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Digital twins from design to handover of constructed assets

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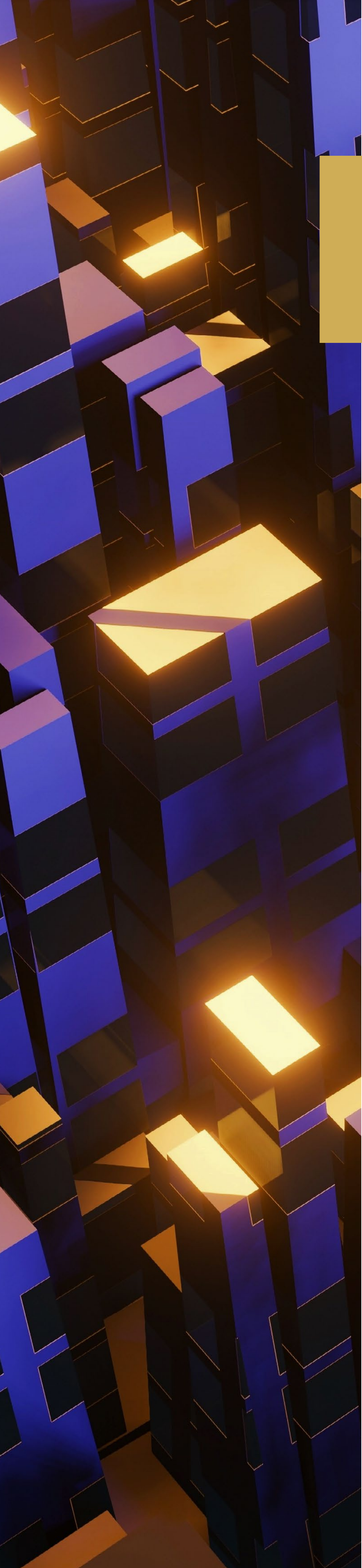

Digital twins from design to handover of constructed assets

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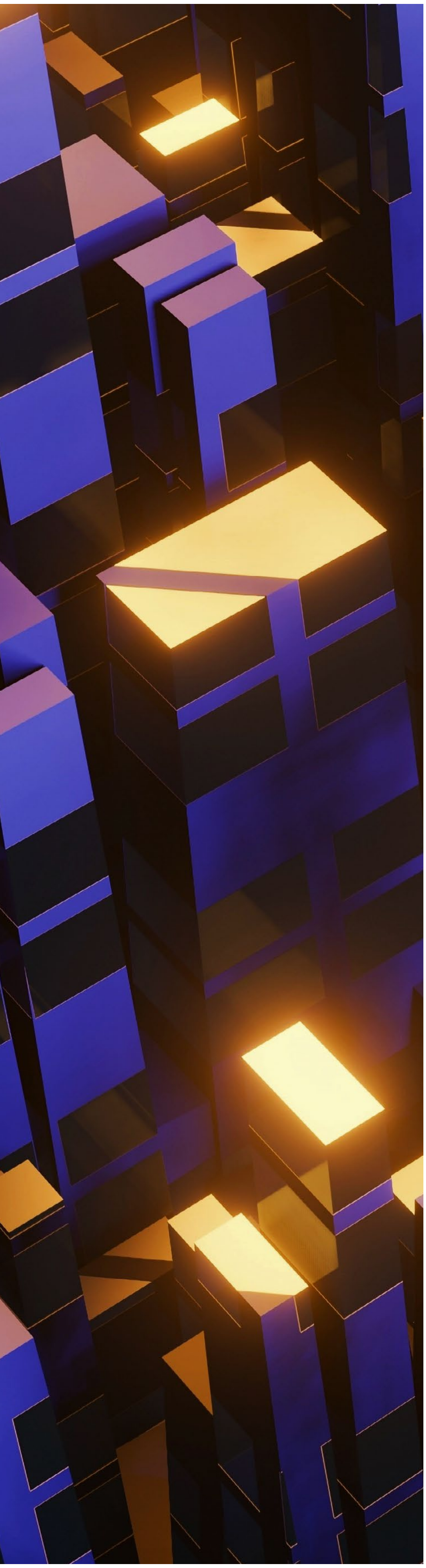

Contents

Forewords

Never before has the surveying profession been tasked with reinventing itself from a position of need rather than choice. The preservation of our traditional roles has, after 153 years, successfully matured to an inflexible point of unquestionable change. With both our current validity and future value creation being arrested by unrelenting technological advancement, we need to take stock.

The indelible mark of our professional status is now required to be seamlessly linked within a 'data-driven' process that will, by default, unlock and dispense with many of the historic and cultural barriers, that in truth, have not served our clients or the wider built environment well. As custodians of an ever increasingly fragile and tempestuous climate change emergency, it is crucial that we not only revisit our ESG-led 'service level agreement' with society but that we do so by pulling on data and information that can justify the scale of the disruption that is now required across our commercial offer(s).

The intrinsic role of digitally enabled, structured data is a theme that I researched at length back in 1993/94, which explored the role of neural networks and hyperlinked expert systems, designed to accurately data mine relevant case law and offer timely consideration of any potential for litigation. By all accounts, that effort is now referred to as a 'process-level' digital twin of the traditional and contentious construction claims process. Today, some 28 years later, I am keen to further demonstrate the power of data via the wide-scale adoption of digital twins during the entire life cycle of a construction project. In seeking to avoid future Grenfell Tower inquiries, it is important that we recognise our obligations to the general public in the delivery and ongoing maintenance of built assets that are not only deemed fit for purpose but are also unequivocally assured of their legislative compliance to key stakeholders.

As a direct consequence of the collaborative nature of our next chapter, it is time to be bold and embrace a 'new business model' tailored to the needs of our respective professional pathway(s). For these reasons articulated throughout this paper, the 'digital twin' must now be embraced by all of us and deployed as part of our 'regulated' day-to-day, professional service(s).

Bola Abisogun OBE FRICS
Founder & Chairman, Diversecity Surveyors

Digital twins are nothing new, but they have now become a reality and broken into the mainstream thanks to technological advances.

In simple terms, digital twins are virtual representations of real-world entities and processes synchronised at a specified frequency. They can be used in many economic sectors, like aviation, manufacturing, automotive, and of course, the construction industry. They are a key to digitalisation and a business imperative that any company that fails to adapt will be left behind in a digital future.

For this reason, Glodon, together with RICS, conducted this assessment of the basics, trends, and opportunities of digital twins in the built environment sector and explored digital twin development, deployment, and use, especially during the design and construction stages, and analysed relations to the work performed by surveyors.

I hope you enjoy this paper on the digital twins that we see as crucial to industrial digital transformation. Changes are inevitable; by better understanding the drivers behind them, we can thrive in the future and make a better contribution to the built environment.

Pierpaolo Franco
Glodon – Vice President, International Markets Development

Executive summary

A digital twin is a virtual representation of real-world assets and phenomena. It is a federated entity of synchronised data streams that give us situational awareness of what is happening and why it's happening. The end-user can then determine what might be the results of the phenomena.

Digital twins are sophisticated tools for educated decision-making. They are an emerging digital operations platform in which the end-user has the choice of which components are relevant for their digital twin experience and the decisions they are about to make based on the data and evidence provided through a digital twin.

A digital twin is as good and as reliable as the data connected to it. The data components connected to the digital twin must be the actual digital replica of what they represent. Placeholders and 'alike' components have no use in digital twin because they make the situation misleading.

A digital twin has several use-cases. It allows us to simulate and animate our physical environment's technical and social performance based on real-time data. It enables us to analyse how our environment performs in daily operations and what are the short-term or long-term implications of that performance.

A digital twin supports our design processes, construction operations, seamless handover, proactive maintenance, and predictive operations planning by visualising multiple data streams in a single system that can be interpreted by a human or decoded by a machine.

Over time digital twins become a representation of different types of data and information, spanning disciplines and life cycle phases for our assets. As the world faces numerous challenges, a renewed approach to designing, constructing, and managing the built environment will be crucial, making the principles and concepts discussed in this paper even more relevant. The sector and the profession will be able to use digital twin systems to deliver constructed assets that are economically viable and socially and environmentally positive for current and future generations. RICS professionals are bound to play an ever-important role in developing, deploying, and using digital twins.

Salla Eckhardt
Director Transformation Services, Microsoft
Chair for National BIM Steering Committee, National Institute of Building Sciences
Co-chair, Digital Twin Consortium
Chair, VRAR Association AEC vertical

Glossary

The below terms do not include legal or other matters defined in local legislative or regulatory requirements.

Actuator	A device that causes a machine or other device to operate.
Asset (or built/ constructed asset)	The output from any building or civil engineering project. (ICMS)
Building information modelling (BIM)	A process supported by technology for the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions. (BS EN ISO 19650-1:2018)
Common data environment (CDE)	An agreed source of information for any given project or asset, for collecting, managing, and disseminating each information container through a managed process. (BS EN ISO 19650-1:2018)
Cyber-physical system (CPS)	A system consisting of physical and digital systems integrated via networking.
Dark data	Data that is acquired through organisational processes but not used in any manner to derive insights or for decision making.
Data	Unprocessed and context-free facts and statistics.
Digital asset	Anything that exists in a digital format for use in pertinent work processes.
Digital shadow	A digital model or replica with a one-way data flow connection with the physical object that it represents.
Federation	A process to create a composite information model from separate information containers. (BS EN ISO 19650-1:2018)
Information	Processed and formatted data with meaning and context.
Information management	A process used to collect, structure, store, share, update, use, and archive data to perform core business functions across the asset life cycle.
Knowledge graphs	Also known as semantic network, graphically describe interlinking and interconnections between network of real-world entities.
Metaverse	A simulated digital world with three-dimensional features that may or may not be overlaid on the real world for shared immersive first-person experiences by a group of users.
Ontology	A set of concepts that define the classification and explanation of entities.
openBIM	A collaborative process promoted by buildingSMART that is inclusive of all participants, promoting interoperability to benefit projects and assets throughout their life cycle.
Point cloud	A set of three-dimensional data points obtained from a laser or photogrammetry scan to develop a digital replica of existing conditions of the built and natural environment.

Project	A single or series of construction intervention(s) with a single purpose or common purposes to create a series of or single constructed asset commissioned by a client, or group of clients, with a defined start and end date. (ICMS)
Semantic model	A digital model enriched by meaningful domain-specific or application-specific information.

Acronyms

4D	Fourth modelling dimension (time) in BIM
5D	Fifth modelling dimension (cost) in BIM
AI	Artificial intelligence
AR	Augmented reality
CAD	Computer-aided design or drafting
CDBB	Centre for Digital Built Britain
CDE	Common data environment
DTC	Digital Twin Consortium
ESG	Environmental, social and governance
IoT	Internet of things
ISO	International Organization for Standardization
ML	Machine learning
RFID	Radio-frequency identification
ROI	Return on investment
VR	Virtual reality

1 Introduction

The concept of digital twins as a means of understanding, delivering, and managing constructed assets has gained significant momentum in recent years, primarily for asset and facility management purposes. RICS, in collaboration with Glodon, has prepared this industry paper to review the current state and future potential of digital twins across the built environment. The paper extends the idea of digital twins upstream from the currently popular view of using digital twins for asset and facility management to the development, deployment and use of digital twins in the early-stage planning, detailed design, entire construction phase and asset handover.

The paper draws on a review of publications on digital twins, an online survey of professionals, and interviews with experts. It begins with a look at several dimensions of a digital twin, including the scale of application, the whole life cycle of the asset and use cases. Further sections describe digital twins' development, deployment, and use during the design and construction phases. The following themes are used to describe digital twins from the perspective of professionals and stakeholders working in the built environment sector, especially those focusing on the design, construction, and handover processes (this includes RICS professionals working within the construction and quantity surveying, project management, building surveying, building control and infrastructure pathways):

- The what (definition), the why (value add), and the how (process) of digital twins within the context of the built environment.
- The emerging role for professionals from design through handover when using digital twins.
- A review of the pertinent future trends and technologies that can influence the potential of digital twins.

Conclusions and points for further discussion are also presented. A bibliography is provided for those interested in more details on this broad topic. The appendix includes case studies highlighting the use of digital twins in the built environment sector.

1.1 Background

Digital twins are on every industry leader's agenda these days, it seems. As seen in case after case in the media and countless conferences, a digital twin can be used in many sectors of the economy, such as manufacturing, automotive, healthcare, aerospace, defence, natural resources, energy, utilities and the built environment. In fact, digital twins of more ephemeral systems, like organisations, are also being developed and used to understand how they function. Several benefits are reported from these sectors, including improved overall product quality, a better understanding of operating costs, availability of digital records of parts and raw materials, improved lead times, better social and environmental outcomes, and revenue growth opportunities for all stakeholders.

Driven by these benefits, the digital twins' market will likely see tremendous growth over the next ten years. As per estimates by Research and Markets, the market size in 2020 was $3.21 billion and will probably reach $184.5 billion by 2030. While over 50% of this growth will come from the manufacturing sector and automotive sectors, this emerging field of activity is also rapidly gaining traction in the built environment sector. Experts project the broad areas related to the built environment (including energy and utilities, economic and social infrastructure, intelligent buildings, smart cities, etc.) to account for 15% to 20% of the overall market share.

But what are digital twins, and how are they relevant to the profession, especially the design and construction phases? And how do they relate to the 'regulated' work performed by built environment professionals?

Most discussions about digital twins in the built environment sector focus on the operation and maintenance phase of assets, as seen by the preponderance of publications addressing this phase. The benefits of digital twins after the handover phase are also well documented and often used to create awareness and hype. This has led to a view that digital twins primarily work to improve asset operation and maintenance, including the planning and procurement for operation and maintenance just before commissioning.

Does this mean digital twins should only be developed and used after the handover of the asset, or for existing assets? The answer is no, as the same technologies and benefits that completed assets enjoy are available for earlier phases.

The designers create the original digital models depicting the design intent, and updates and changes are applied during construction. Optimising the design, and other performance measures such as time, cost, environmental impact, or social outcomes managed by designers, cost management professionals, and construction managers also happens upfront. Since these measures impact, and in fact define subsequent phases, it is important that they be captured in as rich a representation as possible, as early as possible, and digital twins are the best way to do this. Although developing and using a digital twin can be more convenient after the asset's handover and commissioning, critical information created during the design and construction phases would be lost. Losing the information or missing the opportunity to use a digital twin by designers and construction professionals is a loss to clients and other stakeholders as it may affect the asset's entire life.

Emerging thinking suggests that there is also inherent value in employing digital twins during the design and construction phases. Again, many of the efficiencies, process optimisation, environmental, social, and governance, and risk mitigation benefits of digital twins are at least as relevant to design and construction as they are for the in-use phase.

This viewpoint is the key focus of the paper as it aims to equip RICS professionals with concepts and frameworks that will help them discuss implementation with other stakeholders and project team members and meaningfully participate in the development, deployment and use of digital twins. While maintaining an appreciation of digital twins over the asset's whole life, the paper shines a light on the role of digital twins during the design, construction, and handover phases of a project. Similarly, the scope of the industry paper is limited to the application of digital twins at the object, sub-assembly, or asset level while maintaining an appreciation for an ecosystem of connected twins that link multiple digital twins (e.g. for a transportation network or a smart city, or a national twin).

2 What are digital twins?

2.1 Definition of a digital twin

Exactly 28 years ago, Professor David Gelernter, Professor of Computer Science, Yale University, prophesised that 'we will be able to see reality on our computer screen' one day. In his book Mirror Worlds, he wrote, 'Some part of your world – the town you live in, the company you work for, your school system, the city hospital – will hang there in a sharp color image, abstract but recognisable, moving subtly in a thousand places. The Mirror World you are looking at is fed by a steady rush of new data pouring in through cables.'

Now that must have sounded like science fiction at that time, and in fact, Professor Gelernter did not achieve commercial success with his idea. However, this is the idea behind digital twins. While the exact origins of the term and the concept are still debated, the idea was applied in manufacturing in the early 2000s. In 2002 Dr. Michael Grieves presented a formal approach to digital twins in product life cycle management at the University of Michigan. However, mainstream applications of digital twins became available in 2016 as Industry 4.0 began to take hold in the business world. Today everyone is talking about them, including professionals across the construction sector.

