the future with the development of Internet of Things (IoT) and big data analytics (Sehgal et al., 2012, p. 147).

The concept of the Digital Twin dates back to the 1960s, when the idea of matching was first introduced by NASA for the Apollo program to create physical replicas on earth that match their systems in space. The idea allowed them to simulate various scenarios, test different situations and conditions, and evaluate the behavior and performance of their systems. It gained even more momentum when the twin came to the rescue after the technical problems of the Apollo 13 mission were solved by engineers on the ground and tested possible solutions on the ground twin (Barricelli et al., 2019, p. 167669). Later, until the early 2000s, Michael Grieves introduced the concept of digital twins to the manufacturing industry by creating virtual replicas to monitor factories' processes, predict failures, and increase their productivity. The concept gained further attention and recognization when it was listed by Gartner as one of the top 10 strategic technology trends in 2017 and has been embraced by numerous industry giants such as Siemens and General Electric. In this context, many fields seem to adopt this concept because of the potential of the digital twin to accurately represent physical systems (Cearley et al., 2017, p. 2). A few of these fields are listed as follows.

Production: The current progress in the manufacturing industries is defined as the fourth industrial revolution known as Industry 4.0. A report by The Boston Consulting Group (BCG) defined Industry 4.0 as an autonomous integration of nine technologies, all of which can be provided by digital twins. These technologies can be listed as follows (Gerbert et al., 2015, p. 15);

- Horizontal and Vertical System Integration,
- Additive Manufacturing (AM)/Additive Layer Manufacturing (ALM)[3],
- Advanced Robotics[4],
- Cloud Services,
- Big Data and Analytics,
- Cybersecurity,
- Industrial IoT,
- Simulation,
- Augmented Reality (AR).

Digital twins for industrial and manufacturing systems can provide real-time monitoring, control and optimization, while providing digital copies of factories and production lines on which all processes can be tested, improved and optimized without affecting the production flow.

Healthcare Service: As reported in Rasheed et al., (2020), one of the most critical sectors to benefit from digital twins is the healthcare industry. With the increase in wearable device

[3] ALM is the industrial production name for 3D printing.
[4] Advanced robotics emerged in the 1980s as a term for robots featuring sensorisation and a powerful combination of software and hardware to make intelligent decisions, in contrast to traditional machines.

technologies that detect and collect data about people's vital organs, these technologies allow people to take proactive measures that can predict any health complications that may happen to them, avoid any health complications-such as calling an ambulance to the patient's location or any worrisome situation-makes it possible to have digital twins that can receive-like reporting to a healthcare professional (Bruynseels et al., 2018, p. 27). Another application is the use of the digital twin to simulate the function of the human body and to train young surgeons. Also, digital twins can be used in more critical situations, such as performing remote surgery, as suggested by the Laaki et al., (2019). In the same context, it was also emphasized that the importance of a reliable, secure, low-latency network connecting digital and virtual twins is very high for such an application to become a reality. Liu et al., (2019) describe the operation mechanism of dijital twins in healthcare with the following stages. First, dijital twin models must be built on a physical object using advanced modeling techniques and tools (e.g., SysML, Modelica, SolidWorks, 3DMAX, and AutoCAD). Second, real-time data connection and exchange between physical and virtual objects should be executed through health IoT and mobile internet technologies. Third, simulation models are tested and validated by quick execution and calibration. Fourth, models are continuously adjusted accordingly to optimize and iterate digital twin models. Finally, following the behavior of the virtual twin, model results (e.g., diagnosis results) are sent back to the patients. With respect to the digital twin application on patients, the ultimate vision is to have a lifelong, personalized patient model that is updated with each measurement, scan, or exam, including behavioral and genetic data.

Smart Cities: Another area where digital twins can play an important developmental role is in smart cities. This technology can be used to visualize all the resources in the city by becoming a virtual model of the city and to enable the interaction of people and vehicles in the city. It also allows monitoring of infrastructure, utilities and businesses and planning for the future. For example developments as discussed in Kent et al., (2019). Moreover, the spatio-temporal city dynamics can be obtained through sensors in the data acquisition systems and, as the Mohammadi & Taylor (2017) suggest, the physical city can be fed from the data analytics platform in the digital twin to provide its real-time representation in the digital twin.

