Digital twin: the Age of Aquarius in construction and real estate

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Digital twin: accelerating the fourth industrial revolution

In line with the fourth industrial revolution, investing in technological automation has evolved from speculative to mission critical. The digital twin is at the forefront of this movement. First movers in healthcare, energy and transportation are driving inception and creating awareness. From a global market size of $3.1B in 2020, the digital twin is projected to reach $48.2B by 2026.[1]

C-suites often overlook the concept of a digital twin due to fear of the unknown or concern of upfront investment. However, with cataclysms like COVID-19 and climate change requiring global attention; it's no longer only bleeding-edge activists that seek action from corporations. Repeated market disruptions are now forcing business executives to consider out-of-the-box approaches to address challenges with greater agility and speed. Blackrock, a firm with more than $9T assets under management, has incorporated sustainability and climate change as a factor of investment risk.[2] Such initiatives are going to require industry leaders to demonstrate greater commitment toward these hazards. A technology like digital twin offers a tangible approach to digitizing process-driven operations, while building the foundation to address long-term global challenges. Construction and the built environment are beginning to realize the opportunity as well.

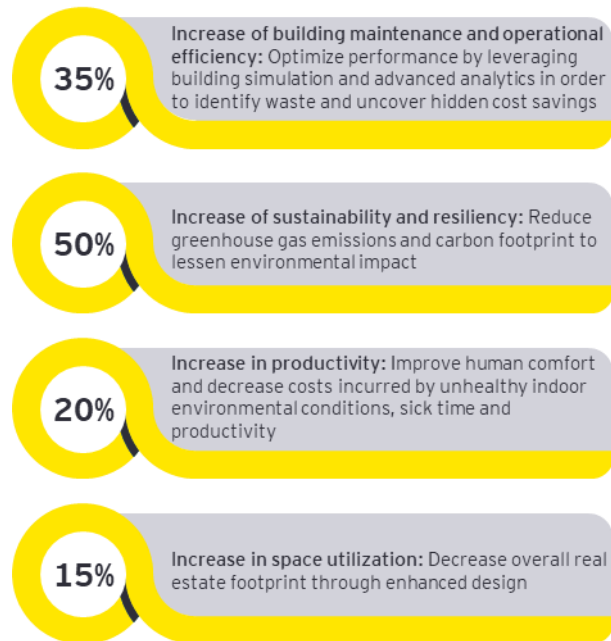Digital twins have four significant value propositions within the built environment:

1. Building maintenance and operations
2. Environmental impact and sustainability
3. Health and wellness
4. People improvement and real estate interface

This white paper provides an overview of digital twin technology and why C-suite leaders should begin adopting digital twins as a conduit for their digital real estate strategy today.
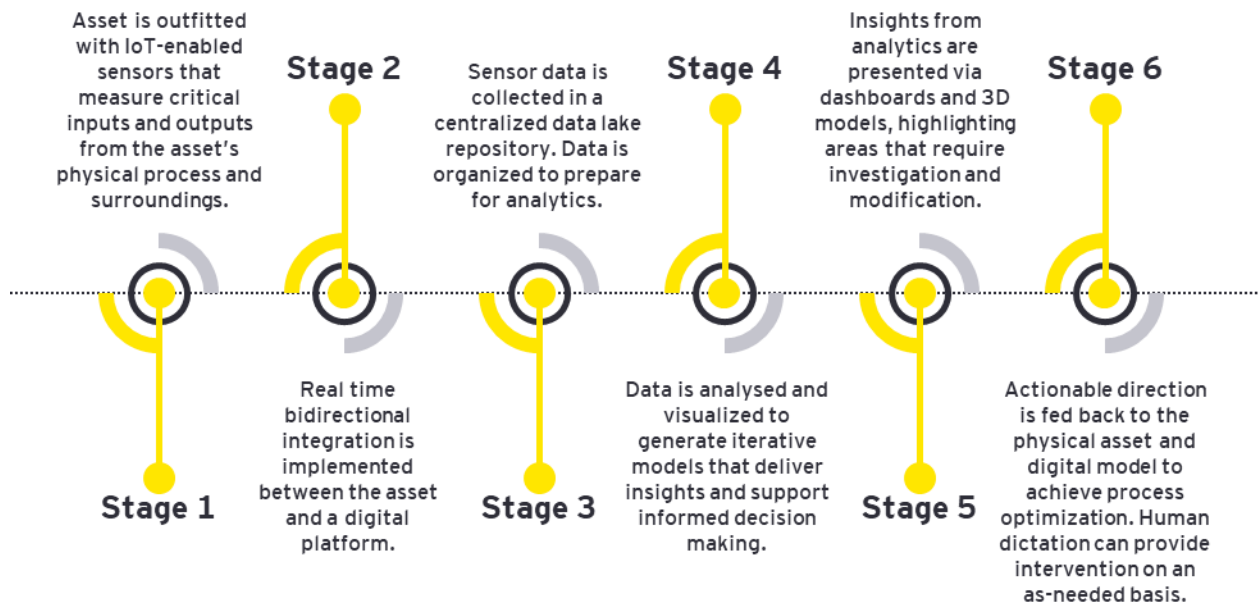
What is a digital twin?

The Digital Twin Consortium defines a digital twin as "a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity".[3] This

Digital real estate benefits

35% Increase of building maintenance and operational efficiency: Optimize performance by leveraging building simulation and advanced analytics in order to identify waste and uncover hidden cost savings

50% Increase of sustainability and resiliency: Reduce greenhouse gas emissions and carbon footprint to lessen environmental impact

20% Increase in productivity: Improve human comfort and decrease costs incurred by unhealthy indoor environmental conditions, sick time and productivity

15% Increase in space utilization: Decrease overall real estate footprint through enhanced design

