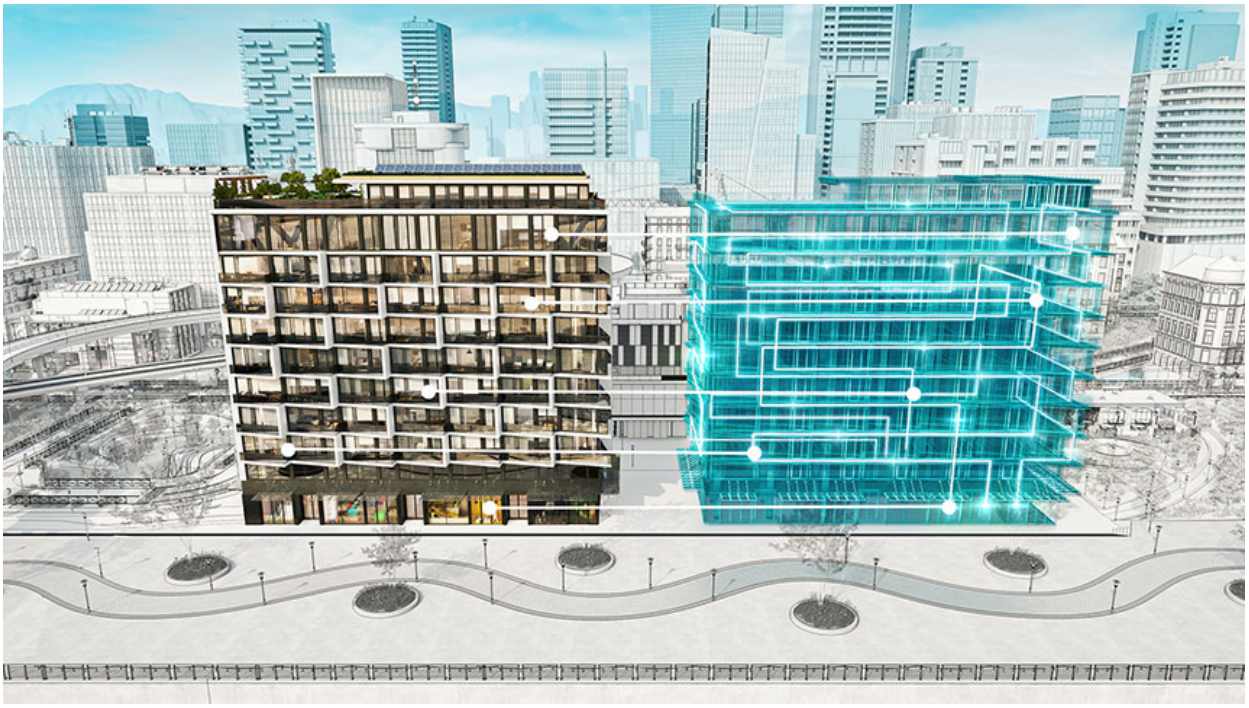

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Achieving Sustainable Development with Digital Twin Virtualization

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November 1, 2022

Executive Summary

The arrival of information technologies has fundamentally transformed the life of every human since its inception. Trillions-dollar industries have been built on top of the advancements. Unfortunately, the Architecture, Engineering, Construction, and Operation (AECO) industry is the slowest adopter amongst the pack.

At the forefront of the digital revolution resides the virtualization movement, which aims to construct a virtual replica of the physical world in the digital space – a Digital Twin (DT). The DT concept is far beyond static 3D models or data collection. The core of DT is to harvest insights from diverse data types with Artificial Intelligent (AI) tools. The insights generated by DT would then help us manage its physical counterpart for optimized performance. The AECO industry has started developing DT capabilities in the form of Building Information Modeling (BIM), which mostly remains in the first level of descriptive DT. There is still quite a long way from the second level of informative DT.

DT virtualization introduces a historical opportunity for sustainable development as it effectively tackles all three pillars of sustainability: Environment, Economy, and Society.

