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Digital Twins for Real Estate

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ABSTRACT

The real estate industry is experiencing a significant transformation driven by technological innovations, with one standout advancement being the concept of digital twins. In the fast-evolving world of real estate, digital twins are emerging as a game-changing technology that enhances property management, design, and development processes. A digital twin is a virtual replica of a physical asset, offering a way to simulate real-time scenarios and help stakeholders make more informed decisions. Digital twin technology represents a monumental leap forward for the real estate industry. By fusing the physical built environment with dynamic digital data, it empowers stakeholders to design smarter cities, construct more efficient buildings, and manage properties with unprecedented precision. Digital twins enhance property management, design, and development processes. This paper explores the applications of digital twins in real estate.

KEYWORDS: *digitalization, digital twin, real estate, real estate industry.*

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INTRODUCTION

Real estate has always been about location, timing, and vision. But today, it is also about data. As cities grow smarter and buildings become more connected, a new concept is reshaping how properties are designed, managed, and experienced: digital twin real estate. The real estate sector is undergoing a profound digital transformation, driven largely by the advent and integration of digital twin technology. A digital twin (DT) is a dynamic, virtual replica of a physical asset, process, or system. In the context of real estate, DT represents a convergence of the physical and digital built environments, powered by the Internet of things (IoT), artificial intelligence (AI), and real-time data analytics. DT is a dynamic connection between the physical asset and its digital counterpart; it allows stakeholders to visualize, simulate, and optimize various aspects of a building's lifecycle - from initial design and construction to operation, maintenance, and eventual renovation or demolition [1]. Figure 1 shows a typical digital twin [2]. It is regarded as the next generation of digitalization for decision making support. The current development of digital technologies has dramatically increased the adoption of digital twin (DT) systems into the energy sector. Figure 2 shows the conceptual model of a digital twin [3].

CONCEPT OF DIGITAL TWIN

The concept of the digital twin was introduced in 2002 by Michael Grieves of Florida Institute of Technology. He applied the concept in manufacturing and proposed the digital twin as the conceptual model underlying product lifecycle management (PLM). The concept was being practiced since the 1960s by NASA. The concept of digital twin consists of three distinct parts: the physical product, the digital/virtual product, and connections between the two products [4]. Figure 3 shows the historical evolution of DT technology [5].

A digital twin is much as it sounds: creating a digital duplicate of the physical entity.

It has two sides, one pertaining to a physical device and the other to a digital rendition of this device. DT is a real time digital replica of a physical device using 3D modeling and sensors. The DT is an emerging paradigm focusing on an enterprise asset such as a system, product or process. Its core goal is to virtually

represent this asset as close to reality as possible. A digital twin may exist before its physical counterpart is made. Technologies enabling DT include AI, IoT, 5G, virtual reality, augmented reality, wearables, and cloud computing. Realizing the full potential of DTs requires a convergence of these technologies. Digital twins integrate AI, IoT, machine learning, and software analytics with spatial network graph to create living digital simulation models that change as their physical counterparts change.

The three main pillars of the digital twin technology are visualization, emulation, and simulation. The foundation of DT is the physical world, which may consist of devices/products, physical systems, process, or an organization. Service is an essential component of DT in view of the paradigm of everything-as-a-service. DT-related services include application service, resource service, knowledge service, and platform service. The process of implementing DT can be divided into four steps: digital representation, synchronous mapping, simulation and prediction, and virtual and physical fusion. Figure 4 depicts the digital twin conceptual architecture [6], while Figure 5 shows DT enabling technology [7].

There are numerous requirements to describe "digital twin." To be considered a digital twin, the model must have some specific characteristics such as [8]:

1. Data is the carrier of information and the key driver of DT. Real-time data is important for knowing the status of the product. Data-driven digital twin can perceive, respond, and adapt to the changing environment.

   Integration of the different nodes is essential for creating valuable data. Sensors communicate the data to the digital world through integration technology between the physical world and the digital world, and vice versa.

