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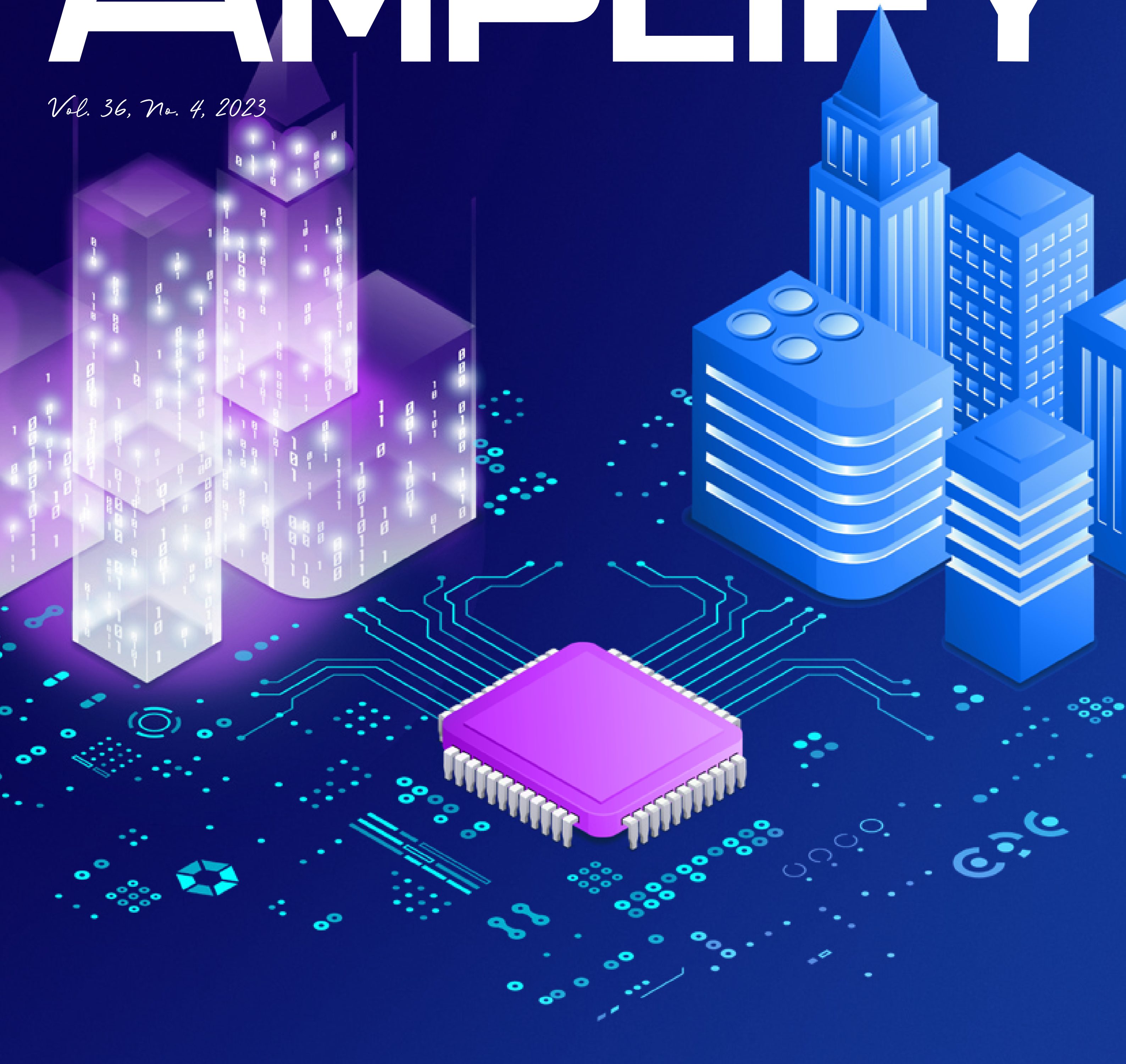
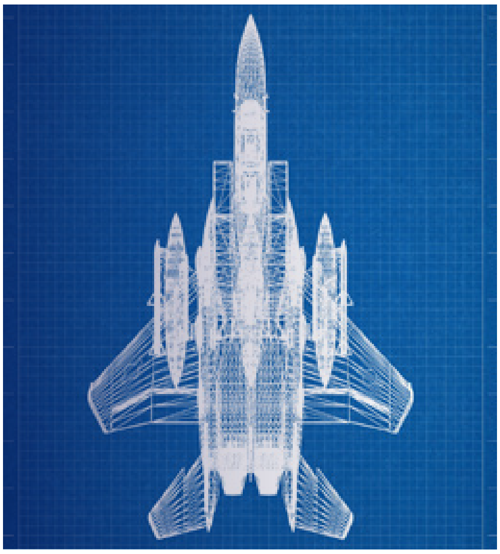


Digital Twins in Practice

CONTENT



DIGITAL TWINS IN PRACTICE

BY RON ZAHAVI, GUEST EDITOR

Digital twins are recognizing rapid adoption across virtually every industry and continue to evolve. In 2021, *Amplify* published its first digital twins edition, which focused on expected value based on this Digital Twin Consortium definition: "A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity."[1] The issue included some use cases and opportunities we envisioned for digital twins.

Over the last three years, we have seen great progress at the Digital Twin Consortium. Membership has grown from start-ups to large global organizations and end users that are implementing digital twins.

In this latest issue of *Amplify*, we take a lessons-learned approach — revisiting the concept of digital twins with an eye toward how organizations are using digital twins, the implementations, and the challenges encountered.

As you might expect, digital twin implementations can fail if organizations start in the wrong place or start too big without building on smaller successes. Such challenges are typically nontechnical and must be addressed at the organizational level by first understanding the goals and the strategy, then by using digital twins to achieve the desired ROI.

We hope the information about digital twin challenges and successes in this issue will help business leaders avoid some common missteps and accomplish their digital twin goals. A great deal has been achieved in three years, but there are still many opportunities and other challenges:

- No single company has a complete digital twin solution, so businesses must rely on several vendors.
- The market is still shifting, so leaders must carefully select vendors — some are likely to modify their products, merge, or be acquired.
- Digital twins make use of many IoT and other related standards, but digital twin–specific standards (e.g., how to integrate simulation engines from different vendors) have not been developed just yet, so integration and interoperability are still opportunities for differentiation.
- Several vendors offer digital twin frameworks designed to make digital twins simpler, but it's important to avoid vendor lock-in.
- Skills, including expertise in various model types, tend to be scarce and costly.

Despite this, progress is being made in leaps and bounds. The *Amplify* authors identified security as a challenge two years ago, and guidance is constantly emerging. For example, a collaboration between the Digital Twin Consortium and the Industry Internet Consortium in the area of the IoT Security Maturity Model (SMM) has developed a digital twin profile for the SMM.

Using the SMM to IEC 62443 security standard mapping, industrial organizations like manufacturers and mining companies can use a combination of these documents to identify the specific control-system capabilities they need to implement to match their investment goals. This type of actionable guidance for product creators, integrators, and asset owners is the type of ecosystem collaboration needed to address gaps and accelerate the market.

The Digital Twin Consortium's academia and research group, which includes a number of universities, is looking to develop curriculum to address skills shortages, and a planned digital twin certification program will close the gaps.

> **DIGITAL TWIN IMPLEMENTATIONS ARE ADVANCING FROM INITIAL DASHBOARDS TO CONTROLLING ASSETS IN A FEEDBACK LOOP**

In the first digital twins issue, we recommended that organizations: (1) learn more about digital twins and digital transformation, (2) understand potential use cases and how their business could benefit, and (3) develop proofs of concept and pilots they could build on.

Today, organizations can do more. Digital twin implementations are advancing from initial dashboards to controlling assets in a feedback loop. They provide an opportunity for improved decision-making and performance-tuning.

Organizations that are already executing on our earlier recommendations should consider:

- Moving from a single digital twin deployment or a single type of digital twin to a broader deployment across other business systems, using multiple types of digital twins
- Integrating their digital twins with enterprise resource planning and other business systems for greater value
- Analyzing earlier experiments to determine the best place to achieve ROI
- Picking a core set of partners and providers to accelerate the path to success
- Expanding the vision for achieving value from data integration to achieving compliance, testing large and expensive assets before they are built, and improving safety
- Identifying which data is most useful for themselves and their supply chain
- Integrating digital twins with emerging technologies, such as virtual reality (VR), augmented reality, artificial intelligence, and the Metaverse

IN THIS ISSUE

The articles in this issue were selected to provide important lessons about real-world deployments and case studies. They also provide insights about industries where digital twins have gained early traction and what types of organizations are adopting digital twins, including those focused on sustainability and those seeking to enable Metaverse scenarios.

In our first article, Carl Faulkner presents a mining industry case study with a focus on data collection, integration, and storage challenges. The article includes lessons learned from the application of a solution designed to facilitate user-friendly access to digital twins as well as the importance of connecting digital twins to other business systems to get the most value.

Next, Jason Radel explores the application of a digital twin framework for the ingestion, application, and visualization of digital twins and the integration of light detection and ranging data, photographs and scans, and other engineering documents. The article includes case studies from the energy and defense sectors, demonstrating how such an approach can be used in managing digital twins in different industries.

> **WE HAVE ENTERED A NEW PHASE OF THE DIGITAL TWIN MARKET, MOVING FROM EXPERIMENTING WITH DIGITAL TWINS TO DEPLOYMENTS WHERE VALUE IS BEING REALIZED**

In our third article, Ruth Kerrigan and her colleagues describe the application of digital twins to building-performance twins at the University of Glasgow, Scotland. They discuss tracking electricity and heating performance in campus buildings and lessons learned, many of which are organizational in nature, not technological. The authors conclude with a methodology for the deployment of performance digital twins and recommendations for addressing some of the issues they encountered.

As mentioned earlier, sustainability has become a recent focus for digital twins, and our fourth article, by David McKee and Tim O'Callaghan, contains a case study from a UK town using digital twins to achieve its net zero obligations. The authors discuss the use of tools to visualize historical data and utilizing new data from various sources to simulate possible outcomes and manage risk.

In our fifth article, Alexander Weber discusses the use of digital twins in radar systems. This is a good example of using digital twins to simulate products that are costly to build (especially if they are built incorrectly) and their use in addressing compliance requirements. Weber explains how the model was verified and how the simulated data corresponds to the real data.

Next, Tim Giuliani discusses how digital twins are being used for regional planning by the city of Orlando, Florida, USA. Here, digital twins are employed via VR to offer an immersive environment so users can experience the impact of various scenarios. The article shows how organizations are bringing together vendors and partners to integrate data, digital twins, and emerging technologies.

Finally, Colin Dominish discusses a variety of revenue opportunities that could be realized by applying digital twins to real estate and buildings. He discusses improving building performance and some opportunities to enhance tenant experiences.

WHAT'S NEXT FOR DIGITAL TWINS?

We have entered a new phase of the digital twin market, moving from experimenting with digital twins and seeing what they can do to deployments where value is being realized. The lessons from these real-world activities can provide insights and guidance for those beginning their digital transformation journeys.

There are still some challenges that need to be addressed, so digital twin ecosystems and consortia are bringing together end users, vendors, governments, and academic institutions to address gaps and ensure we have the foundation we need to achieve greater value over time. We hope this issue of *Amplify* inspires you to leverage digital twins as part of your digital transformation.

REFERENCE

[1] "Definition of a Digital Twin." Digital Twin Consortium, accessed April 2023.

About the guest editor

RON ZAHAVI

Ron Zahavi is Executive Director of the Digital Twin Consortium. He has extensive experience in all aspects of technology management and solution delivery, 20 of those related to Internet of Things (IoT) solutions. Mr. Zahavi is the founder of his own consulting company and has held various CTO/CIO positions, managing technology across several companies and performing due diligence of potential acquisitions. Most recently, Mr. Zahavi was Chief Strategist for IoT Standards and Consortia at Microsoft. His breadth of experience includes work with startups, large companies, government, and private equity firms. Mr. Zahavi has also worked in several business domains, including healthcare, pharmaceuticals, energy, intelligence, and defense. He has served as a board member of the Object Management Group (OMG), has served on the OMG Architecture Board, and several steering committees, including Industry Internet Consortium and Digital Twin Consortium and the program committee of the IoT Solutions World Congress. Mr. Zahavi is author and coauthor of several books, including *Business Modeling: A Practical Guide to Realizing Business Value*. He holds a bachelor of science degree in electrical engineering from the University of Maryland and a master's of science degree in computer science from Johns Hopkins University. He can be reached at rzahavi@aurontech.com.

DIGITAL TWINS UNLOCK BUSINESS VALUE FOR WESTERN AUSTRALIAN MINING INDUSTRY

Author

Carl Faulkner

The mining industry in Western Australia is a key contributor to the nation's economy, with billions of dollars generated each year. The industry has been at the forefront of adopting new technologies to increase productivity, reduce costs, and improve safety, and one of those technologies is digital twins.

Digital twins have been widely adopted by the aerospace and manufacturing industries, but their potential benefits in the mining industry are only starting to be realized. By examining a successful implementation and the lessons learned, we can garner useful information about the use of digital twins in the industry and understand how to improve the deployment process in similar technology initiatives.

Data creation and collection is a challenging process in the mining industry. Mining companies collect huge volumes of data from a variety of sources, including equipment sensors, work management, and engineering systems. The data has a high degree of variability, both in quality and quantity, and there are inherent interoperability challenges due to the wide range of software applications used by mining companies, as well as varying requirements.

For digital twins to be effective, they need a solid spatial data foundation. Specifically, they need accurate, up-to-date, easily accessible spatial data that can be used to engage users, contextualize information, and connect to real-world conditions.

Successfully building a digital twin for a fixed-plant mining operation involves collecting data from a wide variety of sources, including legacy 3D model geometry, geospatial data (e.g., geographic information systems, photogrammetry/point cloud data), nonspatial data sources like streaming Internet of Things (IoT) devices, and contextual data (e.g., engineering, computerized maintenance management systems [CMMS], enterprise resource planning [ERP] systems).

To ensure that the digital twin can drive business value for the operation, the data must be accurate, and the relationship between the spatial and non-spatial data must be easily defined and scalable. The case study below shows this process in action.

> **FOR DIGITAL TWINS TO BE EFFECTIVE, THEY NEED A SOLID SPATIAL DATA FOUNDATION**

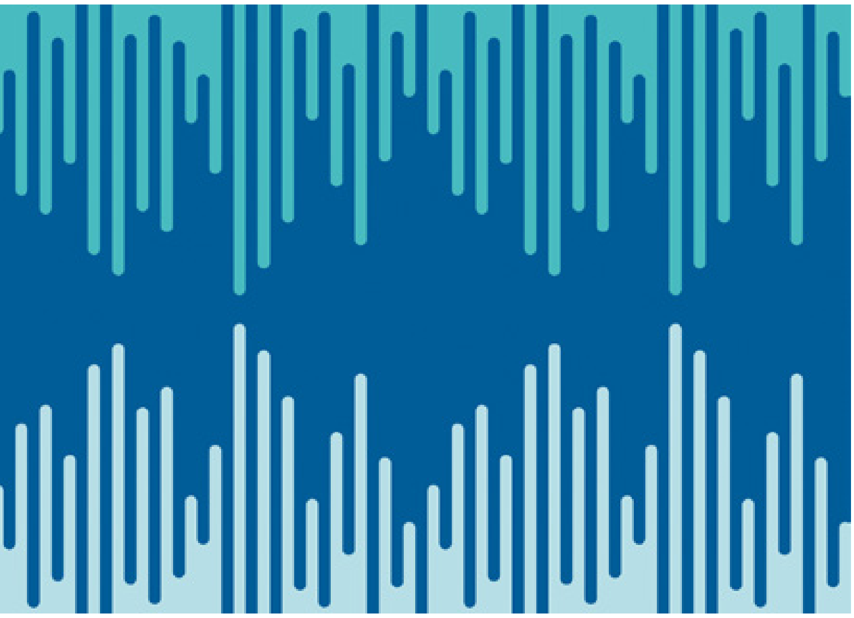
CASE STUDY

A digital interface was implemented at a major iron ore mining company in Western Australia, aimed at integrating data across its operations.

To ensure that value was delivered to stakeholders throughout the development cycle, the project employed a constrained scoping and deployment strategy. For example, once the virtual environment had been established, the equipment in the digital twin was bound to the company's third-party document-control system. This was deployed throughout the organization, and stakeholders had input into the next phase: a connection to the existing process-control system, followed by its ERP system, asset health system, and permitting system.

The solution has now been implemented on multiple mine sites and port facilities, with a rigorous spatial information change management process to ensure the integrity of the digital twin.

Data is integrated from a variety of sources, allowing the organization to easily combine engineering, IoT, and other data to create a comprehensive foundation for its digital twin. This is essential for achieving an accurate, comprehensive representation of real-world conditions and delivering data to end users when it's most critical.