Note: percentage savings based on US commercial building averages

technology uses design, construction, geo-spatial and operational data to represent the asset and its connected systems. To collect and process asset data, the digital twin utilizes internet of things- (IoT) enabled sensors that feed into machine learning (ML) models. These models analyze and learn from previous performance as part of an internet of abilities (IoA) strategy. IoA is the next evolution of IoT, where human augmentation and digital intelligence continuously develop and control an IoT network platform. It introduces a fundamental shift from human-computer interaction to human-computer integration, and the functionalities are mutually connected through various IoT networks within the virtual twin.
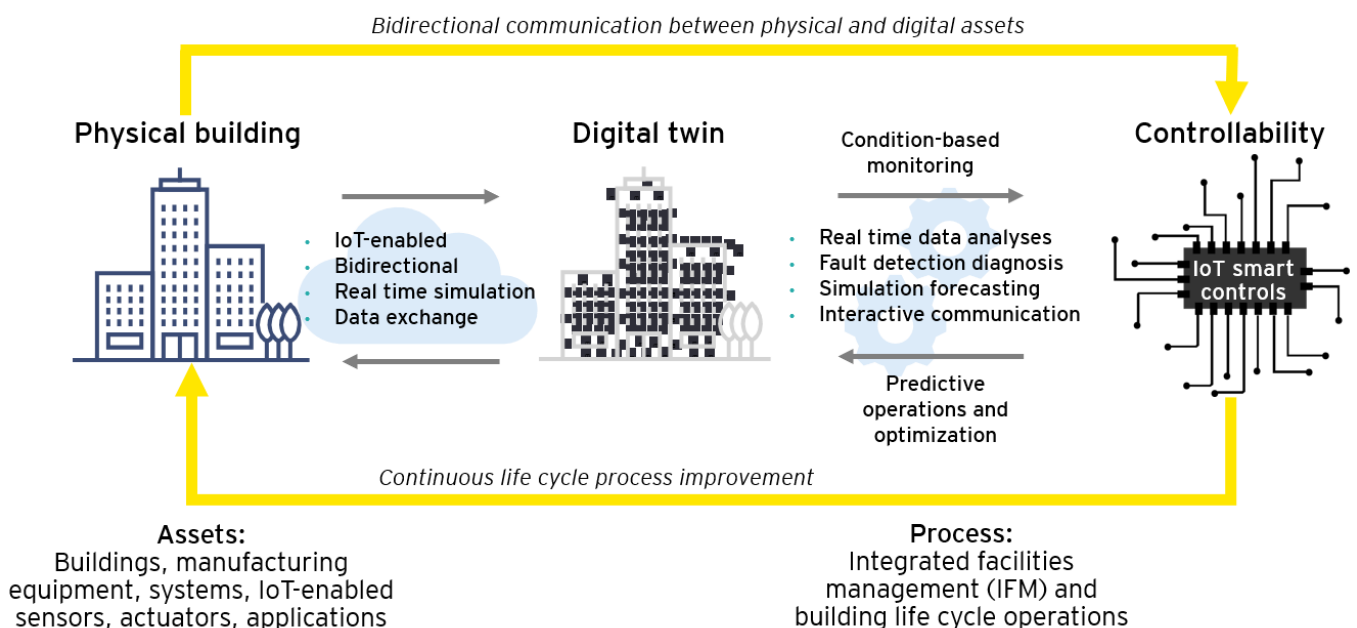
Digital twin architecture

Asset is outfitted with IoT-enabled sensors that measure critical inputs and outputs from the asset's physical process and surroundings.

Stage 2

Sensor data is collected in a centralized data lake repository. Data is organized to prepare for analytics.

Stage 4

Insights from analytics are presented via dashboards and 3D models, highlighting areas that require investigation and modification.

Stage 6

Stage 1

Real time bidirectional integration is implemented between the asset and a digital platform.

Stage 3

Data is analysed and visualized to generate iterative models that deliver insights and support informed decision making.

Stage 5

Actionable direction is fed back to the physical asset and digital model to achieve process optimization. Human dictation can provide intervention on an as-needed basis.

Digital twins in the built environment

When taking this concept to the built environment, a digital twin utilizes spatial data to provide the core framework, equipment and engineering data to understand the systems, and IoT with sensors to capture real time data. This enables the physical building to adapt to human needs, instead of the human conforming to the building's limitations. The aggregated data conducts simulations using physics-based modeling to run "what-if" scenarios to optimize performance. Digital data is then able to deliver actionable insights geared toward efficiency while reducing wasted resources. A dynamic digital replica of the asset, or a virtual copy of the building as shown below, is finally created by collating the historical and live data feeds.

Bidirectional communication between physical and digital assets

Physical building

- IoT-enabled
- Bidirectional
- Real time simulation
- Data exchange

Digital twin

Condition-based monitoring

- Real time data analyses
- Fault detection diagnosis
- Simulation forecasting
- Interactive communication

Predictive operations and optimization

Controllability

IoT smart controls

Continuous life cycle process improvement

Assets:
Buildings, manufacturing equipment, systems, IoT-enabled sensors, actuators, applications

Process:
Integrated facilities management (IFM) and building life cycle operations

Digital twins hold the potential to transform the built environment. Data is information; information is intelligence; intelligence is power. Digital twin technology consumes volumes of data-rich information to support intelligent decision-making within real estate operations more quickly, accurately and efficiently compared to humans. Until recently, gaining access to the right data that enables detailed insight of a building's current and future state performance has been a challenge. Traditionally, static data was used to retrospectively measure how a building performs. However, advancements in artificial intelligence (AI), ML, IoT, IoA and cost-effective sensor technology have now made this possible. Combining these technologies with a digital twin has enabled information to be extracted in real time to efficiently analyze trends while incorporating impacts of external factors like weather conditions, occupancy scheduling, human impacts and resource allocation.

Digital twins have evolved since their onset and can be classified by various levels of complexity. Within the built environment, the digital twin begins at the component level and builds up to the process level.
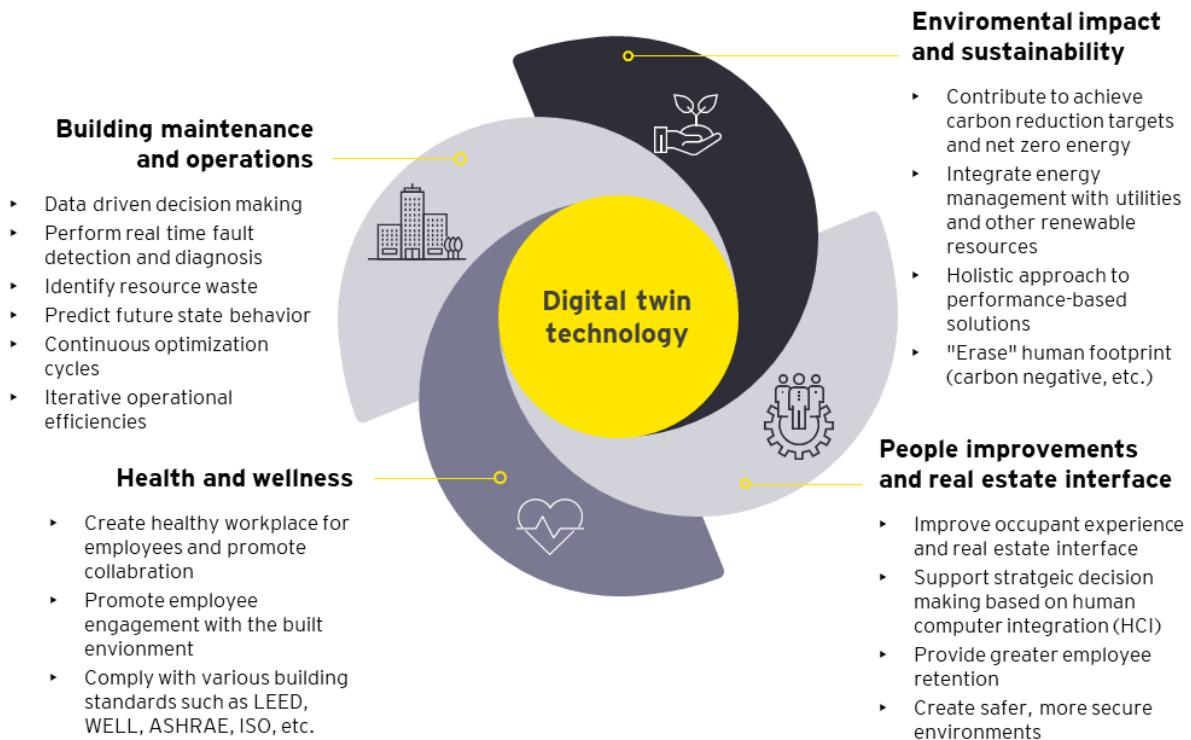
1. **Component level** describes a digital twin of a component of an asset, such as a motor or a fan belt within an HVAC unit. Data from each component feeds into the larger asset to provide real time visibility to its operating performance. Should that fan belt begin to fray, it informs the digital twin of the deficiency, and the data is then automatically routed as a work order to the maintenance team for repair. With advance notice provided by the digital twin's preprogrammed alarm thresholds, a facility operator can take preemptive action to resolve the problem before it causes damage to other components or the asset.
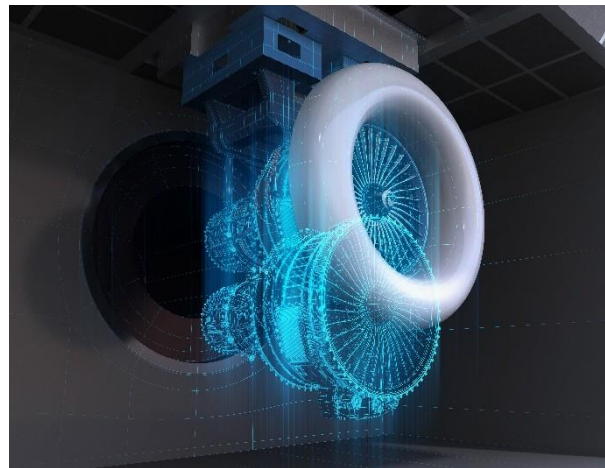
2. **Asset level** is the most common version of a digital twin. It is a model of an entire asset, such as a piece of equipment or a building, that continuously analyzes real-time data to provide process improvements. With access to a digital twin of the asset, companies can experience similar benefits around preventive maintenance at an even broader scale.