There are several available definitions of a digital twin. For example, ISO 23247-1 defines digital twins in the context of the manufacturing sector as: 'fit for purpose digital representation of an observable manufacturing element with synchronisation between the element and its digital representation.'

This definition helps us by focusing on the idea of synchronisation of digital representation and the underlying reality it is modelling. This synchronisation is what makes it a 'twin.'

The Digital Twin Consortium (DTC) provides a sector-agnostic definition of a digital twin that has been adopted and adapted in this study. The DTC hierarchically defines a digital twin, beginning with the most abstract level and drilling down to the benefits of using digital twins.

Definition of digital twins by DTC (also see Figure 1):

'A digital twin is a virtual representation of real-world entities and processes, synchronised at a specified frequency and fidelity.'

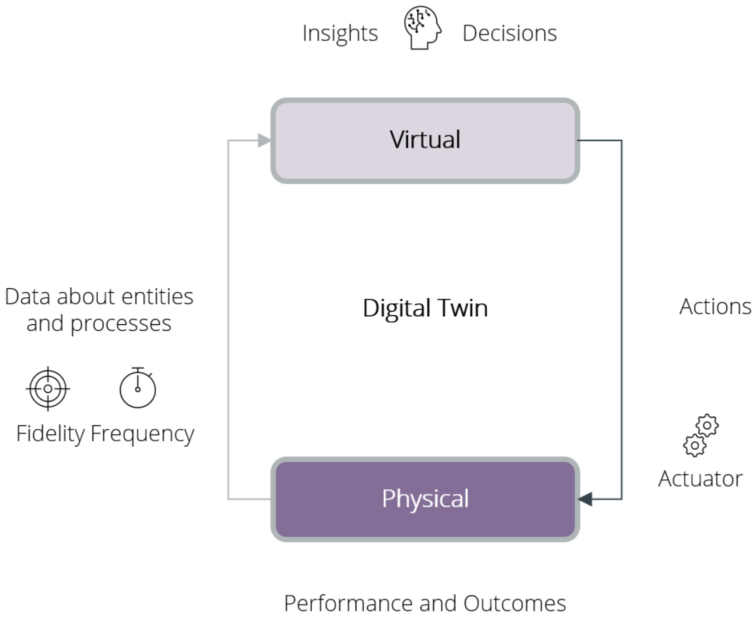

Figure 1: Illustration of a digital twin

Further, as per DTC, digital twins:

- 'use real-time and historical data to represent the past and present and simulate predicted futures'
- 'transform business by accelerating holistic understanding, optimal decision-making, and effective action'
- 'are motivated by outcomes, tailored to use cases, powered by integration, built on data, guided by domain knowledge, and implemented in IT systems'.

DTC's definition adds some key elements. First, they introduce past information to build models that can drive a simulation. The idea of a simulation is important because it allows managers to explore many different configurations of their asset. This in turn leads to their next point about accelerating a holistic understanding and better decision making through the use of these models and simulations.

The Centre for Digital Built Britain at the University of Cambridge **defines a digital twin** as:

'realistic digital representations of physical assets, for example, a digital representation of an aeroplane that can be used to monitor and predict performance, feeding out insights and interventions.'

The following commonly used terms emerge from these definitions of a digital twin:

1. virtual or digital representation
2. real-world entities, processes or physical assets, or elements
3. realistic representation
4. synchronisation, including synchronisation frequency and fidelity
5. monitoring performance
6. insights and intervention.

While the mirrored world may still be a distant dream, digital twins can be applied with an increasing level of sophistication or maturity. Some experts see this at five levels of complexity or sophistication of digital twins starting from:

1. descriptive digital twins (for collecting and visualising data)
2. informative digital twins (converting data into information for generating insights)
3. predictive digital twins (using real-time data to predict future state)
4. comprehensive digital twins (combining levels 1, 2, and 3 to propose interventions for avoiding problems and achieving better outcomes)
5. autonomous and connected digital twins (using artificial intelligence (AI) and machine learning (ML) to reduce dependence on human intervention)

Sometimes (and largely dependent upon the use-case), digital twins are also referred to as cyber-physical systems that provide bi-directional connectivity between the digital and the physical (also known as a cyber-physical-cyber loop). The critical point to all of this is that digital twins create a connected virtual version of an asset or process that can be used to efficiently and sometimes autonomously generate the operating outputs to improve current work processes and practices.

2.2 Defining digital twins in the built environment

DTC provides a sector-agnostic definition of a digital twin, which has been adopted and adapted for this paper. In the following subsections, a description of the digital twins, using the key terms identified in the previous section, is presented for the built environment sector.

2.2.1 Foundational elements

Figure 2 shows the foundational elements of a digital twin using the definition provided by DTC. These elements are presented in the context of a built asset, and the design, construction, handover, operation, maintenance, renewal and end-of-life processes.

Virtual representation is the digital replica of the construction objects and processes (the terms construction objects and processes are used as defined in ISO 23387) under consideration. The virtual representation consists of:

- a set of linked digital assets (a digital asset is anything that exists in a digital format for use in pertinent work processes), like federated building information models (BIM), computer-aided design (CAD) models, images, videos, point clouds, documents, spreadsheets, etc. that capture as-built construction objects.
- supporting data about construction objects and processes, for example data about products, systems, materials, elements, entities, processes, work performance, etc. which provide cohesive information about the real-world entities and processes.

The digital assets and supporting data help create representational and connected computational models of the asset's historical, present and potential future states. The virtual representation changes or evolves from design to the end-of-life phase (decommissioning phase) as additional data and information are added and overwritten or archived when redundant. As real-time data is received during the asset's construction and use phase, further efficiencies can be observed and mined for greater insight or specific scenario planning.

Foundational Elements of the Digital Twin Definition

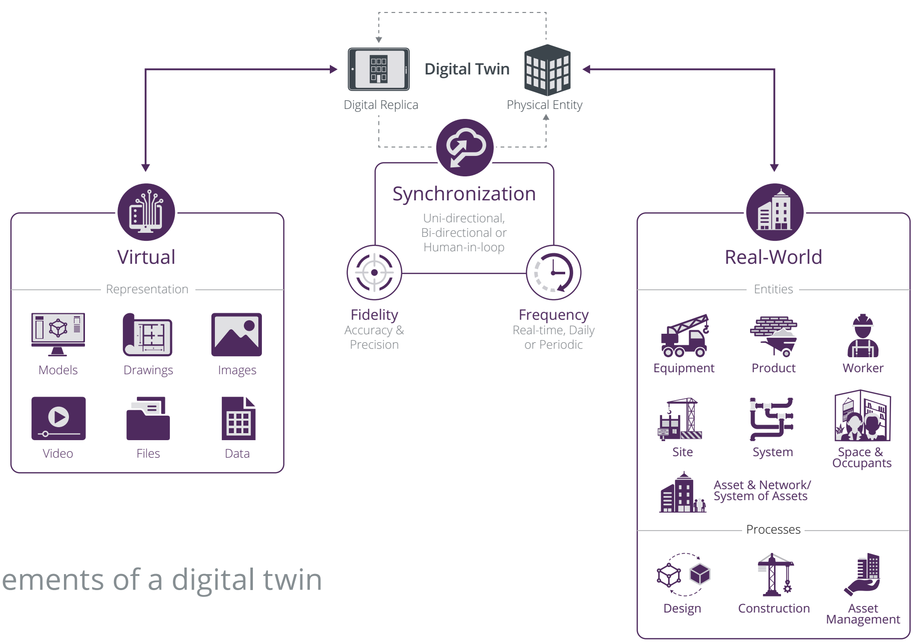

Figure 2: Elements of a digital twin

Real-world entities and processes: entities can be considered at three levels:

- construction objects such as a product, component, system, assembly, or space
- a building or civil engineering asset such as a school building, bridge or industrial plant
- a portfolio of assets such as social housing program, highway network, offshore wind farm, etc.

The physical environment with which these entities interact is also considered, along with the productive and supportive processes used to design, construct, and use these entities. Examples of real-world entities can be a pump, an excavator, a tower crane, a hospital room, a pump room, a building, an office block, a worker, an occupant, a district, or a city, etc. Labour planning or space planning are examples of real-world processes.

Thinking at these levels is crucial since the digital twin development is purpose-driven and helps the developers of the digital twin define the system architecture and technical specifications, ensuring it fulfils the original requirements identified by the stakeholders. At the same time, thinking about the entity and process level tells the users the scale of the digital twin application and the timing of the application over the life of the asset (e.g. pre-project, project, and operation).

Synchronisation is the 'connection' between the virtual representation and real-world entities. Synchronisation is vital and distinguishes a digital twin from any other digital model because it allows a virtual-physical-virtual loop for management, simulations, predictions, and optimisation. The definition of synchronisation is slightly flexible, allowing the connection to be unidirectional (involving sensors that provide data relating to the performance of the real-world entity) or bidirectional (with the addition of control commands to actuators, or to a system connected to actuators) and/or with a human-in-the-loop. Synchronisation is vital because it helps closely match real-world entities and processes to the virtual representation. It helps determine how twins are designed, developed, deployed and used, and are regularly updated (synchronised). The synchronisation mechanism also plays an additional role in connecting the digital twin to:

- other digital twins (making them part of an ecosystem of digital twins)
- other external data sources, such as local weather data, environmental data, economic data, etc.

Frequency determines the timing of physical-to-virtual synchronisation. As the real-world entities and processes change, synchronisation frequency determines how often the virtual representation is updated to match the current state of the connected entities and processes. This update can be in real-time (changes are reflected in real-time as they occur), daily, or at a pre-determined interval. The frequency varies by use case, resources available, type of real-world entity or process, and the available real-time data gathering technologies. Without this regular update, any change in the real-world entity or process that is not captured will make the virtual representation outdated, limiting the use of the digital twin. Trust in the digital twin erodes if the frequency is not clearly understood and rigorously monitored and maintained. It will be less likely to meet the requirements and deliver the intended benefits.

Fidelity is the degree of precision and accuracy applied to the virtual representation, as well as to its synchronisation mechanisms. Fidelity is a data characteristic and is ultimately an expression of the data governance or information management framework in place, specifically focusing on how data is carefully collected, tracked, and maintained throughout the relevant processes that provide data to the model. Depending on the digital twin application, the fidelity has different levels and can vary significantly based on the use cases being served. The primary driver for fidelity in a digital twin is the granularity of the information that is sought to be synchronised. For example, for some use cases it may be adequate to synchronise time series data relating to the energy use of the building as a whole, whereas for other use cases, it may be required to synchronise data relating to energy use by specific plant, equipment, and systems in each floor of the same building.

The digital twin can also be calibrated to receive various types of data from multiple data streams (e.g. video devices, laser scanners, accelerometers, and displacement sensors). Fidelity in this situation is called multi-fidelity because it can be stipulated and varied by the data stream. As with frequency, if data's provenance is not rigorously maintained, trust in the digital twin will suffer. Indeed, project teams' initial adoption of a digital twin will usually require some demonstration of the reliability of both the update cycles and the data generation process.

When using digital twins in the built environment sector, these two elements – frequency and fidelity – determine the effort needed to keep the virtual representation updated. The issue of synchronisation, unidirectional or bi-directional, is especially relevant and critically important.

Figure 3 shows an example of unidirectional versus bi-directional synchronisation between the digital model of a tower crane and the tower crane itself. When the connection is unidirectional, data flows in one direction only from the digital model to the tower crane or vice versa. The resulting twin is called a digital shadow. However, when the connection between the crane and its digital replica is bidirectional, a cyber-physical-cyber loop turns this into a digital twin. This distinction between these two types of connections is significant because it helps distinguish between the digital assets created and used over the asset's life and a connected digital twin.

Another example of a digital shadow can be a digital model of an asset that cannot automatically interact with the asset but can be used to visualise scope changes captured via images and videos of construction progress. The sector has made significant strides in using a virtual representation to drive decision-making concerning a real-world entity (e.g. data collected about the asset via laser-scanning, images, and videos and used for BIM-based progress monitoring). As illustrated in Figure 3, a unidirectional connection between the digital replica and the physical asset in of itself is not a digital twin.

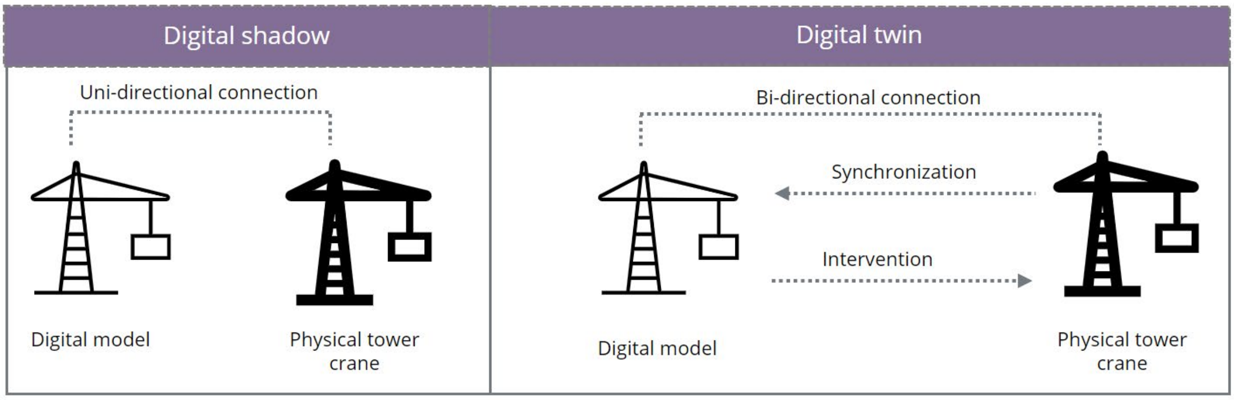

Figure 3: Unidirectional and bidirectional synchronisation (adapted with permission from Sepasgozar 2021)

2.2.2 Components of a digital twin

A digital twin for a constructed asset consists of several components. These components and the underlying system architecture may vary by:

- type of object or asset under consideration
- life cycle phase of the application
- selected use case
- expected outcomes.

Not all scenarios require a complex system architecture. Figure 4 shows these components and their interconnections. A physical object or asset that is being considered should always have a virtual representation consisting of models and other digital assets. This representation provides the static data that documents, for example, design and construction data, and information about the physical entity and its many components and sub-components. The static data is managed by a data management layer that provides consistent storage, interoperability and synchronisation features. For example, a cloud based common data environment (CDE) can serve this purpose. Real-time data as the built asset is stood up is captured and also added to the repository or CDE. Dynamic data about the condition and performance of the physical asset is obtained from asset or facility management systems (e.g. building automation systems, building management systems, or computer-aided facility management systems in the case of buildings), Internet of Things (IoT) sensors, laser scans, images, and videos. The data management layer also manages this dynamic data, which is used to keep the virtual representation synchronised and updated.

The digital twin system's insights and interface component processes the unstructured and structured data in the data management layer. With large volumes of data, it is difficult for the human-in-the-loop to access and assimilate this data directly. A digital twin's insights and interface component help overcome this difficulty by providing analytics, simulation and visualisation capabilities. Visualisation capabilities that use virtual reality (VR) and augmented reality (AR) are sometimes used in digital twin systems. A digital twin could also have an application module that helps build custom applications needed for a particular use case. The applications platform and the insights and interface layer create output that can be used to make decisions about the asset that can be converted into interventions that can be enacted through the actuation layer.