The solution has a user-friendly interface that lets nontechnical users access, analyze, and interpret the information quickly and easily: everyone from frontline workers to senior executives can access information from the digital twin. The digital twin's user-friendly interface and advanced visualization tools make it easy for nontechnical users to understand and analyze data in 2D and 3D formats. The resulting collaboration among users promotes the sharing of data, insights, and best practices.

CHALLENGE 1: DATA COLLECTION

The first challenge in building a data foundation for a digital twin is gathering data from various sources and converting it into a digital format that can be used for a variety of use cases and user engagements.

In fixed-plant mining operations, data is used to control and monitor the operation and performance of equipment like conveyors, crushers, mills, and pumps. Standard process-control systems are used for plant operations, but there is a growing field on the monitoring side. Monitoring data can be collected using a variety of technology and sensors, such as the IoT, vibration sensors, temperature sensors, and flow sensors.

All the collected data can be used to optimize equipment maintenance schedules, improve equipment utilization, enable better decision-making, and reduce downtime. For example, vibration sensors can be used to monitor the health of rotating equipment (e.g., pumps and motors) by detecting vibration-pattern anomalies. By monitoring the vibration patterns over time, maintenance teams are able to identify potential issues before they become critical and schedule maintenance to avoid unexpected downtime.

But the real opportunity comes from combining 3D spatial data, such as engineering information, 3D geometry/geospatial data, and maintenance records (which provide historical context), to enable more accurate analysis and predictions. For example, engineers can use a 3D model of a conveyor system to understand the flow of material through it, allowing them to identify potential bottlenecks or areas of low throughput and optimize the system's layout.

Maintenance records can also inform simulations and analyses of fixed-plant operations. For example, they show the frequency and type of maintenance required for each piece of equipment and the impact of maintenance on equipment performance and uptime. This information can then be used to optimize maintenance schedules and minimize downtime.

By creating a digital twin that includes 3D spatial and engineering context, mining operators can achieve a more accurate and complete representation of their fixed-plant assets. This enables more effective analysis of equipment performance, maintenance, and use, ultimately leading to improved efficiency and reduced costs.

CHALLENGE 2: DATA RELATIONSHIPS & INTEGRATION

The second challenge in building a data foundation for a digital twin is creating data relationships. This involves defining the relationships (or ontologies) between spatial and nonspatial data to ensure the digital twin can be queried for multiple use cases effectively.

The data relationships or ontologies and semantics in mining operations are complex, involving a diverse range of data sources and multifaceted operations. Mining companies must define the digital thread between data sets to ensure the digital twin can be used not only for information access, but also for analysis and further interpretation. This allows the data to be queried at low latency for an optimized user experience.

This is where the value of spatial information can be realized when introducing a digital twin: enabling a simple semantic layer that connects various data sets and their units of range to a common thread of the space and an object or form they relate to in reality.

Data is the lifeblood of successful mining operations, but that data is often siloed, with different teams and systems collecting and managing data independently. This creates challenges for establishing relationships between data sources and makes it difficult to access and integrate data. The problem is compounded by the fact that different data sources use different formats. In addition, data-quality issues like missing or inaccurate values make it challenging to establish integrity and therefore credibility for a sustainable adoption. The lack of standardization across mining operations further complicates matters, making it difficult to establish consistent relationships between data sources and share data between operations or companies.

To overcome these challenges, mining companies need to invest in data integration and management platforms that can aggregate and integrate data from multiple sources, establish relationships between the data, and provide a spatially enabled, unified view of the data for end users. These platforms must be flexible and scalable enough to accommodate multiple data formats and data sources, and they must provide tools for data-quality control and validation to ensure that data accuracy and completeness are maintained during the change management process.

> **THE DATA RELATIONSHIPS OR ONTOLOGIES AND SEMANTICS IN MINING OPERATIONS ARE COMPLEX**

CHALLENGE 3: DATA STORAGE

The third challenge in building a data foundation for digital twins is orchestrating disparate historical data and the associated storge requirements of an ever-growing data ecosystem. The data collected must be stored in a way that is easily accessible to those who need it. Additionally, the data must be processed and analyzed in real time using low latency to gain insights that can be used to improve performance and enable time-sensitive decision-making.

This requires a scalable, distributed data-storage architecture capable of handling large amounts of data from a variety of sources. The architecture must include a scalable solution that can easily access spatial and nonspatial data, a high-speed data-processing engine for real-time analysis, and a flexible data visualization layer for displaying the results and facilitating user interaction.

The ideal data-storage solution for digital twins can combine a powerful gaming visualization engine with cloud computing to ensure that data can be processed and analyzed in real time and is easily accessible by the user, helping decision makers act on the information in a timely manner.

LESSONS LEARNED

Our company has been deploying digital twins for more than five years across the Western Australian mining industry. During that time, we have developed both rapid deployment strategies and Agile methodologies for creating access to critical operational and engineering data sources in an easy-to-use, searchable, interactive environment.

The main challenges we encountered centered around maintaining the integrity and accuracy of the spatial data and developing high-quality automation, access, APIs, metadata for searching, and equipment identifier mapping.

ITERATIVE CYCLES WITH SHORT DEPLOYMENT TIMES WORKED BEST

Having the right spatial data is essential for long-term adoption of this technology, so companies must dedicate enough resources to keep that data current. This work should be automated: updates should be processed by automatic pipelines with as much relevant and immutable information stored as possible. For example, walkway grating should be textured from the metadata in the model, creating realistic environments that do not require manual artistic editing.

Mining organizations have multiple data sources, including legacy 3D model geometry and geospatial data (photogrammetry/point cloud data), plus nonspatial data sources like streaming IoT devices and contextual data (e.g., CMMS, ERP). To enable fast, effective use in digital twins, it's important to define the relationship between the spatial and nonspatial data and make sure standards are adhered to. This relationship often requires considerable planning and mapping to provide the users with a seamless interface. For example, we discovered that the actual state of equipment tag mapping was far from the level needed for these solutions to be effective.

We also found that iterative cycles with short deployment times worked best. For instance, an oil and gas company could not find its equipment in a large new facility because the spatial models would not run on the organization's laptops. This was a great starting point for a digital twin solution, after which stakeholders provided input into which features would generate further value and user adoption. Business leaders asked for access to their document management system, followed by engineering data and process data. The information can be accessed from a single, intuitive, interactive virtual environment. More work is currently being done to integrate events and alarms.

Another company began by linking assets to the document management system, then went to the process-control data, followed by the ERP system. This was quickly followed by health system data and the automated permit-to-work system (once we start providing access to information, there are inevitably further requests).

An essential part of using digital twins to deliver complex systems is ensuring that all the statistical user data is captured. Having a clear understanding of who is doing what and when in the system is critical to gathering the correct information about how to proceed and add value to the organization.

Interestingly, when the remote operations team experienced the mining sites via virtual reality, despite their skepticism, they realized how much value "being there" adds to problem solving, work planning, and understanding the size and magnitude of the remote equipment.

Our journey has been both challenging and exciting, often requiring the use of leading-edge technology and sometimes exposing an organization's shortcomings regarding legacy processes and internal data sets. However, it is clear that the deployment of user-friendly digital twins that enable fast access to the right data improves productivity and supports digital transformation initiatives.

About the author

Carl Faulkner is a Principal Consultant in digital engineering and asset management at Asset Connect. He specializes in technology and data management for mining/oil and gas operations and projects with deep expertise in digital engineering, enabling clients to maximize the value of connected data. Previously, Mr. Faulkner was a digital engineering consultant for large oil and gas asset owners, providing advisory services for inspection management, asset integrity, and advanced work packaging solutions. He has implemented various digital engineering processes, including technology stack advisory, data management frameworks, and business value feasibility. He can be reached at carl.faulkner@sencom.com.au.

EXPLORING DIGITAL TWIN POTENTIAL FOR ENERGY & DEFENSE

Author

Jason Radel

To demonstrate the degree to which digital twins are becoming a powerful tool, this article examines a digital twin framework that was used to create, adjust, and deploy a digital twin of a nuclear power plant in the Middle East and another of a North Atlantic Treaty Organization (NATO) member's naval ship.

The digital twin framework can ingest multiple forms of 3D models/3D data and convert them to a standardized format. This allows any twin created using the framework to be modified without changing the original data, creating an environment in which ingested data can quickly be used to create new applications.

CREATING A NUCLEAR POWER PLANT DIGITAL TWIN

A nuclear power plant wanted a digital twin to use for virtual training, a process that involved combining engineering drawings with scans of the plant; developing a storage method conducive to additions, changes, and variations; producing a visualization via immersive display systems; and creating a platform capable of rapidly crafting training scenarios. The digital twin framework consists of three parts: a *digital twin creator* to ingest and contain digital twin assets, a *digital twin application* where assets could be used to create new applications, and a *digital twin manager* to visualize solutions (see Figure 1).

The engineering drawings supplied by the power plant comprised more than 20,000 i.dgn files. Around 10,000 of the files were tagged with a variety of metadata. Within the files were nearly 10,000 pieces of equipment and more than 100,000 total valves and instruments, all of which needed to be tagged, searchable, and viewable within the digital twin.

Light detection and ranging (LiDAR) data of one of the reactor facilities and surrounding buildings was obtained using Leica RTC360 laser scanners. These instruments take LiDAR data and, immediately after measurement, collect a series of high dynamic-range photographs the scanner uses to create a 360-degree panoramic photo. These are referred to as "sphere maps" because they are overlayed onto the interior of spheres in the 3D space for viewing. The individual point clouds, inherently colorless due to the measurement process, can be colorized by mapping photograph pixels to point cloud positions.

> **THE DIGITAL TWIN FRAMEWORK CAN INGEST MULTIPLE FORMS OF 3D MODELS/3D DATA AND CONVERT THEM TO A STANDARDIZED FORMAT**

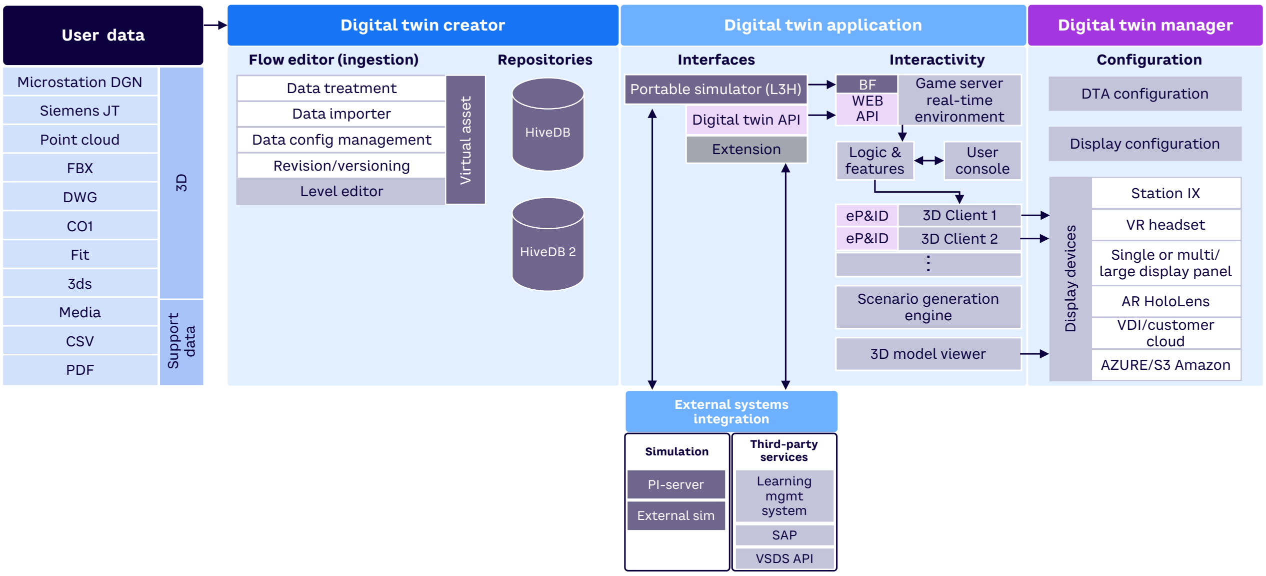


Figure 1. The three-part digital twin framework: the digital twin creator ingests many types of user data and stores it in a common format; the digital twin application creates applications and can interface with external simulation or other services, such as learning management systems; the digital twin manager handles the visualization of the digital twin on a variety of hardware

More than 11,000 of these scans/photographs were captured at the full resolution capability of the scanners, resulting in more than 11,000 colorized point clouds, each approximately 4 gigabytes. The point cloud scans were organized by building, by building level, and (in some cases) by quadrants on the building level. Using Leica Cyclone software, these smaller point cloud groups were combined into a single point cloud using a process known as "point cloud registration." After that, the point cloud was down-sampled by removing points closer than 2 mm from one another (as opposed to down-sampling by measurement angle) so that objects far from the scanners retained full resolution while the resolution of objects close to the scanner was reduced (to shrink overall data size).

The next step was converting all the data into a common format in the digital twin framework. A tool was created to convert a variety of data types into a common format conducive to graphical rendering. The conversion was done using a series of sequential steps, visualized in the user interface (UI) as colored node blocks wired together. These node networks can be saved for later reuse or used as starting points for other, similar data in the future. The process of converting different data types into that framework data format is called "data ingestion."

The ingested data was stored with 3D models, material, and other metadata. The data could then be viewed in a 3D viewer, with textures and lighting properties automatically applied to all like materials (see Figure 2).

After the computer-aided design (CAD) and LiDAR data was ingested, it was aligned and oriented in a common coordinate system, including a common origin, scale, and orientation. Each individual point in a point cloud has an accuracy of roughly +/-2 mm, so the process of combining two point clouds from two scans adds inaccuracy to the resulting data. Although the inaccuracy is small, it accumulates as more point clouds are registered together. For example, the width of a building level measured using 100 or more point cloud scans could be off by as much as a half meter. When viewing the point cloud overlaid onto the CAD model, this offset created an inaccurate association between CAD and point cloud, which was significant when switching between CAD and LiDAR data views.

To fix the inaccuracies between the CAD data and point cloud, the point cloud was "stitched" onto the CAD using foundational components, such as walls, floors, and doorways.

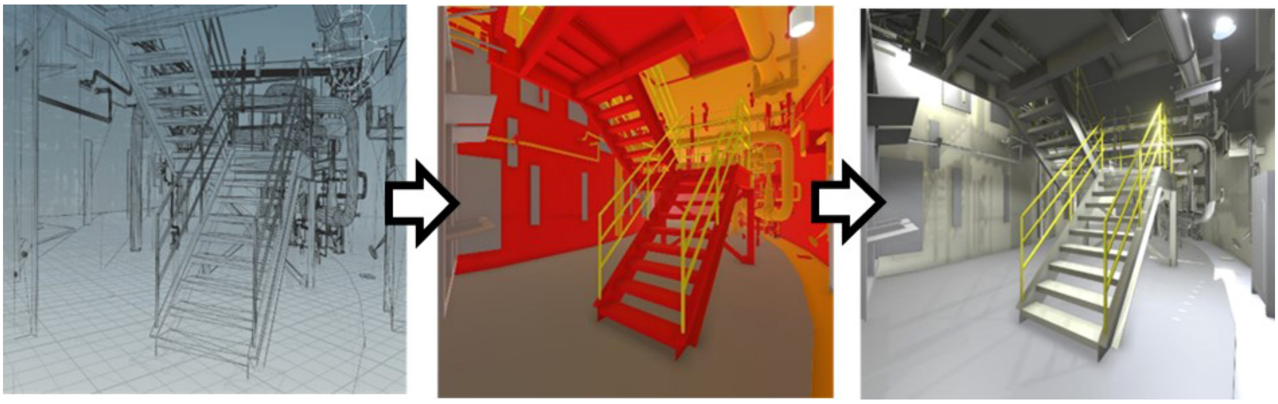


Figure 2. Imported CAD model (left), with material properties tagged (middle), and with final lighting/shading added (right)

The result was a dramatic improvement in accuracy between the CAD model and the point cloud data. The process also effectively located and oriented the panoramic photographs taken from the 3D scanner with respect to the CAD data.

This resulted in a CAD model, point cloud data, and sphere maps with a common coordinate system and scaling. This enabled smooth switching between various data views, including point cloud data, sphere maps, CAD data, or a mixture of these. Figure 3 shows a hybrid view of a sphere map and point cloud data. Distances close to the viewer show sphere map photographs; distances farther from the viewer show point cloud data.

To make the digital twin functional, the digital twin designers worked with a partner to connect the 3D model to simulation software, allowing the digital twin to change based on the data from the simulation.

