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Digital Twin: Engineering the Virtual Replica

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Abstract : *Over the past few decades, digital twin technology has developed into a highly adaptable tool that is commonly used in Systems and Industrial Engineering. It started in the aerospace industry but now serves as a dynamic foundation for various systems in manufacturing, healthcare, smart cities, and large-scale climate models. Digital twins support predictive simulations, such as virtual hearts and interactive Earth models. Future advancements will depend on combining different types of data, validating the models, and incorporating human-centered governance to create reliable and trustworthy digital twins across different fields, ultimately benefiting society.*

Keywords: Digital twin: Engineering the virtual replica

I. INTRODUCTION

Digital Twin is drawing material from practitioners and experts. Today the technology is used by many industries to provide accurate virtual representations of objects and operational processes. A 2019 Gartner survey found that Digital Twins were becoming mainstream with organizations. It predicted that 75 percent of Internet of Things (IoT) organizations will use or are employing Digital Twin technology by 2020.Gartner also predicts that by 2027, more than 40 percent of large companies globally will be employing Digital Twin in their projects to boost revenue.

II. HISTORICAL BACKGROUND

- The idea of a 'digital twin' — which is a virtual copy of a real-world system — started during the early days of the space age.
- In the 1960s, NASA used digital twins to create simulations of spacecraft and fix problems as they happened.Later.
- In 2002, the term 'digital twin' was first clearly used by Michael Grieves in the field of product lifecycle management to help with industrial design and operations.
- By about 2010, NASA had fully embraced digital twins as detailed virtual models of real objects, highlighting that a true digital twin includes three connected parts: the actual physical object, its virtual model, and the data links that keep them synchronized in real time.

III. OBJECTIVES

- To study and clarify the concept of Digital Twin.
- To identify Digital Twin’s significance over other domains.
- To mention various applications where digital twins are getting used.
- To study its pros and cons of digital twins.

IV. RELATED WORK / LITERATURE REVIEW:

The idea of Digital Twins isn't brand new.But in recent years, they've gone from being just a concept to actually being used in real life much faster than before.Experts believe Digital Twins will soon be used together with other technologies like voice recognition, augmented reality, IoT, and artificial intelligence.

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How do Digital Twins work?

1. Data collection:

In IoT situations, a company might use "smart objects" that have built-in sensors already installed.

These sensors keep collecting and sending data continuously.In IT environments, teams can create digital copies of software, applications, and computers using virtualization tools.Then they can use software agents to gather data from or near these digital copies to watch over and analyze them.

2. **Virtual modeling**

A virtual model is a digital copy of an object or system created using data collected from the actual item.It includes important features that allow it to react in a realistic way to different factors like environmental changes and interactions with other systems.

3. Live data integration

Live data integration allows for constant, real-time interaction between the digital twin and the actual physical system.This ongoing exchange of information helps companies boost efficiency, increase dependability, and carry out maintenance before problems occur.Many businesses automate how they share data, which lets them focus on bigger, more important business decisions.

4. Analysis, simulation and informed decision-making

Analytics tools can recommend specific changes in how things are run, like adjusting cloud resources, production levels, or team budgets, to help groups work more efficiently and manage costs better.These tools can also connect with customer relationship management (CRM) systems and enterprise resource planning (ERP) software to make production processes and customer interactions smoother and more effective.

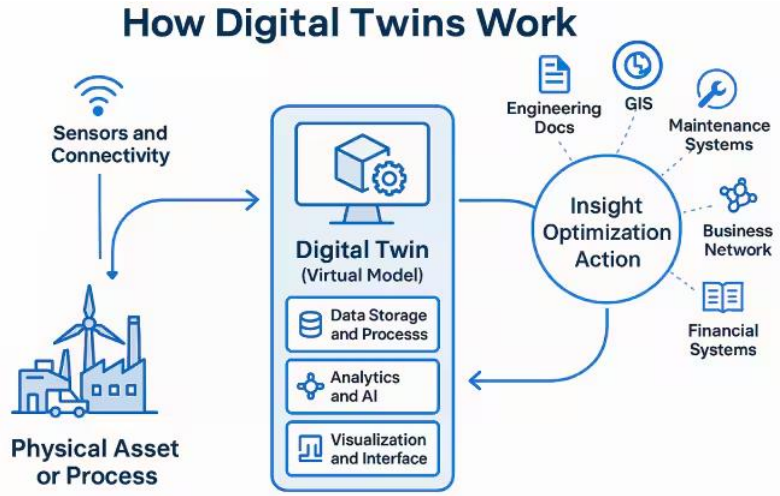


Fig 1.1

V. ROLE OF DIGITAL TWINS OVER OTHER DOMAINS:

1. IoT:

Digital Twins rely on IoT as their main technology in all their uses.IoT uses sensors to gather information from actual objects in the real world.The data sent by IoT is used to make a digital copy of a physical item.This digital version can then be studied, adjusted, and improved.IoT keeps the data up to date, allowing Digital Twin applications to form a live virtual model of a physical object.