3. **System level** is a digital model of a collection of assets that operate together systematically within a program. A campus, portfolio of buildings and manufacturing plant are all programs that could benefit from a system level digital twin. A digital twin of the system of assets allows management to view their portfolio from a holistic perspective to gauge how well the ecosystem of assets function together.

4. **Process level** digital twins provide a big-picture model and overarching framework to an organization. It produces insight into the performance of the entire supply chain, rather than an operational model offered by a system or asset level digital twin. With this type of model, companies can measure operational characteristics that align to its business strategy. A process twin focuses on optimizing throughput, quality and other encompassing attributes of a company in relation to the market.

All four levels present approaches with the same objective – optimizing collective performance. In many solutions, multiple digital twins of various interconnected assets live within a facility. The collection of digital twins is then aggregated into a larger, global portfolio digital twin to analyze a program of assets. The program's framework can then be evaluated with the company's supply chain and market dynamics when taking the twin to the process level. A clear understanding of how digital twins are categorized by function is critical to pairing the right type of digital twin with the right application. Each twin provides different aspects of an entity's operations during its useful life. Efficiencies can be revealed at scale by iteratively implementing digital twins with a bottom-up approach throughout an organization.

The four value propositions

Building maintenance and operations

- Data driven decision making
- Perform real time fault detection and diagnosis
- Identify resource waste
- Predict future state behavior
- Continuous optimization cycles
- Iterative operational efficiencies

Enviromental impact and sustainability

- Contribute to achieve carbon reduction targets and net zero energy
- Integrate energy management with utilities and other renewable resources
- Holistic approach to performance-based solutions
- "Erase" human footprint (carbon negative, etc.)

Health and wellness

- Create healthy workplace for employees and promote collabration
- Promote employee engagement with the built envionment
- Comply with various building standards such as LEED, WELL, ASHRAE, ISO, etc.

People improvements and real estate interface

- Improve occupant experience and real estate interface
- Support stratgeic decision making based on human computer integration (HCI)
- Provide greater employee retention
- Create safer, more secure environments

As mentioned previously, the adoption of a digital twin can reduce real estate operating costs by up to 35%, while at the same time decreasing carbon emissions, delivering a healthier workplace and enhancing the user experience. Digital twin technology is able to accelerate corporate evolution, incorporating sustainable design to drive operational excellence. This workplace transformation has identified four value propositions that address industry challenges and generate cost savings.

Building maintenance and operations

The most tangible impact of a digital twin is in the operations and maintenance phase of the building life cycle. According to a joint study by Harvard Business Review and Microsoft, 66% of global organizations identify energy management as the prime reason to adopt smart technologies. Further, 72% of executives stated that their prime business goal was to reduce facility inefficiencies and operational costs.[4] In addition to savings on operational expenditure, the adoption of digital twins influences users to realize that buildings are more than just physical assets. They are an environment where employees work, interact and spend a significant portion of their lives. From this perspective, digital twins bring to life IoT and IoA that create connected and responsive buildings capable of generating an atmosphere built for the user experience and human interaction. The building adjusts to the humans instead of the humans reacting to the building.

Operations can be up to five times the cost of a capital investment.[5] Maintenance represents a significant portion of these costs incurred as part of the asset's life cycle. The predictive nature of a digital twin can reduce maintenance costs by its ability to collect, monitor and analyze real time data while utilizing ML models to mitigate future risk. Installation of sensors throughout a building can automatically program predictive maintenance protocols, which are deployed as an alternative to traditional maintenance schedules.

> *The predictive nature of a digital twin can reduce maintenance costs by its ability to collect, monitor and analyze real time data while utilizing ML models to mitigate future risk.*

To enable this capability, digital twins can be configured to detect components and equipment running outside of a defined range of parameters or windows of tolerance. As a result, maintenance can be scheduled before a significant problem arises. Similarly, the digital twin can learn to understand how equipment and machinery operate under different external environments. This enables the dynamic digital twin to constantly monitor and predict how equipment will perform in the future. One method is by utilizing weather forecast information. The twin can predict future wear and tear, thus forecasting the need for maintenance activities only when necessary, not predetermined by a static IFM manual. Users can then enhance their planning and optimize other costly considerations such as inventory counts and storage for spare parts. In this scenario, the digital twin sends predicted work orders to maintenance teams and provides details on the exact item requiring service, with location, parts needed and instructions to perform the work.