2. Scalability (ability to analyze different scales of information);
3. Interoperability (ability to convert, match and establish equivalence between representation models);
4. Expansibility (ability to integrate models);
5. Fidelity (ability to conform to the physical model); the core of any DT is a high-fidelity virtual model.
6. Connectivity that indicates the level of communication with its physical counterpart; connectivity by design through IoT which is a paradigm for ubiquitous connectivity. Connect the products/services to a central location with streaming, big data, in-memory, and analytic capabilities to capture sensor data and enrich it with business and contextual data.

These are the most frequent requirements of digital twins.

DIGITAL TWIN IN REAL ESTATE

The real estate industry, historically characterized by physical blueprints, static property tours, and reactive maintenance, is undergoing a profound digital transformation. As the real estate industry grapples with the pressures of achieving Environmental, Social, and Governance (ESG) goals, adapting to post-pandemic hybrid work models, and optimizing operational costs, digital twins (DTs) offer a comprehensive solution. The DT technology is revolutionizing how properties are designed, marketed, operated, and maintained, offering unprecedented benefits across the entire real estate lifecycle. A digital twin in real estate is more than a static 3D model or a Building Information Model (BIM). It is a dynamic, living digital representation of a physical asset, continuously updated with real-time data from Internet of things (IoT) sensors, building management systems (BMS), and external feeds [1]. Figure 6 shows DT real estate [9].

Digital twin technology has found a natural home in the real estate industry. Residential agents are using virtual models to promote listings and more easily find motivated buyers. Digital twins are changing how real estate agents showcase properties, enabling prospective buyers or lessees to view spaces anywhere, at any time. In fact, digital twins enable prospects to explore properties on an even deeper level, revealing details that might not be evident during a quick in-person tour [10]. Digital twins are helping a rapidly rising number of retailers, property managers, and others monitor and control their spaces from afar in real time. Once built, digital twins help property owners and managers understand their overall real estate portfolios in highly intuitive and diverse ways. Figure 7 shows the key components of a DT in real estate [9].

APPLICATIONS OF DIGITAL TWIN IN REAL ESTATE

Digital twins allow stakeholders to visualize, simulate, and optimize various aspects of a building's lifecycle-from construction and operation to maintenance and renovation. Figure 8 shows some applications of DT in real estate [11]. Common applications of DT in real estate include the following [1,12]:

- *Urban Planning:* At the macro level, digital twins are revolutionizing urban planning. By creating virtual models of entire cities or districts, planners can simulate different development scenarios and evaluate their potential impact on critical factors such as energy usage, traffic congestion, and air quality. A prime example is Virtual Singapore, a pioneering national initiative that integrates vast amounts of real-time data from sensors, satellite imagery, and GIS into a comprehensive 3D model of the city. This platform allows city planners to simulate new urban projects, ensuring compatibility with existing infrastructure and minimizing disruptions.
- *Construction:* During the design and construction phases, digital twins serve as advanced diagnostic and simulation tools. Architects and engineers can model various building designs and materials to evaluate their impact on energy efficiency and construction costs. Furthermore, digital twins can simulate construction sequencing to optimize logistics and reduce material waste.
- *Property Management:* The most significant impact of digital twins is arguably in the operational phase of a building. With the rise of smart buildings and urban infrastructure, the need for efficient management tools has become paramount. In property management, digital twins transition operations from reactive to proactive. Traditional maintenance often relies on responding to equipment failures after they occur, leading to costly downtime and tenant dissatisfaction. Digital twins, equipped with predictive analytics and machine learning, can identify potential maintenance issues before they become critical. By integrating with Building Management Systems (BMS), digital twins provide property managers with a centralized, real-time dashboard of the building's health.
- *Property Marketing:* In commercial and residential sales, digital twins act as immersive, 24/7 virtual open houses. Prospective buyers or tenants can explore properties remotely, taking precise measurements and viewing the layout. This not only improves the customer experience but also accelerates the sales cycle and reduces the costs associated with physical staging. Furthermore, by ensuring optimal building performance and personalized environmental control, digital twins significantly enhance the day-to-day well-being and satisfaction of occupants.
- *Predictive Maintenance:* Traditional property management relies on routine inspections and reactive repairs. Digital twins, utilizing AI, analyze subtle deviations in equipment performance to predict failures before they occur. This allows managers to schedule maintenance proactively, reducing costly emergency repairs and minimizing tenant disruption.
- *Building Design:* During the development phase, digital twins allow architects and developers to simulate and test every aspect of a building before breaking ground. Instead of relying solely on 2D blueprints, stakeholders can evaluate the impact of different materials, test space configurations, and simulate environmental impacts such as energy consumption and natural lighting. For example, developers can use digital twins to simulate different building designs and assess their impact on financial returns and energy efficiency. This capability leads to faster decision-making, reduced construction costs, and the minimization of expensive delays.