Education: The Covid-19 pandemic has forced educators and students around the world to develop solutions that keep the education process going despite lockdown restrictions. The issue was significant initially as not all institutions have platforms to host a digitized educational process, but many later implemented the concept of the digital twin for education to allow students from all over the world to participate in an entirely new teaching paradigm. Various solutions have been proposed to deploy and enhance the digital twin for education, such as smart learning environments with personalized adaptive learning frameworks in Peng et al., (2019), integrated data mining tools in Mitrofanova et al., (2019), and integrating IoT technologies in Abdel-Basset et al., (2019).

Next-generation network: The next generation network (NGN) is a set of fundamental architectural changes in the telecommunications core and access networks. The general idea behind NGN is that a network carries all information and services-all kinds of media such as voice, data and video-by enclosing them in IP packets similar to those used on the Internet. NGNs are usually built around the Internet Protocol. For this reason, the term all IP is also sometimes used to describe the conversion of formerly telephony-centric networks to NGNs. NGN is a different concept from Future Internet, which focuses more on the development of the Internet in terms of the variety and interactions of services offered. According to ITU-T[5],

[5] ITU-T: International Telecommunications Union Telecommunication Standardization Sector.

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Next-generation network (NGN) is a packet-based network that can provide services, including Telecommunications Services, and is fundamentally independent of multiple broadbands, the quality of service-enabled transport technologies, and service-related functions. As networks continue to evolve from the fourth to the fifth generation and into the next sixth generation, testing and optimizing these next-generation networks in environments before they are actually deployed is becoming a highly complex challenge. Digital twins of network deployments can play an important role in this challenge by providing a proof of concept whether next-generation networks can meet efficiency, latency, security, etc. For example, deploying a digital twin for complex 5G networks and testing how they can be deployed to serve multiple situations and needs (Nguyen et al., 2020, p. 13).

5. DIGITAL TWIN IN HEALTHCARE

Technological developments throughout the ages have led to the emergence of new tools, techniques and machines. These developments have contributed to practical developments in various fields such as manufacturing, agriculture, education and even the health sector (Nweke et al., 2019, p. 162). One of the best examples of such technological developments is the Internet of Things (IoT). The IoT is integrated into today's lifestyle, connecting everything to almost anything, including smartphones, smart buildings, smart homes, and health wearables. In addition, IoT sensors and devices have contributed to the improvement of health systems by facilitating health workflow, accelerating access to medical records, increasing the accuracy and sharing capabilities of data collected from different sources, as well as combating pandemic (Koutroumpis et al., 2019, p. 2).

It is seen that the birth of digital twins in the health sector and services started with the use of the concept of "*Virtual Self*[6]" and took place in our lives with the advancement of technology. At the beginning of these developments is the widespread use of CT scan in the 1980s. An example of the virtual self is the virtualization of the heart, which is the main point of the cardiovascular system. This model simulates the human heart pumping blood. It will be a resource to identify diseases, evaluate drug effects and determine the most effective method in treatment by simulating blood flow, the ratios in it, cellular interactions on the vessel walls and the reactions of the heart muscle (Björnsson et al., 2019, p. 2).

According to reports published by Institute of Medicine[7], it has been revealed that medical errors cost the lives of 400,000 people every year, mainly due to problems with data shortages. This is more specifically related to the difficulty of accessing information. A patient's medical history, missed and delayed diagnoses, or corrupt health data are examples. IoT technological advances have had a significant impact on connecting the Health system to users. That is to say, individuals' personal devices can capture, store and report relevant health data in real time, thus increasing effective health support and reducing mortality (Pearson et al., 2013, p. 244).

[6] A virtual self is a computer based replica of a person's self which is the form, platform or profile used to explore the virtual world independently.

[7] The National Academy of Medicine (NAM), known as the Institute of Medicine (IoM) until 2015, is an American nonprofit, non-governmental organization. The National Academy of Medicine is a part of the National Academies of Sciences, Engineering, and Medicine, along with the National Academy of Sciences (NAS), National Academy of Engineering (NAE), and the National Research Council (NRC).

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The increase of personal health monitoring devices in the form of mobile apps or built-in sensors can actively monitor the user's vital health parameters such as Electrocardiogram (ECG or EKG), Blood Pressure (BP), heart rate and sugar level, reducing potential errors in data logging (Bosquet et al., 2019, p. 2515). These devices can anonymously capture and transfer data to the cloud and compare it with historical data for symptoms of any disease or notify the appropriate medical personnel (doctor, nurse or paramedic). Fewer errors mean better performance, cost, efficiency and improvements in healthcare where one mistake can literally be the difference between life and death. This can be characterized as the age of smart context IoT health, made possible by the combination of technology and health services. In turn, this can improve quality of life and solve many challenges, such as information sharing, diagnostic inefficiency, monitoring cost reduction, operation optimization, medication errors, etc. (Bosquet et al., 2021, p. 187).

