With ever-increasing complexity in the manufacturing processes, healthcare, aerospace, defense, automotive, and other domains, it is becoming a difficult task for human brains to cope up with required perfection and accuracy. Industries are experimenting with an emerging concept, where digital replicas are created for physical objects to identify bottlenecks and predict outcomes. Within healthcare, this technology can simplify complex tasks like personalizing care, predicting health outcomes, and planning patient care. For instance, a US startup Medical Augmented Intelligence (MAI) created DigiTwin, which converts 2D medical images into 3D that enables clinicians to engage with their patients through digital twins. It can be further explored for pre-operative studies or post-operative surgical outcomes and create better health plans for patients. Shortly, the digital twin is expected to be a prominent asset for healthcare professionals for its ability to analyze real-time data and making informed decisions. Integration with IoT will further simplify the process simulation, health predictions, and accurate disease diagnosis, thus improving the overall quality of life.

By definition, a digital twin is a dynamic digital replica or per se mirror image of a physical object, which is identical in every aspect with that object and creates a connection between the real and virtual world. The digital twin can be a replica of any process, system, device, or individual.

Data scientists study the dynamics of a physical object through operational and functional data captured by sensors attached to the physical object. This data is then used to develop an algorithmic model. The model simulates the physical object to provide insights into the performance and potential problems in near real-time. Data scientists play a major role in analyzing the data which is used to create iterative algorithmic models to generate insights.

NASA introduced the concept by creating a simulated replica of machines sent to outer space that required maintenance and monitoring which was practically impossible. The concept proved vital during the Apollo 13 mission as the engineers and astronauts were able to detect and fix the issues using
digital replicas remotely. In 2002, Michael Grieves at the University of Michigan conceived the idea of implementing mirror images for efficient product life cycle management. Companies such as Siemens and GE implemented this concept for real-time monitoring and predictive analysis of machines.

The foundation of the digital twin ecosystem lies within the following concepts and has been represented as in Exhibit 1.

**Digital Twin Prototype (DTP):** referred to as a digital blueprint of a product that contains information about properties, physical, operational parameters, etc. The digital model is created before manufacturing the product for validating the product design.

**Digital Twin Instance (DTI):** referred to as a digital model of an actual product. There can be variations in the characteristics of the digital model of the product and the actual product and two actual products. Thus, these variations are taken into account through sensors and information records. Baseline information in DTI is added from DTP and then continuously updated through its connectivity to the product throughout the product's lifecycle.

**Digital Twin Aggregate (DTA):** Many such DTIs form a DTA and are focused on establishing group behavior rather than an individual product focus.

Digital Twin Environment (DTE) is created by integrating DTP, DTI, and DTA components for the predictive analysis of a product.

### Need for Digital Twin

Manufacturing industries often face difficulties in monitoring and inspecting the production lines in real-time. Digital twin enables real-time monitoring of real-world objects (machinery) on a digital model. The resultant provides a deeper understanding and error-free operation of the production lines in the manufacturing process. In healthcare, real-time monitoring, effective therapeutic regimen, and preventive care of patients is a cumbersome
processes for healthcare practitioners. With the introduction of the digital twin concept, monitoring and evaluation of patients’ health are simplified, enabling effective outcomes.

Apart from monitoring patients in real-time, the digital twin can be helpful for proactive remote monitoring of medical equipment and predictive maintenance of device/equipment to detect potential problems or technical issues before their occurrence such as maintenance scheduling for medical devices/equipment during downtime. This can prevent disruption of the continuity of care, in addition to saving money, time, and effort.

Another aspect that could be useful is the simulation of the outcome before building a prototype or actual medical device. This results in decreased research and development expenditure, along with reduced iterations and development time.

**Application of Digital Twin in Healthcare**

With wide application and benefits across industries, a digital twin is paving its way in aerospace, defense, automotive, and other allied areas. It is gradually penetrating and addressing the unmet needs in healthcare, though still at a conceptual stage. Some trending healthcare applications are listed here (also represented in Exhibit 2):

- **Predictive outcome:** Patient care is shifting towards preventive care from reactive care. The information related to genetic, biochemical, physiological, and behavioral aspects of an individual is captured to create its personalized digital twin. An individuals’ digital replica can predict and analyze their health outcomes to generate personalized
insights, which would help in implementing preventive strategies and reducing healthcare costs. Digital twins can reduce the time spent by hospital staff in managing patient flow and optimizing inventories by predicting patient-specific outcomes as well as scheduling equipment maintenance.

- **Surgical planning**: The digital virtual replica of a patient empowers the surgeons to plan the surgical procedure in a better manner and identify the risks associated with the surgery. In some cases, the modeling can help to mitigate the need for surgery altogether. A French startup, Sim&Cure, for example, has developed a digital twin that assists surgeons to choose endovascular implants that can optimize aneurysm repair. National Institute of Health (NIH) is developing digital twin models for athletes to accurately predict concussion-related trauma from brain injuries throughout their careers. In the case of any injury, this data will provide an advantage in accelerating surgical procedures and recovery plans.