BENEFITS

The integration of digital twin technology into real estate offers a multitude of benefits. It provides transparency and clarity, particularly helpful when it comes to providing plans for asset management options. Clear benefits range from reduced operational costs and enhanced tenant experiences to improved sustainability. Other benefits of DT in real estate include the following [1,10,12,13]:

- *Accessibility:* Brokers and clients may want to evaluate accessibility of a property for sale or lease, be it commercial or residential real estate. Virtual replicas help realtors show prospects how they might navigate a space while using a wheelchair. You can also study the property for ramp access and elevators to make sure it is ADA-compliant.
- *Cost Savings*: Predictive maintenance enabled by digital twins allows property managers to address issues before they escalate, minimizing costly repairs and unexpected downtime.
- *Energy efficiency:* Sustainability is a growing concern in real estate, and digital twins are proving to be invaluable tools for improving energy efficiency. By providing real-time insights, digital twins help property managers optimize building operations, reducing waste and improving energy efficiency. Sustainability is top of mind for buyers and lessees in the real estate industry. Integrating your digital scans with sensor data can deliver you important metrics about energy consumption and greenhouse gas (GHG) emissions of a building. Advanced

integrations help you even run simulations to see how certain renovations and upgrades could impact a property's carbon footprint.

- *Improve Customer Experience*: Buying or leasing a property is always a big investment to consider, whether it is for residential or commercial purposes. Digital twins improve the property buying and leasing experience by giving you a resource that prospects can return to at any time. Think of it as a 24/7 virtual open house.
- *Streamline Property Operations:* Digital twins simplify key property operations tasks in commercial real estate. Operations professionals have 24/7 remote access to spaces, which means they no longer need to make repeated trips to take measurements, manage inventory, and conduct inspections. Digital twins also act as an immersive 24/7 virtual training space, where employees can learn logistics and how to navigate complex facilities.
- *Sustainability:* The real estate sector is under immense pressure to decarbonize, as buildings contribute to approximately 40% of global carbon dioxide emissions. Digital twins are critical tools for achieving sustainability goals and ESG compliance. They are instrumental in achieving net-zero targets. They provide the necessary transparency to track energy and water consumption accurately, identifying inefficiencies and areas for improvement.
- *Revolutionizing Marketing:* Digital twins have fundamentally changed property marketing by enabling immersive, 24/7 virtual tours. Prospective buyers and tenants can explore properties remotely, taking measurements, observing finishes, and evaluating layouts without needing an in-person visit. This is particularly advantageous for international investors or out-of-town buyers.
- *Human Side:* We need to consider the human side of digital twin real estate. Behind every smart building are people-facility managers, tenants, investors, city planners. For a facility manager juggling multiple systems, a digital twin reduces chaos into clarity. For tenants, it means more comfortable, safer environments. For investors, it offers transparent performance metrics. At its core, digital twin real estate is not about replacing human decision-making. It is about augmenting it.