According to the The Institute of Electrical and Electronics Engineers (IEEE), the digital twin is the third trending technology for 2020. The concept of this technology refers to a digital copy of the physical object. The Digital Twin combines Artificial Intelligence (AI), Data Analytics, Internet of Things, Virtual and Augmented Reality paired with digital and physical objects. This integration enables real-time data analysis, condition monitoring to prevent problems before they arise, risk management, cost reduction and forecasting of future opportunities (Karagöz Güzin, 2018, p. 18). Although the first use of digital twin technology dates back to the 1960s, this technology is just beginning to develop in the field of health and is taking its first steps. The applications of digital twins in the field of health can basically be examined in three groups. The first of these is "*sensors*". The sensors are placed in the parts of a hospital or health institution where measurement is desired and used to design the digital twin. The second is the use of a patient's health data to create a living digital twin to create a person's overall health follow-up. The third is the creation of digital twins in order to perform drug administration experiments before an operation and to monitor a diseased area (Kataria & Vinod, 2018, p. 1953).

For healthcare systems, having a virtual copy of a patient may be the optimal solution for health promotion, increased control over health, and improved healthcare operations. This technology can help monitor a patient's current health status. It will also be possible to predict future trend using medical history and much more.

The Digital Twin paradigm is explored in the context of different purposes in healthcare. An example is personalized medicine, which explores the use of digital twins as a dynamic digital replica of patients, created with historically available information. In this case, the digital twin is intended to be useful for performing more effective care interventions, helping physicians and other intersecting care technologies understand the patient's medical condition (Sönmez, 2018, p. 146). In the context of personalized medicine, there are numerous examples of interventions tailored to individual patient profiles, almost entirely based on genetic profiles. The metaphor of "*Cinderella's Shoe*" is used for these personalized treatments. This metaphor emphasizes that the concept of the digital twin can ideally be applied to the early diagnosis and prevention of the disease, starting with the development of a drug suitable for each patient's own biological or molecular infrastructure, but later on (Goetz & Schork, 2018, p. 956).

The field of personalized medicine was announced by the USA and China in 2015 as the herald of a new era in healthcare. It has the potential to improve the diagnosis and treatment of complex diseases such as cancer and diabetes, thereby keeping patients healthier. As the concept of the digital twin becomes prominent in personalized medicine, it is clear that

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personalized medicine based on personal, genomic, proteomic and metabolic information will open the door for analyzing and identifying treatment targets for specific biomarkers and diseases (Wang et al., 2016, p. 37). In this direction, personal medicine carries the perception of "*curable disease*" to a different dimension and causes modern treatment methods to shape "*social culture*". In other words, if the disease in question is in the onset or preclinical stage, it will also broaden their perspective on what is treatable in the context of preventive medicine and as an early clinical approach (Özdemir & Ağırbaşlı, 2010, p. 29).

Although the use cases of digital twins in personalized medicine are still limited, some digital twins of organs or parts of the human body have already been developed and used as prototypes or pilots (Barricelli et al., 2019, p. 167666). Some examples of this are listed in Table 2.

Table 2. Digital Twin Application Examples and Support for Medical Decision-Making in Personalized Medicine

Target Organ/Disease	**Reference (Company, Journal etc.)**	**Description**
Heart	Living Heart Project, Dassault Systèmes	The Living Heart Project is the first DT organ considering all aspects of the heart's functionality, such as blood flow, mechanics, and electrical impulses. The 3D model of the organ has built with a 2D scan of the heart. The Living Heart Model on the 3DEXPERIENCE platform can be used to create new ways to design and test new devices and drug treatments. For instance, physicians can run hypothetical scenarios like adding a pacemaker or reversing the heart chambers to predict the outcome of treatment on the patient.
Heart	CardioInsight, Medtronic	The CardioInsight Noninvasive 3D Mapping System collects chest electrocardiogram (ECG) signals and combines these signals with computerized tomography (CT) scan data to produce and display simultaneous 3-D cardiac maps. The mapping system enables physicians to characterize abnormal rhythms of the heart through a personalized heart model.
Heart	Siemens Healthineers	Another heart DT has been developed by Siemens Healthineers and used for research purposes by Cardiologists of the Heidelberg University Hospital (HUH) in Germany. Although the first study is still in the data evaluation process, preliminary results are promising. Siemens Healthineers developed the DT model by exploiting a massive database containing more than 250 million annotated images, reports, and operational data. The AI-based DT model enables digital heart design based on patient data with the same conditions of the given patient (size, ejection fraction, and muscle contraction).
Brain	Blue Brain Project, EPFL and Hewlett Packard Enterprise	Hewlett Packard Enterprise, partnering with Ecole Polytechnique Fédérale de Lausannes (EPFL), builds a DT of brain called the Blue Brain Project. The project is one of the sub-projects of the Human Brain Project and aims to build biologically detailed digital reconstructions (computer models) and simulations of the mouse brain. In 2018, researchers published the first 3D cell atlas for the entire mouse brain.