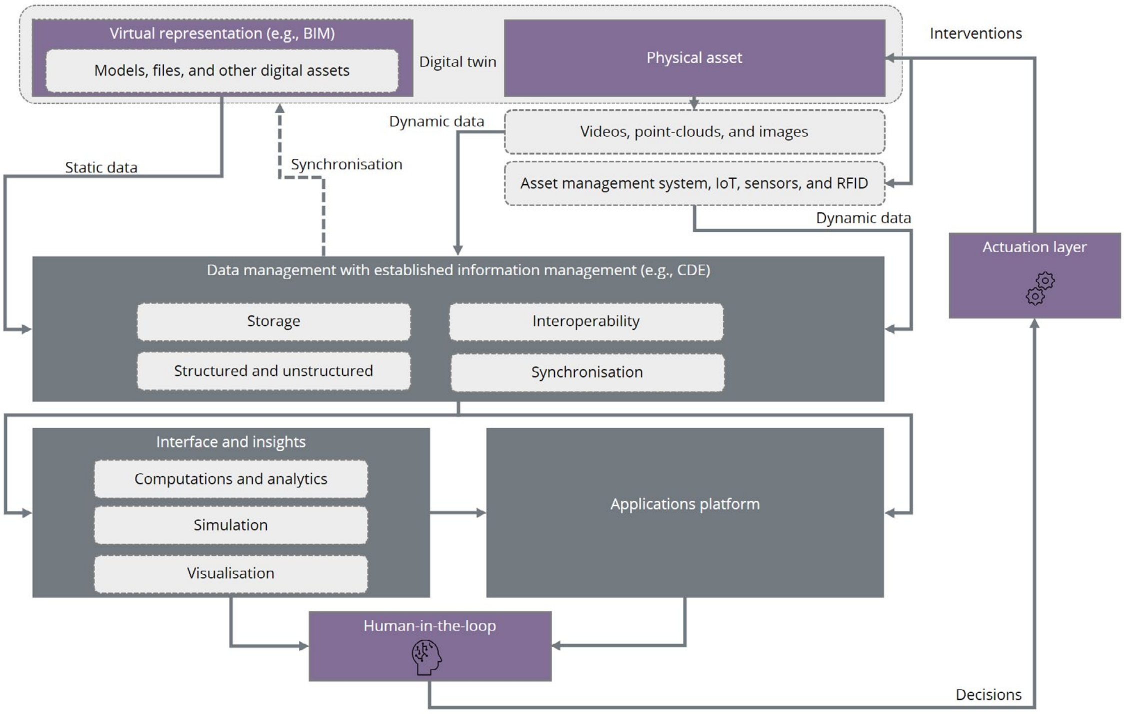

Figure 4: Components of a digital twin

Digital twins are at heart a model, a connected abstraction of the real world. As such, details that are irrelevant to the context of their use are eliminated to make the overall system useful. This is accomplished by designing and configuring the components of the digital twin by considering the following four key parameters.

1. Nature of intervention.
2. Type of project/asset.
3. Scale of application.
4. Life cycle stage.

Table 1 shows these parameters and provides context and description of each.

Parameter	Context	Description
1 Nature of intervention	Greenfield	With no constraints imposed by prior work or exiting entities, digital twins can be considered for the whole-of-life of the asset depending on the use case and its cost-benefit analysis.
	Brownfield	Constrained by the existing assets on the site, digital twin applications require as-built information supplemented by photos and laser scans. Situations may include retrofit, rehabilitation or renewal. There may be limits to when and how the twin is developed and impact the digital twin's ultimate value.
2 Type of project/asset	Horizontal	Infrastructure assets such as transportation, energy, water, wastewater, etc. that have a long lifespan and are generally embedded in the communities that are designed to serve.
	Vertical	Buildings both residential and non-residential such as offices, hospitals, schools, etc. with public and private sector sponsors.
3. Scale of application	Process or product	A digital twin of an individual process, construction object such as product, object, equipment, pedestrian flow, etc.
	System or sub-assembly	A system or assembly of objects, for example, a pump room, office space, vertical riser module, prefabricated plant room, etc.
	Asset	A digital twin of a single building or infrastructure asset.
	Portfolio of assets	Connected digital twins representing assets in a network, for example, a transportation network.
	National twins/ smart cities or regions	An ecosystem or connected digital twins of several assets covering a geographic area or network.
4 Life cycle stage	Design and construction including handover	Digital twins applied to the design and construction phase only.
	Use (operation, maintenance, renewal, and end-of-life)	Digital twins applied to the use and occupational phase of the asset only.
	All stages	Used across the whole-of-life from pre-project to end-of-life.

Table 1: Four key parameters of digital twin implementation

The context helps understand the likely data and information needs and details of the process needed to develop, deploy, use and update digital twins. For example, data requirements may differ for a new construction project versus a refurbishment project. The type of data and the process used to define, create, use, and update data may also be different for a building project compared to a civil engineering project. The scale of application and life cycle stages at which the digital twin is created are also important considerations. For example, the required digital twin in a particular instance might or might not comprise the entire facility. From safety and simple operating requirements, it may only include critical components that are instrumented and provide data connectivity. The life cycle stage chosen for using a digital twin determines the methods used to develop the twin and the benefits it offers. Ideally, digital twins should be created, or at least careful planning of their use should be done as early in the life cycle as possible.

2.3 Golden thread and digital twins

Digital twins represent seamless collection, management, and use of data from the pre-project stage to the end-of-life of the asset. If data and information requirements are not appropriately decided and data is structured inconsistently, the value that digital twins can generate is diminished. Therefore, it is essential that an accurate and current record of the data about every component and subcomponent of the real-world entity or process under consideration is maintained over the entire life cycle. Like BIM, digital twins also require all the project and asset data stored digitally in a repository that links this data, keep an audit trail, and maintains its current and accurate record. Conceptually this requirement can be met by the notion of a golden thread of data or information. The golden thread is not a new concept as it was initially used as a metaphor for organisational alignment in the business world. In the construction sector, the use of the term can be traced back to the period between the UK government's launch of the soft landings policy in 2011 and the 2016 BIM mandate.

More recently, the official reference to the term 'golden thread' appeared in a report entitled **Building a safer future** (by the UK Ministry of Housing, Communities, and Local Government) that resulted from an independent review of building regulations and fire safety following the Grenfell Tower tragedy. The 'golden thread' is envisioned as a tool to use connected information to design, construct and operate built assets safely and effectively. The report states:

'a robust golden thread of key information is passed across to future building owners to underpin more effective safety management throughout the building life cycle.'

Sometimes the golden thread is also called a digital thread because the golden thread of information is stored as structured digital information. These terms are also used to describe the traceability of the digital twin to the exacting requirements, design and construction decisions, selection of objects, and control systems that make up the physical asset. Therefore, the concept of the golden thread is central to the successful application of digital twins to built assets as it focuses on data, information, and information management processes.

This concept of passing critical information from phase to phase is essential for several reasons. First, it ensures that what has been designed is fully understood by all stakeholders. Built assets can be complex, and re-discovering information created during design and construction is costly and almost by definition incomplete.

The resulting incomplete information raises safety, assurance, and performance risks and increases operation and maintenance costs over the asset's life. And additionally, incomplete information limits understanding of such emerging considerations as embodied carbon, life cycle costs, and life cycle carbon emissions.

2.4 Importance of data, information, and information management

Digital twins, first and foremost, rely on accurate, trusted, and reliable data and information about the real-world entities and processes over their life cycle. Data are the unprocessed, context-free facts, and statistics and information are processed and formatted with meaning and context. As explored above, data are central to digital twins' development, deployment, and use; indeed, it could be argued that data and information are the 'point' of digital twins.

A vast amount of data and information are created, managed, and used throughout the asset life cycle, involving multiple project team members and stakeholders. Types and volumes of data and information, the timing of its creation and use, and several other complexities require the use of a structured information management process. This real world fragmentation of these processes and related inefficiencies have been the Achilles heel of the built environment sector, and they slow down the adoption of digital twins as well. Recently, the industry has begun to consider an information management framework to overcome these inefficiencies. The Centre for Digital Built Britain (CDBB) defines the information management framework as a 'formal mechanism to ensure that the right information can be made available at the right time, to the right people and that the quality of the information is known and understood, is required.'

Information management frameworks are used to collect, structure, store, share, update, and use data to perform core business functions across the asset life cycle. Information management processes have matured due to the adoption and implementation of BIM and the related ISO 19650 series of BIM standards. This structured process is also crucial for digital twins because it systematically integrates and embeds data and information over the object or asset's whole life into its digital replica. Figure 5 shows how the data, information, and information management process effectively contribute to developing, deploying, using, and updating a digital twin. Three layers representing the technologies, processes, practices, type of data, and context and life cycle stage describe the importance of data, information, and information management.

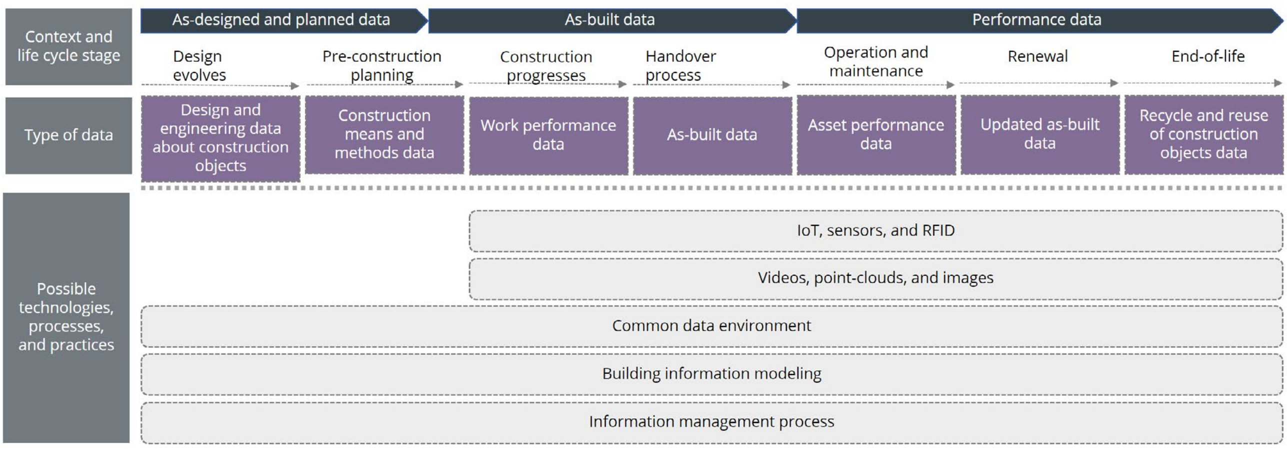

Figure 5: Data, information, and information management for digital twins

Core to data and information management are the technology and process enablers such as information management, BIM, and CDEs. The role of the information management process must be integral to the entire project life cycle. BIM and CDE are heavily relied on during the upstream parts of the life cycle when the focus is to digitally store as-designed, as-planned, and as-built data and information. Many experts call it the static view of the data and information that is central to the development of the virtual representation of the entity under consideration for the digital twin.

Digital twins take BIM and CDE beyond this static representation by considering how the built assets behave and perform over time – past recreations, real-time, or future projections (useful for scenario planning and risk management). The remaining technologies enable this dynamic view of the data and information, especially as the physical asset is stood up and then used. Various technologies make such data gathering from the physical asset possible, including machine vision processing of video and images, sensors, IoT, and radio-frequency identification tags (RFIDs).

BIM is not a must-have for digital twins in the built environment, but it presents an efficient mechanism for creating an accurate and high-value virtual representation. BIM also provides a foundation for the information management framework for the data and information. With so many synergies between the two, many experts predict that digital twins and BIM will effectively merge into one set of systems. Organisations with good BIM practices and efficient usage of structured data, and reasonably mature information management processes in place, may have an easier time adopting digital twins.

While BIM is the process of creating and managing digital information about a built asset, CDE is the digital repository of this information that can be used to collect, manage and disseminate the documentation, graphical model, and non-graphical data to the whole project team. CDE is the digital hub where information is assembled and united throughout an asset's life cycle. Therefore, BIM and CDE can be seen as core to digital twins. Together with the information management process, they can help define, create, store, connect, share, update, secure, and use data and information over the life cycle of an object or asset under consideration.

Since BIM is seen as central to the idea of digital twins, all the challenges that the sector faces in the implementation of BIM may be inherited by digital twins. For example, the definitions, standards and terms used to describe construction objects, assets, or networks of assets still require a lot of attention. Similarly, no internationally agreed data standards are available to streamline the real-time as-built and performance data received from asset and facility management systems, point clouds, sensors, and other IoT devices. Many see this as a challenge, and by some estimates, 95% of the data produced over the life of an asset, especially during the use phase, goes unused. Some call this the 'dark data'. Recent years have seen a groundswell of interest and attention to the use of data in construction. This matters because, without data and information, it is hard to derive benefits from digital twins that will add value and meet key business performance indicators.

3 What is the current state?

3.1 Insights from the survey and interviews

An online survey and virtual interviews were conducted for this study. The research team prepared the survey and then pilot tested it with the help of five experts who are currently using digital twins in their professional practice. Based on the guidance received from these experts, the survey was finalised and placed online in September 2021. By the time the survey was closed in early November 2021, there were 752 views, 366 starts, and 196 responses. Of these, 184 valid responses were used for further analysis. Interviews of twenty experts from different parts of the world were also conducted concurrently. The research team used a semi-structured interview process. The findings of the survey and the interviews are presented in the following two sub-sections.

3.1.1 Survey methodology and results

Key results of the survey are presented here and used to develop the main themes for this paper.

Of the respondents, 50.2% work in the broad areas of project management, construction and quantity surveying, and infrastructure, with 14.8% selecting design and engineering as their primary job role. There was a good mix of organisation sizes represented by the respondents (see Table 2). Micro and small organisations represent 24.3% of the responses, while 37.3% are from large organisations with over 1,000 employees.

Number of employees	% respondents
>1,000	37.3
200–999	17.5
20–199	20.9
4–19	16.4
1–3	7.9

Table 2: Size of the organisations

Of the respondents, 16.9% stated that they are not familiar with digital twins, while 21.5% are using digital twins, and 42.4% are currently exploring the use of digital twins. More details about the current use of digital twins are provided in Figure 6.

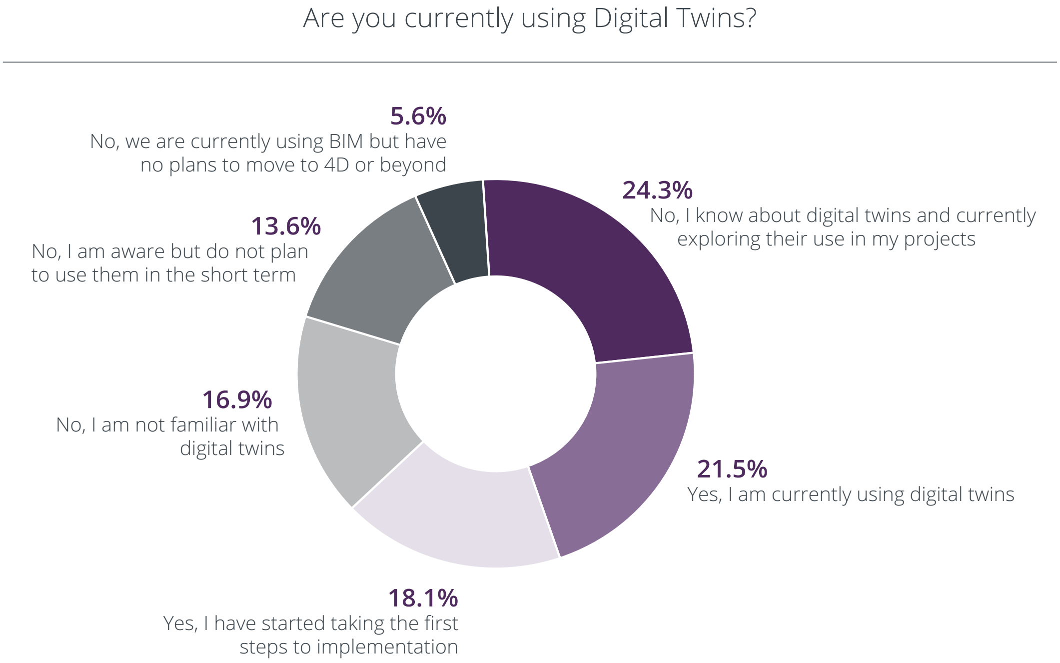

Figure 6: Current use of digital twins

When asked to select the top three current uses or possible uses of digital twins in the design and construction phase, 54.4% of the respondents selected 'Facilitating data sharing to deliver performance efficiencies for all stakeholders' as their top choice (see Figure 7). Other top choices included 53.7% selecting 'Gathering real-time site data for decision making and collaboration' and 41.5% selecting 'Progress monitoring and project controls'. Surprisingly only 27.2% of respondents selected 'Enhancing the handover process' in their top three choices with a fifth overall ranking.