STORING THE DIGITAL TWIN

The philosophy behind storing the data in that digital twin framework was based on two points:

1. Store data such that the original data cannot be altered or corrupted. This prevents the need to recollect or re-ingest large data sets.
2. Store the data such that it can be readily modified, copied, or removed from the digital twin.

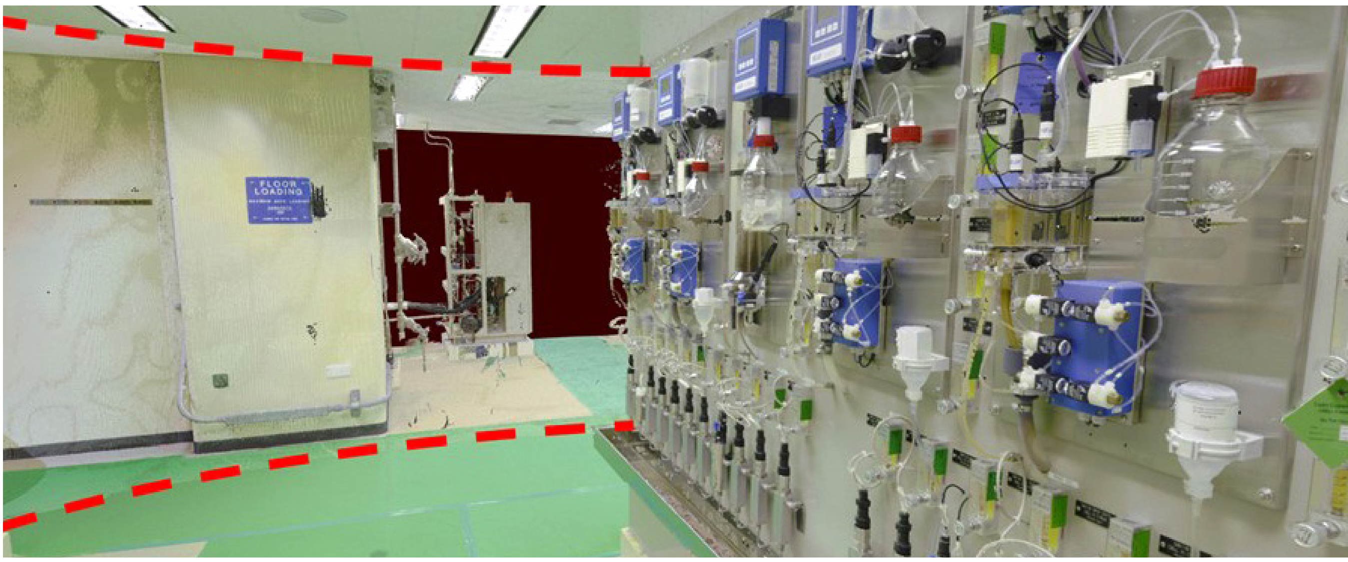


Figure 3. A common coordinate system lets users view hybrid scenes of photographs/point cloud/models in 3D; the scenery within 5 meters of the viewer (up to the red dotted lines) is captured by camera; everything beyond 5 meters changes to point cloud data taken from LIDAR scanners

The data was stored in layers, with the original data set serving as the base layer and layers of modifications applied sequentially to the base. For example, a cabinet could be modified by adding a layer to the cabinet asset that applied burn marks onto its exterior, and another layer could be added to swap components in the cabinet with melted or destroyed components. The final asset could be used in appropriate training scenarios, and the original cabinet asset could be easily recovered at any time for use in another scenario.

The physical storage was done on a series of servers, with data primarily organized by reactor unit, then by building level, then by sectors on these levels. Asset bundles could be created to group systems together (e.g., pipes, valves, and other components connected to the plant's turbine generator system).

This enabled views of isolated systems, a powerful training tool. For example, the turbine generator and all supporting components could be viewed together, with the rest of the plant components hidden. These systems could also be modified to have semitransparent walls, making viewing the internal workings easier.

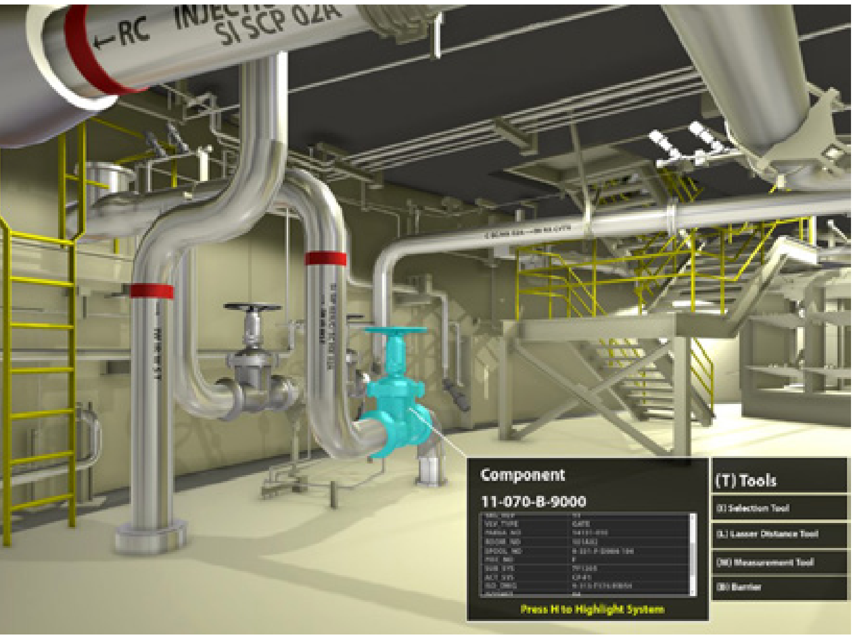


Figure 4. A view of the digital twin; information related to the valve in cyan displays in a pop-up dialog box when a user clicks on the valve

VISUALIZING THE DIGITAL TWIN

3D data, especially complex 3D data, is best viewed on 3D displays. Three solutions were developed for visualizing the digital twin: large flat-panel displays, head-mounted displays, and an immersive theater.

The first viewing option was four 60-inch LCD screens tiled in a 2x2 configuration. These were arrayed on the wall of a classroom at the plant and used for instructional purposes. To provide a sense of immersion, the fields of view that were rendered onto the four display screens were set to be equal to the fields of view that the displays subtend in a user's vision for a viewer seated in the center of the classroom. Although not true 3D, this provided the sense of looking out a window when viewing the 3D scenery, adding to the sense of realism (see Figure 4).

The second visualization solution involved an industrial virtual reality headset with a foveated display. The headset tracks the user's gaze and uses a beam splitter to combine a small, high-resolution display with a larger, more typical resolution display for the viewer's periphery, resulting in increased visual acuity.[1] The display requires powerful graphics cards, but the results are excellent.

The final visualization solution was Station IX, an immersive theater (see Figure 5). The display is 22 feet in diameter and consists of seven curved mirrors combined with projectors and a curved central display screen. The combination of projection imagery and off-axis curved mirrors provides 3D immersive visuals to groups of people located in the center.[2] The system provides highly effective 3D depth perception for distances of 5 feet or more from the user without headgear.

Figure 5. The 22-foot diameter immersive theater uses curved mirrors and projectors combined with a curved front projection screen to provide immersive 3D visuals for up to 5 users

CREATING DIGITAL TWIN APPLICATIONS

The first application for the digital twin involved connecting it to the plant's physical control room simulator, which was created for training exercises. Because our digital twin interfaced with the same simulation, we could connect the physical control room simulator to the digital twin. Changes made in the control room triggered changes in the digital twin that could be visualized virtually in real time. Changes made to the digital twin resulted in changes to instrument readings, alerts, and other data in the control room. For example, an application was created in which a user could virtually perform maintenance on a critical piece of equipment, and if the user made a mistake, alarms and alerts triggered in the physical training control room, providing a useful training tool.

The second application involved providing software tools for plant engineers to create custom applications using the digital twin, for training or other purposes. A set of software tools allowed users to create applications by importing or altering parts of the digital twin, triggering events, and tasking the user to do a certain action or view certain components.

The UI for this tool was designed to be usable by employees with minimal software development experience. Tasks that need to be performed, events that trigger at certain moments, and pop-up messages and dialog are represented as colored nodes in the UI. For example, an emergency response training exercise could be created by selecting nodes that represent the following actions:

- **Dialog prompt node** — prompts user to enter control room
- **Location node** — control room location
- **Fire alarm node** — fire alarm sounds and lights turn on
- **Location node** — exit door location

By wiring these nodes sequentially, a user running this scenario is first prompted to enter the control room. After the user reaches the control room, the fire alarm sounds, and lights are triggered. The exercise ends when the user reaches the correct exit door. Instructors can play back training sessions with students for further discussion.

In the next phase of this project, the digital twin will be connected to real-time data from the plant so actual data from the plant can be used to further improve the digital twin. Successful completion of this phase will demonstrate the possibility of using the digital twin actively in operations, such as allowing virtual control of select components of the power plant.

IN PROGRESS: A NAVAL SHIP DIGITAL TWIN

A NATO member country's navy sought a digital solution to display assets (e.g., naval ships) in a digital format it could use for training, engineering, and operational activities. The project involved creating a tool to support the conversion and management of assets, processes, documentation, and applications into interconnected digital objects, addressing requirements for all lifecycle activities. The tool would also be used during design reviews.

The first phase of the project involves creating a digital twin of a single piece of equipment; the second phase involves creating a digital twin of a naval ship.

The navy provided engineering CAD files for a piece of naval ship equipment in the form of .dgn files. The equipment has roughly 100,000 polygons and consists of between 100 and 300 objects. The data for the ship has more than 1 million polygons and approximately 4,000 objects, each with 30 key metadata attributes. The navy is performing its own LiDAR scanning using Leica RTC360 scanners.

The ingestion process to convert this data into the format used in the digital twin framework was nearly identical to the nuclear power plant, so those pipelines could be used with only small alterations. The navy intends to perform the ingestion process itself in the future, so the UI was improved for ease of use.

Station IX was used to visualize the digital twin for naval leaders, training groups, and design review teams, all of whom can view the digital assets in a highly immersive way.

Two types of digital twin applications are being created for the navy: training and engineering operations. For ship-familiarization training, users will be able to walk through various parts of the ship, click on items to see more information about them, and extend bridges/move cranes to better understand how they work.

For engineering design reviews, teams will be able to view all or part of the digital twins using 3D visualization in Station IX, move and manipulate assets, and view data associated with these assets. They can also compare design drawings to physical parts scanned using LiDAR. In the near future, engineers will be able to edit parts and add metadata and notes to 3D assets; this will become a regular part of design-review meetings.

THE POWER OF DIGITAL TWINS HAS NOT BEEN FULLY REALIZED

Both projects described in this article demonstrate the power and utility of digital twins, especially when created, stored, and used within a common framework. Digital twins provide immersive, realistic visuals for an assortment of applications, and they can can be combined with powerful simulation and control systems as well as real-world data.

However, these applications only scratch the surface of digital twins' potential. For example, a real-world nuclear control room ingests 5,000 variables and displays this data to plant operators via meters, gauges, and flashing lights. Operators turn switches, knobs, and valves to control the reactor and its related components.

An intermediary that records the inputs and outputs to the control room could send that data to a digital twin so the twin reacts in real time to what the operators are doing *and* what the reactor is doing.

If an accident occurred that could cause radiation to be released somewhere in the plant, an operator could quickly step into a virtual environment to search for the radiation leak, determine the affected areas, count the number of nearby workers, and measure the amount of radiation in various areas of the plant. Operators could immediately contact workers to provide detailed, accurate information about the situation.

Taking this scenario a step further, the intermediary could circumvent the control room completely, taking direct control of the plant (or control a ship remotely) using a digital twin.

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LESSONS LEARNED FROM BUILDING-PERFORMANCE DIGITAL TWINS

Authors

Ruth Kerrigan, Fiona Bradley, Simon Bell, Amisha Panchal, Lorraine Robertson, and Gillian Brown

Among the many fascinating applications of digital twins, using them to create a virtual replica of how a real building is performing at a given time ranks high. These building-performance digital twins start by using physics principles to predict how a building will perform, taking into account its envelope, mechanical systems, and energy usage. Real-time data collected from smart meters, wireless meters connected to the Internet of Things, and building management systems (BMSs) is added to create a hybrid physics data model of the building. Machine learning (ML) and artificial intelligence (AI) methods can additionally be used to fill any data gaps (e.g., algorithms that extrapolate data over a 12-month period) and to predict things like internal occupancy or external weather patterns.

Building-performance digital twins can also be calibrated to an energy-efficiency standard such as the International Performance and Measurement and Verification Protocol (IPMVP).[1] The calibrated digital twin can then be used to derive insights into energy-conservation measures, including operational and behavioral measures, shallow and deep retrofit measures, pathways to net zero or positive energy, and end-of-life considerations.

Where a live connection to metered data is available, the digital twin can be deployed to monitor systems in real time to ensure the building is performing according to its design intent. This type of monitoring can be used to close gaps between the building's operational performance and design standards like Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Methodology (BREEAM), nearly zero-energy building (NZEB), and Passivhaus.

This article presents the results from an Innovate UK–funded project called eDigit2Life (Project Ref: 105871). The project involved the creation of a number of performance digital twins based on buildings on the campus of the University of Glasgow, Scotland.

UNIVERSITY OF GLASGOW DIGITAL TWINS

Building-performance digital twins were created for two new buildings on the university campus: the James McCune Smith Learning Hub (JMS) and the Advanced Research Centre (ARC), completed in 2021 and 2022, respectively, as well as for the university's library, which was completed in 1968.

For this article, we have chosen JMS and the library to discuss (see Figures 1 and 2). Figure 3 shows the campus-level digital twin, with the energy consumption of each building simulated using OpenStreetMap data and information on the buildings from the University Estates team. These buildings have not been calibrated, but they provide benchmark data from which the university can derive simple insights.

> **THE DIGITAL TWIN CAN BE DEPLOYED TO MONITOR SYSTEMS IN REAL TIME**

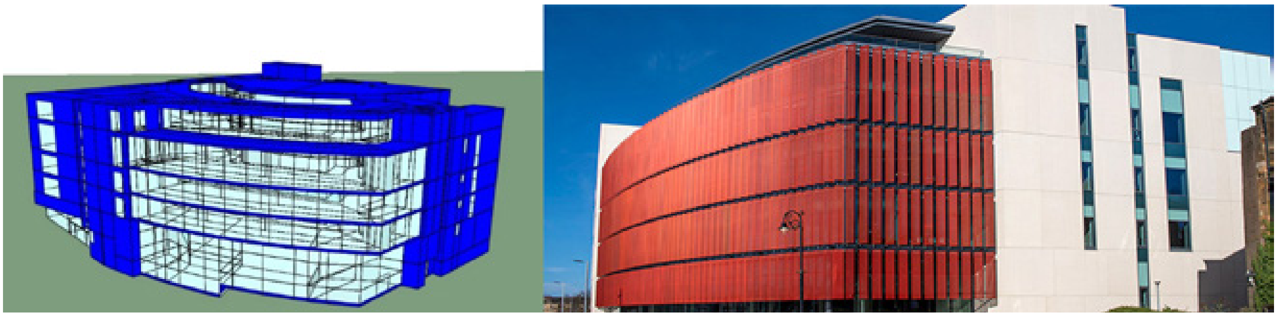

Figure 1. Model vs. real image of James McCune Smith Learning Hub (source: IES [left] and the University of Glasgow [right])

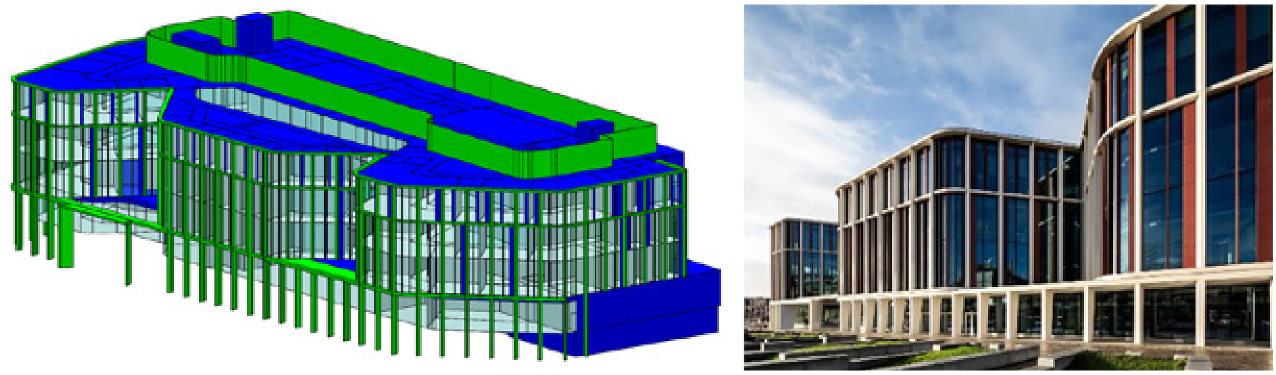

Figure 2. Model vs. real image of the University of Glasgow library (source: IES [left] and the University of Glasgow [right])

Figure 3. Campus-level digital twin (source: IES)

For the new buildings, the design team used the modeling software tool Revit to create a building information model (BIM). The mechanical, electrical, and plumbing engineers converted the BIM to an energy model using Integrated Environmental Solutions (IES) Virtual Environment (VE) dynamic simulation modeling software and created an initial model to ensure the building would comply with the relevant industry standards for energy performance.