Communicating predictive maintenance requests is nearly as critical as detecting them. The use of a real time mobile application that connects to the digital twin has become a common method for relaying information. It provides insight into the current state of the building's essential systems, including water, electricity and gas usage. If a component were to break or a unit shuts down, the service professional would receive a notification on their device. The technician is then able to view the 3D model of the building at a moment's notice to drill-down on the digital representation of the issue at hand. Historical and current operating data is provided, and the user receives a comprehensive listing of a unit's specifications, maintenance records and forecast failures. This ultimately expedites the process for detecting and resolving problems at an exponentially faster rate, thus minimizing facility down time.
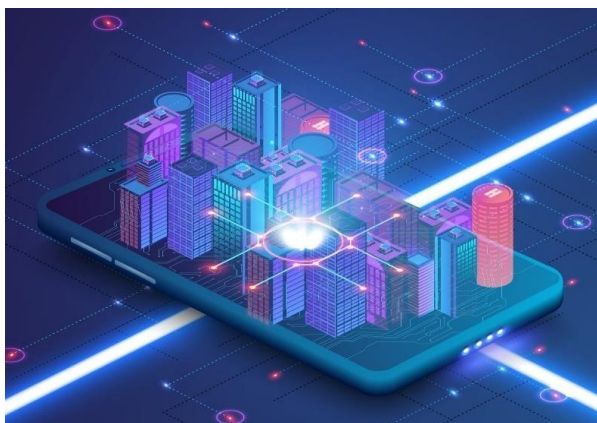

REScan is one such company that utilizes a mobile application to work with the digital twin of a building. As an operator navigates stairs, opens doors and walks through corridors, REScan's custom scanner technology is able to capture 250,000 square feet per hour from an eye level point of view. Once digitized, it streams the physical world to smart phones, making spaces remotely viewable, analyzable, editable and ready for spatial computing applications. The detailed 3D data enables automatic object finding, which provides contextual information for decision makers, AI algorithms and robotic applications.[6]

Environmental impact and sustainability

Solutions that reduce resource usage are increasing in value – not only for the cost savings opportunity, but due to the social responsibility to address climate change. By leveraging digital twins, IoT sensors and IoA augmentation; owners and facility managers can reduce a building's environmental footprint by decreasing energy consumption from various components and systems. These optimization capabilities not only capture significant energy savings, but also enable companies with large carbon footprints to drastically reduce their emissions and global impact. Google's Nest Learning Thermostat is an example that utilizes IoT sensors paired with the building's heating and cooling system. It detects the room's temperature and humidity and programs the heating, ventilation, and air conditioning (HVAC) system to adjust appropriately – in real time. By leveraging AI and ML, the thermostat identifies pattern recognition and desired spatial conditions on specified days and timeframes during the week, creating dynamic schedules for the HVAC system.[7]

Another example where a digital twin was used to reduce energy consumption comes from Nanyang Technological University (NTU), a pioneer in academia for promoting smart technologies and infrastructure. With its vision to be the greenest campus in the world, NTU explored the use of digital twins to reduce its energy, water, carbon and waste across its campus of over 200 buildings. Real time data was analyzed to uncover hidden energy and cost saving opportunities across the various campus utilities.

During the first five years of facility operations, Phase 1 analysis was performed as a preliminary investigation designed to extract high-level optimization savings. It resulted in a 21% reduction in campus energy consumption, reduced 8.2 kilo ton (kt) of its carbon emissions and provided S$3.9 million in cost savings during this time frame. Utilizing Phase 1 information as a baseline, Phase 2 further drilled down on high-consumption utilities and collected data from a range of sources, including automated meter readings, utility bills, building management systems (BMS), IoT sensors and operational databases. The investigation involved deploying sub hourly time-series data analyses and advanced analytics to identify additional energy and cost savings.

ROI payback period (in years)
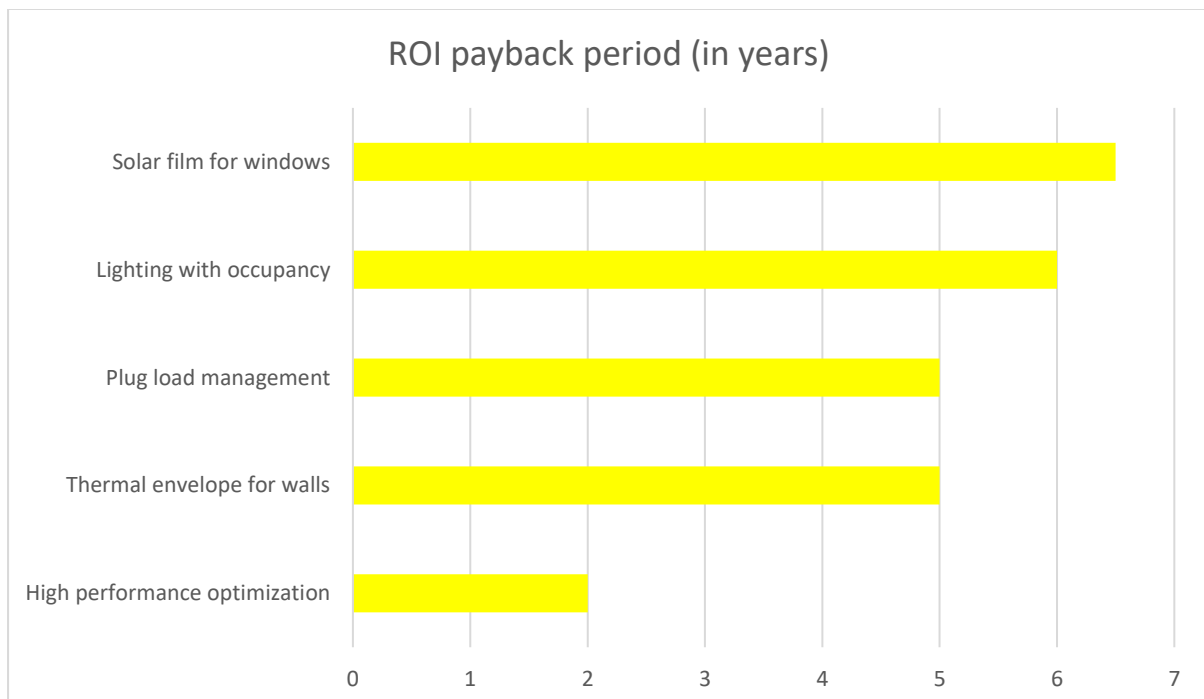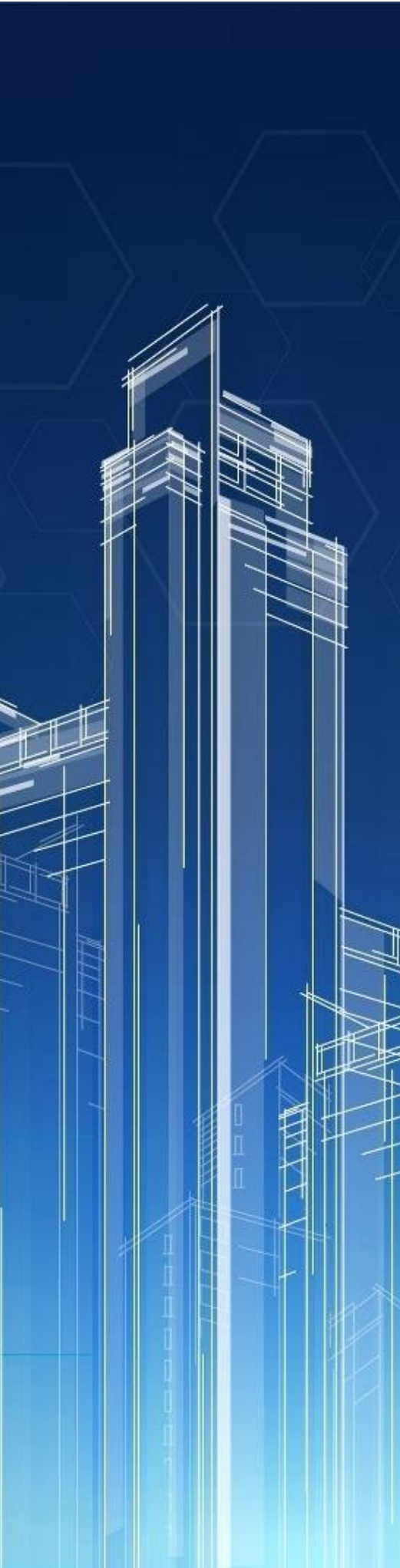
In the final stage, virtual digital twin models were created using data from Phase 1 and Phase 2 (a total of ten years) to compare the impact of installing a range of potential technologies. Through an iterative process of simulation analysis, the compelling results provided the university confidence in moving forward with investing in five technologies that were projected to produce the greatest return on investment (ROI). Technologies included high resistance envelopes for walls and roofs, lighting with occupancy sensors, curtain wall upgrades, plug load management and high-performance optimized chillers. The adoption of these technologies resulted in a total of 31% energy reduction, reduced 9.6kt of carbon emissions and provided S$4.7 million of cost savings over the ten-year period, placing NTU on track toward achieving carbon neutrality.