2. Cloud Computing:

Cloud computing offers Digital Twins the ability to process data using advanced computing technology and store data in the cloud.With cloud computing, Digital Twins can keep large amounts of data stored in a virtual environment and

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access the information they need from anywhere.This helps Digital Twins handle complex systems more efficiently and manage the challenge of storing huge volumes of data.

3. Artificial Intelligence:

AI can help Digital Twins by offering a powerful analytical tool that automatically looks at the data collected and gives useful insights, predicts possible outcomes, and suggests ways to prevent issues from happening.

4. Extended Reality:

XR allows digital versions of real-world objects to exist alongside them, enabling both digital and physical items to interact in real-time.Digital Twins use XR technology to create accurate digital models of physical objects, letting users engage with digital content in an interactive way.

VI. APPLICATIONS OF DIGITAL TWINS

- **Process design and optimization**
  In this,Digital Twins eliminates problems before they occur.Digital Twin helps turn existing assets into tools that optimize processes, save money and make a way for innovation.
- **Aerospace:**
  From design and engineering right through to assembly and maintenance, digital twins help teams make better decisions by letting them see and work with CAD models and other data in real-time.
- **Architecture:**
  Using a Digital Twin, architects and designers can easily turn their design models into an interactive experience in AR and VR, making real-time design reviews more engaging and efficient.They can also place full-scale 1:1 models in AR on the construction site, helping to clearly convey the design ideas to all involved parties.
- **Automations:**
  In the automotive industry, digital twins are used to simulate and test new design ideas before actual production starts, improve manufacturing processes, and even predict how a car will behave under various conditions.They also allow for scenario simulation and real-time visualization of results in a safe virtual environment.For sales and marketing, digital twins help create highly realistic images and interactive 3D tools that use existing 3D data.
- **Construction:**
  Digital twin and AR technology allow the construction industry to optimize project data, streamline collaboration, and better visualize projects from design through to operations and maintenance. By using AR to bring valuable BIM data to the field, contractors are able to capture and communicate design errors in just a few clicks, allowing stakeholders to resolve issues quickly and avoid costly rework.
- **Energy:**
  Energy companies generate a wealth of data.Digital technologies like real-time 3D can visualize this data to provide right-time insights, better-informing decisions around production, maintenance, safety and security, and optimization.
  Top use cases of digital twins in energy:
  - **Learning, training and safety** -Transform job-critical learning and training into interactive, immersive environments across key scenarios.
  - **Site operations and maintenance** – Get insight into the design, management and performance of assets, while tracking your sites' status remotely in real-time with a digital twin of any facility, pipeline, or physical asset.
- **Infrastructure:**
  Digital twin technology helps builders, planners, and operators across cities worldwide better understand and optimize these spaces for public use. By using advanced, interactive models and live IoT data, stakeholders are

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able to simulate traffic flow, mobility patterns, and even the effects of climate change and shifting landscapes surrounding key infrastructure like airports, roads, and transportation hubs.

Digital twins bring geospatial, model, and sensor data together to visualize spaces in real-time, giving decision-makers the data they need to optimize operations and resource allocation.

With digital twins, planners and designers are able to simulate how people, vehicles and everything else moves through a space or even an entire city, and model how they will move in an updated or changed landscape, helping to inform key decisions around design and infrastructure maintenance.

- **Government:**
  Nowadays,new technologies are being deployed rapidly and putting challenges on government agencies and contractors that need to stay at the forefront of cutting-edge development. Digital twins help reduce the risk, time and cost of designing, developing, deploying and supporting cutting-edge applications in simulation and training and beyond.
- **Manufacturing:**
  As emerging trends such as the fourth industrial revolution (4IR) continue to gain traction, manufacturers are using digital twin technology to transform their product lifecycle.Over 80% of companies who implemented immersive technologies identified improvements in their ability to innovate and collaborate in their production, manufacturing, and operations work phases, according to a Forrester Consulting study commissioned by Unity.
- **Retail:**
  Spurred on by the pandemic, the need for retailers to leverage digital twins for design, planning, operations and more has increased exponentially. The importance of engaging customers online likewise increased overnight, and retailers looked to this technology to create immersive virtual experiences to continue connecting with shoppers.
- **Top use cases of digital twins in retail :**
  - **Design and planning** – Create 3D virtual stores to visualize and simulate the optimal experience prior to construction; utilize planograms and store planning applications to maximize space, improve efficiency, and collaborate remotely.
  - **Sales and marketing** : Retailers can use digital twins to increase conversion and make purchase decisions more accurate, which limits returns and mitigates the environmental footprint of e-commerce.