Human air-way system	Oklahoma State University's Computational Biofluidics and Biomechanics Laboratory	Researchers developed a prototype of human DT, named "virtual human V1.0", with the high-resolution human respiratory system covering the entire conducting and respiratory zones, lung lobes, and body shell. The Project aims to study and increase the success rate of cancer-destroying drugs in targeting tumor-only locations.
Brain aneurysm and surrounding blood vessels	Sim&Cure	Sim&Cure developed a DT to treat aneurysms, which are enlarged blood vessels that can result in clots or strokes. DT of the aneurysm and the surrounding blood vessels (represented by a 3D model) allow brain surgeons to run simulations and understand the interactive relationship between the implant and the aneurysm. Although preliminary trials have shown promising results, further evaluation is required.
Multiple Sclerosis (MS)	Frontiers in Immunology (journal)	Multiple sclerosis, also called the 'disease of a thousand faces', has high complexity, multidimensionality, and heterogeneity in disease progression and treatment options among patients. This results in extensive data to study the disease. Human DTs are promising in the case of precision medicine for people with MS (pwMS), allowing healthcare professionals to handle this big data, monitor the patient effectively, and provide more personalized treatment and care.
Viral Infection	Science (journal)	Human DTs can predict the viral infection or immune response of a patient infected with a virus by integrating known human physiology and immunology with population and individual clinical data into AI-based models.
Trauma Management	Journal of Medical Systems (journal)	Trauma management is highly critical among time-dependent pathologies. DTs can participate from the pre-hospital phase, where the physician provides the patient first aid and transfers them to the hospital emergency department, to the operative phase, where the trauma team assists the patient in hospital emergency. Although there is no real implementation yet, a system prototype has been developed.
Diabetes	Diabetes (journal)	Human DT can also participate in diabetes management. California-based start-up Twin Health has applied DTs by modeling patient metabolism. The DT model tracks nutrition, sleep, and step changes and monitors patients' blood sugar levels, liver function, weight, and more. Ongoing clinical trials show that daily precision nutrition guidance based on a continuous glucose monitoring system (CGM), food intake data, and machine learning algorithms can benefit patients with type 2 diabetes.

Resource: Barricelli et al., (2019); Corral-Acero et al., (2020); Zheng et al., (2021); Erö et al., (2018); Voigt et al., (2021); Laubenbacher et al., (2021); Croatti et al., (2020); Shamanna et al., (2020).

The strategy that the "*Swedish Digital Twin Consortium (SDTC)*" is trying to develop for personalized medicine is a fair sample in this context. SDTC strategy, which is the focus of the digital twin concept in personalized medicine, includes the following principles (SDTC, 2021);

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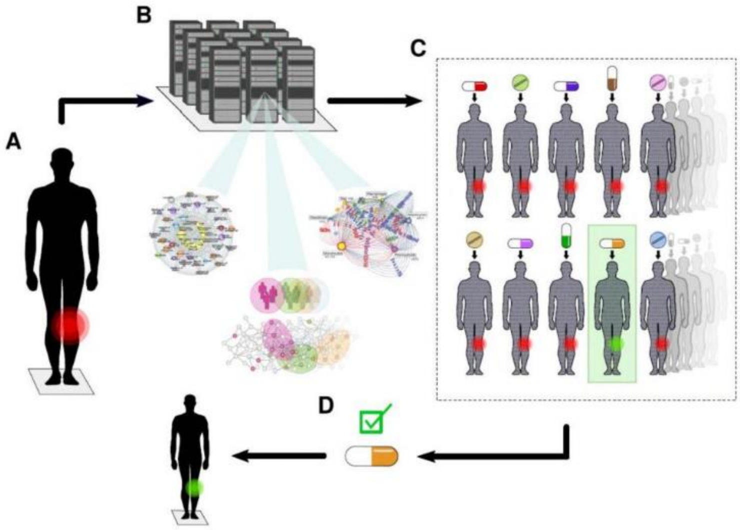
1. Creating unlimited replicas of network patterns of all molecular, phenotypic and environmental factors related to disease mechanisms in individual patients with digital twins.
2. Computationally treating these digital twins with thousands of drugs to identify the best performing drug.
3. Treating the patient with this drug (Figure 3).