Utilizing historical and real time data provides NTU the opportunity to forecast year-over-year savings, continuously optimizing and fine-tuning building operations resulting in additional ROI as time progresses.[8]

Health and wellness

According to International WELL Building Institute (IWBI), the leading global movement to transform health and well-being to the built environment, "our physical environment impacts our health more than lifestyle, medical care and genetics". As we spend 90% of our time indoors, the built environment leads to a profound impact on people's health, wellbeing, happiness and productivity.[9] A survey of employees working in WELL-certified office buildings reported that 92% of the respondents enjoyed a positive effect on health and wellbeing.[10] Technology like digital twins can directly correlate with and enhance WELL programs, as it too places people at the heart of design, construction and operational decisions.

With increasing emphasis of employee wellbeing in response to COVID-19; digital twins are expected to play a pivotal role in ensuring workplaces are healthy and safe. Digital twins provide organizations with an 'advanced toolkit' to reduce the spread of airborne viruses. Smart sensors monitor and maintain air quality and with advanced thermal screening and computational fluid dynamics (CFD), digital twins predict air flow and particulate dissemination to analyze heat transfer patterns. By monitoring carbon dioxide (CO_2) levels, owners can also meet multiple requirements detailed within the WELL building standards.

Sensors also maintain optimal lighting conditions and thermal comfort. WELL explains that light is the primary driver of our internal body clock, or circadian rhythm.[9] Occupancy sensors can help maintain adequate lighting and automatically switch off or dim lights when an area is not in use. By running real time simulations with this information, the dynamic digital twin can ultimately provide the user suggestions for how to best operate and maintain healthy spaces.

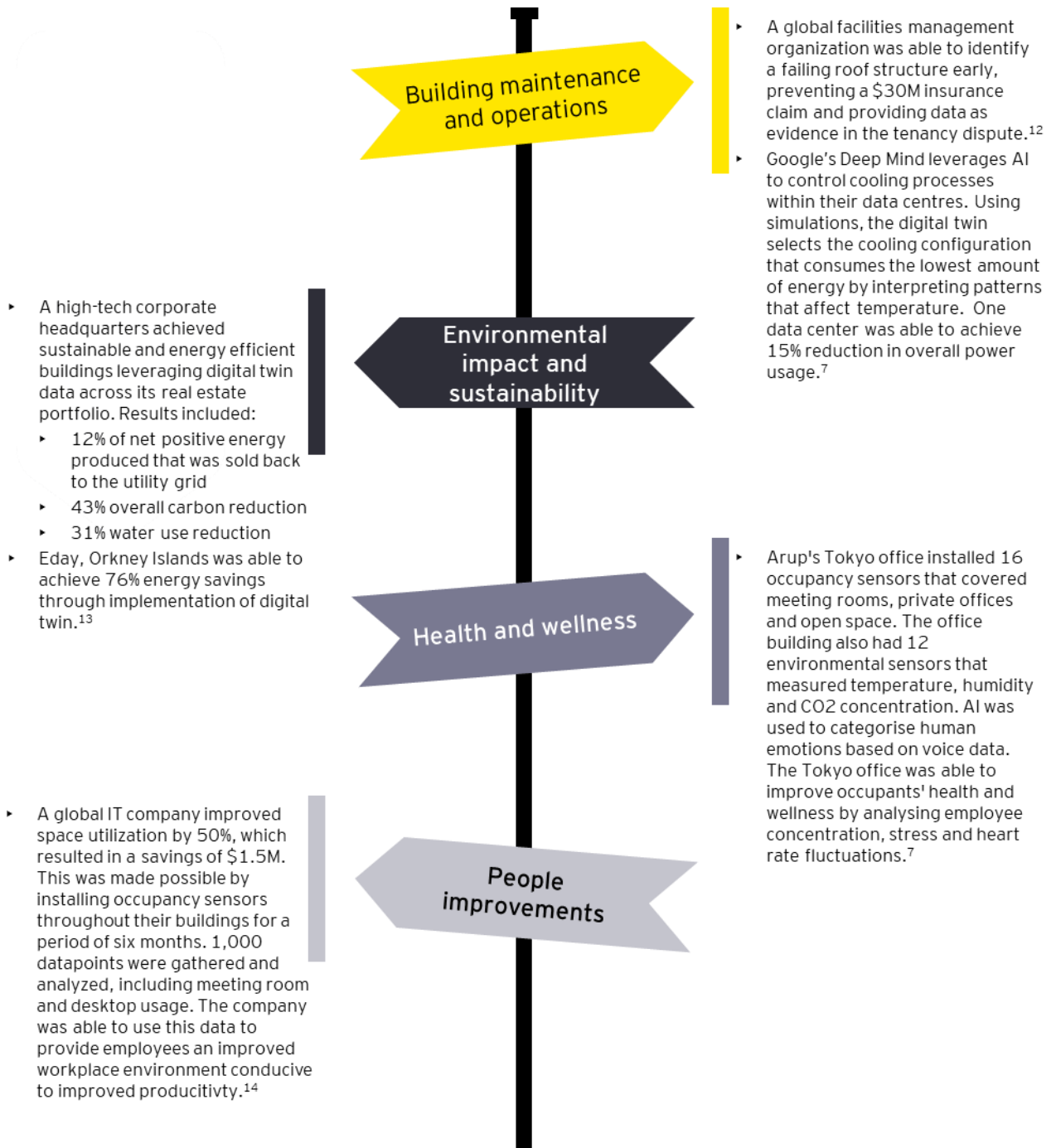**People improvements and real estate interface**

According to a study by JLL, 30% to 40% of office space is underutilized during a workday.[11] Digital twins can be a viable solution to track occupancy patterns and understand where these inefficiencies lie. Camera and IoT-enabled sensors are installed to collect data points and measure real time space utilization. This can help the C-suite understand if large conference rooms and common areas are actually used. Similarly, it may also show that more coffee makers and a bigger kitchen is needed to alleviate the que every morning.