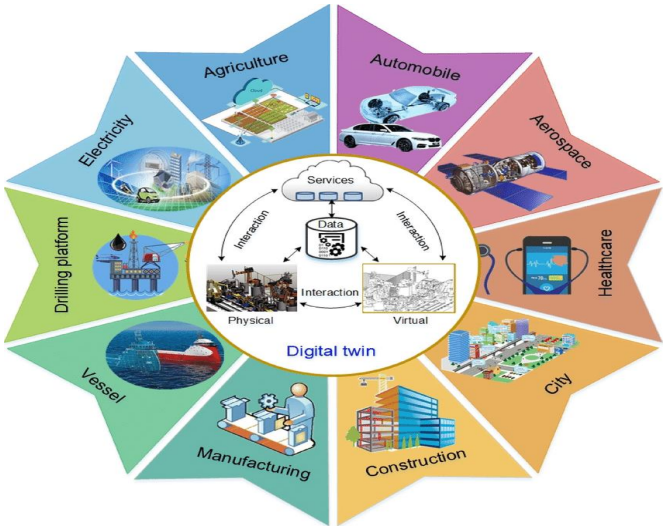


Fig 1.2

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VII. BENEFITS VS LOSS

Pros	Cons
Improved Outcomes Digital twins can enhance patient outcomes through personalized treatment plans and monitoring.	High implementation cost The initial investment for digital twin technology can be unaffordable for many companies due to high cost.
Cost efficiency Using digital twins can lead to effective cost savings in healthcare operations and patient care.	Data privacy concerns Sometimes,storing and processing personal health data raises significant privacy and security issues.
Predictive analytics Digital twins enable predictive analysis,leading to earlier interventions and better management of health issues.	Complicate integration Integrating digital twin technology with existing systems can be technically challenging and time-consuming.

Table 1.1

VIII. GROWTH OF DIGITAL TWINS TECHNOLOGY OVER PAST YEARS.

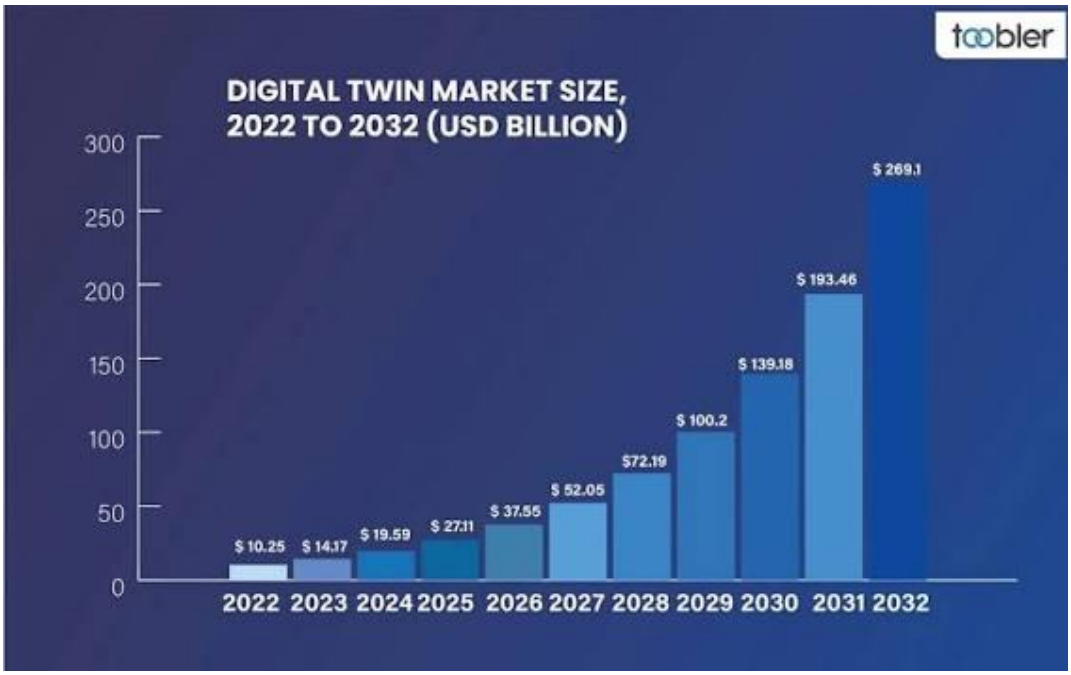


Fig 1.3

IX. CONCLUSION

As per the research done in this article,Digital Twins are nothing but the virtual replica which is widely used in domains like supply chain management,aerospace,retail management,architecture,government officials,automations and many more. While talking about this technology,we should first study about its fundamentals.Digital Twin is not a standalone technology its a mixture of IoT, augmented reality and of course Artificial intelligence.Collectively this technologies helps to create virtual replica of any object,process or system which continuously updates by real-time

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data collected by IoT sensors or softwares. Realtime visibility,predictive maintenance, cost-effective prototyping and better collaboration are some of the advantages of Digital Twins while high initial cost,complex data integration,privacy risks and high storage demand are some of the disadvantages seen.

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