CHALLENGES

In spite of their immense potential, the widespread adoption of digital twins faces several challenges. Challenges regarding data integration, data silos, data governance, interoperability, economic barriers, security risks, and cost remain. Other challenges of DT in real estate include the following [1,9]:

- *High Costs*: Developing a functional digital twin requires significant investment in IoT hardware (sensors), cloud computing infrastructure, and specialized talent (data scientists and AI engineers). The cost and complexity of implementation - requiring substantial investment in sensors, computing infrastructure, and specialized expertise - can be prohibitive for smaller property owners. This high barrier to entry can make digital twins prohibitively expensive for smaller property owners, limiting their use to large-scale, premium commercial assets.
- *Privacy Concerns:* In addition to operational data, digital twins often collect information regarding tenant behavior, movement patterns, and space utilization to optimize building efficiency. This raises significant privacy issues. Property managers must navigate complex data protection regulations to ensure that the collection and analysis of occupant data do not infringe upon individual privacy rights, requiring strict governance and anonymization protocols. As digital twins rely on continuous data collection from various sources, ensuring data security and protecting tenant privacy are paramount.
- *Interoperability:* Real estate portfolios often consist of buildings constructed in different eras with disparate management systems. For a digital twin to function, it must integrate seamlessly with various IoT devices, sensors, and legacy software. The lack of industry-wide standardization makes this interoperability a complex and ongoing challenge.
- *Data Silos:* One of the most pervasive challenges in real estate is the fragmentation of data, creating data silos. Information regarding asset management, maintenance records, energy usage, and structural design is often stored in disparate, disconnected systems. Real estate portfolios often consist of diverse buildings with disparate systems, making data integration difficult.
- *Complexity of Integration*: Transitioning from a static BIM to a dynamic digital twin involves merging static architectural data with real-time operational data. The infrastructure required to support real-time synchronization, high-fidelity modeling, and seamless system integration remains fragmented. Many commercial real estate

companies find it technically daunting to synchronize these diverse data streams without encountering software conflicts or system latency.

- *Cybersecurity Risks*: As buildings become smarter and more connected, they also become more vulnerable. The reliance of digital twins on continuous data collection introduces severe security and privacy concerns. A digital twin acts as a centralized repository for highly sensitive operational data. If compromised, malicious actors could gain access to critical building systems, such as HVAC controls, security cameras, and access protocols.
- *Skills Gap:* The real estate sector traditionally relies on established construction and management practices. The introduction of digital twins requires a workforce skilled in data analytics, IoT management, and AI-skills that are currently in short supply within the industry. A recent study indicated that only a fraction of commercial real estate companies feel equipped with the necessary skills to operate a digitally transformed business.
- *Resistance to Change:* Cultural resistance within organizations often impedes digital transformation. Construction teams and traditional facility managers may be accustomed to reactive maintenance and legacy systems, viewing new digital tools with skepticism. Overcoming this requires comprehensive change management strategies, phased rollouts, and extensive training to demonstrate the practical benefits of the technology to end-users.

FUTURE OF DIGITAL TWINS IN REAL ESTATE

The real estate world is changing quickly with the help of new technology. The future of real estate is inextricably linked to the evolution of digital twin technology. The future of digital twins in real estate is intertwined with advancements in AI and machine learning. As these technologies mature, digital twins will become increasingly autonomous, capable of self-learning and executing complex optimizations without human intervention. As the industry continues to navigate the complexities of modern urbanization and environmental responsibility, digital twins will undoubtedly serve as a foundational tool for the intelligent, resilient real estate of the future. Realizing this future requires navigating complex challenges related to data governance, cybersecurity, and system interoperability. As the technology matures and standards coalesce, digital twins will move from innovative pilot projects to essential core infrastructure, fundamentally reshaping the real estate landscape into a more efficient, sustainable, and data-driven industry [1].

CONCLUSION

Digital twin technology is not merely a passing trend; it is a fundamental paradigm shift in how real estate is designed, built, managed, and valued. By bridging the physical and digital worlds, digital twins empower developers, owners, and managers to make data-driven decisions that enhance efficiency, promote sustainability, and elevate the human experience within built environments. Digital twin technology holds the promise to revolutionize real estate by fostering sustainable, efficient, and responsive built environments. The integration of digital twins is fundamentally altering how properties are valued and managed.