A GEOMETRY MODEL WAS CREATED BASED ON AVAILABLE ARCHITECTURAL DRAWINGS

The eDigit2Life team took the compliance model and updated it to include information on each building's energy-usage patterns and the unregulated loads that had not been considered in the compliance model. (Note that UK compliance models mostly focus on building assets such as the envelope and major systems. Thus, they are not representative of building energy usage and occupant behavior once in operation.)

Using information from the as-built documentation, the team added occupancy profiles based on building use and investigated small power electrical equipment loads. Next, data was collected from the BMS and design profiles (e.g., space temperatures, equipment efficiencies, lighting loads, and HVAC flow/return temperatures) and added to the model. The resulting hybrid physics-data model was calibrated according to IPMVP to create the building-performance digital twin.

For the existing building, a geometry model was created based on available architectural drawings (e.g., BIM or Revit model). An energy audit of each building was carried out to collect the additional data required for a thermal template of the model.

Information relating to the energy heat and flows of the building is important when creating a building-performance digital twin. For example, to create an accurate model, the team must know the heating set-point and set-back temperatures, the schedule for the heating controls, and the amount of domestic hot water consumption for each zoned area.

Data on other factors contributing to internal heat gains should also be gathered, including equipment that emits heat (computers, monitors, lighting) and the number of people in the spaces. Small power electrical equipment, plug loads, lighting types, and occupancy profiles are all very important to creating accurate building-performance digital twins. None of this information would be contained in a standard BIM.

Next, a calibrated model was created using information from the energy audit and accounting for unregulated loads, bringing it into close correlation with the metered data (see Figures 4 and 5).

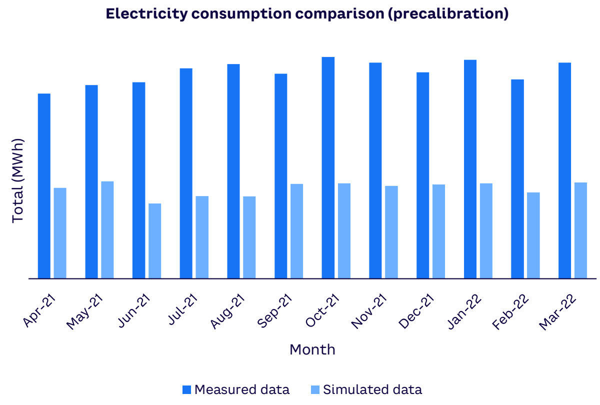

Figure 4. Performance gap between compliance model and utility data in JMS — electricity

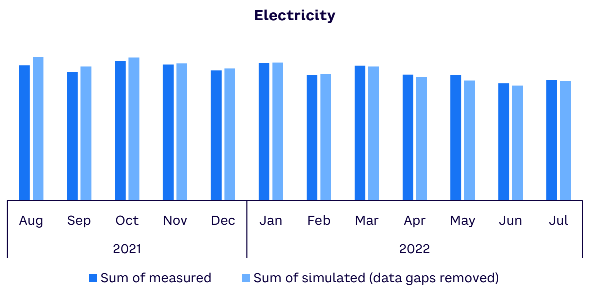

Figure 5. Monthly calibration — simulated vs. actual electricity in JMS

OPPORTUNITIES FROM BUILDING-PERFORMANCE DIGITAL TWINS

Building-performance digital twins can be used for a variety of purposes:

- Monitoring operational energy on an ongoing basis to ensure the design intent of the building is being met
- Ensuring optimum energy performance while maintaining healthy environmental levels in the building (e.g., thermal comfort, ventilation, day lighting, glare)
- Testing a range of interventions and refurbishment options on existing buildings to work toward net zero goals
- Monitoring compliance with sustainability regulations, such as environmental, social, and governance (ESG) regulations; EU taxonomy for sustainable activities; EU Climate Benchmarks regulation; and EU Sustainable Finance Disclosure Regulation
- Creating net zero energy plans or decarbonization pathways for single buildings or, where applicable, groups of buildings across a portfolio or campus
- Identifying solutions for fossil fuel divestment for individual buildings or groups of buildings (e.g., net zero energy or positive-energy blocks)

A calibrated model for the library was created in the same way as for JMS. Figures 6 and 7 show the calibration of monthly and time-series data.

Using this digital twin, three scenarios were modeled for improved performance:

1. Adjusting start/stop times and closing upper floors during low-occupancy periods
2. Basic electrical retrofit, including replacing all lighting fixtures with LED fixtures and implementing power management software
3. HVAC equipment upgrades, including better control of ventilation systems

The building-performance digital twin predicted reductions of 15% on energy and carbon emissions, 9% reductions for the electrical retrofit, and 23% for HVAC upgrades. The university is hoping to begin scenario one once the current exam schedule has completed; the other two scenarios are being considered alongside a range of other campus-wide energy-saving initiatives.

LESSONS LEARNED

The eDigit2Life project started in April 2020, just on the cusp of the COVID-19 pandemic. The initial plan was to examine only new buildings, but because of construction delays from the pandemic, the project leaders decided to expand the scope and examine several existing buildings. This turned a negative situation into an opportunity to demonstrate the benefits of digital twins for both types of buildings and discover many important lessons.

NEED TO CONNECT DESIGN & STANDARDS

Currently, compliance models are created during the design stage of the building lifecycle and are not used beyond that stage. Additionally, there are many ways to measure performance, and minimum performance standards are well-known to produce large gaps between design and operation. Similarly, when adjustments are made for occupant comfort, changes are sometimes made that go against the design intent of the building, such as increasing set-point temperatures. Furthermore, design-stage modeling, however accurate, is always based on historical data, briefing assumptions, occupancy assumptions, and behavioral assumptions.

Thus, clients of building projects need to be educated that minimum compliance standards will not achieve sustainable outcomes and efficient buildings in operation and governments, and standardizing bodies need to be aware of the dangers of using compliance metrics as operational targets.

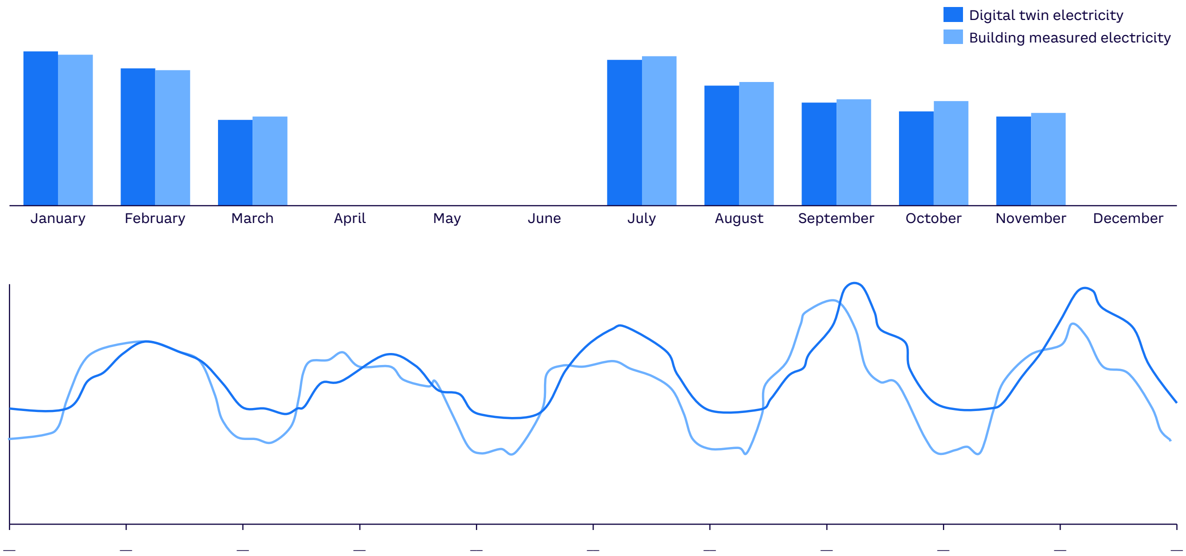

Figure 6. Performance digital twin of the university library — electricity

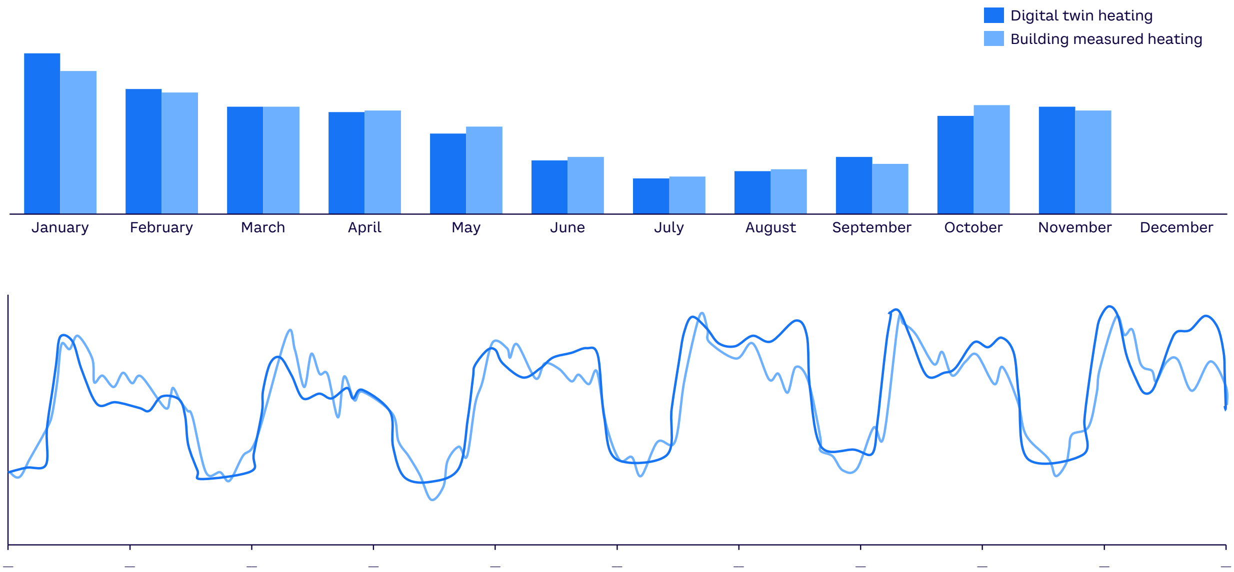

Figure 7. Performance digital twin of the university library — heat

NEED TO CONNECT PROCUREMENT & CONSTRUCTION

The building construction process is currently siloed. Procurement practices are based on outlined specifications that do not include information on the building's final intended use. For example, for the new JMS and ARC buildings on the University of Glasgow campus, the proposed BMS was specified at the design stage with the intent to access the BMS data using a live connection that would enable operational energy monitoring, ensuring the building performed to its design intent. Unfortunately, a remote server to enable remote access of the data was not included in the contract. This demonstrates a need to include building "in-use" scenarios in the specifications of different equipment to ensure the procurement team has all the information it needs to make the best decisions. Similarly, when equipment such as air-handling units break or reach end of life, the procurement team may simply select the replacement equipment based on lowest cost. The performance digital twin could be used to demonstrate how a slightly more expensive unit would provide better ROI and lower carbon emissions, contributing to the university's sustainability goals and long-term investment plan.

NEED TO CONNECT FACILITIES & ENERGY MANAGEMENT

Often, building-operation roles are siloed and lack communications workflows. For instance, a typical facilities manager is responsible for fixing things as they break (reactive maintenance), while a typical energy manager is responsible for energy performance. However, in many organizations, these two departments do not work closely together due to organizational separations for historically valid reasons. The University of Glasgow addressed this by creating a sustainability team that includes representatives from facilities, energy management, and IT.

NEED FOR STRONGER FOCUS ON ONGOING OPERATIONS COSTS

In many construction projects, too much emphasis is placed on capital expenditure during the building design phase, leaving out important considerations about the operation cost of running the building. In cases where the building is being constructed for sale to a third party, it is more obvious why operational costs are not a concern, but these omissions sometimes occur when the building is being constructed by the intended building occupant. Most often, a lack of industry-shared knowledge and/or expertise are the cause.

For instance, the estimated operational cost is often linked to compliance metrics. These are not a true reflection of the building's operation because small power loads and other plug loads, which can be considerable, are not included in the compliance model. Performance digital twins are an ideal way to solve this type of problem, ensuring the final building in operation performs to its design intent.

NEED TO FOCUS SOONER ON SUSTAINABILITY

During construction, the sustainability focus tends to be on reducing waste, using sustainable materials, and ensuring speed of delivery. Further education for all on the impact on the building's final operation is required. Performance digital twins can help demonstrate impacts of pre-operation decisions on building-efficiency metrics.

NEED TO BASE PLANT EQUIPMENT SIZES ON AVERAGE OPERATIONS

Chartered Institution of Building Services Engineers (CIBSE) loads are designed to ensure mechanical plants are sized to perform optimally at peak times. This can lead to specifying and installing oversized systems, as peak loads may only occur a few days per year. This project highlights the need to look beyond CIBSE loads and base plant equipment sizes on more realistic average annual operation figures. This would allow for a certain level of tolerance in times of extreme external temperatures (e.g., two or three very hot days in July that are out of step with climatic norms). Performance digital twins can easily provide the data needed to make that determination, thus avoiding equipment oversizing.

NEED FOR GOVERNANCE AROUND BMS DATA FEES

Performance digital twins require large amounts of data, and the more comprehensive that data is, the more accurate the twin will be. Preprocessing of data and connections with protocols such as Haystack and Brick can help streamline the import of data from the BMS, but there are barriers that can block the performance digital twin from being built in the first place.

For example, BMS manufacturers and system installers can require building owners to pay a fee for every BMS data point provided to another system, creating a significant barrier to accessing the data needed to deliver an accurate performance digital twin.

Building-owner education is needed to help ensure contracts do not block access to their data, and governance may be required to prevent BMS manufacturers from impeding decarbonization of the built environment. How this governance would be applied to ensure it is still lawful needs to be examined.

NEED FOR MANDATED MEASUREMENT & VERIFICATION

As mentioned previously, when using CIBSE guides, building-services systems can be oversized, which has a negative impact on operational efficiency. More evidence on the real performance of buildings is therefore required. This can only be achieved through better measurement and verification of a building's performance, which is currently not mandated.

PROPOSED METHODOLOGY: ENABLING PERFORMANCE DIGITAL TWINS

Figure 8 identifies recommendations to the Royal Institute of British Architects (RIBA) Plan of Work[2] stages that would facilitate performance digital twin adoption. These recommendations would lead to buildings that perform as their design intended, helping decarbonize the built environment.

At a high level, the goal is to ensure operational efficiency is considered during all stages of the construction lifecycle and that performance digital twins are used to enable iterative design approaches throughout. Interoperability between tools and technologies is a key requirement to achieving these goals.

Representatives from IT, facilities, and energy management should be included throughout the process, starting with initial predesign conversations. Energy-performance metrics should be included at the early concept design stage to reduce the risk of costly interventions later on.

Fit-out design should happen much earlier than is typical: during the technical design stage. Even if the end use of the building is not fully known, the building will have designated zones of use (e.g., toilet, kitchen, common area, office, meeting room). Standard fit-out designs should be allocated to these spaces (including plug loads, appliances, and other small power loads) and incorporated into the energy modeling as soon as possible. This can be used in an iterative manner to size the plant and to inform the final fit-out design to ensure optimum operation of the final installed systems.

Use cases for the mechanical plant, environmental machinery, and all equipment should be included with fit-out specifications to ensure the procurement team is aware of the final use for all equipment. Following this, the building should be commissioned to the as-built performance and recommissioned on a regular basis to ensure no changes have been made that could negatively affect the building in operation.