- On the environmental front, DT is the best platform to facilitate Integrated Design Process (IDP), the most environment-oriented project delivery method we have. Future smart cities will be built on the foundation of DT, fulfilling people's needs while minimizing emissions and waste.
- On the Economic front, DT improves the process of every project phase, leading to success by cutting costs and improving quality. At the same time, DT's autonomous, transparent and intelligent features benefit all project stakeholders by bringing business intelligence and peace of mind to asset management.
- On the society front, DT revolutionizes community engagement. DT empowers community innovations by breaking down the technical barrier. Persons with accessibility needs can contribute knowledge to the design and make significant impacts. A select few no longer monopolize the process, and decision-making is democratized. DT serves a vital purpose even after the project is built, as it transforms into a virtual community hub.

The adoption of DT faces several challenges. The nature of the AECO industry is unpredictable, fragmented and tech-adverse, which greatly hinders the research and development toward DT adoption. The initial investment in building the software, hardware and human resources necessary for DT often deters owners from investing in the beginning. Especially when the North American AECO industry lacks the intense competitive pressure in other parts of the world. Lastly, DT for the AECO industry is still fairly new, so further research is needed to develop the optimal adoption framework and standardize it for the industry.

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1.0 Introduction

Technologies such as cloud computing, the Internet of Things (IoT), and artificial intelligence (AI) have brought revolutionary breakthroughs in many industries. Regretfully, the Architecture, Engineering, Construction, and Operation (AECO) industry has not enjoyed much of the benefit as it is one of the minimally digitized industries in the economy [1]. The start of Building Information Modeling (BIM) implementation signifies some optimistic outlook for the future of the AECO industry. However, BIM adaptation has been slow due to a lack of interest, the technology-adverse status quo, and the complex nature of construction [2]. It is not very encouraging to learn the facts. However, from another perspective, it is also a historical opportunity for the first adopters to harvest the technology's substantial benefits and achieve sustainable development. Numerous industries have validated the concept and matured associated technologies. The way has been paved, and the time to take action is now!

1.1 What is Digital Twin?

The 21st century has been defined by the digital revolution, with virtualization at the forefront, exemplified by Facebook changing its name to Meta and investing billions in creating the metaverse. One might think of virtualization as a new concept, but quite the contributory, the idea has always intrigued people. A whole genre of movies like The Matrix was popularized by people's fascination with integrating life into the virtual world. There might still be a long way to achieve the visions in the film, but it is closer than most expect - in the form of Digital Twins (DT).

Simply put, a DT is the virtual replica of a physical asset or system. However, DT is beyond static schematics or 3D models as it dynamically evolves with its physical counterpart by exchanging data and influence. An intelligent DT would utilize AI to generate insights from a wide range of data, including structured data from IoT sensors, unstructured data from work orders and occupant feedback, and contextual data like community profiles. The generated insights would, in turn, aid the maintenance decision-making and influence the physical asset's performance. Eventually, prescriptive modelling would be engaged to test different scenarios in the virtual world before physical implementation. DT would bring about a fundamental shift in how professionals design, construct and operate assets, meanwhile empowering the community to participate in the process.