Figure 3. Digital Twin Concept for Personalized Medicine



Resource: Swedish Digital Twin Consortium, 2021.

It is seen that the patient at stage A has a regional disease symptom (red) in Figure 2. In stage B, this patient's digital twin is created in unlimited copies based on computational network models of thousands of disease-related variables. In stage C, each twin is treated computationally with one or more of thousands of drugs. This results in digital treatment of a patient (green). In stage D, the drug with the best effect on the digital twin is selected for the treatment of the patient.

Another example is strategic planning. By creating a hospital's digital twin, operational strategies or medical processes, it is possible to use its digital counterparts to determine what actions to take and eventually leverage simulation possibilities (Cearley et al., 2017, p. 5). In summary, human digital twins' can benefit from the health sources where each living and non-living entity generate a massive digital footprint (Schwartz et al., 2020, p. 25; Corral-Acero et al., 2020, p. 4558);

(i) A formal healthcare system (e.g., electronic health records, lab test results, medical images, insurance, and pharmacy data),
(ii) Digital health devices (e.g., Bluetooth-connected glucose monitors, smart watches),
(iii) Patient surveys,
(iv) Real-world health data sources obtained from studies,
(v) A variety of non-health and non-clinical sources reflecting lifestyle and habits (e.g., local weather, air quality level, buying habits, patient activity on social media),
(vi) and hospital processes.

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In particular, advancements in personal health monitoring devices in the form of mobile applications or built-in sensors can actively monitor a user's vital health parameters such as ECG, BP, heart rate, and sugar level, which reduces the potential errors of data recording (Elayan et al., 2021, p. 16752).

6. ADVANTAGES AND DISADVANTAGES OF DIGITAL TWIN

A wide variety of data regarding possible performance outcomes can be obtained even before the product is manufactured with the use of digital twins. This data helps generate insights to optimize potential disruptions in production and operation, and can enable products to be designed more effectively, reducing potential capital expenditures.

Even during the production phase of the product, systems can be monitored in real time with this technology, thus achieving and maintaining the highest efficiency throughout the production process. Again, thanks to this technology, it is possible to decide how to evaluate the products that complete their life cycle. Risky processes at every stage can be simplified, time can be saved, physical effort can be reduced and the most suitable equipment can be selected and the life of the equipment can be extended. The many advantages of commissioning digital twins can be summarized as follows (Angulo et al., 2019, p. 314);

- *Real-time monitoring, control and data acquisition:* Real-time updates via the digital twin are exchanged between physical and digital systems, allowing all to be monitored. Updates allow obtaining all the necessary data for business decisions and providing control over the physical system when necessary.
- *Business continuity through remote access:* As the digital twin is accessible to remote users around the world, it guarantees the participation and cooperation of all relevant parties in times of downtime, even though they are not physically present in the physical system.
- *Increased efficiency:* Digital twins facilitate the testing process of various scenarios and situations before they are implemented in physical systems, providing a platform to pre-test solutions and apply the best ones to increase overall system efficiency.
- *Highly informed decision support:* All real-time data is collected on a single platform. At the same time, data analytics tools are easily accessible to feed. This enables faster, more informed and more efficient business decisions to be made.
- *Predictive maintenance and optimized scheduling:* Integrating artificial intelligence and machine learning techniques into the digital twin, predictions can be made to evaluate optimal maintenance times to avoid downtime. AI techniques can also optimize business process planning for improved productivity.
- *Advanced risk assessment:* The digital twin allows various solutions to be virtually tested and analyzed regardless. In other words, it offers the chance to evaluate these solutions without affecting the physical system.

Although digital twins promise the potential to improve product quality, reduce production and maintenance costs and seem to become more important in the near future, the risks they contain are also thought-provoking. Besides all these advantages, digital twins can be too complicated for a specific and simple problem. In addition to involving various risks related to integration and cost, they always pose privacy and security threats. Especially when technologies such as Internet of Things (IoT) and cloud computing are used in this context, systems become susceptible to hacking and viruses (Scheerder et al., 2017, p. 1617).