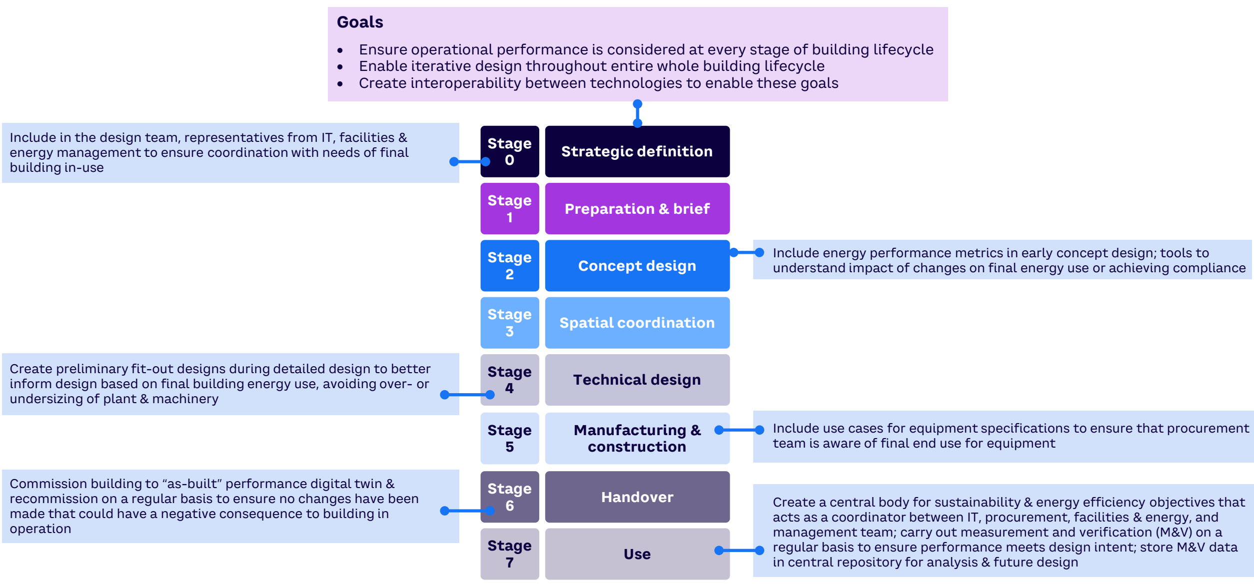

Figure 8. Recommendations for additions to RIBA's Plan of Work to enable performance digital twin adoption

Once the building is in operation, a central committee comprising IT, procurement, facilities, and energy management teams should be created. Measurement and verification should be carried out on a continuous basis, and the data should be held in a central repository to inform future design.

RECOMMENDATIONS FOR GOVERNANCE MODELS & STANDARDIZATION BODIES

Based on our work on the eDigit2Life project, we believe there are several ways governments and/or standards bodies could support the use of digital twins in building design, construction, and operation:

- More education across project delivery and design teams is required with respect to: (1) compliance modeling and what it should be used for and (2) why performance gaps occur and, therefore, the importance of measurement and verification.
- The methods for achieving compliance need to be reexamined to go beyond looking at the building as an asset, to take into account the building's final fit-out, occupancy, and user behavior.
- Whoever is responsible for the capital expenditure of the building should also be responsible for the operational expenditure for the first few years of the building in operation.
- Building owners should have access to their energy data at all times and should not have to pay extra to receive it.
- There should be governance on knowledge sharing of measurement and verification data. This could be held by a centralized body like CIBSE that can access the data, perform research into future energy design and standards, and publish the findings for all.

CONCLUSION

Performance digital twins can combine physics data, metered data, and AI/ML methods to provide building owners with insights into the performance of a building or group of buildings. Those insights can be used to improve performance and help building owners reduce energy use and carbon emissions as well as plan future decarbonization.

The eDigit2Life project involved creating a number of performance digital twins for buildings on the University of Glasgow campus that were used to derive insights for better performance management.

The project proved that the technology to create performance digital twins exists, and those twins can contribute to the decarbonization of our built environment. However, the project uncovered multiple nontechnical barriers currently preventing their proliferation:

1. The need for operational-performance discussions to take place at the very beginning of any new building or building-renovation project.
2. The need for iterative design to take place throughout the building process, including: (1) early energy and compliance analysis during initial concept design and (2) beginning fit-out design during technical design development. This would inform better system sizing.
3. The need for operational use cases to be included in equipment specifications so that procurement teams can purchase the precise equipment needed.
4. The need to establish a centralized committee focused on sustainability and energy performance that meets frequently from the beginning of the project and continues until regular building operations begin.

The project also exposed the need for more education on the purpose of compliance models, increased measurement, verification and data analysis, and compliance modeling that advances beyond the current approach (which tends to look at a building only as an asset). Other recommendations include mandated approaches to ensure operational expenditure is considered in design and mandates to enable access to the building's energy data by the building owner.

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ACCELERATING THE JOURNEY TO NET ZERO WITH DIGITAL TWINS

Authors

David McKee and Tim O'Callaghan

The world's chances of avoiding the worst effects of climate change are rapidly decreasing due to our failure to reduce greenhouse gas emissions. We can only reach the emissions levels necessary if every business, city, and region moves rapidly toward its net zero obligations.

Digital twins can become a key tool in this mission, prompting action by providing data and insights on our current state and helping simulate varied future scenarios. Most importantly, these technologies can help hold us accountable.

The NN2NZ project in North Northamptonshire, England, UK, kickstarted a regional decarbonization journey by providing a digital twin platform based on 12 stakeholder questions (see Table 1).

The twin is designed to unify data, provide a framework for consistent monitoring of interventions through 2030, and provide visualization tools for interactive engagement with a diverse set of stakeholders. The project includes interventions for transportation, buildings, energy systems, and food and farming.

A significant part of combating climate change involves our cities becoming net zero. This journey must be considered from multiple perspectives, including transportation and mobility, infrastructure such as housing, and supply chains for the region and local businesses. As United Nations Secretary General António Guterres puts it: "We urgently need every business, investor, city, state and region to walk the talk on their net zero promises. We cannot afford slow movers, fake movers or any form of greenwashing."[1]

Without a holistic perspective, we risk making decisions that in isolation make a positive impact but collectively make the situation worse. Unfortunately, that holistic perspective is incredibly complex, involving hundreds of trade-offs to find even a local optimum. The volume of data (often in disparate unstructured formats) presents an additional barrier to exploring solutions and adds to the complexity and expense of (traditional) analytics and simulation tools.

	WHAT WOULD BE THE IMPACT OF ...
1	... various levels of cars, trucks, and buses shifting to EVs on CO_2, NO_2, and traffic congestion?
2	... various levels of cars, trucks, and buses shifting to e-fuels on CO_2, NO_2, and traffic congestion?
3	... banning non-EVs in urban centers on CO_2, NO_2, and traffic congestion?
4	... households giving up their cars and vans on CO_2 and NO_2 levels?
5	... homes (sorted by affluence), businesses, and public sector organizations buying 100% renewable energy from the grid?
6	... increasing solar photovoltaic carport canopy coverage across various-sized parking structures?
7	... installing small (10 m) wind turbines above solar canopies in parking structures?
8	... improving household efficiencies: reducing room temperatures, using energy-efficient appliances and cooking equipment, and reducing water usage?
9	... improving roof, wall, and full-thermal insulation across homes?
10	... converting gas heating systems to air-source heat pumps?
11	... building new homes to passive standards?
12	... people changing their diet to locally farmed products?

Note: With CO_2 measured as both tons of CO_2 equivalent (tCO_2e) and a percentage reduction, and NO_2 measured in micrograms per cubic meter ($\mu g/m^3$) as well as percentage reduction; each question is controlled by a set of levels of adoption of appropriate intervention

Table 1. 12 stakeholder questions the digital twin solution focused on answering

As technology for things like electric vehicles (EVs) advances, automation merges with increasingly interdependent environmental, safety, accessibility, economic, and health requirements — and the number of highly complex potential intervention scenarios escalates. Even just evaluating the approach to decarbonizing transportation (with levels of necessary investment) is labor-intensive, time-consuming, and costly to the extent that stakeholders often have to make decisions before the analysis is complete. After the decision is made, there may be no way to ensure a positive impact or hold governments and companies accountable.

In this article, we describe how a partnership between Slingshot Simulations and Electric Places in North Northamptonshire developed a way to rapidly prototype a digital twin that can accelerate: (1) the time to assimilate and analyze disparate data sets, (2) the time to decision-making, and (3) the time to intervention. We examine the challenges of data integration, data visualization for inclusive stakeholder engagement, and orchestrating analytics and simulations.

PROJECT NN2NZ

North Northamptonshire, with a population of 350,000, is a mixture of large market towns and more than 100 villages with a strategic growth plan through 2031 for 31,100 new jobs and 35,000 new homes. The aim of the NN2NZ project was to create a cost- and risk-adjusted road map for North Northamptonshire to achieve an equitable transition to net zero ahead of 2050.

The initial challenges were:

- Determining how to create a holistic view from hundreds of data sets
- Deciding which interventions to prioritize
- Determining how to link intervention to impact on a data and evidence basis
- Determining how to forecast scale and impact over time against the greenhouse gas (CO_2e) gap
- Determining how to interactively engage a diverse set of stakeholders ranging from policy makers to the general public

The digital twin incorporates data from thousands of low-carbon projects, technologies, and behavior initiatives, along with the carbon-saving impact of the interventions (see Figure 1). It might consider, for example, what if:

- Every south-facing roof had solar
- Every parking structure had solar and wind
- People gave up their second cars
- No one drove to work

In this project, the role of the digital twin is to:

- Aggregate data from diverse source for evidence-based decision-making. This includes land use, traffic data, building energy performance, social and demographic indicators, census data, and 3D data like roof shapes.

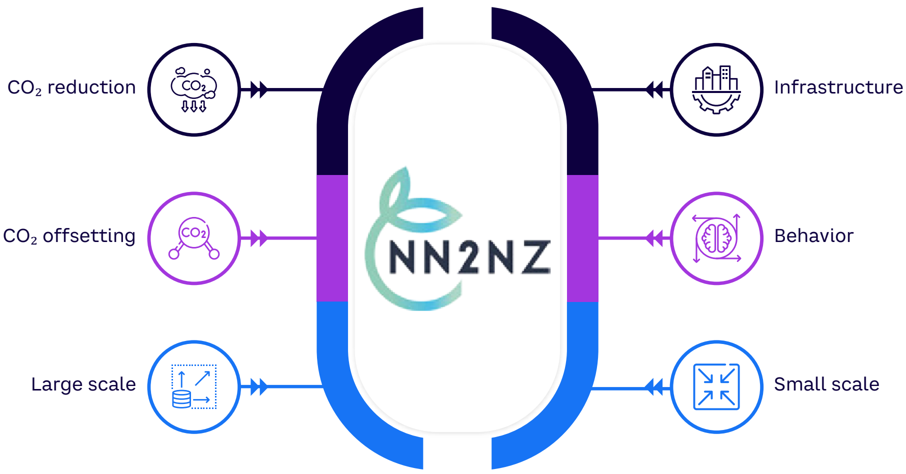

Figure 1. The NN2NZ project brings together disparate data to explore scalable solutions for reducing CO_2

- Analyze and simulate potential interventions to understand the trade-offs between impact and timing of interventions so that location-specific quick wins can be considered.
- Interpret and communicate through visualizations, such as heat maps, red/amber/green (RAG)-rated infrastructure, and interactive 3D models.
- Optimize multiple constrained objectives and give all stakeholders (planners, city councilors, developers, and the public) the ability to "optioneer" net zero futures, regardless of their analytical expertise or lack thereof.
- Monitor and respond to the positive or negative impact of interventions in real time.

BUILDING THE DIGITAL TWIN IN NORTH NORTHAMPTONSHIRE

The digital twin was built using Slingshot Simulation's platform with a four-step process: aggregate, analyze, interpret, and explore.

First, all relevant, available historical data was sourced and integrated into a knowledge graph, taking into account three dimensions: time, space, and context. This was stored in a structured data lakehouse where the disparate data sets were automatically linked to each other based on those dimensions (see Figure 2).

Second, an analytics platform was used to bring together statistical pre- and post-processing, geospatial analytics, and traffic simulations. For the pilot project, 23 analytics workflows were built so a variety of interventions could be explored.

Third, to interpret the impact of interventions, each workflow incorporated the "impact factors" of the intervention, such as CO_2e reduction. Each intervention was attached to a slider control to allow users to dial an intervention up or down for exploration. Figure 3 shows the baseline transport simulation configuration that uses the open source Apache Sumo transport simulator to look at the impact of emission zones on CO_2.

Figure 4 shows the impact from Question #9 in Table 1 — insulating walls. With a target adoption of 75% of households, the impact is a reduction of 376 tCO_2e per year, but a more likely result taking into account affluence shows a lower impact: only 146 tCO_2e per year.

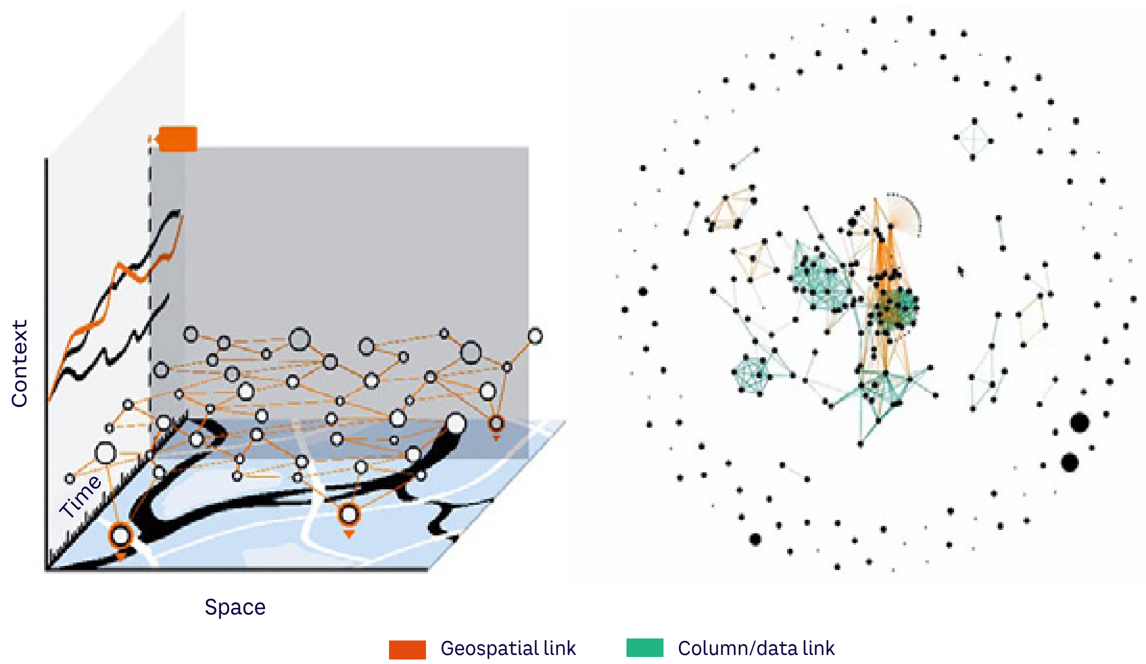

Figure 2. The data lakehouse is structured across the three dimensions of a contextual knowledge graph, time series data, and spatial data (left); the project data is shown on the right with each data source as a point in the graph

Figure 3. Baseline configuration for emissions zones using open source Apache Sumo transport simulator

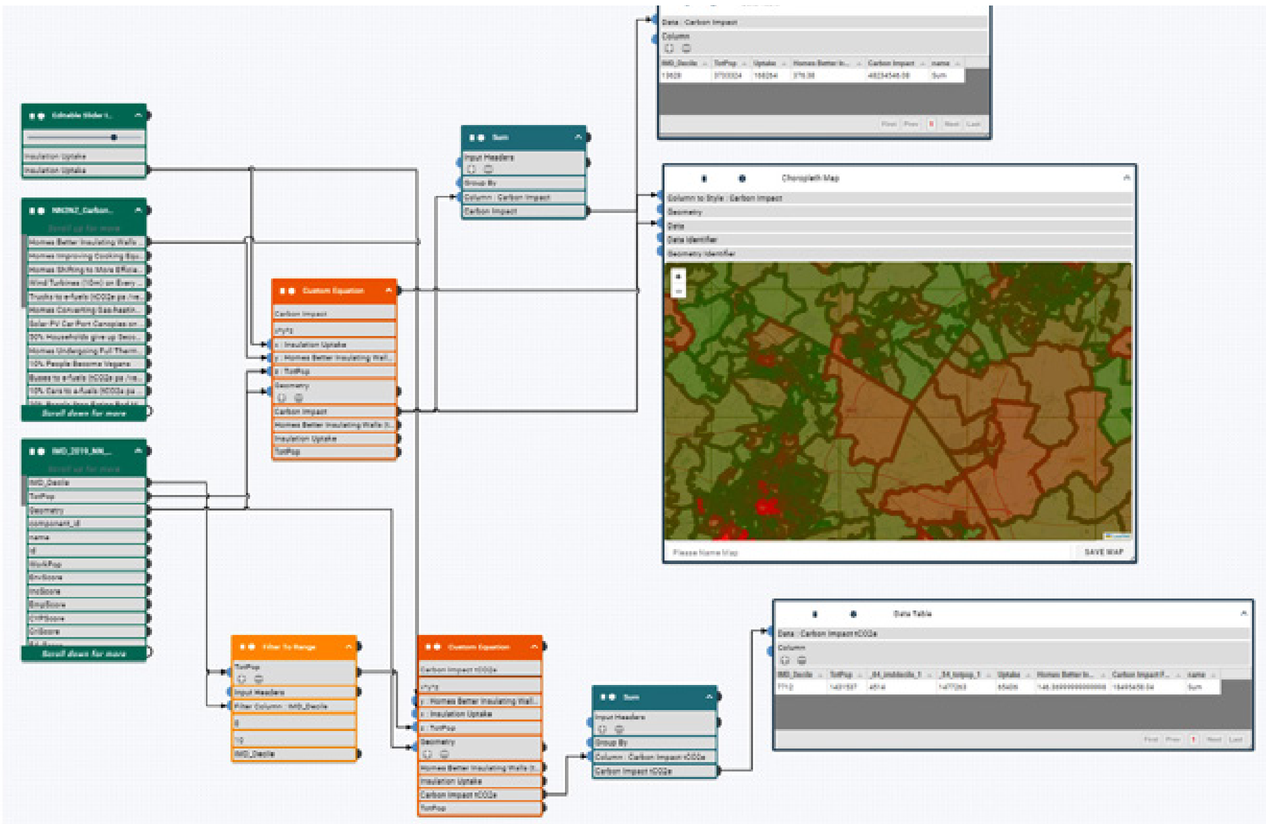

Figure 4. Analytics workflow for Question #9, showing the impact of insulating building walls with a blanket adoption vs. affluence-weighted adoption and visualized using a choropleth map

Finally, the results are explored visually using RAG networks, choropleth maps, and 3D models. For example, Figure 5 shows the relationship between:

- Land use of council-managed and privately owned assets
- Energy systems, including both power distribution substations and EV charging infrastructure
- Walking and cycling network for active mobility
- Environmental factors like rainfall and flooding

In this way, for areas most at risk of flooding, the impact of that on infrastructure and the impact on specific communities in the region become apparent. Virtual reality and 3D flyovers were used to engage the broader community, giving community members the opportunity to explore the impact of interventions on their lives without needing data science skills.