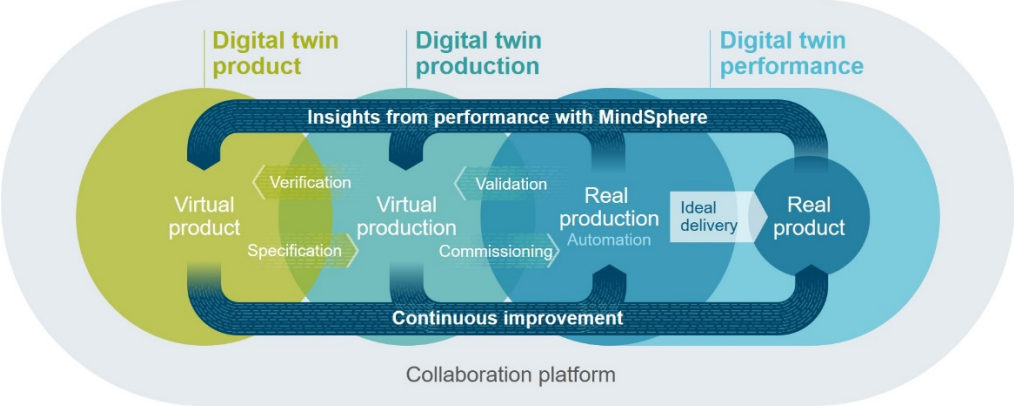


Figure 1. Iterative Design Process with DT [3]

1.2 History of Digital Twin

Dr. Michael Grieve first proposed DT as a concept at the 2002 American Society of Mechanical Engineers Conference [4]. The manufacturing industry quickly adopted the technology in the years following its introduction. Some advanced manufacturers now have full-scale digital factories operating in the virtual space to simulate, monitor and predict the physical factory's performance. Unfortunately, the AECO industry was of the slowest adopters. Some limited advancement was only made recently in the form of Building Information Modeling (BIM) technology. However, most projects in the AECO industry still do not have BIM integrated [2].

1.3 Levels of Digital Twin

DTs can be classified into five levels by progression: descriptive, informative, predictive, prescriptive and autonomous [5]. In its current form, most BIM adoption can be considered a descriptive twin, providing a static version of design and construction data in companion with 3D models. The next level - informative level DT would link with real-time sensor data to provide analytics and updates accordingly. Much of the current research effort in the AECO industry is pursuing the informative level DT by developing better sensors and algorithms [6]. The remaining levels of DT are still far away from the AECO industry, but the concept has been proven in other industries like manufacturing. The predictive level DT leverages data and analytics to foster business knowledge insights, creating predictions on asset performance. The prescriptive level DT enables simulations for possible future scenarios and tests different maintenance/construction regimes before real commitments are made. The final form of DT is fully autonomous, as it learns and acts on behalf of users based on their profiles.

2.0 Digital Twin and Sustainability

In the broad sense, sustainability refers to "meeting the needs of the present without compromising the ability of future generations to meet their own needs [7]." To contextualize what sustainability means in practice, three pillars are identified as the foundation: environment, economy, and society.

2.1 Environmental Conservation

Integrated Design Process (IDP) is one of our most advanced environmental performance orientated project-delivery methods. IDP is a collaboration process that spans a project's lifecycle, from design to construction, operation and occupancy. All stakeholders contribute to the project's final success are encouraged to be involved every step of the way[8].

Two key challenges to the successful adoption of IDP are lifecycle and collaboration. To maintain a consistent narrative throughout the project lifecycle, documentation must be preserved and updated as the project develops, which is traditionally difficult to achieve as the project change hands between phases. At the same time, effective collaboration is always hard to manage, especially between diverse people with diverse disciplines. The age of digitization presents DT as the answer to both challenges. DT would store and update information throughout the project lifecycle, which stakeholders can easily access. Collaboration is facilitated on the common co-creation platform, highlighting changes and conflicts while providing AI-based recommended resolutions. This revolution in collaboration dynamics has automated many hectic processes in the past, reducing communication friction to a minimum.