Therefore, private, confidential or many valuable data will be in danger of being stolen. This is one of the leading factors limiting market growth in the digital twin. In this context, system developers must address digital ethical issues raised by different parties interacting with data not only from companies but also from partners and customers. Systems developers and implementers need to consider the concerns that require them to think about the value of data and its contribution to processing. This is especially critical for personal medical records (Fuller et al., 2020, p. 108965).

Developing digital twins is a significant investment, and the realities of investment can be at a disadvantage. Namely, it may be possible for big companies to have the necessary capital and human resources and create an oligarchy. Of course, this is not always the case. Small companies can contribute certain modules-such as statistical and graphical environment R-that others can purchase. Another situation is that digital twin technology creates unequally distributed equipment and knowledge. In such a case, the gap between rich and poor, urban and rural can widen. Another disadvantage of digital twin technology can be listed as follows (Jones et al., 2020, p. 50);

- *Distrust of companies and technological infrastructures in the protection of privacy and personal data:* The Internet, which becomes more personalized with each passing day, is open to a large number of intruders. The importance of this issue has increased in recent years, both for companies, governments and consumers. In this period, in which the transparency and reliability of the public and private sectors in accessing, using and benefiting from personal data are increasingly concerned, in addition to the concern about data leaks that may occur as a result of security weaknesses, hacking, internal support or inaccuracy, especially digital which is a matter of debate what effect the privacy issue will have on the adoption of twin technologies.
- *Lack of Human-Centered Approach:* In today's traditional Cloud-centered IoT ecosystem, information collected from connected devices is stored, the way and purpose of storage, authorities with access to and control of information, economic benefits and direct economic benefits from the outputs obtained from the analysis of information when the expertise is evaluated, it is observed that the architectures used and the systems designed are more business, information and technology oriented. Noting that the lack of a human-centered approach is one of the most important barriers to unlocking the potential of the digital twin, Gartner identified one of the main strategic trends of 2019 and 2020 as "Human-Centered Smart Spaces". Making the digital twin concept a natural part of people's interactions with the digital world and their daily lives, establishing infrastructures that will efficiently distribute applications, services, services (such as Machine Learning, Artificial Intelligence) over the digital twin, adopting an approach that emphasizes the human dimension of technology makes the acceptability of the digital twin easier.
- *Restricting the value and realm of freedom to information:* In today's technology age, where information is now a tangible asset, the size of the amount of dark data produced in the context of the digital twin ecosystem reveals how the financial and value creation potential of the digital twin is limited. Due to reasons such as resource and time constraints, costly, heterogeneous and unstructured data, ambiguity of the guide data or data source, low quality and efficiency in the data collection process, the data is either out of the knowledge of the enterprises or stuck in the closed private systems of the enterprises and only the company's own and is shrouded in darkness at the initiative of the reach of its few stakeholders. Although, in an ideal digital twin

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> concept, information is expected to follow a multidimensional flow among all actors, the enterprise-centered approach observed in the technological dimension manifests itself with a one-way flow and a tendency to provide benefits to enterprises in the economic and informational dimension. Therefore, the direction of any financial benefit to be obtained from the information obtained in the context of the digital twin is directed towards the companies. From a consumer perspective, consumers' demands to be active participants in development processes, innovative approaches, and economic benefits have also been observed, rather than passively waiting to benefit from the digital twin ecosystem.

The advantages and disadvantages of using digital twins in the context of health services have attracted the attention of many researchers, especially ethicists, in recent years (Bagaria et al., 2020, p. 7; Björnsson et al., 2020, p. 2; Bruynseels, 2020, p. 348). The use of digital twins in healthcare has not only raised important hopes for improving diagnosis and treatment, but has also sparked debate about its social and ethical implications (Bruynseels, 2020, p. 349). That is, it is stated that digital twins threaten many of the socio-ethical issues related to the understanding of privacy and individuality that have been associated with personalized medicine and health in the past (Korthals, 2008, p. 227). But whether the digital twin will ultimately exacerbate or mitigate such existing concerns remains uncertain. Effective implementation of digital twins in healthcare requires wide patient data collection and storage. However, the access and the integration of these sensitive patient data, including biological, physical, and lifestyle information over time by healthcare organizations or insurance companies, raise ethical questions, where the confidentiality and security of information remains paramount (Corral-Acero et al., p. 4561). For instance, insurance companies may make precise distinctions for premiums based on new data points processed through digital twins (e.g., physical activity, eating habits), especially on people whose health data suggests an impending negative event, making care more difficult to access at the time when it is most critically important to receive a potential misuse of digital twins (Schwartz et al., 2020, p. 28). Additionally, some experts have raised concerns about the cybersecurity of digital twins databases, where the risk of a cyber-attack cannot be denied (Popa et al., 2021, p. 3). Additionally, since the convergence of these technologies and the dijital twin concept in healthcare are in most cases still in their early development phase, technical limitations arise, and include everything from data collection to software design.