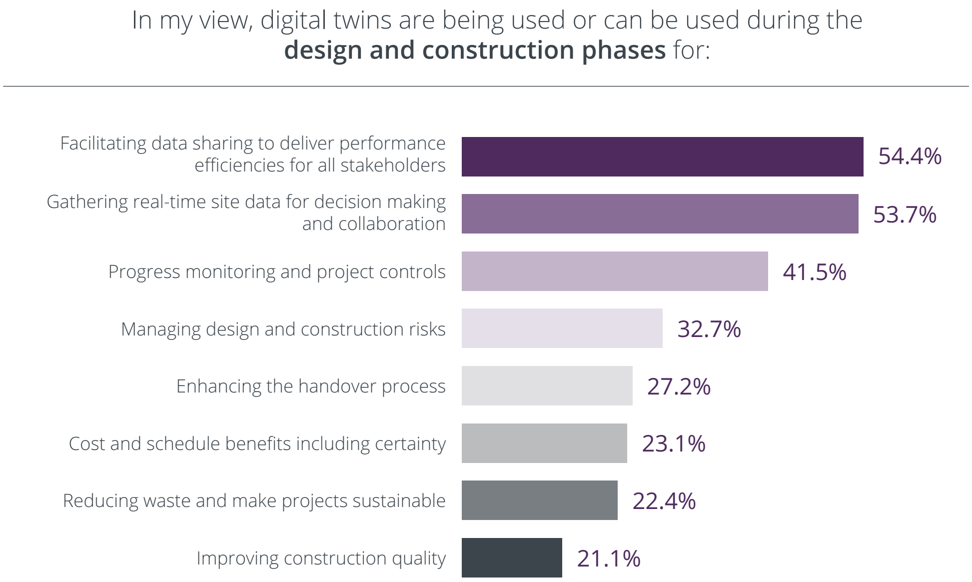

Figure 7: Top three choices of uses during design and construction

In Figure 8, the top three selection of uses during the operation phase are provided. 'Gathering real-time asset operation and maintenance data' received the highest rank.

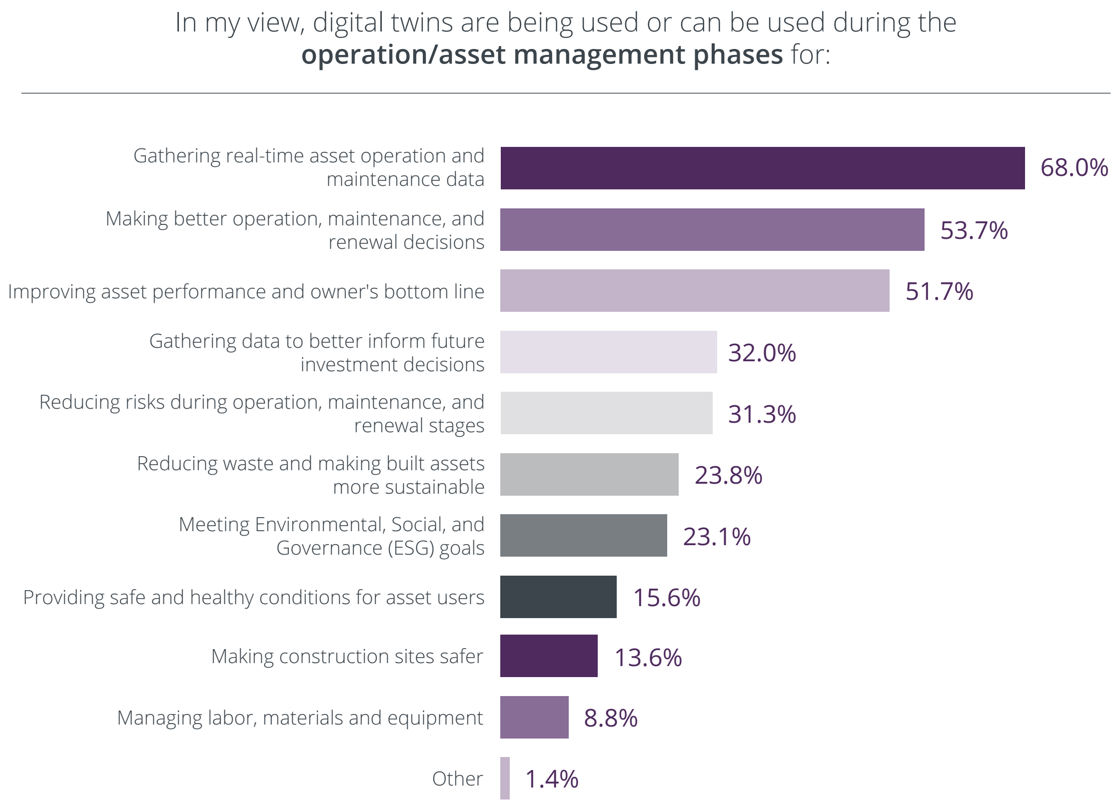

Figure 8: Top three choices of uses during operation phase

In the top three choices of digital twin deliverables demanded by clients', respondents ranked 'As-built BIM models' as first with 53.1%, 'Dashboards showing connected real-time asset data' as second with 48.4%, and 'Digital assets for various work processes' as third with 46.9% of respondents (Figure 9).

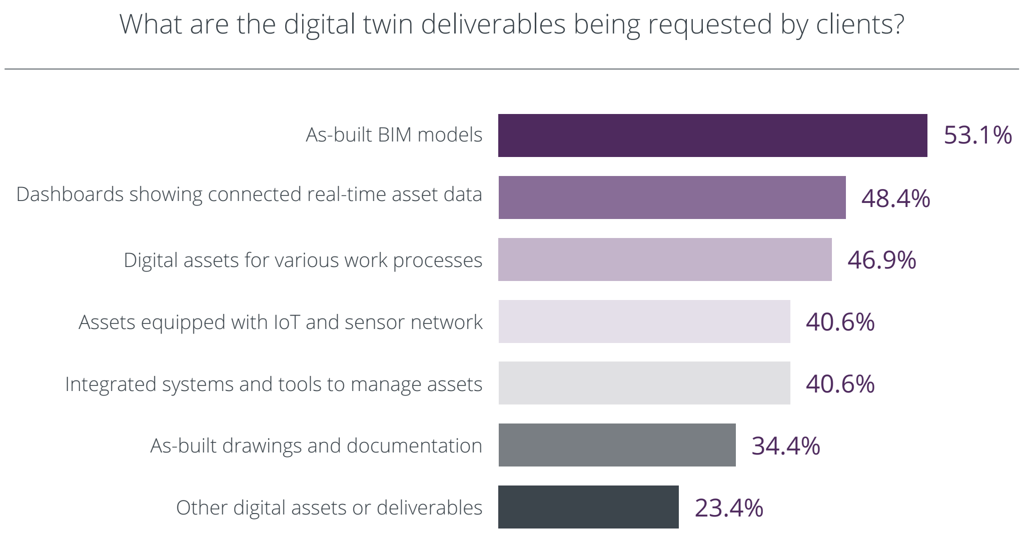

Figure 9: Deliverables requested by clients

When asked if they would deploy a digital twin on project, 64% of the respondents saw the benefits of developing, deploying, and using digital twins over the whole-of-life of the asset (Figure 10).

Given the option, and if you had no roadblocks, would you deploy a digital twin on your projects even if it is not mandated by the client or project sponsor?

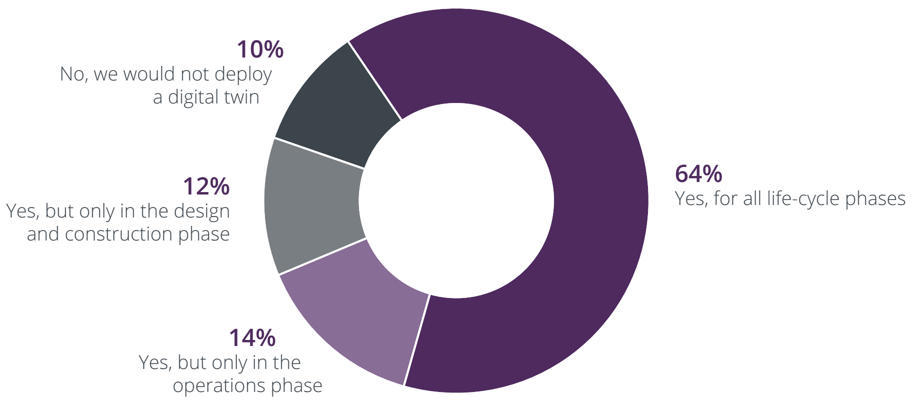

Figure 10: Life cycle uses of digital twins

'High costs, including direct and hidden costs,' 'No demand or financial support from clients,' and 'Perceived complexity due to lack of information and training' were ranked as the top three blockers that hinder the use of digital twins during the design and construction phases (Figure 11).

Rank in the order of importance the blockers that you think hinder the use of digital twins during the **design and construction phases**.

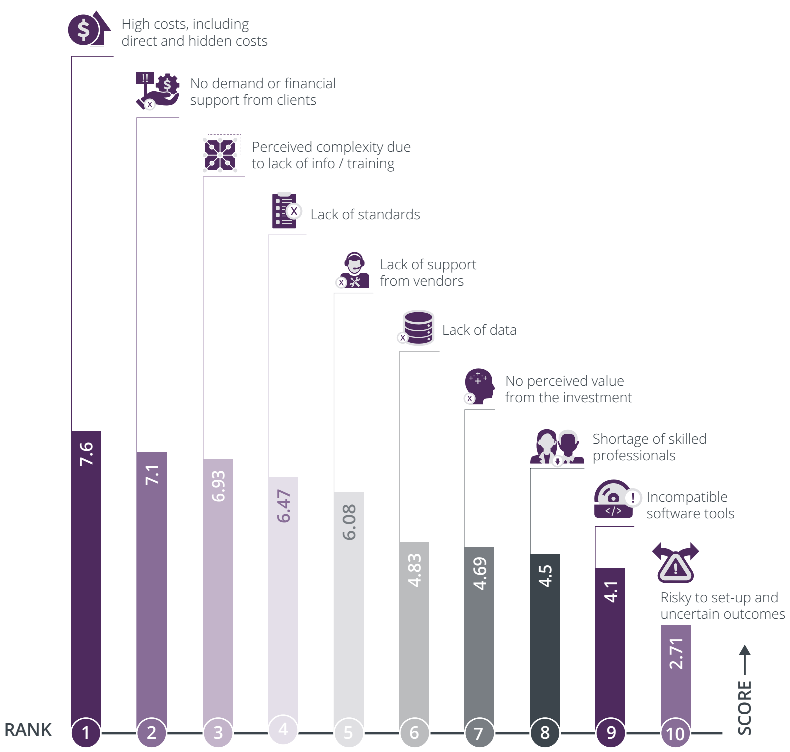

Figure 11: Blockers during the design and construction phases

'High costs, including direct and hidden costs,' 'No demand or financial support from clients,' and 'Lack of standards' were ranked as the top three blockers that hinder the use of digital twins during the operation and maintenance phases (Figure 12).

Rank in the order of importance the blockers that you think hinder the use of digital twins during the **operation and maintenance phases**.

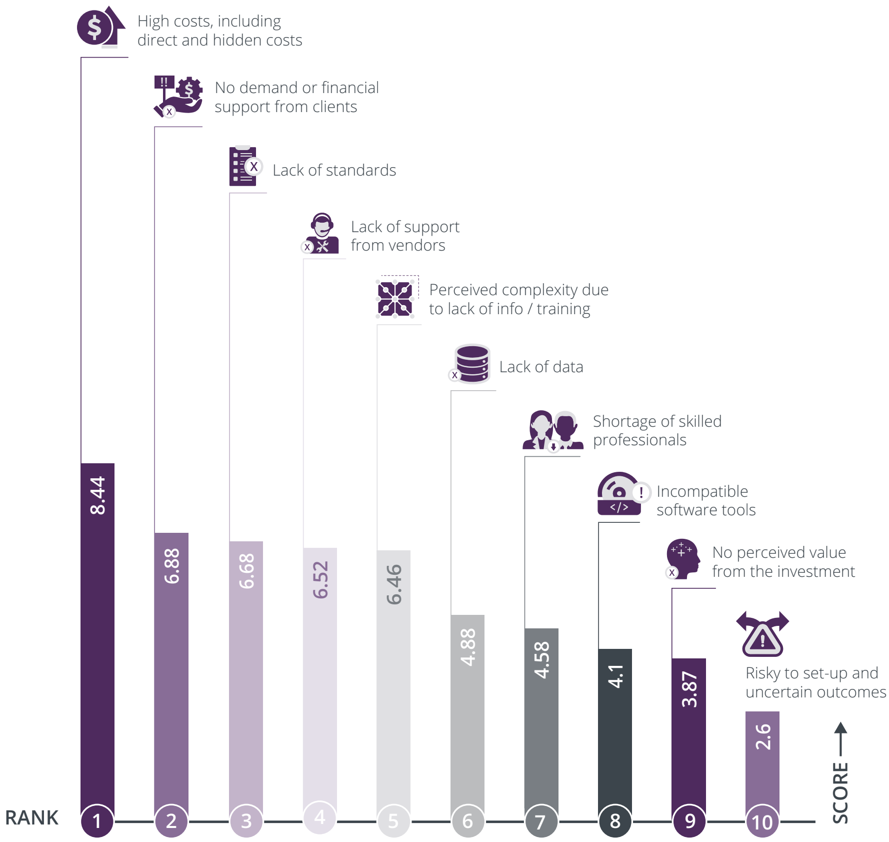

Figure 12: Blockers during the operation and maintenance phases

From the survey, it is clear that digital twins in the built environment sector are still developing. While they present several benefits, there remain numerous blockers to their use.

3.1.2 Findings from expert interviews

A semi-structured interview was used to gather insights from 17 experts involved in digital twin applications. The following questions guided the interview process:

- What is the current state of digital twins in the built environment sector?
- How do you see digital twins working in the design and construction phases?
- What are the three things holding back the use of digital twins in the built environment sector?
- What should everyone know about digital twins that they miss?
- How are you implementing digital twins in your organisation?
- What do you believe are the benefits of implementing digital twins?
- Are customers asking for digital twins? What exactly are they asking for?
- What should a professional do when asked, ‘can you help us create digital twins for our projects and assets’?

The main insights received from the experts are summarised below.

Definition of a digital twin: while standard definitions of a digital twin are now available, there is still confusion in the use of the term in the built environment sector. A digital replica without connections (synchronisation) with the physical asset is often incorrectly portrayed as a digital twin. Additionally, the experts pointed out that the traditional uses of building information models for progress monitoring, schedule simulation (4D planning), collaboration, etc. or laser scans of construction processes or existing assets may also be mislabelled as digital twins.

Data as the key driver: data, information, and information management are key drivers to the development, deployment and use of digital twins in the built environment sector. From the interviews, it became clear that digital twins rely on a repository of static and dynamic data of real-world entities and processes. Similar to the importance of information management in BIM, the success of a digital twin application depends on information management processes adopted by the implementation team. Digital twins, when implemented correctly, will first and foremost meet the client’s information requirements and make the right information available to the right people at the right time, enabling them to make the right decisions. As the data and information gets managed efficiently, project teams can use it to conduct analytics using AI, ML and other predictive methods to enhance the value derived from a digital twin.

Return-on-investment: experts pointed out the importance of keeping the return-on-investment central to the decision of using digital twin on projects and assets. Without understanding the purpose and conducting a cost-benefit analysis, the use of digital twins may not be successful. Experts also pointed out that return on investment generated through the creation of digital twins remains challenging to quantify. Perhaps smaller, well-defined and short-duration digital twin initiatives can be undertaken to gain experience and establish parameters for value for money analysis. Developing strategies to define the use cases, creating a structured process for benefits realisation, and learning from previous implementations can help overcome this difficulty.

Maturity of BIM adoption: while BIM is not a mandatory starting point for a digital twin, most experts pointed out that organisations with high degrees of maturity of BIM adoption and processes are better positioned to use digital twins. Most experts shared from the experience that BIM is currently the best tool for authoring static data for construction objects, specifications, schedules, and design and construction documentation, and therefore is becoming a vital part of digital twin initiatives.

Part of digital transformation: large and medium-sized organisations consider digital twins part of their broader digital transformation efforts. Many organisations are taking digital twins as a natural progression of their other digital technology programs, especially BIM.