Path of travel is also a pivotal data point that is often overlooked. The digital twin can assist in designing roads, ingress / egress and parking diagrams to align with peak traffic flows. Inversely, the digital twin could optimize employee's schedules to skip high traffic periods. Shaving off 20 minutes of commute time every day can lead to substantial ROI, especially for large campuses that host thousands of employees. It also leads to increased health and safety due to less congestion and when considering emergency action plans. This paves the way for future planning and design, which is discussed later in this paper.

In addition to design and space allocation, digital twin modeling can help improve the real estate experience and productivity. Using voice recognition, occupants can adjust environmental conditions around them to improve comfort. Should a conference room monitor stop working, the digital twin would immediately send a work order and the AI assistant could provide a quick update to the occupants as to when the issue will be resolved. The AI assistant would then transfer the reservation and data displayed on the monitor to another conference room that is available with similar resources and provide the occupants direction on where to go.

Building owners can also enhance the security for their employees and assets by installing automated security systems within the digital twin. AI image recognition in the IoT network would monitor areas that are typically monitored by security personnel. Threat detection is substantially improved and no longer requires as large of a security team. Companies can reduce labor costs pertaining to security up to 50% by leveraging a digital twin model.[7]

A global facilities management organization was able to identify a failing roof structure early, preventing a $30M insurance claim and providing data as evidence in the tenancy dispute.[12]

Google's Deep Mind leverages AI to control cooling processes within their data centres. Using simulations, the digital twin selects the cooling configuration that consumes the lowest amount of energy by interpreting patterns that affect temperature. One data center was able to achieve 15% reduction in overall power usage.[7]

Building maintenance and operations

A high-tech corporate headquarters achieved sustainable and energy efficient buildings leveraging digital twin data across its real estate portfolio. Results included:

- 12% of net positive energy produced that was sold back to the utility grid
- 43% overall carbon reduction
- 31% water use reduction

Eday, Orkney Islands was able to achieve 76% energy savings through implementation of digital twin.[13]

Environmental impact and sustainability

Health and wellness

Arup's Tokyo office installed 16 occupancy sensors that covered meeting rooms, private offices and open space. The office building also had 12 environmental sensors that measured temperature, humidity and CO_2 concentration. AI was used to categorise human emotions based on voice data. The Tokyo office was able to improve occupants' health and wellness by analysing employee concentration, stress and heart rate fluctuations.[7]

A global IT company improved space utilization by 50%, which resulted in a savings of $1.5M. This was made possible by installing occupancy sensors throughout their buildings for a period of six months. 1,000 datapoints were gathered and analyzed, including meeting room and desktop usage. The company was able to use this data to provide employees an improved workplace environment conducive to improved producitivty.[14]

People improvements

Examples of industry applications across the four value propositions of digital twins

How to activate change?

With any new initiative, organizations need to understand the business case to move forward. This includes becoming aware of an opportunity and requires in-depth research, evaluating facts and organizing logic to reach a conclusion that provides meaning and value. Once the conclusion is determined, the initiative must be one that is worth pursuing and the business desires to manage. From the inception of a construction or real estate project, stakeholders, including financers, developers, designers, contractors and property managers, begin by addressing several tactical questions:

‣ How are we monitoring our asset's performance throughout its life cycle and mitigating associated risks?

‣ What are my largest operational and maintenance expenditures and how can they be reduced?

‣ How will technology drive decisions that impact the resiliency of my building's sustainability and health of its occupants?

‣ What is the digital thread that weaves the planning, design, construction and operations of my building together to make more intelligent decisions?

‣ How can we maximize the value of the data that is collected from my facility?

The integration of digital twin technology with practically every stakeholder presents a strategic solution to navigate challenges across the full spectrum of an asset's life cycle, as well as the greater digital real estate footprint of an organization. The benefits of digital twins are diverse; however, they can generally be categorized into the following three key business drivers:

1. **Creates a centralized database and single source of truth:** Consolidating data into a single platform provides a foundation for advanced analytics powered by AI and ML models to anticipate and prevent equipment failures and enable performance optimization. Data lake repositories capture substantial amounts of raw unstructured data from multiple sources. Analytical processing organizes the collected data using cloud-based data libraries, and generates trend and pattern recognition that is utilized to improve the performance of an asset or process.

2. **Supports decision-making for allocating investment dollars:** Determining the best way to allocate investment dollars is critical in construction and real estate. Digital twins make use of data to identify performance gaps at both the building and portfolio levels. The technology provides deeper insights for deciding where to invest in new assets or where to make upgrades to existing assets.

3. **Accelerates continuous process optimization:** Seeking opportunity for continuous improvement will always rank high on C-suite agendas. Digital twins enable predictive and condition-based monitoring of assets that optimizes processes such as fault detection diagnoses and preventative maintenance programs. Digital twins are designed to integrate with other technologies to amplify these efforts and ultimately merge siloed systems across an organization.

Why invest now – is the juice worth the squeeze?

Digitally minded C-suite leaders are shifting their focus to long-term investments and strategies, not solely on short-term ROI. These executives understand continuous process improvement and that digital strategies are followed in incremental steps that build upon each other. This is typically done by initially implementing technologies that can be quick wins and provide high ROI. As new technologies are deployed, a centralized and integrated system that "speaks" with each technology becomes increasingly important, yet increasingly more challenging to develop. In comes digital twin to the rescue. Digital twins combine the three key business drivers into a comprehensive framework, building from existing investments that companies have made in enterprise information systems, big data, analytics and IoT.

> *While the setup of a digital twin may be perceived as a "heavy lift", the life cycle benefits far outweigh the upfront effort and initial investment. Its continuous development increases efficiencies and drives long-term operational ROI.*

Digital twins play a critical role in managing the complex integration of multiple technologies and assets as a centralized system. It also presents the opportunity to implement a digital twin at any stage of project delivery – both with new construction and existing buildings. A commercial office building can take two to three years to progress through financing, planning and design; two to three years to construct and commission; and 50 to 100 years in life cycle facility operations. It is through the operations stage where a digital twin is most impactful. With its continuous improvements through AI and ML, the impact and financial savings continue to grow over time. Digital twins provide stakeholders a holistic view to better manage their assets with more timely information, greater accuracy and deeper insights into their operations, therefore delivering increased ROI as time progresses.

