CODEN [USA]: IAJPBB ISSN : 2349-7750

INDO AMERICAN JOURNAL OF
PHARMACEUTICAL SCIENCES

SJIF Impact Factor: 7.187
https://doi.org/10.5281/zenodo.14165428

https://www.iajps.com/volumes/volume11-november-2024/23-issue-11-november-24/

Available online at: http://www.iajps.com *Review Article*

A REVIEW ON DIGITAL TWINS

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Article Received: September 2024 Accepted: October 2024 Published: November 2024

Abstract:
Digital twins (DT) are among the most promising technologies that are propelling the digitization across a number of industries. The term "digital twin" (DT) describes a digital representation or duplicate of any real thing. The real-time, automatic bidirectional data interchange between digital and physical twins is what sets DT apart from simulation and other digital or CAD models. Implementing DT in any industry has several advantages, such as lower operating expenses and time, higher productivity, enhanced decision-making, better predictive maintenance. Because of the emergence of Industry 4.0, which has led to increasingly sophisticated goods and systems that rely on gathering and storing ever-increasing volumes of data, its use is anticipated to increase rapidly over the next several decades. This study examines various industrial sectors where the application of DT is utilizing these opportunities and how they are advancing the industry. Successfully connecting that data to DTs can lead to a number of new opportunities. The use of digital twins in many different sectors including aerospace, healthcare, manufacturing, education, smart cities, and the pharmaceutical industry and explain the benefits and future prospects of digital twins.

Keywords: *Digital twin, Industry4.0, Healthcare, Pharmaceutical industry, Manufacturing, System simulation, Predictive maintenance.*

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Please cite this article in press S. Mounika et al ***A Review On Digital Twins*** *Indo Am. J. P. Sci, 2024; 11 (11).*

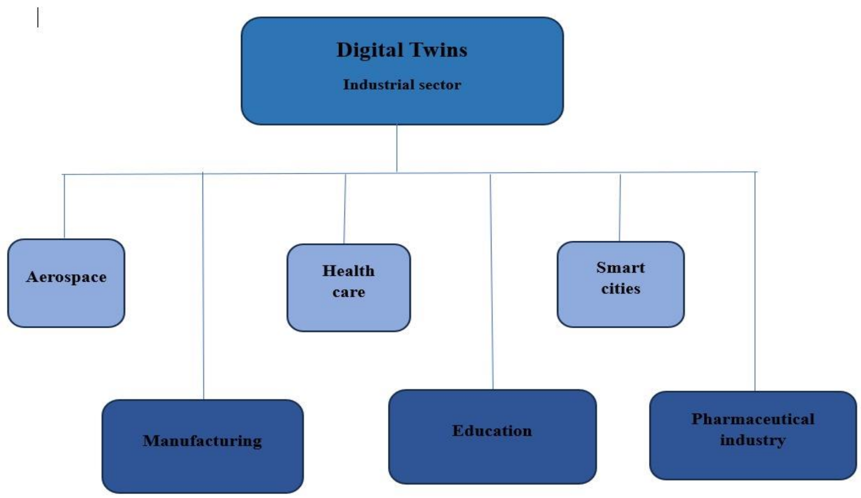
INTRODUCTION:

A digital twin (DT) is made up of virtual representations (VR) of real-world things created by computers. These models use information gathered straight from the physical objects to continuously adjust to changes in operations. Digital technologies can be applied to cyber-physical systems [1]. The DT concept was first introduced in 2002 by Michael Grieves, and since then, the concepts and their associated technologies have evolved significantly [2]. The use of digital twins has increased over the past few years, particularly because of their many practical applications and future potential. As information and communication technology develops, more conventional materials will evolve into smart linked devices, opening the door to new smart services and eventually revolutionizing entire sectors [3]. A digital twin maintains an up-to-date digital representation of the entities of interest in the real world, serving as the basis for thorough insights for the best possible decision-making. Digital twins use real-time and historical data to represent the past and present, modeling or even predicting possible futures. Digital twins have emerged as a key idea in Industry 4.0 [4] in recent years, particularly in the process of creating industrial assets that involves various research fields such as artificial intelligence, modeling, and the Internet of Things (IoT).

There are numerous benefits to managing the physical things by using a DT. For instance, it is feasible to forecast future system behaviors and enhance process productivity by employing systems or other machine learning approaches to assess and optimize system behavior. For this reason, DTs are frequently used to avoid service interruptions during maintenance. The digital twin concept is increasingly influencing other industries, including healthcare, in addition to production and Industry 4.0 [5]. The DT model is being investigated in the healthcare industry for many reasons. Customized health is one example [6], which investigates the usage of the digital twins as dynamic copies of patients made using data the past. For the purposes of fostering innovation, enhancing efficiency, and boosting profitability, modern competitive marketplaces require the implementation of modern digital technologies [7]. A surge in the use of computer technology in manufacturing sectors has resulted from the increased interest in these technologies and their promotion in various facets of economic activity [8].The DT's ongoing coordination with a production technique and its evolution is a crucial feature; for instance, modifications to the wiring, physical configuration, or fixed position should also be taken into account in the VO.As a result, when designing the system, it must be flexible and take into account new computational models or changes existing procedures. In this context, the Digital Twins are used in different sectors and their applications, challenges, and future prospects of digital twins.