Requirements and use cases are unclear: no industry standards are available to guide the listing of requirements while developing and delivering a digital twin for a project, including establishing use cases, roles and responsibilities, security, privacy and legal requirements. BIM protocols can serve as a template for setting requirements for digital twins. Multiple blockers still hinder the use of digital twins in the sector.

Exemplar projects: several demonstration projects have been recently completed or are currently underway. These projects clarify the 'what,' 'why,' and 'how' of digital twins. However, limited case studies and examples exacerbate the inability to demonstrate the full benefits of using digital twins during the design and construction stages.

These key insights from the survey and expert interviews guided the development of this paper.

4 How are digital twins used?

4.1 Developing and using digital twins from design to handover

A digital twin can be created at any project or asset life cycle stage. However, the creation of the digital twin, or detailed planning for its creation at an early stage of the life cycle and its use in the pre-project or project stage, is desirable. A clear business case and value proposition must determine when and how a digital twin would be used. While the application of digital twins is important over the whole life of the asset, the purpose of this section is to discuss in detail this issue from design to handover.

Table 3 presents typical scenarios of digital twin applications from the design phase to the handover phase. Based on the type of asset and use case, actions needed during the design, construction and handover phase are described. In the case of an existing asset undergoing some type of intervention or a new build, a strong case can be made for creating and using the digital twin in the design stage itself. For a renovation, refurbishment or retrofit project, the proposed design interventions can be added to an as-built model of the existing asset along with the context capture of the environment in which the asset exists. This can be part of the digital twin created during the design stage and used in detailed design, construction and handover. Similarly, the project team can create and use a digital twin from the design stage itself on a new build.

Life cycle stage → Type of asset ↓	Design	Construction	Handover	Use
An existing asset with no planned intervention	No action needed	No action needed	No action needed	Digital assets are created from as-built information and point cloud data. Digital twin developed, deployed, used and continually updated for operation, maintenance and end-of-life
Existing asset undergoing renovation, refurbishment or retrofit	Design data and other digital assets produced for the renewal	Construction data and other digital assets produced while undertaking renewal	Digital twin with data, information, and models developed and handed over	Digital twin deployed and continually updated for operation, maintenance, and end-of-life

Life cycle stage → / Type of asset ↓	Design	Construction	Handover	Use
A new asset with no digital twin requirements during design and construction	No action needed	No action needed	The traditional handover process used	Digital assets are created from as-built information and reality capture. Digital twin developed, deployed, and used for operation, maintenance and end-of-life
A new asset with digital twin provisioning during design and construction, and deployed and used during the in-use phase of the asset	Design data and other digital assets produced and updated	Construction data and other digital assets produced and updated	Digital twin with data, information, and models developed and handed over	Digital twin deployed and continually used and updated for operation, maintenance, and end-of-life
A new asset with digital twin provisioning during design and construction, and deployed and used for the whole of life, including the project stage of the asset	Design data, other digital assets including a digital replica produced, and replica used for simulation and further what-if analysis	Construction data other digital assets produced and updated, including an updated digital replica produced along with the physical asset, and used during construction	Digital twin with data, information, and models developed and handed over	Digital twin continually deployed, used, and updated for operation, maintenance, and end-of-life

Table 3: Developing and using digital twins from design to handover

4.1.1 Design stage

During the design stage, the main contribution to developing a digital twin is producing and creating digital assets such as BIM, drawings, images, and other types of design data and information about the construction objects and the asset itself. Careful consideration to consistent classification of elements, and definition of a data dictionary that is complete enough to fulfil the intended use cases, are foundational requirements. Verification and validation of data is essential, the familiar cliché 'garbage in, is garbage out' will fully manifest itself otherwise. A virtual representation that acts as a representational (graphical) and computational model is developed. The delivery of digital assets during design is guided by the overall information management process adopted for the digital twin. At the design stage, the careful planning of the sensing layer (e.g. sensors, IoT devices, and asset and facility management system) can also be conducted and integrated with the design of the physical asset. Design specialists, vendors, and suppliers may be involved in specifying the sensing layer at this stage.

The use of the digital twin can enhance the design process and the creation of digital assets. This happens in two ways:

1. Using digital twins, the designers and engineers have an opportunity to model, simulate and conduct what-if scenarios to improve and optimise their design. In a connected environment, they can also see how their asset design fits with existing assets and the surrounding environment. This can be performed at an individual asset scale to a district or city level. For example, at the design stage, the environmental impacts of the proposed design can be conducted with the help of the digital twin.
2. The design can be informed by data, information, and evidence received from various sources in a connected ecosystem. This can ensure tight coupling between the design, construction, and operation of built environment assets. Digital twins can improve the built environment's operational efficiency by integrating and automating the historical data and information from downstream processes such as asset management and facility management to inform performance-led design. While not possible on all projects, early involvement of construction and asset and facility management experts along with the use of digital twins can enhance the detailed design process. For example, a digital twin at this stage can be used to study the environmental, social, and governance criteria before making investment decisions. In the future, digital twins can facilitate a performance-based design process.

The opportunity during the design phase is to create simulations of how the asset will operate and how end-users will use it, from traffic flow analysis to occupancy to energy use. By starting with simulations that can be validated in the actual asset, design intent can be carried forward and iterated with actual data once the asset is operational. For infrastructure projects, as the economic use of the asset is usually integrated into the asset itself, much of the work of a digital twin's modelling and simulation can be pulled from the operating specifications and model requirements of the process-specific equipment and other assets within the facility.

4.1.2 Construction stage

The physical asset is stood-up during construction. Large volumes of data are generated, updated, used and stored during construction. This is the stage where as-designed, as-planned, and as-built data about the asset can be merged. Any changes (captured by images, videos, point clouds) during construction can be merged into the virtual representation using the as-built data. The use of BIM and related processes such as 4D (three-dimensions plus time) and 5D (4D plus cost) BIM helps streamline the management of data and information during this phase.

In the construction stage, the sensing layer (e.g. sensors, IoT devices, and the asset and facility management system) is assembled and installed as part of the physical asset and marked on the virtual representation for handover.

As part of the digitisation that has continued to progress through the construction industry, the following four developments are beginning to knit together to improve the information management process during construction.

- BIM has become integrated into workflows at almost every level of the construction process.
- Site data has grown as sensors, drones, laser scanning, and other digital tools become part of site-based workflows.
- The supply chain has matured, allowing real-time inventory tracking from the factory to the gate and onto the site.
- Prefabrication and industrialised construction have changed how much of what gets built is produced in-situ and how much is produced near-site or offsite.

Taken together, construction teams are now better positioned to create, deploy and use digital twins from the inflow of materials, products and prefabricated components, the models of the asset itself, and the analytics to make those flows of data into valuable insight. Digital twins, in turn, can be effectively deployed during construction. Many site-based processes can be enhanced by using digital twins. Production management, work performance, health, safety, and wellbeing of workers, materials, and equipment tracking, can all benefit from the use of digital twins. Examples of application of digital twins during this stage include site safety, progress monitoring, supply chain management, enhanced as-built modelling, improved handover, etc.

4.1.3 Handover

The handover of an asset can be significantly improved when digital twins are used. The traditional handover is generally inefficient and uses a fragmented and siloed approach to passing on the necessary data and information to the asset manager or operator. This may lead to missing information, difficulty assessing critical information or tedious processes due to a lack of interoperability of systems. As-built BIM models have been used to partially overcome these issues, but regular updating of these models with performance data is still a challenge. As the design and construction process progresses, large volumes of data are generated and updated in the form of models, images, videos, point clouds, etc. This data is only as valuable as the asset manager's ability to access and operate, which can be a huge issue. These as-built BIM models (or asset information models) are still document-centric, do not provide a virtual-physical-virtual loop, come together towards the end of the project, and do not use recommended information management processes and practices.

On the other hand, a digital twin will allow a knowledge graph of the real world entity to be composed based on a selected ontology that represents the various entities, their inter-relationships and the information associated with them, integrated from many data sources, one of them being the as-built models (or asset information models). The digital twin collates all the handover information into a cohesive information model that is easy to access, use, and update during the operation, maintenance, renewal and end-of-life stages. Applicable to both new and existing facilities, a digital twin promotes best information management practices, reduces risks, and captures performance data and knowledge. As the creation of the digital twin begins early, the design and construction teams can continuously stage and validate asset data to assure data quality and accelerate and enhance the handover process.

4.2 Role of project professionals

Creating a digital twin is not easy in any context and creating them during design and construction may be among the more difficult and complex undertakings. However, after almost a decade of extensive and intensifying digital transformation, the time to consider digital twins during the design and construction processes has come.

When an asset owner seeks to develop the digital representation of the asset, it is essential to take into consideration the purpose that ultimately the digital twins will serve, e.g. a digital twin for construction site safety or a digital twin for enhancing the health and wellbeing of occupants of an office building. This purpose will dictate what type of data is important and needs to be collected, its frequency, the system it will be required to be connected to, and the industry standards required to store the data. The sophistication and accuracy of the digital information created will ultimately impact the business outcome; therefore, it is essential to understand key stakeholders and customer needs and address them appropriately. So, capturing the requirements and deliverables of a digital twin initiative are essential. Alongside this, it is also necessary to understand the legal and regulatory implications and how security, privacy, and accuracy of data and information can be ensured.

Project professionals including construction managers, cost managers, and quantity surveyors, play a critical role, with the opportunity, and responsibility, to be the creator and steward of data and be at the foundation of their asset owners' digital twin journey. A professional, especially one involved in project management, quantity surveying and construction, is at the centre of data creation and, therefore, a key player and enabler in this journey. The role of a project professional is central to the creation and use of digital twins for both existing and new assets. For example, creating a digital model of an existing built asset is familiar to all experienced surveyors. The need for an accurate as-built survey is fundamental for creating a digital twin of built assets. The technological evolution that has followed over the last 20 years has led to the development of various hardware, software and devices to measure and acquire the existing assets and rapidly translate that to a building information model.

4.2.1 Making a business case for digital twins

Digital twins require resources, effort, and investment in the pre-project, project and use phases. As such, adopting and implementing a digital twin on a project would require careful analysis and decision-making. Project teams can assist (and work with specialist consultants) in this analysis and decision-making process, carefully tying the analysis to the outcomes and benefits of the digital twin. If a decision is made to proceed with the use of a digital twin, project team members can help build a detailed business case and a detailed implementation plan, including procurement and delivery plan of the twin. Numerous resources are now available to conduct the analysis, make a go or no-go decision, and then take the remaining steps (e.g. the Digital Twin Toolkit by CDBB, Digital Twin Navigator for NHSScotland, IET Digital Twin report, DTC's maturity levels, etc.). Broadly the following questions should be answered:

- Why is the digital twin needed, and what is the core purpose?
- What are the asset performance indicator(s), and what part(s) of the asset needs improvement?
- What are the detailed (employers) digital twin requirements, and what are the primary and secondary deliverables?
- How are the asset data and information collected and stored?
- How will the digital twin be procured?
- How will the digital twin be created, implemented, deployed, used and maintained?

Figure 13 shows a process that can be followed in answering these questions. Each step shows the main question to be answered and the primary decision made in each step. For example, the 'why' question is addressed in step one. Clear linkages to the proposed digital twin's value, outcomes and benefits are identified. A decision to proceed is made based on the use cases and how they add value to the asset and the stakeholders. A detailed analysis can be conducted using the aforementioned frameworks for large and complex assets.

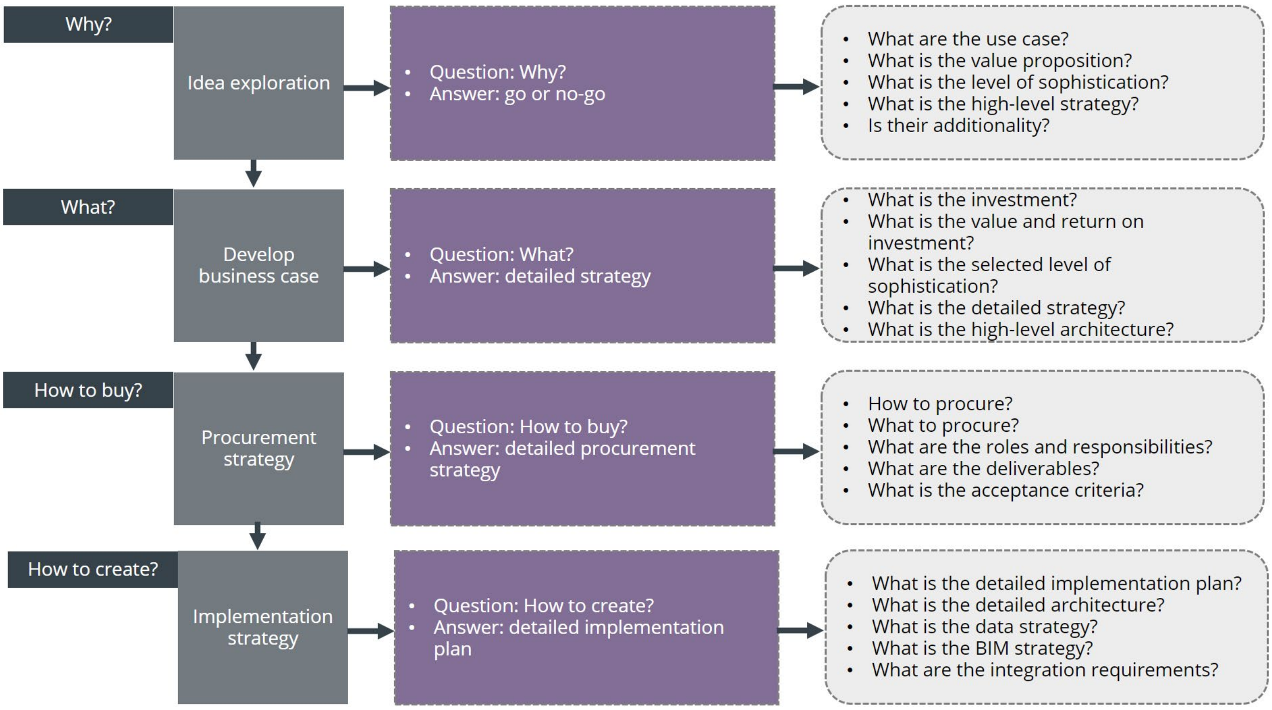

Figure 13: Need assessment of digital twins

4.2.2 Participating in the information management process

Construction managers, cost managers and quantity surveyors can play a leading or supporting role in the information management process. Successful creation, deployment, use, and updating of a digital twin depend on a sound information management process. Numerous information management protocols are already in place as part of the BIM adoption and implementation journey. These can be used to establish data and information models, specific data and information flow, roles and responsibilities, collection and dissemination work practices, and related standards in conjunction with BIM and CDE. Project professionals can guide the project team in establishing information exchange processes, enabling information integration, and coordination and collaboration of the team for sharing, updating, and securing data and information in a digital twin.

4.2.3 Understanding the legal and regulatory issues

Since digital twins act as a central repository of static and dynamic data and information, some legal and regulatory issues must be considered. The data captured with a digital twin includes as-designed, as-planned, as-built and performance data. These data sets are dynamically merged. A golden thread connects and tracks this data and information over the life cycle of the object or asset under consideration. Sitting on top of this data and information is the ability to predict and forecast how real-world entities and processes are likely to behave or are behaving.

Data and information stored in a digital twin can therefore cut across contractual boundaries and life cycle stages and provide a connected digital record of the asset from design to end-of-life. Thus, a highly advanced form of digital twin can be seen as a live document held digitally with ‘fingerprints’ (e.g. using blockchain technology for highly complex interconnected and inter-operable digital twins) of people recording their decisions about the asset’s design, construction and use.

While, on the one hand, this provides an accurate and updated record of asset data, it does bring some unique legal and regulatory issues to the forefront. The legal environment for digital twins is impacted first and foremost by data ownership issues. This will have to be addressed contractually, keeping in mind the extended period the data may stay live in a digital twin. The contracts will have to address confidential data and information issues and shared ownership in cases where a complex system within a digital twin combines data and information from individual objects provided by different team members. As digital twins break down silos and enhance collaboration, the issue of data sharing and accuracy will also have to be contractually resolved.