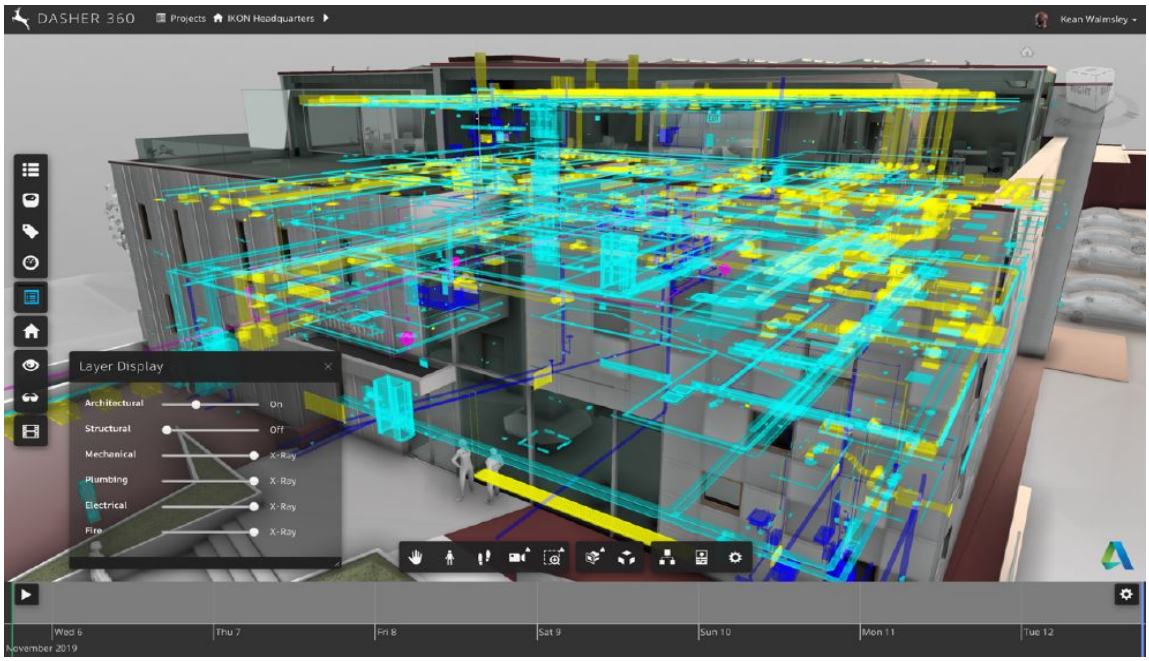
DT addresses today's most significant challenges, including staggering population growth, climate change, and the pandemic. For example, the DT of a city's traffic system combined with autonomous and connected vehicle technology can optimize the traffic flow to address a much higher transportation demand from the rising urban population. The optimized traffic would reduce emissions by reducing travel time and idling time. DT has significantly reduced a building's energy usage by dynamically managing the HVAC system based on predictive visitor traffic flow. The same mechanism can modify indoor airflow to minimize the spread of pathogens [5]. DT will be the foundation for future smart cities.

2.2 Economic Success

DT's economic benefits can be categorized by project phases or stakeholders depending on the project context.

Design Phase

DT promotes iterative optimization during the design phase, minimizing potential rework and reducing time loss. Feature such as automatic clash detection facilitates multiple designers to contribute to the same design without worrying about design conflicts. The AI detects the errors automatically so they can be rectified before the finalized design, mitigating costly reworks down the road.



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Construction Phase

A construction team with DT integration has reduced construction costs, improved the quality of work, and enhanced project management. Contractors in the field can visually see the designed placement of pipes through augmented reality (AR), which accelerates productivity while minimizing the error rate. DT can autonomously perform resource, materials, schedule, quality, and sequence management for the construction management team. Work progress and automatically sort out the schedule using established workflow logic while suggesting areas to maximize schedule efficiency.

Operation Phase

Building operators are often challenged with balancing occupant expectations and physical constraints. There is a vast number of possible maintenance schemes leading to different outcomes in which decision-making becomes more of an experience-based art. DT allows operators to access and visualize data from a central data hub, which helps discover trends and develop long-term plans. Work processes are better automated as DT help with predicting failures to create effective practice maintenance. Based on DT in other industries, a predictive ML that predicts the future can improve maintenance work processes by 15-20% [9].

Owner and Manager

The owner can utilize a superior decision-making process through the business intelligence DT creates. Scattered data points such as ROI, property deterioration progression, and work orders are aggregated into easily digestible points through AI processing. The DT automatically tracks relevant changes and updates itself accordingly, providing the owner transparency, control, and peace of mind.