Working of digital twins in different sectors:

Actually, digital twins are having a significant impact on a variety of industries. It makes it possible for real-time monitoring, simulation, and analysis by producing a digital duplicate of a real-world system, process, or object. Here are some examples of how digital twins are used successfully in different industries.



Flow chart-1: digital twins in different sectors

Aerospace:
NASA and the U.S. the air Force were the first to investigate DT in the developing fields of aerospace and aeronautics [9]. The aerospace industry can create new products more quickly and affordably, improve the quality of production lines, and cut down on aircraft maintenance time because of DT[10]. In this sector, DTs are mostly used to improve the spacecraft's or space vehicle's performance and dependability, anticipate and address maintenance problems, and make the staff missions safer. Any defects identified by DT may be fixed by initiating in situ repairs or suggesting suitable mission modifications, which would increase the mission's performance and success rate[11].

In order to maximize mission success, the application simulates the flight prior to the actual vehicle's launch. The number of objects that an airplane carries has a significant impact on how long it can last; a 20% weight decrease can increase an aircraft's lifespan by up to 200% [12]. An aircraft's useful life can be ascertained by recording and processing its load spectrum with the aid of DT technology. In this field, the primary use of DT began with the goal of maximizing the space vehicle or aircraft's performance and dependability.

Healthcare:
One of the biggest sectors in the world is healthcare, which permeates every aspect of daily life. In order to maximize care, cost, and performance in the healthcare sector and to support strategic and well-informed decision-making, the DT technology in the healthcare system examines hospitals, operational strategies, capabilities, personnel, and care models [13]. The human body as a whole, a single system (digestive, respiratory), a single organ (liver, heart), a finer level of body components (cellular, subcellular, or molecular), a particular disease or disorder, or other important biological organisms (e.g., a virus that is interacting with one DT of the human body/organ) can all be the subject of a DT [14]. For this, humans cannot be integrated with sensors, making it difficult to connect them to their DT, in contrast to other industries. However, based on its data, the human DT can be able to recommend the best course of action for the patient once it is built.

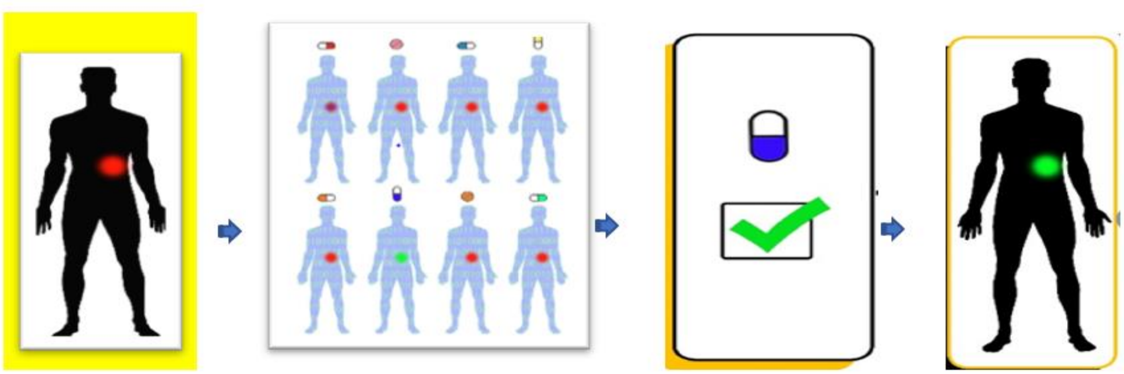

A B C D

Figure 1: Health care

Digital twin concept for the personalizes medicine. (**A**) A patient with a local symptom of the disease (red). (**B**) Patient's DT is virtually treated with the different treatments in various combinations. (**C**) Treatment shows the best results is chosen. (**D**) Personalized medicine is given to the patient to treat them (green) [15].

Manufacturing:
While the development of DT started from the Aerospace sector, the industry which is researching the technology the most is the manufacturing industry. DT can be used by producers in each of the product's four stages [16]. Four stages are design, manufacture, operation, disposal. Designers can test different versions of the product and select the best one by using DT to virtually check their product design during the design phase [17]. Designers can learn which aspects are most popular with customers and which require development by using real-time data from previous generations' products [18]. This facilitates and expedites the entire design improvement process. In manufacturing phase, DT can be a useful tool at this stage in resource management, production planning, and process control. A DT can help in (i) lay out planning by evaluating the production system continuously. (ii) production planning and control by planning and executing the orders automatically and improving decision support by means of a detailed diagnosis, (iii) maintenance by evaluating and

analyzing machine conditions, identifying any changes in the production system [19]. Manufacturers can create a maintenance plan based on the real-time product operation condition that is provided by the product's DT after it has been sold and is in use. The services of (i) actual time state evaluation, (ii) energy utilization analysis and estimated, (iii) managing customers and analysis of behavior, (iv) intelligent optimization and updates, (v) product maintenance strategy. Disposal, the product's last stage, is frequently overlooked. As a result, when a product is discontinued, information that could enhance the following generation system or product is frequently lost [20].