Given the complex nature of the digital twin, the whole area of disputes and liability will take on a new meaning and need a reassessment.

On the one hand, a digital twin, with the help of a golden thread, can determine when, how and which party decided regarding an issue under consideration, it may be very complex to ascertain causal linkages to the source of the problem. As time progresses, these issues will have to be resolved, with construction managers, cost managers and quantity surveyors playing a pivotal role in highlighting these issues and suggesting best practices. Some valuable insights from the application of BIM can be adopted to address these issues, including who owns the digital twin.

4.2.4 Managing security and privacy

Digital twins also pose security and privacy challenges. With both static and dynamic data and information about the performance of an asset stored in one repository, it is vital to consider data privacy and security in a robust manner. It is important to consider how to keep the data and information safe and private, and protect against breaches of the twin itself. This is a risk that the project team must holistically address. It is essential to protect the virtual representation, the physical asset, and the synchronisation mechanisms between the two. At the same time, data and information stored in a digital twin must also comply with privacy regulations and be protected against illegal access. Appropriate security and privacy arrangements must be addressed upfront as the digital twin is created.

5 Why are digital twins important?

5.1 Benefits of digital twins in design and construction

Whether it is for a completed building, a group of assets, or the process that creates these assets, one of the purposes of a digital twin is to make design, construction, handover and use of these asset more efficient. The efficiency gains are possible due to the integrated and connected use of data and information. With data and information pertaining to the design, construction and actual performance of the asset, stakeholders gain better understanding of both the digital and physical versions of the asset. This allows decision-making to be data-driven, model-centric and collaborative. Digital twins produce real-time data that is actionable, driving insights that can be used to improve strategic, design, operational and maintenance decision-making. Another key benefit of digital twins is that they dynamically integrate data and information throughout the asset life cycle. This leads to short- and long-term efficiency and productivity gains.

The physical asset cannot be analysed for what-if scenarios; therefore, a synchronised digital version is used instead to remove inefficiencies from the design to improve downstream processes. Appropriate use of digital twins will add value and provide better outcomes for all stakeholders over the asset's life. Fundamentally, digital twins can help drive better outcomes from the assets, such as improved site safety on a construction project, increased workplace productivity in an office building, or better rider experience on a transit system. In the context of construction, the core opportunity is to use digital twins to create a tool where construction operations can be viewed as a single system, at different levels of abstraction, and thus managed more thoughtfully at different timescales, organisational levels, and operational scales.

To be accepted, digital twins must create value. The value created must pass the additionality test, they must provide benefits beyond what is possible today with the help of BIM and other currently used model-based and data-driven work practices.

Digital twins can help the design, construction, and handover process by:

- improving the design, construction, and delivery of new assets
- integrating existing assets and conditions in the design and construction process
- enhancing the handover process by verifying as-built conditions with as-built data and information
- streamlining the materials supply management
- integrating the life cycle steps and the input of project team members
- using historical data and information from downstream processes in design and construction
- improving investment and financing decisions by simulating economic considerations in conjunction with environmental, social, and governance criteria
- reducing errors, rework, and fragmentation in work practices by providing access to real time work performance data from the construction site
- facilitating the timely intervention of emerging risks and, in turn, enabling increasingly predictable cost and schedule outcomes during project execution
- reducing life cycle costs by enhancing time and cost certainty of the delivery process
- increasing productivity and operational efficiency of design, construction and handover processes
- enhancing collaboration across the project team during the design, construction and handover phases
- improving worker safety, health and wellbeing by providing actionable insights from the workface
- reducing environmental impacts, primarily by reducing upfront embodied carbon emissions by comparing options
- reducing overall life cycle costs and carbon emissions through timely and tested interventions, and
- improving asset performance and improving total cost of ownership through efficient design, construction, and handover processes.

6 How do emerging technologies influence the future of digital twins?

The built environment sector has seen an explosion of technologies in the past decade, several driving the emergence of digital twins. The following emerging developments are critical to the future of digital twins:

Computer vision: Computer vision (or machine vision) is among the most promising technologies for creating, using and updating a digital twin. Computer vision is a set of techniques and methods that allow automated analysis of incoming video and imagery from the construction site or an existing asset. Video cameras are typically already on construction sites and completed assets, so a recent wave of breakthroughs have provided increasingly powerful machine vision applications that can interpret everything from movement of workers to completion of work to occupant density and more, all of which provide the data that builds a digital twin. This flow of data is often real-time or near-real-time and increasingly forms the information backbone of the digital twin. Starting from simple object detection, modern machine vision solutions can be made more intelligent to speed the provisioning of data needed to populate and update a digital twin. This can include:

1. Presence or absence of materials, products, equipment, etc.
2. Extraction of quantities of materials and sub-assemblies.
3. Movement of workers, plant, equipment and products.
4. Presence or absence of safety equipment, especially personal protective equipment (PPE).
5. Progress or completion of work put in place, including quality assurance and control.

Data fusion: Digital twins require multiple data sources to extract timely and actionable insights. Data fusion removes the burden of processing the raw data from various sources so the end-user can focus on the insights. It can help combine and process sensor data, data obtained from images, videos, asset management and facility management systems and models. Advancements in this technology are likely to impact the successful use of digital twin in the built environment sector.

Artificial intelligence and machine learning: The amount of data and information available within a digital twin system is not manageable by humans without the aid of computer tools to assist in data processing, analysis, and sense making. AI and ML synthesises the data within a digital twin system and convert it into a human consumable format. AI and ML can be deployed to find patterns in data, translate from one format to another, recognise and classify data, and otherwise provide advanced data processing to gather useful intelligence. Advances in AI and ML such as deep learning, natural language processing, predictive analytics, and advances in quantum computing will influence how user-friendly digital twins can be made in the future.

Digital platforms: No single out-of-the-box solution can be used to create digital twins. While a platform approach is preferable, and several are being developed (for example, see Figure 14), it is realistic to expect that full-cycle digital twins will include products and data connections to multiple products and phase-specific platforms. A digital platform (or ecosystem) combines products, software, concepts, ideas, or thinking that is open to end-users and other firms (complementors) to extend and create value-adding solutions. In the case of digital twins, a BIM-based platform (e.g. the openBIM initiative started by buildingSMART) may become the core product with boundary objects or modules (e.g. application programming interface, software development toolkit, etc.) available to develop complementary products and apps. A BIM based platform alone may not be adequate to provide a flexible, extensible and composable environment to build digital twins. Progress in the development, governance and use of such platforms is needed to progress the adoption and implementation of digital twins in the built environment.

Whole-process	Engineering (E)	Procurement (P)	Manufacture (M)	Construction (C)	Delivery (D)	Operation & Maintenance (O)
Scenario	• All-discipline integrated design • Whole-process simulation • Coordination between all participants	• Smart supply & procurement • Digital credit information • Supply chain finance	• Digital marketing • JIT production • Automated production	• Process priority scheduling • Smart construction site • Twin building	• Digital delivery of completed works	• Predictive maintenance • Personalized and accurate services
Value	• Improving design quality and efficiency	• Integrating and optimizing supply chain • Constructing transparent value chain	• Demand-driven intelligent production	• Improving construction quality • Reducing project costs • Increasing efficiency	• Constructing project digital assets • Supporting smart operation and maintenance	• Improving quality of operation and maintenance services • Reducing operation and maintenance costs
Evaluation indexes	• Approximate 100% of building function rationality • 50% reduction in design cycle	• 80% increase in supply-demand matching efficiency • 60% reduction in credit service costs	• 65% increase in marketing efficiency	• 70% reduction in engineering changes • 50% increase in management efficiency • 80% reduction in engineering rework	• 50% increase in construction efficiency of operation and maintenance digital model	• Approximate zero equipment failure rate • 20% reduction in Operation and maintenance costs

Figure 14: Platform approach to digital twins (source: Glodon)

Internet of Things: IoT and sensors can play an important role in a digital twin. But currently, IoT sensors are complex for field teams to specify, install and maintain throughout an ever-evolving construction site and asset in use. As the value of the data and analysis that these sensors can support becomes more commonly understood, some of the resistance to installing and maintaining a network of sensors may subside, and direct and indirect costs will reduce. Many product vendors, technology vendors, distributors and system integrators operate in this field making it a very fragmented specialism. As the demand grows, the industry is working to resolve these issues by adopting system interoperability and integration protocols and this could have a significant impact on the future of digital twins.

Simulation: With an abundance of data available from a digital twin, the ability to conduct what-if analysis increases. For example, AI-driven what-if simulations of a construction project schedule based on historical project data can provide insights into any likely delays and related cost overruns that the project may encounter based on current performance. Simulation techniques can also play an important role in comparing options and understanding and predicting performance. Future developments in simulation methodologies and techniques are therefore crucial for the future of digital twins as they can help drive better decision making. Progress in areas such as agent-based simulation, mixed-method simulation, multi-physics simulation, and integration with geographic information systems is something to watch.

Collaborative work practices: Digital twins both promote collaboration and require collaboration. Previous studies have shown the importance of developing a collaborative culture in construction enterprises using integrated collaborative technologies. Considering digital twins are an integrated collaborative environment that use state of the art digital technologies, they can support superior decision making and better project, asset and business operations. Identifying, developing, and managing collaborative business relationships within or between organisations is crucial for digital twins' progress in the built environment sector to support information-based decisions and collaborative behaviour. With digital twins, the mantra of the right information, at the right time, and to the right team members can be achieved. This will require collaboration between team members to become pervasive. Identification, development, and management of collaborative business relationships within or between organisations is crucial for digital twins' progress in the built environment sector.

Supply chain management: Modern construction sites are seeing a wave of innovation and interest in how products, materials, components, etc. are supplied to the job site. Visibility of prefabricated components produced on-site, near-site, or offsite is helping enhance worker safety, productivity, and predictability. RFID, machine vision, and other label-based means of tagging and tracking large numbers of items play a crucial role in supply chain management. This real-time data when integrated into a digital twin system means project teams can use automated progress monitoring to manage risk and forecast performance. Therefore, advancements in supply chain management are likely to influence the future of digital twins.

Skills and competencies: People will play a central role in the progress of digital twins. They will benefit from the development of digital twins, especially an ecosystem of connected digital twins for the built environment. People will also play a central role in creating, deploying, using and updating digital twins. This will require new skills, competencies and pathways to entry into the profession. Without investing in people the industry cannot fully realise the benefits of digital twins.

7 Summary

Digital twins are being established across the built environment sector to manage and improve the design, build and operation processes of assets through holistic understanding and improved decision-making. The approach is gaining traction among the various stakeholders. This paper argues both for their expanded use within design and construction phases, and extension of their use across all phases, for improved speed, safety and operational efficiency. Indeed, as a method of managing complexity, nowhere is the need more acute than in the construction phase, where complexity and risk are often a primary concern for owners, constructors, and other team members, including chartered surveyors.

Digital twins provide this unique ability to manage complexity through the consumption, processing and display of real-time data flows superimposed on static design and engineering data. These data flows can be a challenge to organise correctly, as the original data creation methods are usually not built for use in a digital twin. As a result, keeping the data current is a critical focus area, or trust in the digital twin as a decision-making tool can erode. Technology partners are emerging to help with this, from data preparation to event-driven systems that provide alerts and manage heterogeneous data from heterogeneous sources. These technology partners include providers of BIM-based solutions, those who offer solutions for cloud-based CDEs to integrate file-based information flows, and those who are creating data centric (not BIM centric or file centric) platforms that leverage BIM as one of the many data sources for creating digital twins.

Notably, the level of complexity a digital twin is designed to manage will vary, as will the phase of the asset life cycle in which it is developed, deployed and used. These key areas of context should guide technology selection as well as the processes used to create and maintain the digital twin. For example, a digital twin created for managing the construction phase of a single building will differ from that created for managing the ongoing operation of a university campus with numerous built assets.

After years of experience gained by applying BIM in the built environment sector, management of data and information has emerged as the main thread that connects project team members and life cycle phases to achieve desired outcomes. Similarly, data, information, and their management will be central to the growing application of digital twins in the built environment sector. This is confirmed by the fact that 54.4% of the respondents ranked ‘facilitating data sharing to deliver performance efficiency for all stakeholders’ during design and construction and 68% ranked ‘gathering real-time asset operation and maintenance data’ during asset operation and maintenance as their top choice for the use of digital twins. Quantity surveyors and construction project managers are central to the expanding use of digital twins. They play a crucial role in the processes related to data, information and information management.

Over 60% of the chartered construction and QS and project management professionals who responded to the survey do not currently use digital twins. As professionals tasked with managing schedules, quantities, budgets, project scope, risks and supply chains, they have not had as much exposure in using digital twins compared to other professionals involved in asset operation and management.

This paper highlighted how construction and project management professionals could help develop, deploy and use digital twins during the design, construction and handover stages. Their role is likely to expand and increase as the industry shifts towards a whole of life and whole of asset worldview.

Digital twins are expected to continue to develop as a critical tool in all phases and the overall asset life cycle, especially in light of continued environmental, social and governance (ESG) requirements. These requirements are increasingly difficult to fulfil without a whole-of-life view of a construction project and the resulting asset.

In an industry where roles continue to evolve and change, digital twins offer all stakeholders an effective new tool to drive professional excellence and thus the profession's importance to and relevance in a sustainable built environment. However, to make the most of this data-driven technology or system, pre-determined budgetary commitments must reflect the data and technology requirements of the digital twin use cases. It is envisioned that the foregoing presentation of digital twins is a step towards helping project teams make those collective resource allocation arguments successfully.

In the coming years, the sector and the profession will see the technologies that underpin digital twins continue to mature. Sensors, machine vision, data governance, modelling and visualisation technologies promise to make digital twins more powerful, useful, and easier to create and maintain. Entirely new additions to the scene, such as AR- and VR-enabled 'metaverse', are expected to be part of these developments, but so would ubiquitous laser scanning, AI-powered voice data collection, and other developments perched on the horizon.

Ultimately digital twins will become a repository of different types of data and information, spanning disciplines and life cycle phases. To enable this, the industry must align various data sources and data standards so that construction objects can be defined in an interoperable manner. For example, life cycle cost data provided by cost management professionals must integrate with design and construction workflows so that decisions can be made based on real-time cost estimates. Similarly, data about the operation of an asset should also be aligned to the various workflows needed to operate and maintain an asset. Process (or practice) standards and data standards will play a significant role in achieving this goal. Rather than targeting to develop an all-encompassing standard, progress on the digital twin front can be made by aligning existing international standards such as the International Cost Management Standard (ICMS), International Building Operation Standard (IBOS) and the RICS Data Standard.

RICS professionals are bound to play an ever-important role in developing, deploying, and using digital twins.

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Appendix A: case studies

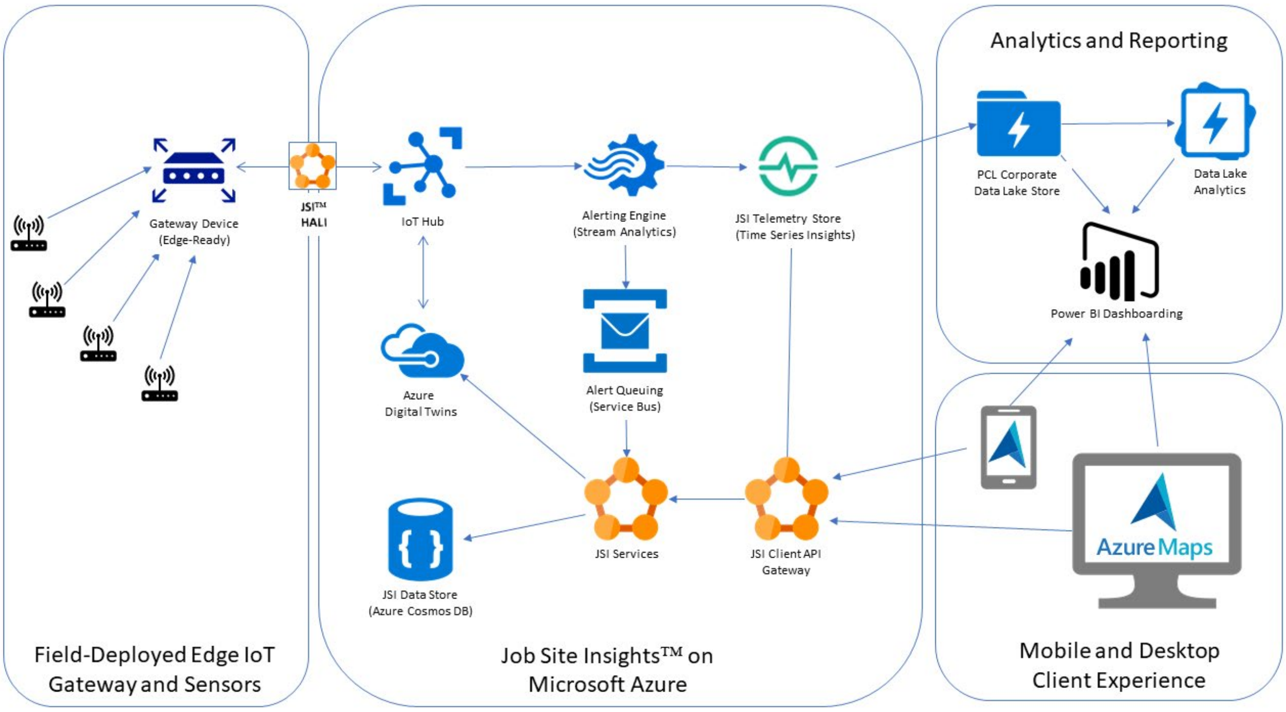
A1 Enabling smart construction on 250 construction sites

Purpose

Using the mobile-ready Job Site Insights™ application from Latium Technologies, PCL Construction enabled a single-pane view into all aspects of construction. By gathering and analysing the Internet of Things (IoT) data in real-time, PCL improved project quality, safety, efficiency and productivity.