- **Personalized medicine**: Personalized medicine is one of the growing approaches in medicine. This aims to address the issue by providing treatments of diseases and disorders, and intervention aimed for prevention and treatment. It is aimed at personalization with precision as it is tailored to the variables, e.g., environmental, genetic makeup, and lifestyle factors that make each patient unique. Having the ability to model individual patients with varying physiological traits and mechanistic differences, digital twins are thus a natural, complementary strategy to implement personalized medicine. A patient’s digital twin can be useful in personalizing treatment regimens for a particular individual, without having long wait times for screening/diagnostic results. For example, Oklahoma State University’s researchers have created a digital twin of the respiratory system to simulate aerosol drug particle movements for its delivery in lung cancer therapy.

- **Medical Education and Training**: Digital twin in combination with augmented/virtual reality is rapidly gaining momentum to address the training and education needs of healthcare practitioners. Numerous companies have simulated medical anatomy and surgical procedures to minimize the usage of cadavers and inspiring interactive learning.

*Exhibit 3* represents a few use cases in the healthcare domain that showcase the benefits of the digital twin concept.
Some Notable Examples of Digital Twin Concept

- Siemens Healthineers created a digital replica of the human heart using about 250 million images and reports. This software not only facilitated an in-depth understanding of heart conditions but can also help in predicting illness or any underlying health issues.

- Sweden’s Linköping University has created a digital twin of mice affected by rheumatoid arthritis. The modeled version is aiding the researchers to understand drug efficacy and create a replacement for clinical trials on human beings.

- French startup Sim&Cure has developed a digital twin to treat aneurysms. The software creates a patient-specific 3D model of the aneurysm and surrounding blood vessels. It enables surgeons to select a variety of devices for operating the patient based on the digital twin study.

- In 2018, Babylon in collaboration with Bupa released personalized digital twins at the pilot scale. The models were created with a
combination of artificial intelligence and deep learning technology to visually represent the patient’s medical history. Personalized digital twins appeared as transparent human figures with detectable organs, wherein the patients can click on each organ and access information on organ health and future fatality risks.

**Digital Twin is touching different Healthcare Stakeholders**

The digital twin is a step towards a highly advanced digital revolution with unprecedented efficiencies to make the world a better place for humankind. Optimization, prediction, and simulations are the keys to a successful implementation of digital twinning. *Exhibit 4* represents how the stakeholders in the healthcare segment are utilizing the digital twin to deliver quality care.

![Exhibit 4: Digital twin affecting various stakeholders in the healthcare segment](image)

Although the benefits of creating a digital twin are too vast and still not fully explored, there are certainly some bottlenecks for its success.

> Digital twins can pave the way to precision medicine at scale. They have the potential to improve outcomes for patients while lowering healthcare costs and lessening the cognitive burden on physicians.
> 
> – Ghada Trotabas, Executive Vice President, Marketing and Commercial Excellence at Siemens Healthineers (CMO)

- Digital twin needs to be created for each individual, which is costly, so a proper compensation mechanism must be implemented to reimburse/pay for
generating such virtual models.

- A huge data chunk is required to be stored and processed regularly for creating and continuously updating digital twin models, which makes it a time-consuming process.
- Even the data handling capacity for healthcare organizations needs to be updated so that they can handle such large data sets.
- Digital twin requires complex data integration, algorithms, and data structuring, so extensive training is required to ensure patient safety.
- Privacy and security are some concerns in the area of digital technologies to avoid data breaches. As the analytical data is vulnerable, entities need to assess their security protocols. Strict regulations and guidelines are required to safeguard the data of individuals.

**Conclusion**

The idea of creating a digital replica of a physical asset to monitor, analyze, and predict seems promising for the healthcare industry which is heading towards value-based care driven by definite outcomes. Complex algorithms are utilized to create replicas & digital models of patients, healthcare facilities, and medical devices, which could be critical in addressing issues like personalizing care delivery, predictive maintenance of healthcare facilities, and increasing R&D costs. It is expected that in the future the pre-clinical and clinical trials can be replaced with the digital twins of animals and humans. Companies should increasingly adopt the digital twin concept to cut down their research and development costs, improve the quality of life of their patients, and bring more treatments on the market. Although data integrity and limited availability of trained researchers to develop and monitor highly complex algorithms for digital twins are some of the major concerns that can poise resistance to the progress of its advancement in healthcare, but the introduction of strict regulations like the General Data Protection Regulation (GDPR) and upskilling programs will ensure a smooth journey for digital twins in the healthcare segment.

**References**

1. Deloitte
2. HappiestMinds
3. Entrepreneur
4. Frontiers in Genetics
5. Elecks
6. HiTechNectar
7. Siemens Healthineers Whitepaper
8. Siemens Healthineers
9. Medical Plastics News
10. Informa
11. Geospatial World
12. Forbes
13. Clinical Trials Arena
14. Medtech Boston
15. NEC
16. Hannover Messe
17. TechCircle
18. Identity Management Institute
19. Med-Tech News
20. The Globe and Mail
21. AI