Education:

The field of education is an intriguing one where DT has begun to find use, particularly in technical education courses where the systems are intricate and practical instruction is essential. Because a DT represents various areas and reflects the performance of systems and sub-systems, it creates a better understanding of systems and facilitates and speeds up knowledge exchange across a variety of technological disciplines, making it an excellent tool for communication in education [21]. Benefits of using digital twins for learning include: Authentic learning experiences that promote effective knowledge construction, skill mastery, learning transfer, and self-efficacy. Digital Twins is a great tool for distant learning students, for whom accessing a physical twin is not possible. Learning about the physical twin behavior in real world under different operational conditions. DT ensures the safety of both student and equipment.

Smart cities:

A smart city is one that makes use of information and communication technology to effectively manage its core systems by detecting, evaluating, and integrating important data to make informed decisions about the city's needs, including those related to public safety, livelihood, the environment, city services, industrial and commercial activities. In smart cities, DTs are also being used in urban design to enhance people's quality of life. A DT has the power to alter our perceptions of our cities and living areas.

Digital Twins in Pharmaceutical industry:

Digital Twins have a potential to support smart manufacturing in the pharmaceutical manufacturing at several stages of production and process development. Because a DT may represent real parts with different models, it can greatly speed up the process of choosing a production route and its unit activities during the process design stage. By predicting product quality, productivity, and process features, DT simulations can help understand process variability and save time and money compared to practical trials [22]. During the operation phase, the DT may continuously evaluate the system to provide insights for process control and improvement, and real-time process performance can be tracked and viewed at any time. Using methods like Quality by Design (QBD), Continuous Manufacturing (CM), flo wsheet modeling, and PAT implementations [23], the pharmaceutical sector has made significant improve ments in this direction. The integration and developm ent of DTs as a whole is still in its infancy, but some of the tools have been well studied.

PAT Method: Process Analytical Technology:

Data collection is an essential part of creating a DT. The applications for PAT methods in the pharmaceutical sector are numerous and include testing tablet content consistency, quantifying crystal particle size, and ensuring mix homogeneity [24]. Additionally, the US FDA has acted to encourage the usage of PAT tools in pharmaceutical manufacturing in order to guarantee the quality of the finished product.

Process Modelling:

DTs depends heavily on data and models, and the pharmaceutical industry is becoming more interested in creating and using tools and techniques that make this easier [25]. Various kinds of models have been created for enhanced control, system analyses, material property identification and prediction, and batch and continuous process simulations. The modeling techniques fall into three categories: hybrid, data-driven, and mechanical. The discrete-element technique (DEM), finite-element method (FEM), and computational fluid dynamics (CFD) are frequently employed for mechanistic modeling approaches in pharmaceutical manufacturing [26]. For the purpose of creating models, data-driven modeling techniques gather and use a lot of experimental data; the models that are produced are solely based on the datasets that are supplied.

Data Integration:

Large volumes of data are collected when IoT devices are used in pharmaceutical production processes. The virtual component must receive this collection of process data and CQAs in an effective and real-time way. To make reliable predictions, a number of pharmaceutical process models also need material qualities.

Benefits of Digital Twins:

Digital technology brings numerous benefits across various fields. Here some benefits are Speed prototyping and redesigning products: The design and analysis cycles shrink as a result of models' ability to investigate multiple situations, which makes easier and faster the prototype or redesigning process [27]. Cost-effective: Since DT is mostly created using virtual resources, the total cost of development gradually reduces.

Problem Prediction and System Planning: By using DT, we are able to estimate the issues and mistakes that will arise in the physical twin's future states, which gives us the chance to plan the systems [28]. Data that is dispersed across several software programs, databases, hard copies, etc. must be synchronized in order to establish a DT, which makes it easier to retrieve and keep the data in one location.

Future prospects of Digital Twins:

Increased use in the banking, healthcare, and manufacturing sectors. integration with new technologies (IoT, VR, and AI). Better predictive and data analytics skills, as well as improved modelling and simulation methods. Higher usage in smart cities and urban planning. Development of immersive and interactive digital twin experiences and Transformation of business models and revenue streams. In Healthcare: Personalized medicine, predictive diagnostics, and virtual patient modelling.

CONCLUSION:

Digital twins are revolutionizing various industries by providing real-time, data-driven insights that enhance decision-making, streamline operations, and improve outcomes. Across sectors like healthcare, manufacturing, energy, smart cities, pharmaceutical industry and more, digital twins bridge the gap between physical and digital worlds. They allow for predictive maintenance, reduce downtime, optimize resource use and enable scenario testing, making operations more efficient and sustainable. In pharmaceutical sector the key elements of a DT in pharmaceutical production include PAT techniques, data management systems, unit operations. As technology advances, digital twins will likely continue to unlock new possibilities, fostering innovation and driving the future of a connected, optimized world.

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