The tools allowed stakeholders to perform options analysis to understand the impact of interventions on the carbon gap with consideration for social demographics and the best areas to target first. Figure 6 shows the potential impact of heat pumps on carbon emissions with respect to the carbon gap at key dates of 2030, 2040, and 2050. This is shown holistically and broken down by household affluence, with more affluent households being significantly more likely to be able to afford the installation costs.

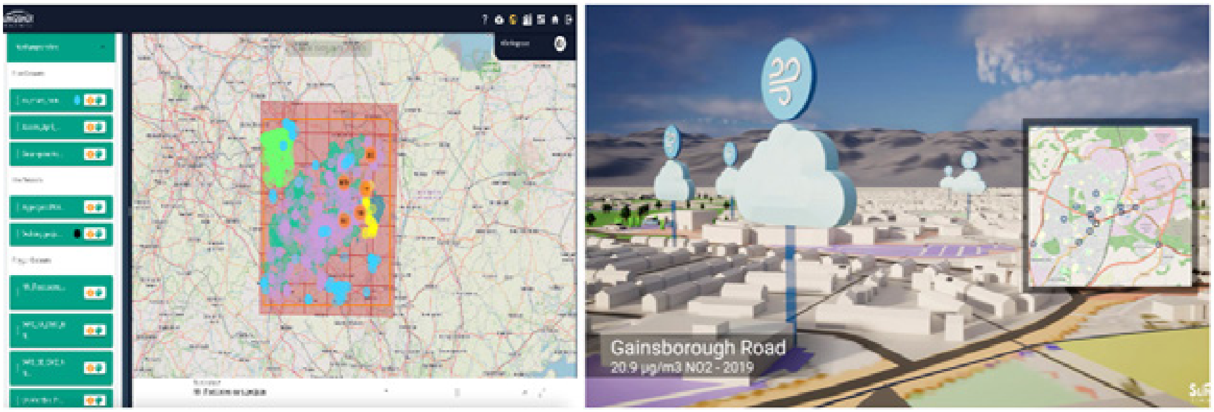

Figure 5. Example visualization of the relationship between disparate data sets across land use and ownership, energy systems, walking and cycling routes, and weather phenomena (left); a snapshot of a 3D flyover over the town of Corby, North Northamptonshire, to help engage with local stakeholders (right)

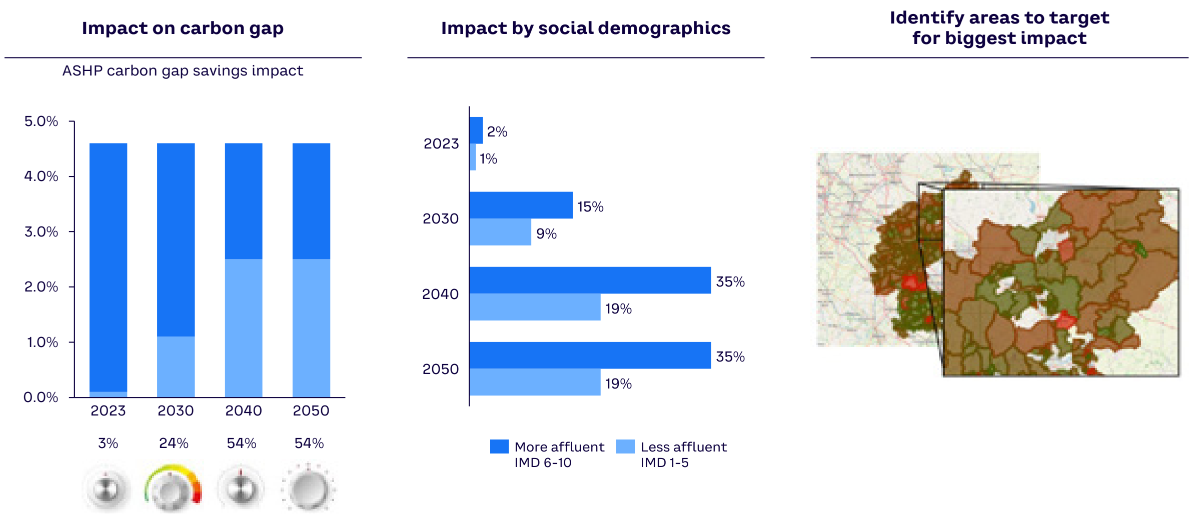

Figure 6. The forecasted impact of air source heat pumps on the carbon gap between now and 2050, assuming average adoption across the population (left), the adoption weighted by household affluence (middle), and a map showing which communities in the region should to be targeted first (red being higher priority)

NEXT STEPS FOR NORTH NORTHAMPTONSHIRE

With the first phase of the net zero journey for North Northamptonshire well under way, the digital twin is being used to assess and plan the first round of interventions. The next phase involves creating a simpler user experience that sits above the workflow no-code notation to allow non-data scientists to quickly "optioneer" scenarios across the set of 12 net zero questions being asked.

The team hopes to take a natural language approach in which each intervention is stated as a simple question with dials that can be adjusted and automatically ranked against the most significant factors. For example, looking back at the original 12 questions, a user might want to know: "What is the impact of CO_2 emissions if EV adoption increases to 30%?"

> **THE TEAM HOPES TO TAKE A NATURAL LANGUAGE APPROACH**

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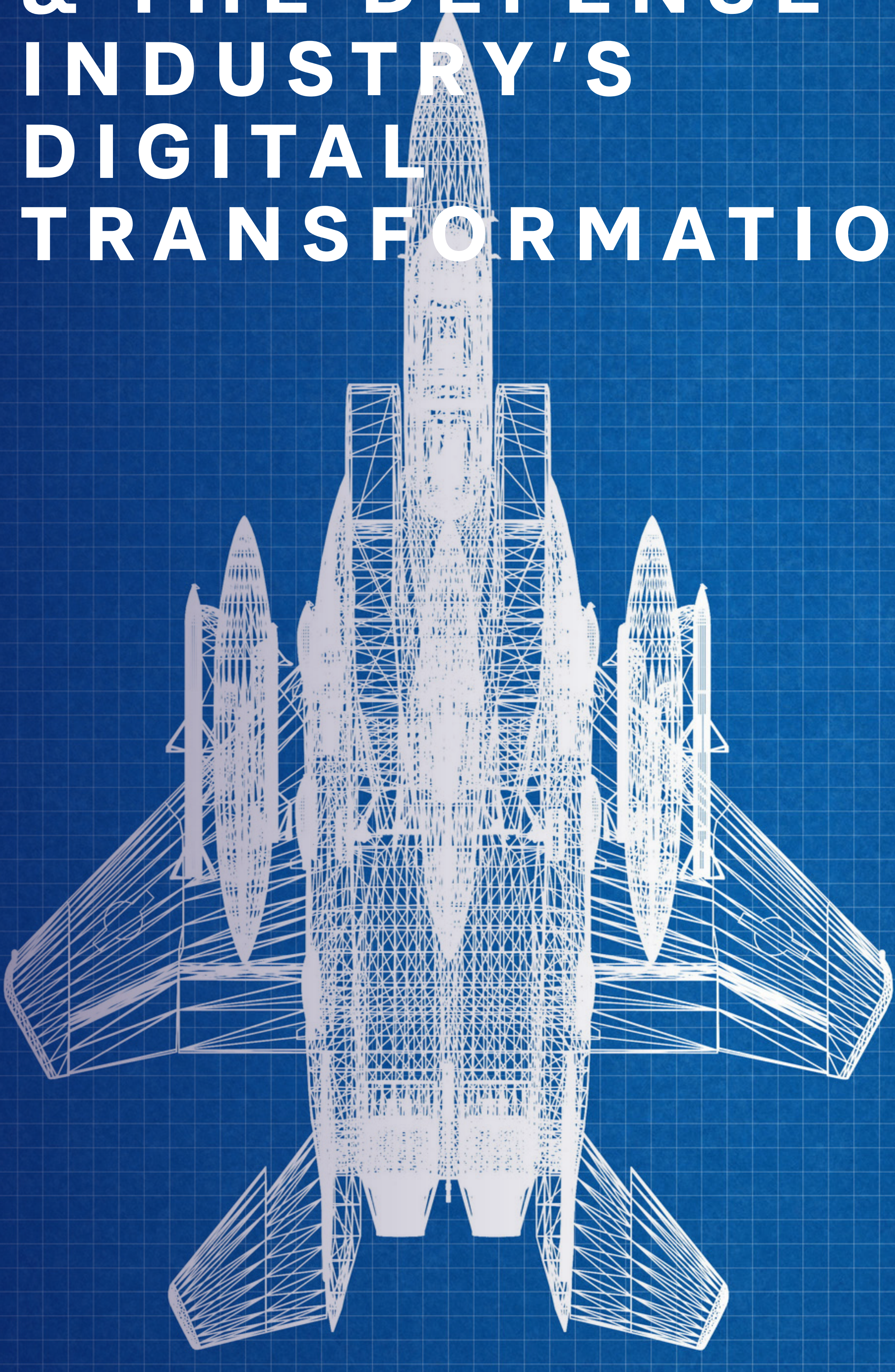
DIGITAL TWINS & THE DEFENSE INDUSTRY'S DIGITAL TRANSFORMATION



Author

Alexander Weber

Digital twins are becoming more commonplace in the defense industry, including one for solid-state radar developed by a US Department of Defense (DoD) contractor to assess high-fidelity search-and-track radar-performance metrics. The metrics are comparable to the deployed system the digital twin represents (referred to here as the "end item"), reducing testing costs for the contractor and DoD.

Cost savings from the radar digital twin (RDT) stem from the ability to digitally assess end item software, verify system-level requirements, support pre-mission analysis and events without hardware, and conduct virtual warfighter training and exercises.

Millions of dollars have been saved from these activities, savings that increase year after year and can be reinvested into product development. Expansion and adoption of these types of digital twins are expected to support additional cost savings and faster product delivery as they evolve (see Figure 1).

RDT model development costs less than traditional modeling and simulation (M&S). RDT's use of wrapped tactical code (WTC) methodology is also an advantage: it keeps development in lockstep with the development of the end item system. (Note that "tactical code" refers to the end item software.)

RDT provides various configurations to support multiple use cases. Its interface is identical to the end item radar system, so it supports interoperability with defense system (DS) models that adhere to the end item interfaces. RDT supports a high-fidelity, non-real-time configuration. This configuration is used for singleton radar simulations (using parallelized Monte Carlo simulations[1]) and integration into traditional modeling and simulation.

RDT also supports a medium-fidelity, real-time configuration. This configuration is used for pairwise testing with other DS models and as substitute for the end item radar in interface-level testing and assessments. The digital twin's operators include the prime radar contractor, sister contractors that develop DS models, and warfighters (primarily pilots and sailors).

A deployed radar system requires multiple cabinets of equipment to keep up with demanding real-time requirements. RDT's hardware requirements are lower because they're based on the computing resources needed for the deployed radar systems minus the resources needed for redundancy and processes not required in the twin, such as calibration. This allows RDT to be run in both a real-time and a non-real-time configuration on a single computer with a single software build.

> **RDT MODEL DEVELOPMENT COSTS LESS THAN TRADITIONAL MODELING AND SIMULATION**

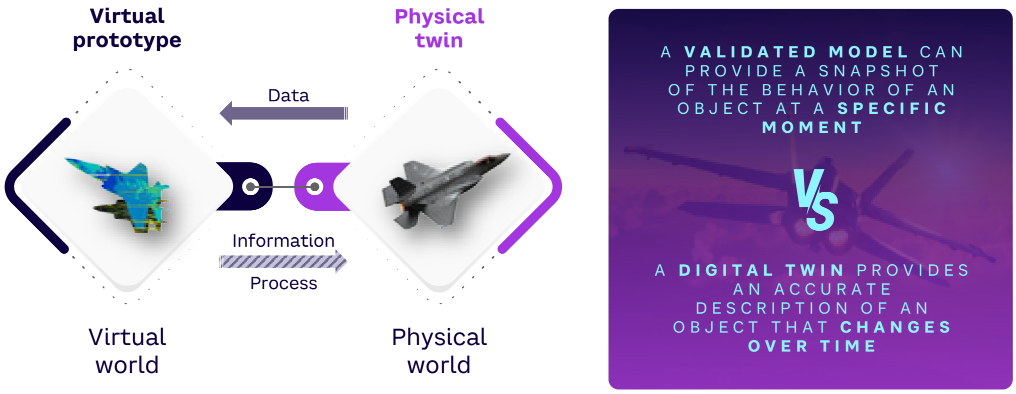


Figure 1. Digital twin overview

This configuration can be scaled to execute multiple instances of the RDT and run in parallel in a clustered or cloud computing environment to allow for Monte Carlo statistical variation and support high volumes of data. This data is used to assess the radar performance across hundreds or thousands of simulations. Note that RDT is platform-agnostic; it can be run on any machine that meets RDT's minimum hardware requirements. Cloud computing solutions are the most popular choice for running RDT.

RDT's Modular Open Systems Approach (MOSA) architecture allows for the construction of additional digital twins.[2] The additional twins represent variations of the radar system with little changes to source material. Various radar components can be swapped depending on the configuration the user wants to test. Components of RDT are also swappable with traditional M&S components.

This blend of end item–deployed code and M&S models facilitates issue isolation and identification in both models. The end item–deployed code uses the same input as a system integration lab or test environment, so issues identified in fielded configurations can be easily tested with RDT.

In addition, RDT outputs the same data as the deployed system, due to the WTC methodology. This allows the same debugging tools, strategies, and procedures developed for the deployed radar system to be used with RDT, supporting reuse.

RDT provides quick assessment of the end item–deployed software in a simulated environment. Since RDT uses WTC methodology, the performance of the end item system, including its features and bugs, are present within RDT. RDT builds are produced in lockstep with the deployed system.

RDT's ability to mirror the behavior of the deployed system has been a leading driver of ROI. For example, RDT is capable of being deployed at the same time or sooner than builds that make it to the laboratory floor. RDT loads are regression tested with the same inputs as the builds in the deployed configuration. Crashes, software bugs, and radar-performance issues associated with these loads are thus identified earlier in the test cycle for the end item system. Early identification means issues can be resolved with less effort (versus needing to staff a laboratory of engineers to run the same inputs as RDT).

Issue identification using RDT is more sophisticated than identifying problems in single-input situations. Radar performance metrics require much more than one test in the laboratory to assess. Typical test input in the end item configuration runs for dozens of minutes and requires multiple engineers to process the data. This process is often repeated to get a larger data sample size.