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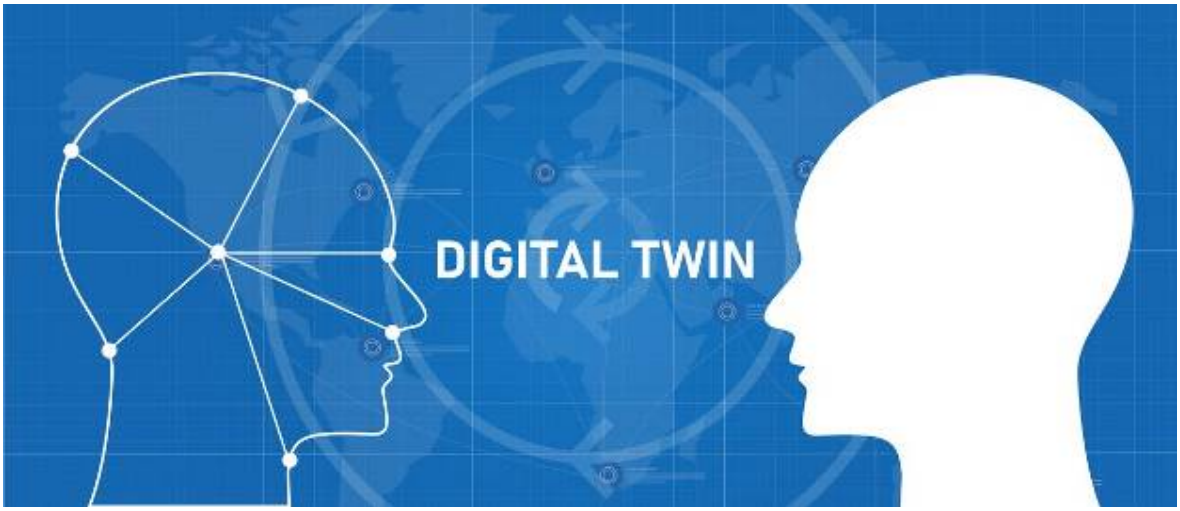

Figure 1 A typical digital twin [2].

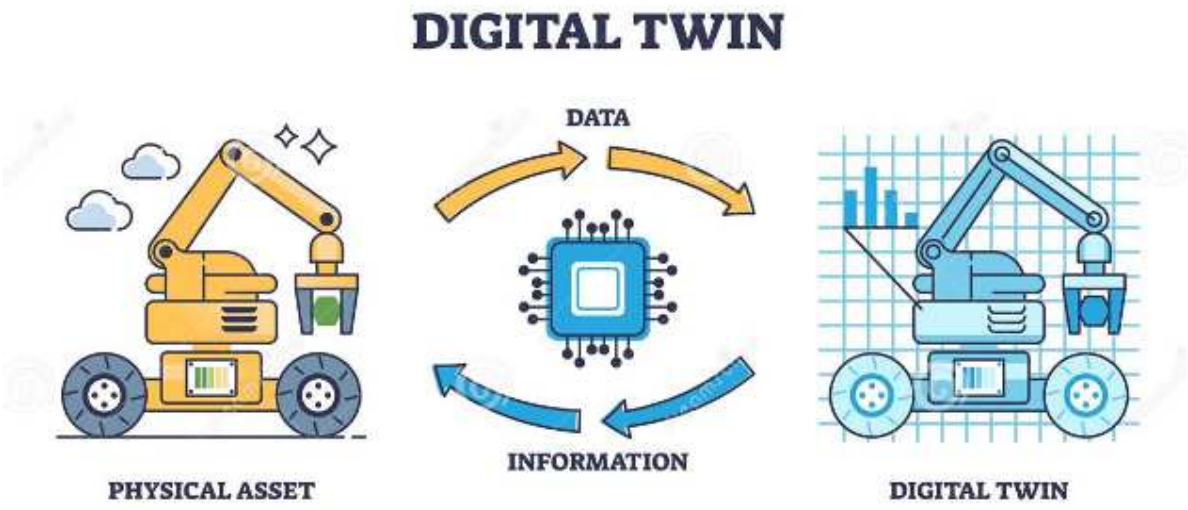

Figure 2 Conceptual model of a digital twin [3].