While business leaders should not solely depend on short-term ROI's; identifying quick returns are also possible with digital twin technology. As indicated in the chart below, by analyzing existing data and running simulations, practitioners can realize 10% to 20% of energy savings within a short time frame.
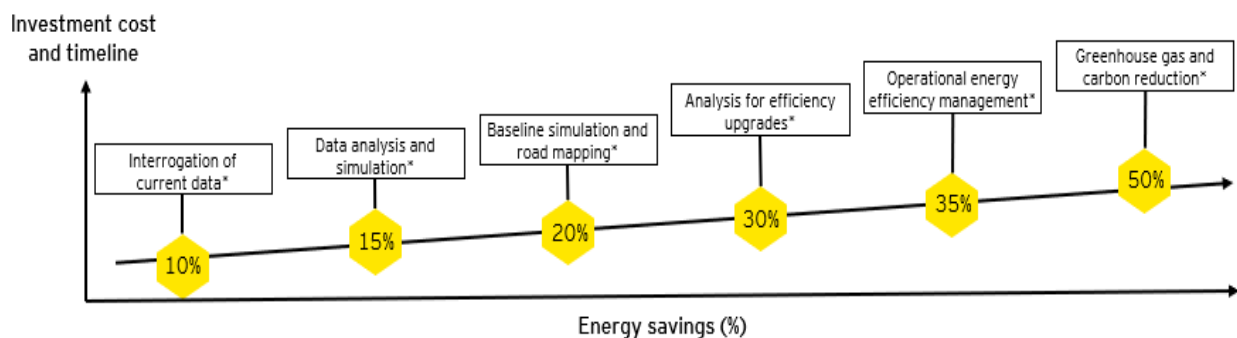
Note: These statistical targets are based on averages from actual project findings and may vary from project to project.

Users begin by analyzing existing data from their building networks to identify opportunities and capitalize on inefficiencies. Operational data can help identify pain points such as energy management system (EMS) deficiencies and HVAC units that require maintenance. Simply making the effort to assess historical data collected from utility bills and meter readings can help practitioners realize 15% in energy savings.
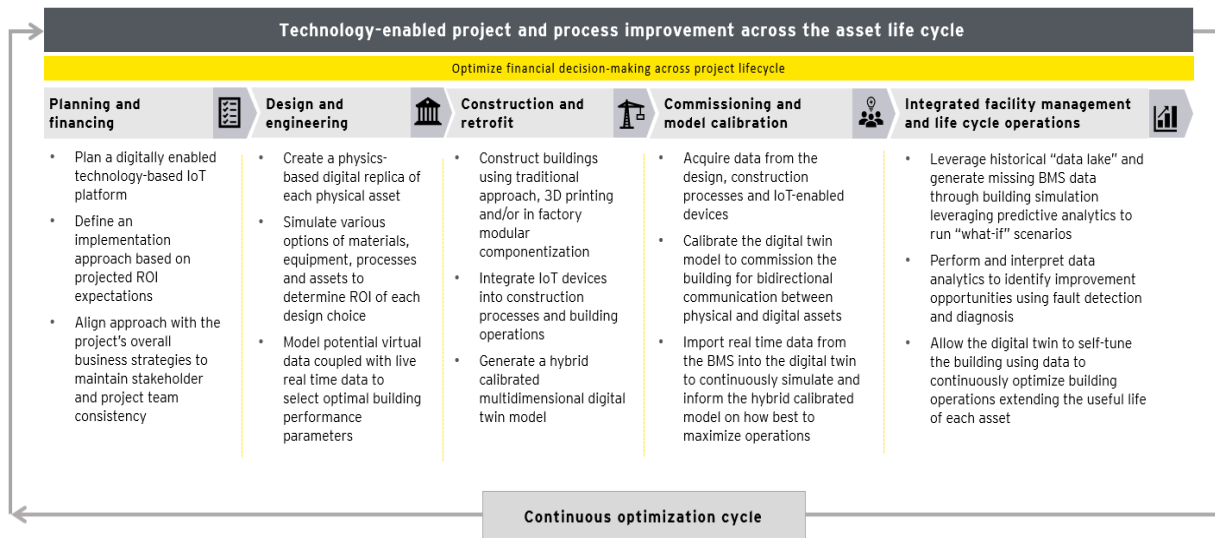
Virtual models can then be created to identify and analyze alternative solutions. Performing simulation and calibration with these models, a firm is able to establish a digital road map that

outlines future technology implementation to capture additional operational efficiency. The identified opportunities can lead to a 35% reduction in energy costs. By incorporating ML and AI with the digital twin, adapters can eventually realize up to 50% savings in energy consumption and expenditures throughout the life cycle of a building.

Capitalizing on opportunities throughout the asset life cycle

While digital twins are expected to revolutionize many industries, construction and real estate are particularly positioned to benefit from its continued adoption. How digital twins are used, and their resulting returns, will depend on the stage of the real estate life cycle at which the digital twin is implemented.

The following section outlines the key uses of digital twins across each stage of the asset life cycle.

Technology-enabled project and process improvement across the asset life cycle

Optimize financial decision-making across project lifecycle

Planning and financing	Design and engineering	Construction and retrofit	Commissioning and model calibration	Integrated facility management and life cycle operations
• Plan a digitally enabled technology-based IoT platform • Define an implementation approach based on projected ROI expectations • Align approach with the project's overall business strategies to maintain stakeholder and project team consistency	• Create a physics-based digital replica of each physical asset • Simulate various options of materials, equipment, processes and assets to determine ROI of each design choice • Model potential virtual data coupled with live real time data to select optimal building performance parameters	• Construct buildings using traditional approach, 3D printing and/or in factory modular componentization • Integrate IoT devices into construction processes and building operations • Generate a hybrid calibrated multidimensional digital twin model	• Acquire data from the design, construction processes and IoT-enabled devices • Calibrate the digital twin model to commission the building for bidirectional communication between physical and digital assets • Import real time data from the BMS into the digital twin to continuously simulate and inform the hybrid calibrated model on how best to maximize operations	• Leverage historical "data lake" and generate missing BMS data through building simulation leveraging predictive analytics to run "what-if" scenarios • Perform and interpret data analytics to identify improvement opportunities using fault detection and diagnosis • Allow the digital twin to self-tune the building using data to continuously optimize building operations extending the useful life of each asset

Continuous optimization cycle

Financing, planning and design

At the inception of a project, planners and architects are challenged with producing a design that can realistically be executed in the defined budget and schedule constraints. Everything from design briefs to detailed architectural drawings, modelling, testing and iterative changes must be considered before a project can take shape in the physical world. Each step of the process must be communicated between architects, engineers and other stakeholders in the supply chain. With the adoption of digital twins, construction processes can be planned, visualized and optimized before the commencement of physical operations.

Using a combination of historical and real time data, a digital twin develops a design that generates powerful insights and leads to an improved future-state reality. It incorporates historical data from component, asset, system and process level digital twins of previous projects. Architects are then able to utilize the digital twins and determine features, such as the ideal location of a building's orientation, to maximize efficiency and lessen the impact on its surrounding environment. By leveraging data such as pedestrian foot traffic, the twin can run simulations to determine where an entrance should be located and provide maximum accessibility with minimal disruption to pedestrian traffic flow. Testing "what-if" design options in physics-based simulations that accommodate real time factors (climate, solar, utilization, occupancy) enables users to reap benefits from informed decisions before one shovel hits the dirt. The design is further enhanced by ML and AI incorporated from the previous projects and saves time on scheduling while weeding out inefficiencies in the building process.