Another point is on simulation. Digital twins hold great potential, especially in precision medicine, where they can be used to simulate individual treatments and visualize potential treatment outcomes and disease progression for each patient. But for years, while computer simulation of the human body has been limited to some organs or certain processes, concerns about what can be replicated and simulated in the future are troubling (Raden, 2020, p. 15). In other words, while the digital twin industry is rapidly becoming a standard approach to diagnosis and treatment rather than a niche effort focusing on a specific organ or physiological process, this rapid change can be frightening, especially from a patient perspective. Dijital twins can show great performance in a short timeframe, but their predictive capability alone might not be considered sufficient for therapy selection and preventive care.

The issues regarding the quality of the digital twin in health is another point that needs to be emphasized. Whether the social and economic costs required for the improvement needed in this area are worth the benefits is sometimes questioned, but there is consensus that the digital twin will only get better as a diagnostic and therapeutic tool (Harris, 2020, p. 3). Because, with the contribution of other sectors, the concept of digital twin is facing increasing interest due to

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the increasing availability of technological devices (e.g., wearable devices) to collect disease evidence and patient data. In addition, there are already successful digital twin applications in healthcare for predictive maintenance and performance optimization of medical devices and hospital management systems.

Data bias is another issue that needs to be emphasized in the context of the digital twin in health. Digital twins require a data model built on a balanced dataset where any individual's data can be compared. However, at present, many healthcare-related datasets incorporate racial, gender, or other demographic sources of bias (e.g., white men are more represented). Using these datasets to build human digital twins without any correction would intensify the already existing bias and finally result in a suboptimal recommendation system for any patient who does not fit the typical demographic profile of the dataset (Schwartz, 2020, p. 11). Accessibility to technology is another important issue in the field. As a new application in healthcare, there is not yet a clear business model on how digital twins will reach patients. In case DTs-based treatments or preventions are not accessible to everyone or are not covered by health insurance, their use will widen an already existing socio-economical gap by providing access to knowledge and expertise to patients rich enough to afford the treatments themselves or whose system is not willing or able to pay for digital twins applications (Popa, 2021, p. 5).

In addition to all these, there are some technical limitations brought by digital twin applications in subjects such as data collection and management in health, process and interface design. Human DTs require deep and detailed datasets and new Electronic Health Records (EHR) designs which will foster data mining and the automated collection of clean data. Currently, an important roadblock for Human DTs is that electronic health records and healthcare information systems are highly heterogeneous and difficult to operate (Corral-Acero et al., 2020, p. 4561). Moreover, information is often in an unstructured format, and its extraction requires either manual work or further implementation of automation through natural language processing technologies. The quality of the data supplied also plays a vital role. Although sensors can efficiently collect data and transfer it to Human DTs, hospital data collection processes can be more expensive and time-consuming (Erol et al., 2020, p. 5). Currently, most of the data from individuals is collected through blood tests, imaging systems, and health scans. The hospital data collection processes thus create a burden on digital twin processes. For example, it is not easy to achieve excellent image quality in computerized tomography (CT) scans of heart patients, and the output generally depends on the expertise of radiology staff; this is especially true in the case of less experienced radiology staff. Experts in the field indicate that the next big milestones in digital twins will not be related to advancements in AI research but will deal with fixing the problems with small-scale, messy data in healthcare (Corral-Acero et al., 2020, p. 4561). Although digital twin applications have been defined as fully autonomous processes, there is a crucial need for interdisciplinary knowledge (e.g., biomedical, mathematics, bioengineering, and computer science) and people's experience due to the complex nature of human beings (Erol et al., 2020, p. 6). Moreover, digital twin software designers should work on a user-friendly interface for digital twins to facilitate communication among digital twins software, patients, and physicians (e.g., to discuss optimal treatment based on informed consent). However, experts in the field note a lack of user-friendly software for digital twins applications in healthcare (James, 2021, p. 51).