RDT's parallelization feature allows hundreds or thousands of these simulations to be done in less time versus the end item system (on the order of 100x less). Since RDT exists in a digital-only environment, it can easily be paired with automation. The output of these parallelized simulations can be fed into analysis scripts that assess key radar metrics across the distribution of data.

This led to the discovery of harder-to-find edge-case issues in the end item software, saving thousands of person-hours. Figure 2 shows RDT Monte Carlo simulation output of RDT for low-level radar-performance metrics. The colored curves are 10 individual simulations, run in the clustered cloud computing configuration, and the black curve is reference data from the end item radar system. The figure shows how closely the end item radar system tracks with the RDT.

FACILITATING RADAR SYSTEM VERIFICATION

DoD works with its contractors to define radar system requirements, which can range from high-level functionality to low-level, radar-specific performance metrics. RDT's use of WTC methodology lets potential buyers observe radar functionality, as written in the requirements, within the twin. Government personnel can assess and observe the behavior of proposed radar systems at their own sites without the need to buy hardware and without support from the contractor.

> **FOR REQUIREMENTS TO BE VERIFIED USING RDT, THE MODEL FIRST MUST BE VALIDATED, KNOWN, AND ACCEPTED**

Formal verification of radar system requirements requires a government witness and an assessment of the data produced during testing events. Certain requirements cannot feasibly be tested using the end item radar system for several reasons, including the amount of data required for verification and hardware limitations. RDT excels in these situations — it is inherently not hardware-limited due to its ability to be clustered and run in non-real-time.

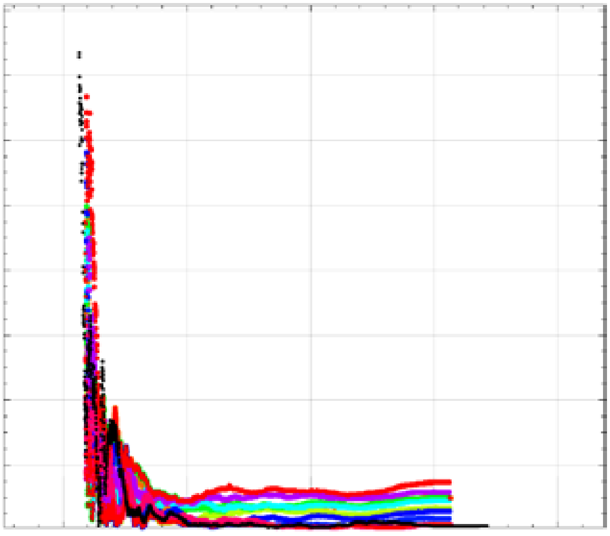


Figure 2. 10 RDT Monte Carlo simulations (shown in color) vs. referent deployed radar system (shown in black) vs. time

Radar system-level performance requirements have now been verified solely using RDT, and requirements for newer radar systems' verification test procedures are being written to include it. For requirements to be verified using RDT, the model first must be validated, known, and accepted. RDT must be compared to the deployed end item radar system and match all customer-defined criteria. These criteria range from low-level sensor measurements to high-level metrics involving the objects identified by the radar. Validation requires data from live data-collection events. Once validated, RDT is then accepted by the government and used in additional federated models to represent the end item radar configuration. At this point, RDT can be used for event pre-mission analysis.

Figure 3 shows the output of the end item hardware in the loop radar system with RDT output overlaid. Both charts show low-level radar metrics as a function of time. We can see that the curves follow the same trends. Closer analysis shows that RDT is within the acceptability criteria for formal validation as specified by DoD.

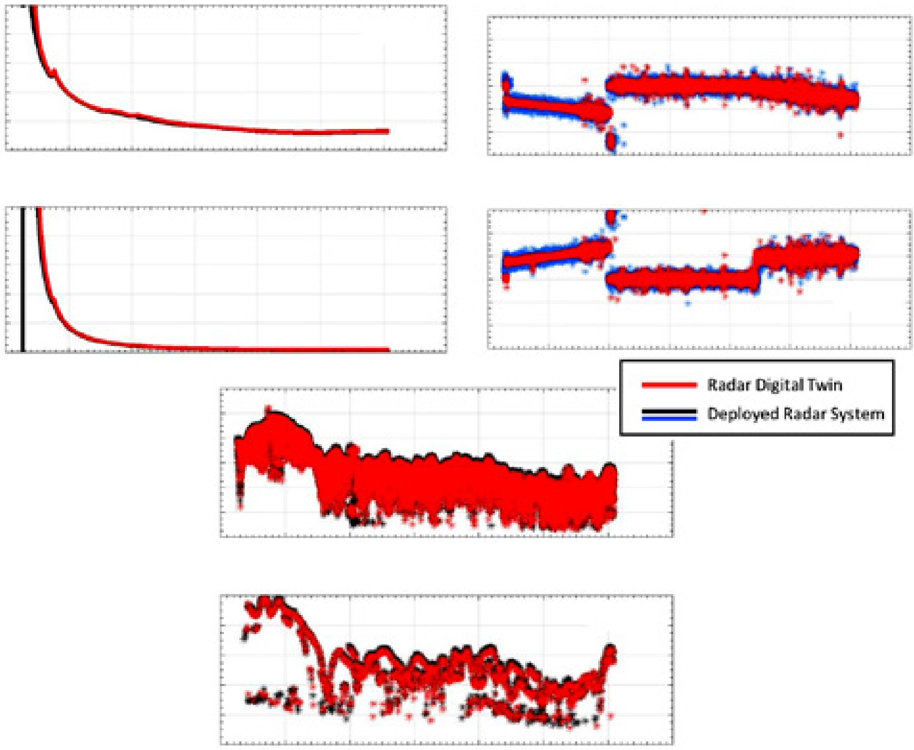


Figure 3. Example RDT data vs. referent deployed radar system data vs. time

For testing purposes, DoD conducts events using live equipment for potential radar systems to observe. Pre-mission analysis events occur prior to these events. RDT is heavily used in these events to generate accurate data representing the mission. These events take place over months. DoD and contractors work in tandem to ensure that the systems will be ready and that the event will be successful. Recently, RDT has been used during these events. RDT's WTC methodology allows developers to assess performance and identify and resolve issues in the end item system during the event lead-up.

Traditional M&S is commonly used in pre-mission analysis, but it does not use WTC methodology, introducing risk. Historically, traditional M&S has been used to develop the design for a radar system. As the design matured, the end item–deployed software would enter development, trailing the traditional M&S. In preparation for an event, teams would use Monte Carlo statistical variation simulations of the traditional M&S to assess potential performance. This can introduce risk, as the end item software is not being tested to the same degree. The teams have identified issues in the end item software late into development with this methodology.

In recent years, the digital twin has been maintained during the development of a radar system, including through to the pre-mission analysis. Having RDT as another test point helps the development team identify issues earlier and gives the teams a more accurate look at the expected radar performance before execution. A blend of traditional design with a digital twin facilitates faster development across most systems engineering development phases.

DIGITAL-ONLY MISSIONS

Given the cost of months-long test events, DoD is now investing in digital-only missions. These events use a federated model to create interoperability between various parts of the DS. The federated model components include RDT along with digital twins for other mission participants.

The digital missions provide the same level of configurability and output as the end item system, execute in non-real-time, and require only a single operator to configure the system. The rest of execution is done overnight on cloud-based computers. The resulting data is assessed using automated scripting solutions, and information on issues flows to each digital twin development team.

During these digital events, the teams have identified deployed radar system software issues in a purely digital environment, marking a milestone in DoD's movement toward a digitally transformed work environment.

INTEGRATION WITH OTHER DEFENSE SYSTEMS

RDT's real-time configuration is an important tool for interface-level testing with other digital twins or M&S models. RDT's MOSA architecture allows radar components to be swapped with M&S models or lower-fidelity variants. RDT uses a medium-fidelity signal-processing model during real-time configuration to ensure simulations are running on time. This version of RDT can be delivered to the other elements of the DS, where radar-to-radar and radar-to-command-center interoperability is tested. This configuration has led to the discovery of numerous software issues in product interfaces.

This real-time configuration can be scaled to represent the radar system in laboratory environments. In situations where hardware is limited or under contention, RDT can be used in place of the end item system. This configuration, referred to as "tactical representation mode," is just now being adopted in government radar programs. Similar to digital twin to digital twin interface-level testing, RDT is used in tactical representation mode to test the interface of the radar with the end item code from other products, such as a battle manager, another radar, or a command center.

Whereas laboratories often use tools to simulate operator button presses, tactical representation mode incorporates that automation into the model. RDT in tactical representation mode is a new configuration in this environment, and it offers the same interface and configurability as the deployed system without the need for large amounts of computing resources.

CONCLUSION

Digital twins are an important part of a larger push toward digital transformation in the defense industry. Although their initial development was challenging and adoption has been slower than desired, more industry players are now recognizing their potential and investing in them.

Since its development, RDT has provided millions of dollars of benefits each year, leading its developer to believe that RDT, and digital twins in general, will eventually become part of everyday development and data analysis at DoD. RTD's ability to identify design issues, participate in events, and facilitate requirements verification has more than proven its worth.

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About the author

Alexander Weber is a Senior Engineer at Lockheed Martin Rotary Mission Systems–Radar Sensor Systems, where he leads the Solid State Radar Digital Simulation Team. Mr. Weber has created a radar digital twin, which has been provided to the US Department of Defense (DoD) — and is used in high-fidelity radar performance predictions. His interests center on expanding digital twin use cases into additional aspects of radar development. Mr. Weber earned bachelor of science degrees in electrical engineering and physics from Widener University and a master of science degree in computer science from Rowan University. He can be reached at alexander.s.weber@lmco.com.

ORLANDO'S DIGITAL TWIN HAS POTENTIAL TO INFLUENCE REGIONAL PLANNING

Author

Tim Giuliani

The Orlando, Florida, USA, region is thinking big when it comes to economic and community development. It recently unveiled a digital twin that uses 3D technology to map 800 square miles of the region, recreating 40 square miles in high fidelity. One of the most comprehensive regional representations in existence, the project began in 2021 and is now in use by the Orlando Economic Partnership (OEP) to demonstrate the area's value proposition to companies considering the four-county Orlando region for relocation or expansion.

ORLANDO AS A SIMULATION HUB

Orlando's long history with simulation made it an ideal candidate for a digital twin project. Before becoming the theme park capital of the world, Orlando, with the help of its top aerospace and defense companies, developed the ultimate thrill ride: flying to the moon. Not surprisingly, the Orlando region remains an important hub for Florida's aerospace, defense, and modeling, simulation, and training (MS&T) industries.

In 1957, Lockheed Martin built its Orlando plant in anticipation of increased activity at Cape Canaveral's rocket-launch site. In 1986, the University of Central Florida opened with the mission of producing a workforce to support the growing space program at the Kennedy Space Center and Cape Canaveral Space Force Station (formerly known as the Cape Canaveral Air Force Station).

Today, Orlando is recognized as the MS&T capital of the world: five US military branches have significant MS&T procurement activities in Orlando.[1] Every year, local companies compete for more than US $6 billion in MS&T contracts that flow through the region, many commissioned by the Army, Air Force, and Navy simulation centers located in Orlando.[2]

Simulation-based technology touches many of Orlando's core industries and drives innovation in sectors from aerospace and defense to education, healthcare, and gaming. The city established itself as a leader in digital simulation as far back as 1968, when the US Navy opened the Naval Training Center.[3] Orlando's MS&T ecosystem supports collaboration between academic institutions, business partners, and the military thanks to organizations like the National Center for Simulation and Team Orlando. The city of Orlando also hosts the *Interservice/Industry Training, Simulation and Education Conference* every year, the world's largest MS&T event.

SELECTING TECHNOLOGY & PARTNERS

OEP wanted to showcase the strength of the region's innovation ecosystem, create an immersive way to engage developers in Orlando's story, and highlight the features that establish the region as a business destination. OEP leaders made the decision to create a high-tech marketing center in the organization's new office in downtown Orlando.

To deliver an immersive experience for business leaders interested in Orlando as a business location, OEP leaders decided to create a digital twin of the region instead of a traditional model. The decision was based on marketing benchmarks and lessons learned from other organizations with marketing centers, including the Water Street Marketing Center in Tampa, Florida. But instead of a 3D-printed physical twin of a small portion of downtown like Water Street's, OEP leaders opted for an experience true to Orlando's digital roots.

Having followed digital twin development by innovative Orlando companies like Oracle, Siemens, and BRIDG (Bridging the Innovation Development Gap) — a public-private partnership bringing advanced microelectronics research to market through the fabrication of silicon wafers — Orlando leaders decided to develop a digital twin that would serve as a dynamic, versatile representation of the region.

For insight on how to move forward with such a project, OEP convened a task force in the fall of 2021. The task force included executives from Electronic Arts, Duke Energy, University of Central Florida, Full Sail University, Universal Orlando, and the Orlando Utilities Commission who worked to identify potential hardware, software, and technology platforms for use in creating its digital twin.

The group selected San Francisco, California, USA-based Unity Technologies as the lead technology partner for the project. Unity had experience building digital twins for other organizations, including Tyndall Air Force Base, and its open source gaming platform was important to the type of digital twin OEP wished to build. One important feature was its ability to ingest a large number of data types from a variety of sources.

The high-resolution graphics, images, and photogrammetry provided by Unity give Orlando's digital twin an extremely realistic look — viewers get an immersive experience and a comprehensive understanding of the Orlando region's geography and landscape (see Figure 1). Because the platform is open source, companies can plug their own data into the digital twin to create an even richer model and simulations related to climate change and infrastructure planning, including new transit routes to connect Floridians with areas of high job growth.[4]

OEP has invested more than $1 million in the digital twin's hardware and software. That includes a partnership with visual design and production studio DCBolt to create the hardware for the digital twin and with digital development studio 302 Interactive for the virtual reality (VR) companion application. Since the digital twin was unveiled in October 2022, it's been used in nearly 100 demonstrations for executives, consultants, community partners, and organizations.

Figure 1. Orlando regional digital twin (source: City of Orlando, Florida, USA)

Figure 2. Interacting with digital twin via virtual reality (source: City of Orlando, Florida, USA)

VIRTUAL ORLANDO

The 160-square-foot digital twin incorporates holographic elements to highlight priority areas for economic development in high resolution. Economic development project managers offer business executives demonstrations of the twin, controlling the experience via a tablet and providing a unique experience to each visitor. OEP staffers are trained to navigate the digital twin to present relevant data layers and information, including demographics, infrastructure, quality-of-life amenities, utilities, and transportation. The twin incorporates data sets owned by OEP, licensed from others, and public data from a variety of sources.

The digital twin can also be viewed and interacted with using a Meta Quest VR headset (see Figure 2). This device gives OEP staffers a way to bring the digital twin on the road, allowing executives to see, without leaving their offices, what it would be like to live and work in Orlando.[5] Reactions to the VR demonstration have been overwhelmingly positive, with executives noting the contrast between viewing data-filled PowerPoint slides and looking at a virtual representation of the region.

The 800-square-mile map highlights five geographic areas: downtown Orlando, Lake Nona, the Central Florida Research Park in Orange County, Lake Mary-Heathrow in Seminole County, and NeoCity in Osceola County. The digital twin helps the Orlando region stand out to site selectors and corporate CEOs by highlighting developable land, available real estate, areas of interest for a variety of industries, infrastructure connectivity, and talent availability.

REACTIONS TO THE VR DEMONSTRATION HAVE BEEN OVERWHELMINGLY POSITIVE

OEP has learned that when a company is making a relocation or expansion decision, its planners typically visit three to 10 cities. The digital twin helps executives, consultants, site selectors, and community partners better understand the Orlando region without having to spend multiple days in a car.

Orlando's digital twin could be viewed as a more in-depth version of Google Maps. During demonstrations, site selectors and business leaders can experience a "flyover" of the region with overlays of relevant data points. They can also view heat maps with demographic information, transit routes, rail spurs, and fiber optic cable connections.

NEXT STEPS

Orlando's digital twin currently incorporates operational and sensory data; future versions will include scenario mapping and machine learning. Plans also call for the twin to be stored in the cloud, allowing for access from outside the marketing center.

OEP leaders see the digital twin as the foundation for a platform that will serve as a critical resource for decision makers in the area and play a vital role in Orlando's economic future and smart city planning. For example, stakeholders could use the digital twin to simulate climate change mitigation projects based on historical rainfall totals and flooding patterns. Decision makers could predict traffic bottlenecks using sensor data from stoplights and highways, informing transportation planning. City planners could use historical population data to predict future density for use in transit mapping, housing development, and power grid expansion.