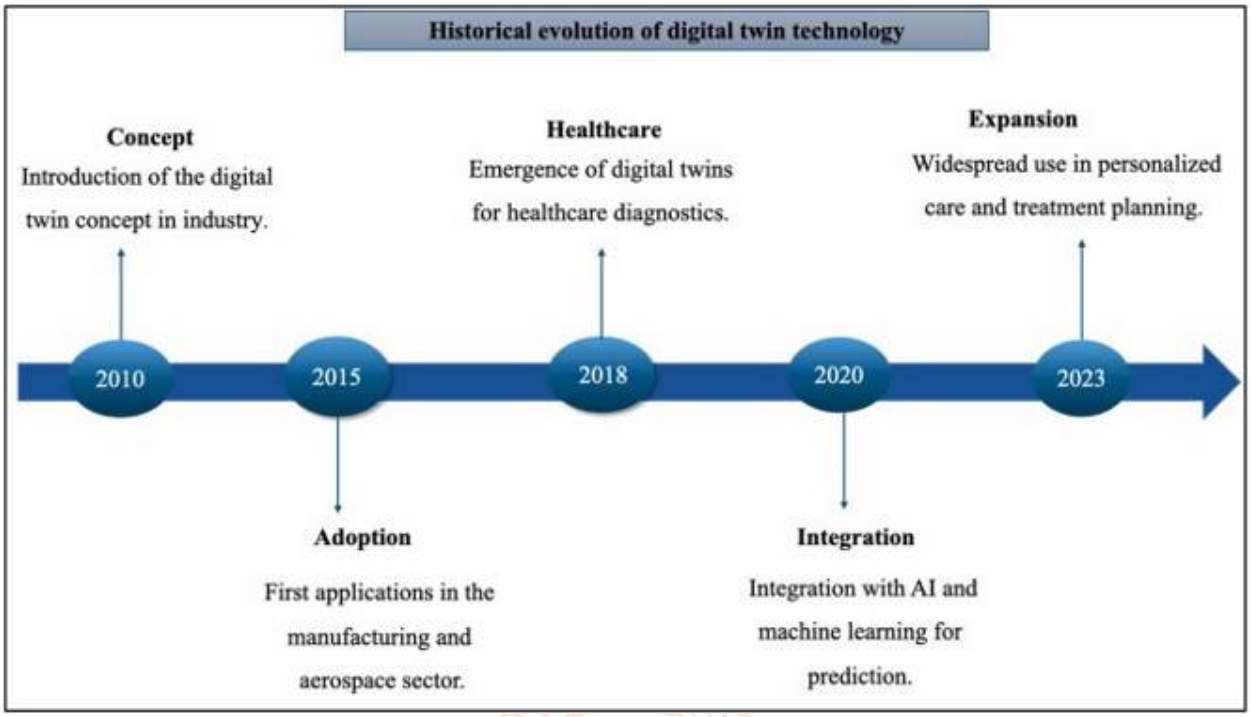

Figure 3 The historical evolution of DT technology [5].