AECO Firms

A firm that adopts the DT technology would have a faster design process with better quality. Meaning they would outcompete other firms who can not deliver such results. In addition, DT enables the firm to venture into a knowledge business by selling business intelligence and peace of mind. This fundamental transforms the role of AECO firms from "soldiers" (who follow the order and are limited in the scope of work) to "skilled mercenaries" (who provide solutions in a complete package).

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2.3 Community Empowerment

Community objections derail many development projects, and at the same time, many projects do not meet the community's needs. Traditional community engagement methods such as surveys and questionnaires fail to inform the community beforehand, often resulting in unhelpful answers that are overly generic or unrealistic. The community possesses invaluable knowledge on what is needed in an accessible and enjoyable facility since they are the end-user of such a facility. Unfortunately, most of the community lacks the technical know-how to contribute to a traditional design process until it's too late and mistakes are made. Building an effective communication channel with the community is one of the biggest challenges in modern development projects.

What if the republic experiences the new building and its surroundings "in person" before construction starts? Technologies such as AR and virtual reality (VR) combined with a DT does just that. Anyone can walk around the proposed design and provide intuition-based feedback, bypassing the technical requirements. This engagement would be particularly useful in accessibility design, as no one understands accessibility needs better than people who live it daily. Community members with accessibility needs can bring a vital perspective to the design team and make an irreplaceable contribution.

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The design engagement can be taken to another level through gamification and DT. A possible new design process would have professional architects and engineers creating a baseline design as a basic DT. Some components and parameters in this baseline design can be edited within a prescribed limit. The baseline design is then gamified and released to the community for a design competition. Video games such as Cities: Skylines provide a glimpse into the future of this collaborative design scheme. This new scheme grants agency to the community in the design process while ensuring compliance and safety. The ultimate vision is to democratize knowledge creation by empowering the community to innovate and impact the key aspects of their project.

The DT does not get retired once the project is built. On the contrary, the DT can be transformed into a new community hub in the virtual space. Our life has become increasingly digital, especially after the COVID-19 pandemic, where people are forced to isolate. The definition of a community expanded beyond the traditional scope. Anyone can now be a part of the community, even when they are physically thousands of miles away. A virtual community hub serves as the platform where people meet fellow community members and share a dialogue.

DT might still be a rare bonus feature for buildings, but it would not be long until it becomes the expected standard. Checking online reviews before visiting a tourist site or restaurant has become the standard practice for many people in this generation. Not long into the future, people will not feel comfortable visiting a place without visiting there virtually, and a building with no digital presence might be at a significant disadvantage. Imagine not being able to find a building on Google Maps. Will you be comfortable visiting that building?

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3.0 Challenges in Digital Twin Adoption

The manufacturing industry has the most advanced adaptation of DT thanks to its predictable environment, limited scope, standardized processes and quantifiable parameters [10]. Meanwhile, the reality in the AECO industry is quite the opposite - complex systems, arbitrary classifications, diverse environments and unpredictable conditions. The AECO industry's fragmentation and tech-adverse tendency also hinder its research and development efforts into DT [1].

Since the DT is a dynamic model requiring real-time data feed from the physical twin, it would not be possible without connectivity and sensor technology. Unfortunately, the unpredictable and often harsh site conditions in the AECO industry often limit projects' ability to adopt DT. Currently, the sensor and connectivity technologies are often insufficient or overpriced for most AECO projects [2].

The DT has the potential to reduce the project cost over its lifecycle. However, the up-front investment often deters the owner in the beginning—implementing the DT needs significant monetary investment into equipment and software while also requiring considerable investment in training and process redesign [2]. The status quo has worked for the AECO industry for hundreds of years. Thus it is hard to convince the industry to overcome the "do not fix what is not broken" mentality.

Lastly, DT as a technology is still in its infancy for the AECO industry. The concept of DT is ambiguous, and the application looks very different depending on the industry. The AEC industry would need to invest in research and development efforts to mature the technology and customize it for AEC applications [2].

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