New construction and building renovations

Historically, progress monitoring is collected through field personnel, which often spurs major inconsistencies. It is common for reported progress to be exaggerated, especially on delayed projects. This often causes over-optimistic percent complete predictions and unachievable schedule milestones. By automating data collection and comparisons, the digital twin can reduce human errors and bias. Project managers and general contractors can strategically install sensors and cameras in various locations around the site and on personal protective equipment to collect real time data for objective reports on actual project progress.

Implementing real time progress monitoring and optimization, the model self-corrects and intuitively responds to its environment. Users can then leverage digital twins to monitor performance as compared to the original design plan and specifications. Should construction deviate from design; the digital twin immediately recognizes the inconsistency and flags the situation with the project team. Additionally, the twin is able to monitor the physical locations of equipment, material and labor utilizing GPS technology. With the average construction worker spending 15% to 20% of their daily time simply looking for stuff (tools, parts, the Superintendent for direction, etc.) – the digital twin can provide as an enormous efficiency lever.[15]

Commissioning and calibration

The most critical step to accessing the full functionality of a digital twin is calibrating the model with the building to create a bidirectional communication highway supported by cloud-based integration. To capture and fine-tune the data, physical sensors are coupled with virtual data outputs placed within each cubic foot of the model. Data is further imported from the BMS, generating a hybrid calibrated 3D digital twin. This refined model then predicts and detects high risk disruptions. In essence, the physics-based twin becomes a true replica of the as-built conditions.

As physical assets and organizations expand, users face growing challenges dealing with multiple data streams and platforms. Often, on a stand-alone basis, data does not add much value. Digital twins help standardize collection and integration of data from disparate and siloed systems. A comprehensive digital twin can represent millions of heterogenous mobile and fixed assets and create a multidisciplinary environment by adopting open platforms and open sources. In turn, the digital twin builds large distributed networks allowing decision makers to access deeper insights.

Using the digital twin model to commission and calibrate the building increases the level of accuracy to match design by 90%. Once the building is operating, the continuous commissioning and on-going calibration syncs both the digital and physical

assets. The digital asset makes the building aware of its operations and self-tunes as needed to ensure consistency and efficiency. Deviations that fall outside of acceptable tolerance ranges are identified and the digital twin is able to self-correct the physical environment as conditions change.

Life cycle operations and maintenance

The digital twin continues to improve itself over time. Complex ML and AI algorithms find unique insights and prescriptive actions a trained professional would be unable to identify. Users can preset, adjust and assign priorities to various objectives, including energy usage, carbon emissions, thermal comfort and load profiling. Multiple cloud-based simulations identify a range of datapoint options that align to a weighted value assigned to each objective. Datapoint outliers are identified using Pareto curve analysis and the model determines which combination will yield optimal results. As business priorities are constantly evolving, the dynamic modeling provides an agile approach to decision-making and management. Instead of sending costly facility engineers out to assess and adjust a piece of hardware, the physics-based model knows exactly what to do to self-correct, yielding better utilization and financial savings of on-site staff, as well as greater accuracy of building operations.

> *As business priorities are constantly evolving, a digital twin's dynamic modeling provides an agile approach to decision-making and management.*

Frequently, IFM operational manuals have certain preventative maintenance programs that include replacement of parts or pieces of equipment purely based on static time intervals (e.g. 'replace fan belt every 30 days'). However, a dynamic digital twin may determine that the same fan belt actually has 45 days of useful life. Should the fan belt begin to fray, the model's preset windows of tolerance recognize a deviation from optimal performance and submits a work order for replacement. This example can be extrapolated to scale across an entire building ecosystem, campus and portfolio.

Understanding the challenges

Cybersecurity and data privacy are becoming increasingly important as the ability of digital twins to bidirectionally control assets continues to expand. IoT-enabled sensors and other sources collect a host of sensitive information regarding occupants and the design of assets. To mitigate potential cyber-attacks, a secure environment must be designed to adhere with industry security standards. Legal requirements such as the General Data Protection Regulation (GDPR) in the EU have been enacted in the last decade, making it necessary for firms to place strong controls around data encryption, access privileges and security audits. A sustainable, holistic framework that addresses ongoing technology threats, governing security solutions and resiliency requirements is critical for maintaining controls and mitigating risk.

Human impacts also manifest. Similar to access and security on a smartphone, collecting this sensitive data has benefits that can far outweigh the downside. However, many employees are becoming hypersensitive to data collection in the workplace. For the digital twin to be effective in improving health and wellness, this must be addressed with the firm's labor force by obtaining consent to the "opt-in" settings.

Other challenges include managing stakeholders and developing the right skill sets for implementation. Resources with advanced analytical capabilities, strong industry understanding, and technical know-how of the necessary tools are required to successfully adopt a digital twin model. This will establish new positions, such as data scientists and systems engineers, within construction and real estate firms. Furthermore, resources with project management and business process skills are critical as they develop a formal road map and steer the implementation. This is needed to ensure that every investment sought by the firm has a purpose, plan and direction aligned with adoption.

The way forward

As construction productivity has constantly declined in the United States since 1964, the digital twin presents an opportunity to shift archaic business models to the Age of Aquarius. Construction and real estate have operated on simple hand-made drawings for thousands of years.[16,17] Only recently are we seeing the very basics of digitization come into play. In astrology, the Age of Aquarius is the forthcoming astrological age, or the earth's precessional rotation for the next 2,160 years. Technological innovation paired with the digital twin will take us to this next coming of age. With global housing crises, consistently overdrawn budgets and schedules, global warming, pandemics, slowing production, demographic changes, more demanding workers and greater globalization, the world cannot afford to wait for digital enhancements to mature at the traditional pace. The most innovative companies realize this; hence the rise of investments and profiles of "PropTech" companies.

While digital twins are not a new concept, their deployment with IoT connectivity, ML, AI and enhanced BMS is just beginning to take shape. As a result, the potential is profound. The benefits of physics-based digital twins are expected to continue expanding over time, with layers upon layers of data informing and improving the way buildings are designed, built and operated. The influx of aggregated information will achieve operational efficiencies at scale, moving the global needle to drive sustainability efforts and reduce climate impacts.

It is typical for innovation in technology to lead to skepticism. However, so do all market disruptors. Digital twins are becoming the market differentiator that will have the greatest impact on building efficiencies, cost optimization, operational intelligence and decarbonization. Class-A commercial real estate assets will be digitally connected, intuitive, adjustable and integrated with physical infrastructure. It is going to be these high-quality assets that are going to allow investors and building owners to yield higher income, reduce cost, retain employees and tenants, and develop sustainable operations.

The question is: are construction and real estate firms that generally operate on thin margins willing to make the upfront investment to capture future ROI? By taking this initiative, the early adopters will reap the greatest benefits and be considered as pioneers in building the next generation of real estate. It will provide these firms a competitive advantage in the industry while incorporating a user-centric business model. This will transform companies of today and create the now, next and beyond of the digital built environment.

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