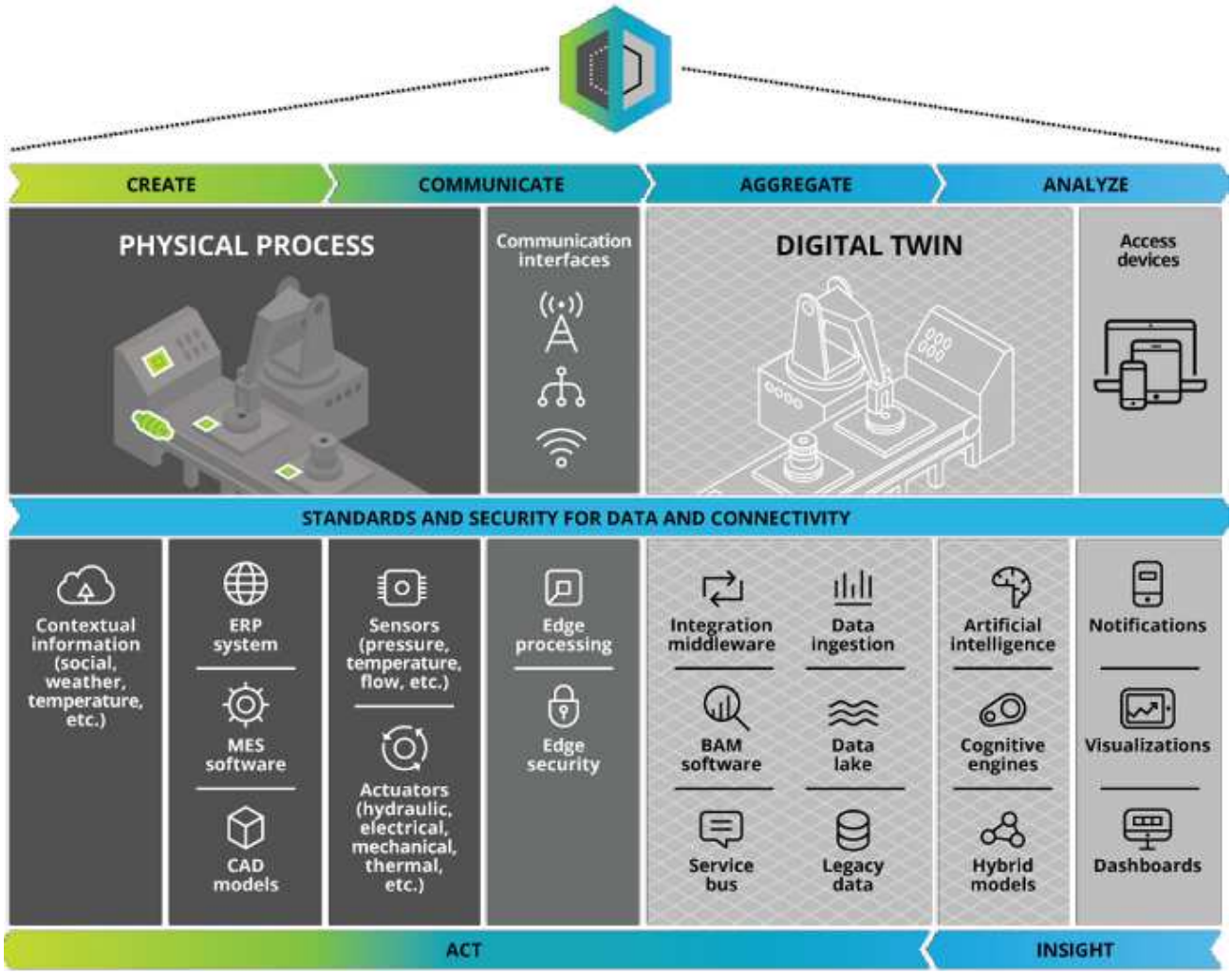

Figure 4 The digital twin conceptual architecture [6].