PCL recognised that it needed to continue to embrace technology to continue becoming a better builder and deliver on client needs, and the company embraced IoT to make that happen.

By enabling real-time data access and analytics, PCL increased job-site safety, operational efficiencies, quality, and worker productivity. The constant flow of real-time data from IoT sensors – plus decades of historical data from other PCL projects – not only aids in the monitoring of job sites today, but it also provides PCL with an ever-increasing pool of critical data it can use with machine learning to do predictive analytics that make construction even smarter.

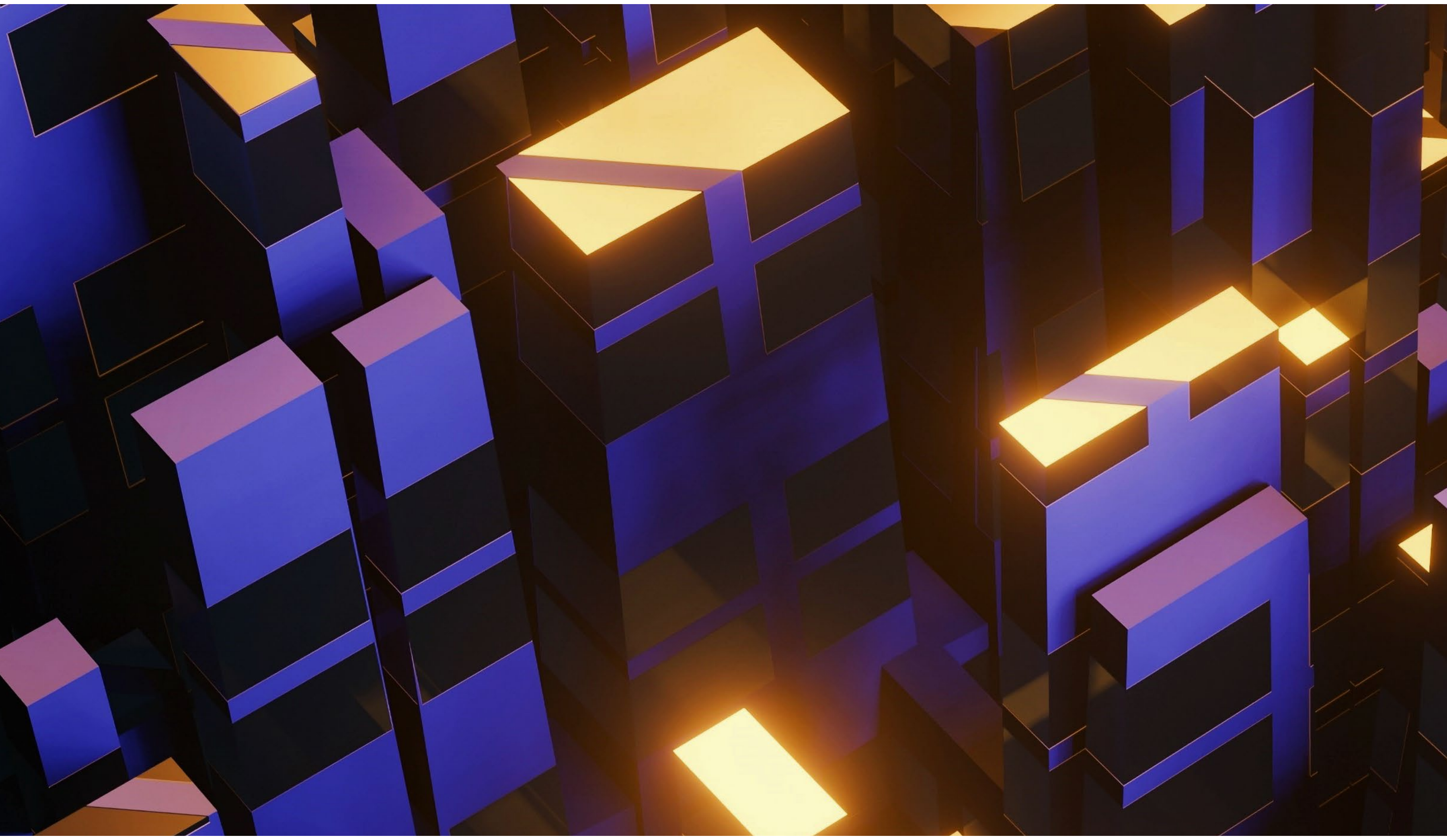


Challenges addressed

- Water leaks and flooding (enhance risk mitigation, reduce rework).
- Concrete strength and maturity (enhance schedule).
- Air quality and dust particulates (enhance safety).
- Location, utilisation of tools and materials (enhance efficiency).
- Carbon-based and electrical energy saving (reduce carbon footprint).
- Temperature and humidity (improve quality, reduce rework).

Outcomes delivered

- Better environmental outcomes.
- Improved productivity.
- Labour health, safety, and well-being.
- Improved customer satisfaction.
- Data-driven decision making.
- Insights through integration of real-time data.



A2 Smart Energy Digital Twin for Bridgend County Borough Council, Wales

Purpose

Buro Happold has implemented a Smart Energy Digital Twin for Bridgend County Council in Wales, in the UK.

The purpose was to create an accurate digital representation of the local authority energy network. This model was used to conduct iterative network design, validation and simulation of options at the property level, thermal modelling, and predictive load management for low-carbon energy impact.

The aim was to create a real-time district heat network that automates optimised plant, pipe sizing, and network routing based on peak load analysis using actual property data in conjunction with established benchmarks. The digital twin uses an automated approach for a complex phased development plan and compares multiple options, including distributed vs. centralised systems that streamline the design process. The twin allows design iterations to be rapidly analysed as soon as new building data becomes available, reducing costs and maximising comfort to consumers.

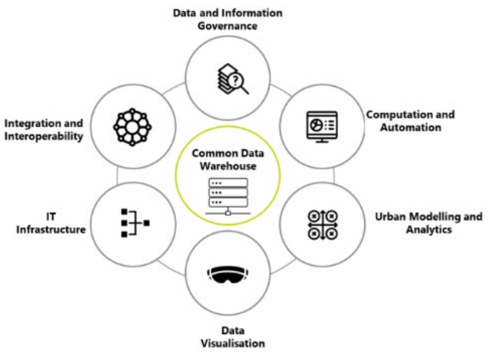


Figure A1: Buro Happold Digital Twins solution delivery methodology

Figure A2: User interface – energy centre network profiles, monthly heart energy supply and load curves

Figure A3: User interface – pipe capacity, velocity pressure and pressure gradient, pipe length and diameter and flow velocity

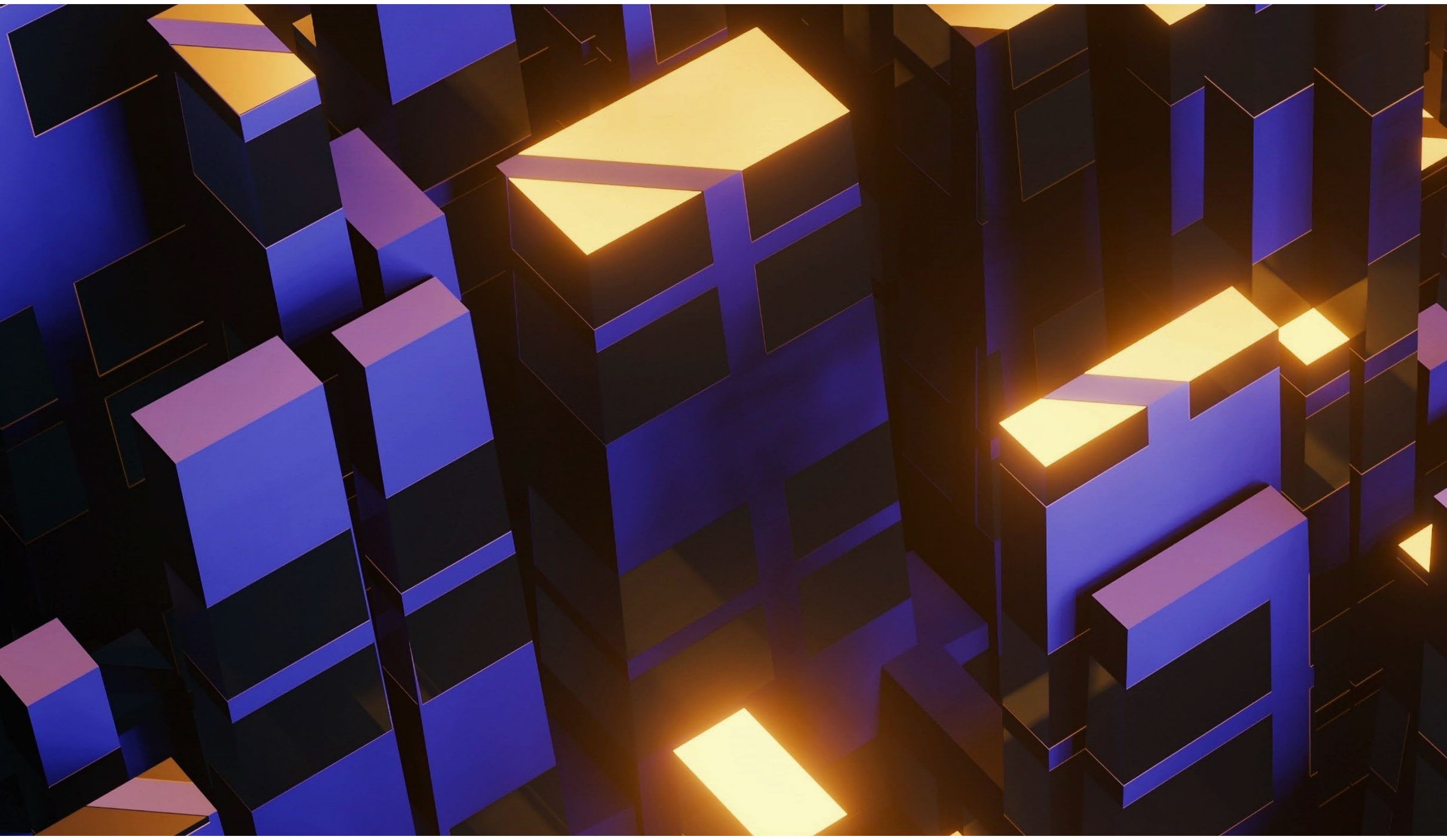
Figure A4: User interface – typical daily household heat energy profile, monthly and quarterly heat energy requirements

Challenges addressed

The digital twin allows for the optimisation of the design of the energy network system, providing the local authority with accurate real-time information and understanding of the impact of various alternatives to make informed decisions on the best outcomes with the ability to explore alternative options faster. Therefore, the local council can interrogate different network configurations to gain deeper insights on social, environmental, and economic benefits.

Outcomes delivered

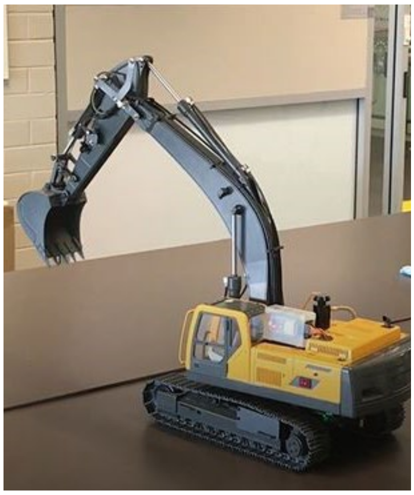
- Accurately modelling and optimisation of residential energy profiles.
- Optimised network planning and design based on real-time assessment of new energy network demand requirements.
- Places Bridgend County Borough Council at the forefront of low-carbon energy innovation in the UK with the use of a digital twin.



A3 Excavator digital twin

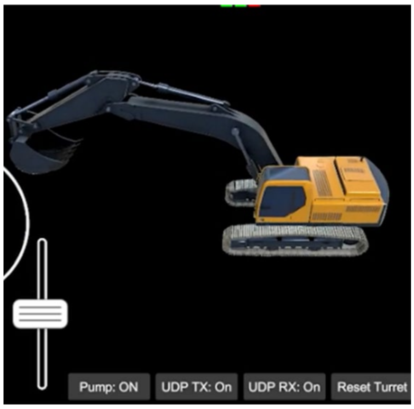
Purpose

ConXR Development, School of Built Environment, UNSW Sydney have developed a way to connect both the physical model of an excavator and the simulated version of the excavator to talk to each other. This practice is the first step forward in developing a remote supervision platform, collecting data from the field, and helping the operator run the excavator from a distance.



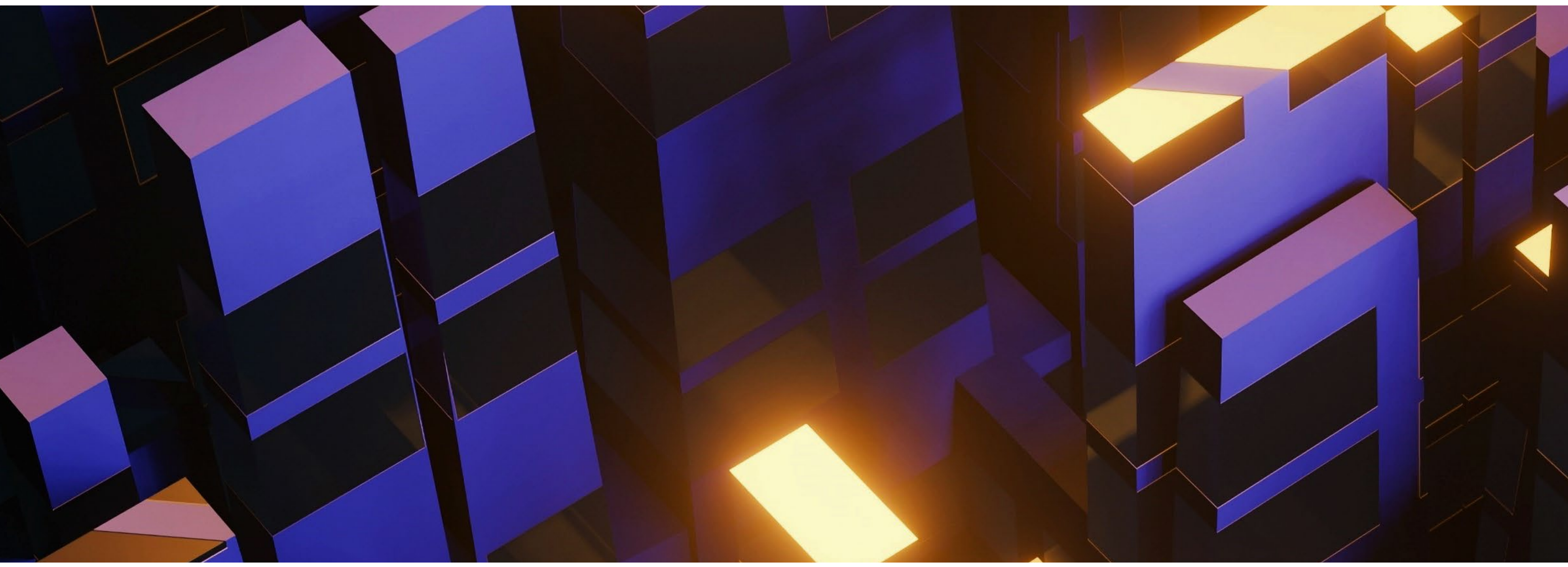
Challenges addressed

The concept underlying this practice is to develop mechanisms to continue the excavation process remotely during any kind of disruptions such as COVID-19. This practice can be further developed and applied to different construction operation tasks to ensure the task can be done remotely. The data can be exchanged for supervision and remote operation.