In healthcare management, the digital twin application can contribute to optimizing hospital operations. Large companies such as GE Healthcare and Siemens Healthlineers have already developed digital twins and are currently tailoring their digital twin services for hospitals to respond to challenges such as growing patient demand, increasing clinical complexity, aging

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infrastructure, lack of space, increasing waiting times, and rapid advances in medical technology requiring additional equipment implementation (Barricelli et al., 2019, p. 167658). Using digital twins, different possible solutions can be tested in virtual environments (Liu et al., 2019, p. 49094) before scheduling and implementation in the real setting (e.g., bed planning, staff schedules, surgical simulation, and virtual drug experiments). For instance, GE Healthcare developed the Capacity Command Center to build digital twins of patient pathways in Johns Hopkins Hospital in Baltimore. By applying simulations and analytics, the hospital can predict the patient activity and plans capacity according to demand, thus significantly improving patient service, safety, experience, and activity volume. The final aim of digital twin application in hospital management is to help hospitals, other healthcare organizations, and policymakers to manage and coordinate patient care initiatives from a social and population perspective (Barricelli et al., 2019, p. 167659). For instance, in extreme cases such as pandemics, hospital management can simulate different possible conditions (and their potential solutions in virtual environments before implementing them in the physical space. Finally, digital twin application in hospital operations will allow hospitals and other institutions to timely allocate their resources to increase efficiency, save cost and avoid predictable crises.

The digital twin is driving and will continue to trigger a linear, evolutionary change in healthcare. This means that the change is coming to accelerate already existing trends, rather than to produce a revolutionary change in technology's direction. However, this slow but steady change is extraordinarily complex. So although the width of the "*digital twin*" label has a positive effect, individuals may have a hard time catching the future of the digital twin (Harris, 2020, p. 6). This causes the future of digital twins to up in the air in many areas, not just health.

7. CONCLUSION

Digital twin technology is one of the main foundations of the digital transformation process. It allows the creation of digital copies of physical systems, which can provide numerous benefits such as real-time monitoring, increased productivity and efficiency. This article highlights the importance of the network connecting physical and digital twins and the requirements that must be present in the connectivity network to ensure that the two twins stay in sync, protect and secure data so that digital twin users can experience it. In order to increase the high quality of service and increase the distribution of digital twins in more areas, attention was drawn to the future directions for the advancement of digital twin technology, continuous optimization and development of key enabling technologies to fulfill the requirements of digital twins discussed earlier. Actual planning, deployment and testing of digital twins for complex physical systems will aid this development process by identifying issues and highlighting areas that require further development and optimization.

Since the advent of Digital and Smart Healthcare, the world has accelerated the implementation of various technologies in this field to promote better healthcare operation and well-being of patients, increase life expectancy and reduce healthcare costs. The digital twin is emerging as a promising and game-changing technology in healthcare. The Digital Twin is expected to change the concept of Digital Healthcare and take this space to another level never seen before. Healthcare represents a field of application where the introduction of digital twins can have a devastating effect. In this field, digital twins are not just used for physical computational assets (vital sign monitors, diagnostic machines, operating theaters, etc.). They are also effective in managerial paradigms. Digital twins appear to play two different roles in healthcare. These are as follows (Erol et al., 2020, p. 2);

1. Design and management of health institutions
2. Patient care

These models help plan beds, staff schedules, and operating rooms to maximize care for patients while controlling costs. A healthcare organization's digital twin allows managers to test solutions to problems such as shortages of hospital beds, tips for operating rooms, or the spread of infectious agents before implementing the best-performing solution. A human body's digital twin, on the other hand, allows doctors to better discover, try treatments, and operate on an individual before the disease occurs. In these systems, national initiatives are important for practical and scalable solutions to specific problems.

The Digital Twin can be used for a lot of research and is essential for developing real systems. How to simulate roughly 40 billion body cells in a human and create a digital twin remains a question in mind. These cells are the cells that make up the heart, ear, nail, fat, liver, lung, hand, arm and many other organs and perform different processes. Each cell confronts us with its own life adventure. Cells produce energy by breaking down the nutrients and molecules they contain and processing the proteins, fats and sugars they obtain. They reproduce by dividing, and when they complete their lifespan, they die. This suggests whether biochemical life can be simulated like a chemical plant. These questions in mind are looking for a solution with the digital twin, which is an artificial intelligence infrastructure (Qi & Tao, 2018, p. 3590). Thanks to the large data repository created by entering many medical records in the past into the system, it enables to analyze the diseased state or the process in the cells. Hans Lehrach, Director of Max Planck, predicts that if genetic analysis and the creation of digital twins with computer simulations become routine, treatment costs will decrease and the health system will be better protected.

DECLARATION OF THE AUTHORS

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