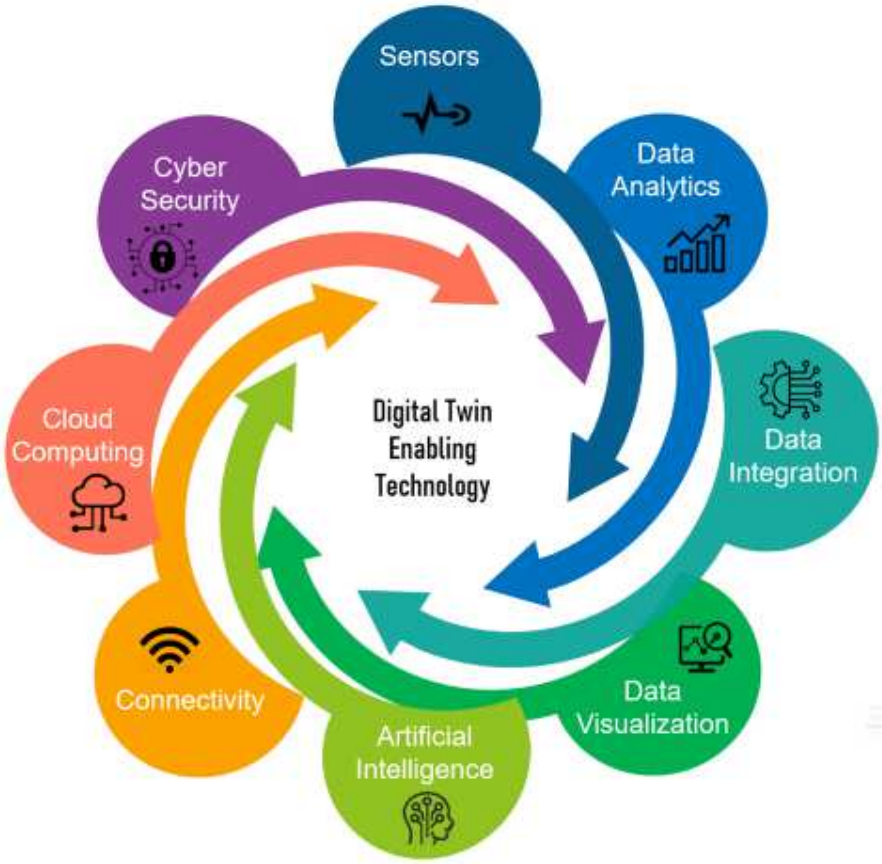

Figure 5 DT enabling technology [7].

Figure 6 Digital twin real estate [9].

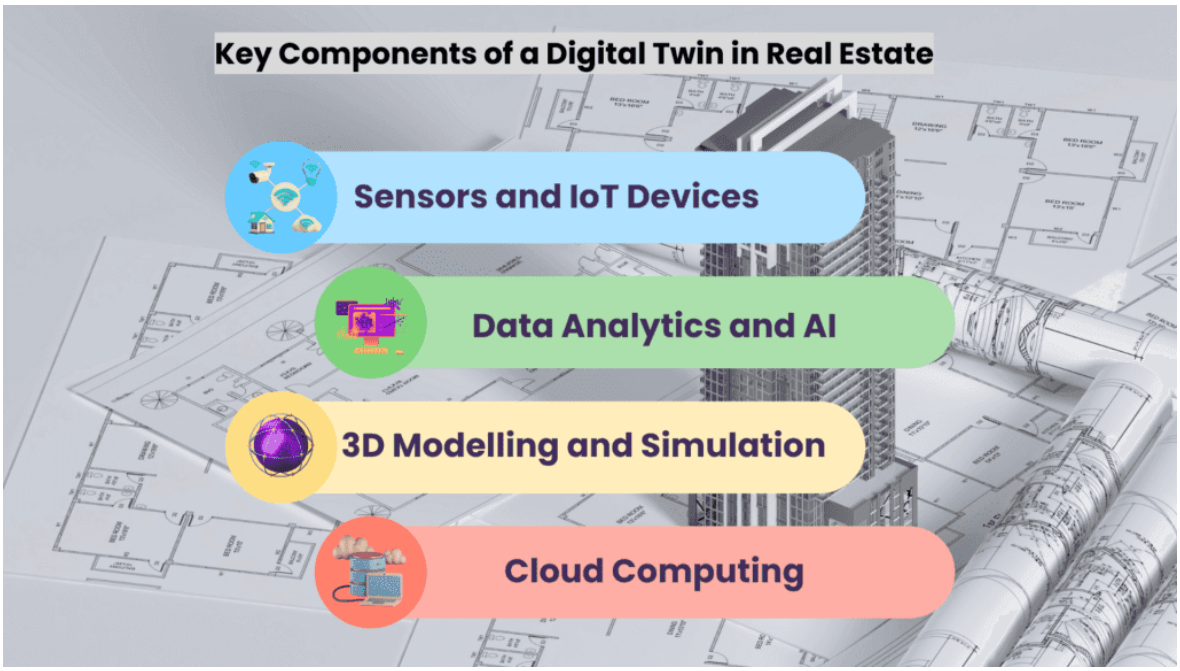

Figure 7 Key components of a DT in real estate [9].

Figure 8 Some applications of DT in real estate [11].