Outcomes delivered

- Connect physical model to the simulation.
- Control the physical model by iPad and changes in simulation.
- Visualise the excavator move in the virtual model.
- Allow trainees to use both versions for learning how to operate an excavator in different situations.



A4 Xi'an's Glodon R&D Building

Purpose

Considering China's sustainability targets, Glodon decided to use their Digital Building Platform for the construction of Xi'an's R&D Building. It uses this approach through the life cycle (from design to operation) by using an integrated and innovative solution based on the digital twin paradigm. Consequently, besides meeting the sustainability (COP26 and Sustainability) targets, the advanced use of digital twin with AI allowed understanding of how to manage the company's assets better. Even when the building is still under construction, real-time information shows significant results in ensuring the achievement of these goals.

Challenges addressed

Digital twins are getting more attention in the built environment sector due to their potential values and promising benefits. However, some implementation challenges must be addressed. First, there are only a few solutions available in the market, and this indicates a digital twin is not an option for everyone, especially small and medium enterprises.

Secondly, data is the key to digital twins. Disconnected data at each stage of the life cycle weakens the value of the digital twin. Lack of accurate design and construction data means modellers need to rebuild models using technologies such as point cloud, which is expensive and time-consuming.

Finally, digital twins must be mapped to the organisation's business model. On this basis, it was important to show the added value to both stakeholders and the company's shareholders to ensure successful implementation of the digital twin. So, by standardising the process as part of the project life cycle, it helped eliminate these challenges (risks) and understand the value of the digital twin application to this project.

Outcomes delivered

Glodon (Xi'an) Digital Building R&D Mansion Tower: The building has a total construction area of 66,278 square meters, a frame shear wall structure, three floors underground, and 12 floors above ground. The project started on 16 September 2019 and its structure was completed on 25 May 2021.

The digital building platform is also a production line based on the digital twin, which drives the physical production line for synchronous operation and collaborative management. The project control unit conducts real-time scheduling, production scheduling, logistics scheduling, and construction scheduling between the factory and the site through this platform, forming integrated management.

Glodon (Xi'an) Digital Building R&D Mansion Tower

With the help of BIM technology, integrated with the on-site IoT and AI technology, the real-time twinning of the model data and actual data was applied. The whole process was data-driven, and the on-site industrial construction was initially designed to ensure the quality of process standardisation. The data-driven lean construction was also implemented.

Through the digital building platform, based on the smallest process management unit- five elements of lean management affect the project's success: progress, cost, quality, safety, and environment. In the office, digitisation was conducted in terms of process-level in-depth design, scheduling, resource procurement and supply, and other business so that design, scheduling, and procurement are in place. Digital building platform helps digitise the office, construction site, and working surface and enables them online. Driving the allocation of relevant resources through the business needs on the construction site, ensuring the supply of labour, material, and machine and the operation on the construction site in place.

Through data-driven lean construction, the dynamic optimisation of progress, timely payment of costs, guarantee of quality, and accident prevention were also applied. At present, 80% of the process tasks have clear operating standards, and the building's quality standards have been upgraded.

The whole schedule management process has been dynamically optimised through planning and scheduling to the last level and task execution to the minimum. In addition, the labour team and suppliers were paid on time according to the process tasks (in contrast to traditional payment method payments were based on the contract progress measurement).

Relying on the data driving force of the digital building platform, AI learning, graphics technology, cloud computing, etc. were innovatively applied to develop an increased intelligent bill of quantities. With the help of big data, the designer, developer, contractor, and building materials suppliers were connected to offer data services such as material selection and pricing throughout the whole life cycle.

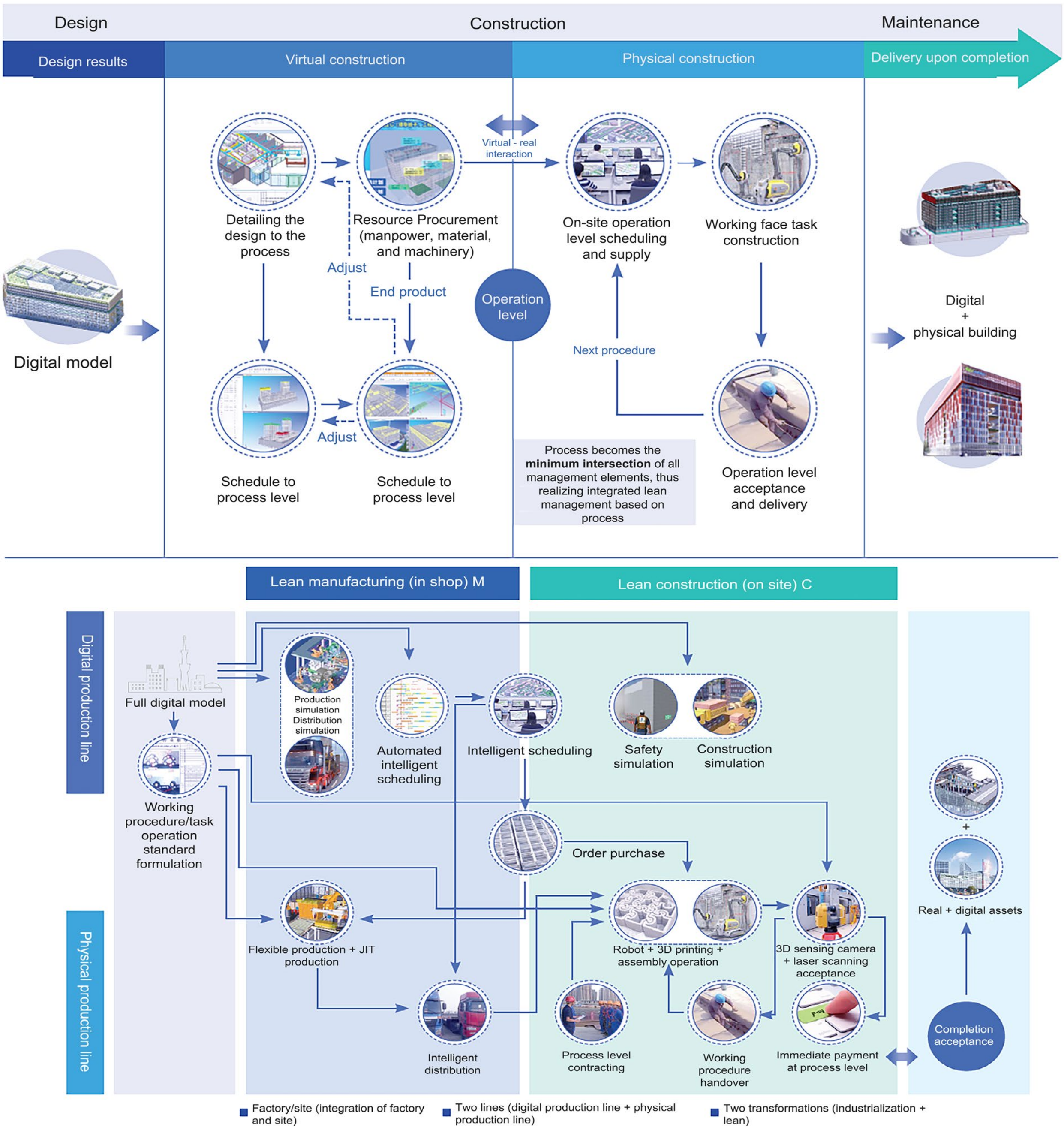
Through evaluation, an industrial supply chain service-based platform was also built to provide new ideas and models for the transformation and upgrade of supply chain finance. Moreover, by using the digital building platform, Xi'an Building has been 'built twice.' In fact, two 'buildings' will be delivered (virtual and physical building).

For the virtual building, digital models will be delivered through digital virtual construction such as collaborative design, virtual production, virtual construction, and virtual operation and maintenance. Then, the industrial intelligent lean construction that integrates both digital production line and physical production line will help deliver the high industrial quality of the physical building.

Based on cutting-edge science and technology, the digital building is implemented to offer industrial quality and human-oriented healthy buildings and thus fully meet people's individual needs. The intelligent building can implement a comprehensive analysis through deep cognition, intelligent interaction, and self-evolution. The cloud, among other services, can also quickly compute based on the actual data from various sensors in the building. Consequently, the building is becoming a 'living body,' analysing the indoor environment such as temperature, humidity, and wind speed, monitoring health status, and providing other humanised services.

Digital technologies run into and merge with the building industry, significantly impacting its digital transformation. The development paradigm of the digital building platform that digital twins fully support converts the building industry into a dynamic ecosystem that offers better cooperation. Thus, a value chain supply is developed.

The traditional building industry must be deconstructed from all elements, processes, and stakeholders and reconstructed through digitalisation, online system, and intelligence to build the new design, construction, and O&M.



A5 Transforming the management of IPUT's real estate portfolio with a digital twin

Purpose

IPUT are Ireland's leading commercial property investment company and the largest offices and logistics assets owner in Dublin. They own and manage a portfolio comprising over 5.2 million square feet. They design and build assets that are certified against industry-leading environmental efficiency, digital connectivity, and sustainability benchmarks. To operate assets efficiently, they need to ensure handover from construction into operations is based on sound data that is associative and contextual to support operations workflows. (Tom Costello | Head of Construction– IPUT Plc)

Invicara was appointed to develop the digital twin concept for IPUT, implement its technology, engage the design teams and contractors in their BIM process and develop digital twins of multiple new developments, including the Wilton Park development. The first building to have a digital twin was The Exchange, a newly constructed building that IPUT acquired in 2017. Even though a digital repository of building information was handed over, the information was in disconnected silos, so it was challenging for the building manager to access the right information when needed efficiently.

Once the first digital twin implementation for The Exchange was complete, it convinced us that we need to get a digital twin at the handover of all our developments. We extended the solution to fully integrate the digital twin with the existing building automation system and smart meters, to get analytics on energy use and equipment performance. We are committed to achieving net-zero carbon by 2030, and the digital twin of our portfolio is helping us get there. This practice is the first step forward in developing a remote supervision platform, collecting data from the field, and assisting the operator run the excavator from a distance. (Glenn Cran | Head of Asset Services – IPUT Plc)

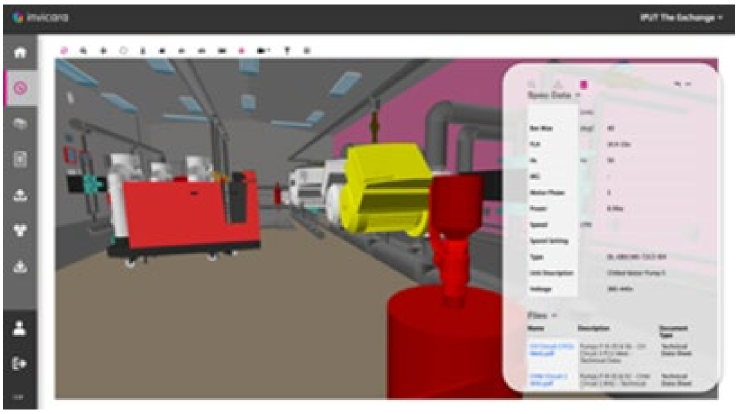
Challenges addressed

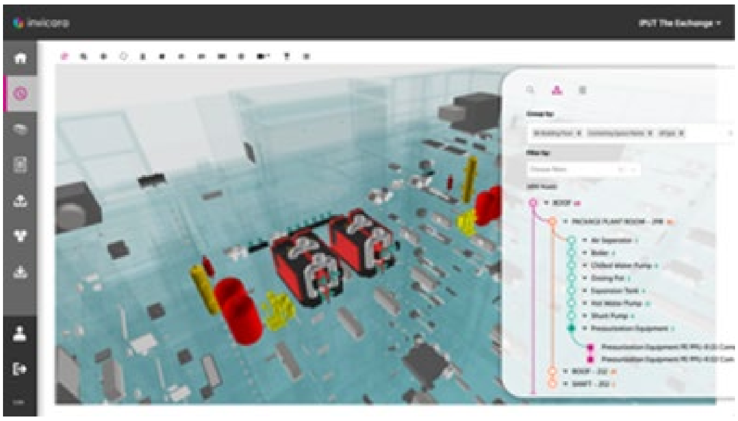
From the outset, the digital twin was scoped to address specific challenges experienced by IPUT through very clear use cases, user roles, and user journeys (workflows). The first use case was to eliminate the need for IPUT's building managers to access, search and join multiple data sources, both within their organisation or by contacting external firms, to find building information. IPUT required the digital twin to create a data hub that delivered accurate and contextual information to address business and operational use cases, improving services availability and occupant comfort while reducing costs. The second use case was to apply analytics on data from the BMS system, energy meters, and IoT sensors, identify plant anomalies, its energy performance, and trigger proactive interventions, supported by contextual information for decision-making.

Finally, **IPUT is committed to achieving net zero carbon** of their portfolio by 2030. To achieve this, IPUT wanted a platform that would assist them in developing and delivering a digital transformation strategy through composable applications that have outcomes based on progressively evolving requirements.

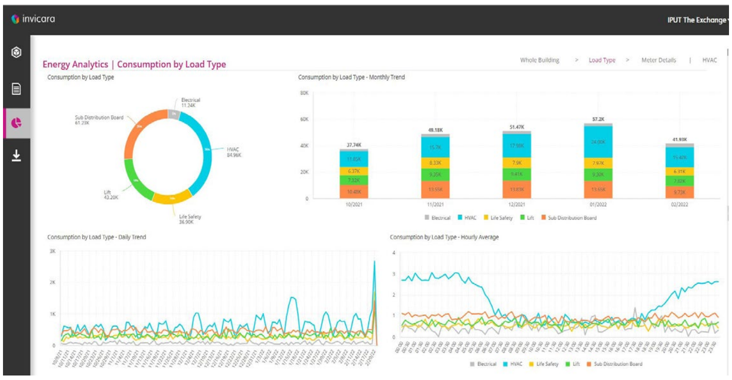
Outcomes delivered

With all information related to equipment, systems, spaces, and relationships, the digital twin is integrated to the existing BMS system, smart utility meters and indoor air quality sensors to automate fault detection, energy analytics, and diagnostics. By accessing the digital twin from a desktop or a tablet using a web browser, all information is available immediately, improving the productivity of the involved team members and reducing wasted time. 3D visualisation allows users to locate equipment and quickly identify connected systems and spaces. This enables users to easily access equipment status, asset information, performance, and energy data, diagnose problems, and plan mitigation efforts by co-relating issues with the information on service history, service requests, and preventative maintenance schedules.





IPUT can reduce reactive maintenance costs, extend useful asset life through proactive interventions, improve energy performance to meet their net zero carbon goals, and optimise the occupants' comfort and wellbeing.



The composable nature of the **Twinit.io** platform enables IPUT to learn from experience and continuously improve the solution to address the existing use cases while enhancing the solution for future use cases. The digital twin has provided IPUT with a platform to test and develop its digital transformation initiatives, measure the outcomes, and establish the return on investment.

Delivering confidence

We are RICS. Everything we do is designed to effect positive change in the built and natural environments. Through our respected global standards, leading professional progression and our trusted data and insight, we promote and enforce the highest professional standards in the development and management of land, real estate, construction and infrastructure. Our work with others provides a foundation for confident markets, pioneers better places to live and work and is a force for positive social impact.

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