The digital twin is also a way for Orlando to showcase its role as a leader in developing immersive technologies, something city leaders believe more companies will seek as the Metaverse matures.[6] OEP leaders believe Orlando's digital twin demonstrates this technology's potential, taking it out of the realm of product and building design and into processes like urban planning, climate-related planning, transportation planning, and utility-expansion projects.[7] In short, OEP leaders see a direct link between technologies like digital twins, the Metaverse, and local and regional prosperity.

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Tim Giuliani leads the Orlando Economic Partnership, a private-public partnership with a team of 40 and a board of directors comprised of business, government, and higher education leaders. Mr. Giuliani serves as the first President and CEO of the Partnership, which has thrived after successfully merging two legacy regional business organizations. Previously, he was President and CEO of the Raleigh Chamber of Commerce, North Carolina, USA. Mr. Giuliani also led the Gainesville, Florida, USA, Area Chamber of Commerce and Council for Economic Outreach. He has served on the executive committee for the Association of Chamber of Commerce Executives (ACCE), is an active participant of the US Chamber Committee of 100, and is a board member for the Greater Orlando Sports Commission (Florida, USA) and Visit Orlando. He is also a Certified Chamber Executive (CCE). Mr. Giuliani earned an MBA from the University of Florida. He can be reached at tim.giuliani@orlando.org.

DIGITAL TWINS FOR PLACES:

NEW REVENUES AWAIT

Author

Colin Dominish

The benefits of digital twins have been much debated since they first appeared in the space industry in the late 20th century. Fast adoption and benefits flowed in some industries, but many are still questioning their value. Adoption across the property and real estate industry has been haphazard, with little focus on new revenue streams. This article explores the potential for revenue streams from digital twins for places.

Most of the digital twins in property and real estate have been a response to changes in our society and on our planet. A recent paper by the Australian Computer Society titled "Data and the Digital Self" noted that "major drivers for this change to a digital future world are coming from the intersection of a growing, ageing, and urbanizing population; a globally changing climate; and a response to an increasing number of global challenges and pandemics."[1] Hidden among these drivers are opportunities for digital twins to unlock new revenues during placemaking.

The term "placemaking" is even harder to define than digital twin, but in this article, we mean creating places with social, environmental, and economic value that are meaningful, vibrant, and enduring. Placemaking requires a combination of global competence and authentic local engagement. It means defining the best of all possibilities while being disciplined enough to deliver that vision sustainably and in partnership with the community.

Digital twins have the potential to solve some significant challenges that exist in property and real estate:

- Reduce real estate costs
- Decarbonize buildings facing rising energy prices and increased regulations
- Improve building resiliency
- Enhance the workplace experience
- Solve low occupancy issues[2]

This involves property and real estate organizations:

- Better accessing, integrating, and optimizing valuable data buried in varied data offerings
- Implementing fully connected building platforms that leverage data models and ontologies
- Providing greater interoperability across expanding partner ecosystems to enable greater insights and value-added processes

The list of components and interfaces that could make up a digital twin for use in property and real estate is large. Typical areas are shown in Table 1.

> **DIGITAL TWINS HAVE THE POTENTIAL TO SOLVE SOME SIGNIFICANT CHALLENGES**

TECHNOLOGIES	BUILDING PERFORMANCE	PLACE EXPERIENCE
• Advanced analytics • Artificial intelligence • IT-OT convergence • IoT & connected devices • Cloud-based offerings • Virtual & augmented reality • Mobile applications • Underlying cybersecurity framework to protect data	• Building mgmt systems • Building automation systems • Smart lighting • Access control • HVAC • Chillers • Motion sensors • Environment monitors • Embedded networks • Fire & emergency • CCTV & security systems • Lifts/elevators • Waste management • Parking	• Chatbots • Surveys • Workplace collaboration suites • Haptics • Mobile applications & network data • Bespoke calendar solutions • Payment transaction platforms • Customer & service insights from fault & service mgmt systems • Event, room & desk booking systems • Transport & weather portals • Building regulation websites

Table 1. Possible components for property/real estate digital twins

MAJOR BENEFITS OF PLACE-RELATED DIGITAL TWINS

Using digital twins, placemaking can enter the digital realm, unlocking benefits such as:

- An end-to-end view of the physical-property life-cycle, unearthing cause and effect between how places are created and how they are subsequently used
- The ability to simulate differing outcomes for the use of place by varying inputs and discovering new outputs
- Applying predictive analytics (using artificial intelligence [AI] and machine learning [ML]) to forecast what might happen next to improve the use of places

With that in mind, some benefits for the property and real estate industry may already be obvious to the reader. For example, digital twins can optimize building performance and efficiency, improve occupant and tenant experiences, drive sustainable outcomes, and increase revenues (see Figure 1).

OPTIMIZED PERFORMANCE & EFFICIENCY

Digital twins can help property professionals optimize their operations, reducing costs and increasing efficiency. For example, by monitoring energy consumption, digital twins can identify energy savings and reduce utility bills. They can predict maintenance needs for buildings and equipment to avoid costly repairs and downtime. Real-time data can optimize the HVAC, lighting, cleaning, and waste management systems.

Property and real estate professionals were asked to do more for less because of the COVID-19 pandemic. For instance, the shift to hybrid working left them having to rethink how spaces are designed, how they operate, and how they attract and retain top talent. Tools and data to redefine and optimize space tend to be fragmented across multiple systems and are often contained in spreadsheets, limiting the ability of property professionals to create accurate forecasts. In other words, the task of optimizing smaller spaces to meet greater utilization expectations lacks proper support.

Figure 1. Potential benefits from applying digital twins in property and real estate

ENHANCED TENANT EXPERIENCES

Digital twins can improve tenant experiences by providing insights on factors like temperature, lighting, technology, workplace behaviors, and occupancy levels. For example, at Sydney Place, a vibrant mixed-use precinct in one of Sydney, Australia's oldest and most-loved gathering places, a next-generation environment was put in place to support people's health and well-being. Sensors capture the level of ambient light, ambient temperature, sound pressure, humidity, carbon dioxide, and volatile organic compounds. By feeding this data into a digital twin, any significant variance in levels can quickly be identified and addressed to ensure the environment operates at the most effective levels for tenants.

Digital twins can also identify ways to maximize workplace performance and grow employee engagement and retention by focusing on how people use the office while keeping in mind how the office operates. Workplace managers are starting to see how data-driven initiatives can result in collaborative, hybrid work environments people want to return to, despite a previous preference for working from home.

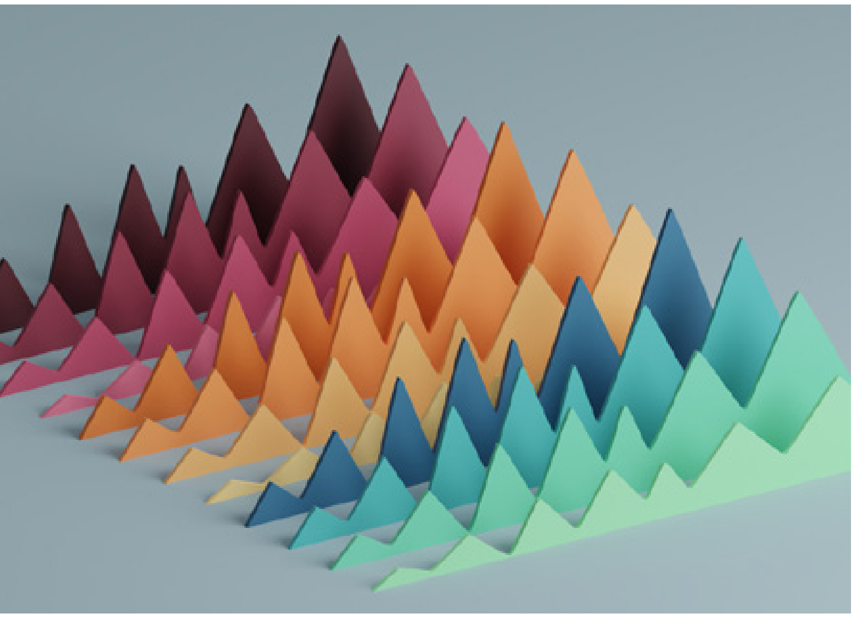
SUSTAINABLE OUTCOMES

Digital twins can clearly illustrate how buildings can be constructed in the most efficient manner. They can be used to select the most sustainable and least resource-intensive materials, forecast how much energy is required to operate a building effectively before building it, model renewable-energy sources in the building design, and forecast the nature and volume of waste products created by the building. After construction, digital twins can be used to manage building operations, a cost-efficient way to ensure they operate within planned sustainability levels.

Sustainability benefits are multiplied when digital twins are used to compare findings across a portfolio of buildings. Property and real estate professionals can maximize value by leveraging insights from a successful initiative in one location across all the places they manage.

10 POTENTIAL REVENUE STREAMS

To become more valuable, buildings need to provide places for people to work, live, and play. Digital twins help with this by contextualizing, integrating, and synthesizing tenant experiences to extract cause and effect.



A report called "The Great Return: Emerging Insights from the Pandemic and Their Impact on the Future of the Workplace" found that "the workplace can create strategic advantage for businesses by stepping up the way it supports innovation, connection, and customer engagement."[3] A study titled "The Tenant as a Customer: Can Good Service Improve Commercial Real Estate Performance?" noted that attention to satisfying the needs of occupiers might reduce void periods and maintain rental income when property supply exceeds demand.[4] In "Data and the Digital Self," the Australian Computer Society stated:

> Efforts to create joined-up customer experiences make it easier to engage with service providers and hopefully deliver more effective outcomes. For many years, businesses have tried to create a better, more attractive customer experience, delivering increasingly personalized services. New services and capabilities promised by access to data and digital technology present enormous benefits for users and citizens — delivering services and information to people when they need it, wherever they happen to be, whenever they need it and in whatever circumstances.[5]

These observations point to new revenues being unlocked through greater understanding of how people experience places. Here are 10 examples:

1. IMPROVING RETAIL SALES

Digital representations of footfall within a mall provide real-time data and insights into the performance and behavior of shoppers. Often visualized as a heat map, they provide greater understanding of how people move while in the mall. Property owners can then create virtual scenarios to learn what happens when certain changes are made. Increased footfall? Longer dwell times? Channeling shoppers toward tenants with low patronage? Advanced digital twins can use city-wide data sets to understand how shoppers move across multiple retail assets (or travel past those assets without visiting them).

For example, Lendlease activated retail spaces within PLQ, 313@Somerset, JEM, and Parkway Arcade in Singapore using its Podium Property Insights digital twin during the 2023 Chinese New Year holiday. Using its inhouse mobile phone app, it deployed a digital wallet, and Web3 enabled play for customers involving finding digital objects placed within the retail centers. A digital twin of the retail malls was used to "place" the objects.

Forty-nine tenants participated by providing 26,000 compelling in-store offers that could be collected by customers as part of the game. More than 1,500 wallets were created within 48 hours, and many customers traversed two or three malls to collect the digital objects. Average play time was around 15 minutes, and 33% of customers redeemed the offers within the first two weeks of the campaign.

2. BOOSTING AD REVENUE

Mapping advertising signage locations in a digital twin to understand the frequency they are passed by onlookers and knowing how long people look at the signage (by cameras and sensors informing the digital twin) gives property owners a greater understanding of what attracts eyeballs. Digital signs with rotating content can be matched to people interacting with the sign (e.g., using amalgamated data of search histories on retail mobile-phone applications to determine which ad gets displayed the longest).

3. IMPROVING SERVICE AVAILABILITY

Visitors making their way through a place are often unaware of the full range of products and services available. Location-based services address this by pushing services or information to visitors. Digital twins can provide a more sophisticated version, giving visitors an opportunity to select products and services of interest before or during their visit. For example, being able to select a car park, order a meal, locate a desired product in a store, book a haircut, receive an alert about dry cleaning pickup, and buy a movie ticket before entering a retail precinct lets shoppers maximize — and possibly widen — their set of experiences when they arrive. In coming years, autonomous services provided by robots will change the way people are served within a place. Linking availability and access to autonomous services (like a car-parking robot or a waiter robot) from within the digital twin will likely increase adoption.

4. PROVIDING IMMERSIVE ENTERTAINMENT

Immersive entertainment companies blend visual technology (virtual, augmented, mixed, or extended reality), audio technology, dynamic interfacing, and other interactive tools to create a deeper user experience.

For example, Austrian company Limes designs environments for creating immersive live experiences. Its integrated high-tech concert and multipurpose venues are made for the digital age, enabling unique live spaces where artists, presenters, and audiences can immerse themselves in spectacular multidimensional events, unleashing their creativity and pushing live entertainment to the next level. Audiences participate by being physically present while being virtually immersed in a digital twin of the location where they can interact with each other.

5. PROVIDING VIRTUAL TOURS

Digital twins create virtual staging and tours of properties that attract visitors and potential buyers (or renters). The Louvre Museum in Paris created a digital twin of the museum that allows visitors to take a virtual tour of its collections. The tour includes detailed 3D models of the museum's galleries and exhibits, providing visitors with a realistic experience and generating additional revenue. Real-time data gathered on visitor behavior and preferences during digital tours can be used to optimize the physical space's layout and lighting to improve the visitor experience in the real space.

6. PROVIDING GAMIFICATION FOR TRAINING AND EDUCATION

Gamification in the workplace is on the rise, helping workers mitigate risks in complex environments and better perform difficult work tasks. Worker actions can be tracked by integrating sensors and capturing data in a digital twin. Gamified actions are then selected in the digital twin according to the task and worker preference. Several digital twins can interact with each other to provide holistic information about the workplace, work patterns, and employee knowledge within the gaming engine. This provides a richer understanding of risks in the work environment, challenges related to certain tasks, and ways for workers to enhance productivity and effectiveness while remaining safe.

7. PROMOTING THE CIRCULAR ECONOMY

In "Digital Twins for the Circular Economy," the authors note that:

> Accurate information plays an important role for the circulation of materials and products. It influences the economically and ecologically successful execution of processes such as reconditioning and the corresponding supply chain management. Digitization concepts, such as digital twins, enable the relevant information to be made available to the right actor at the right time in a decentralized manner.[6]

The article describes the complex interactions required by multiple actors to enable a recursive supply chain that supports a circular economy. The digital twin is touted as "a virtual collection of information regarding a specific product and its entire lifecycle — from the design phase to end-of-life management." With supply chain challenges currently faced by the building industry after the pandemic, and a continued focus on sustainable outcomes for the future, digital twins could become an important way to track materials from assets at their end of life and recycle them into new buildings.

This concept is being applied by Lendlease at the Milano Innovation District (MIND) in Milan, Italy. Located at the former Expo 2015 site, this is a new region for science, technology, and knowledge that takes a humanistic approach to building and design and is setting new standards for sustainability, wellness, safety, and productivity.[7]

The project envisions the precinct's new and older physical buildings as existing within a single digital ecosystem. Transitioning away from traditional design processes (which are applied to one building at a time) creates consistent experiences and reliable services for tenants, regardless of the building in which they're located. AI, the Internet of Things (IoT), and cloud technologies are advancing the capabilities of individual buildings in most new precincts, but Podium Property Insights is providing MIND with a software-defined, containerized digital twin architecture that's changing building design across the precinct.

New possibilities for reconditioning the site have evolved from combining various technologies to solve the unique problems and requirements of the MIND precinct in a cost-effective, integrated fashion. Determining how buildings should respond as the precinct grows means asking questions like:

- How do we gain data from the way people live, move, and operate within a space?
- How do we take a good building and make it better?
- How do we improve as we move to the next building?

The project leverages the best available technology in the emerging spaces of data, ML, IoT, and digital twins; the key is the way each component is brought together to solve real problems and create value specifically for the precinct.

8. PERSONALIZING UTILITY CONSUMPTION

In "The Future of the Office Building," the authors describe how "buildings can generate revenues from virtual power plants by capitalizing on control of energy usage. These virtual power plants can alter office-building business models by providing a new stream of potential revenue for building managers."[8] Digital twins provide the perfect way in which to replicate the complexity and identify ways to connect stakeholders within the virtual power plant while simulating and predicting better potential outcomes and revenue-generating scenarios.

9. OFFERING SPACE AS A SERVICE

Companies are constantly looking for business models that let them deliver value to customers in new ways. For instance, a Germany-based compressed-air specialist is using a digital twin to increase the efficiency of its configure/price/quote system. It recently introduced "simulation as a service" for technical verification of customers' proposed configurations.

In "Space as a Service: The Trillion Dollar Hashtag," Antony Slumbers says the property and real estate industry should be doing the same. He writes: "We need to be zooming out and connecting all the dots in a quest to produce a user experience for our customers that is the sum of every human + machine skill at our disposal. We need to ... start with the wants, needs and desires of our customers and work back from there."[9]

Giving tenants the ability to configure, price, and quote their desired building or property would allow them to get what they want, where and when they need it. Instead of finding a space and trying to turn it into a place, they would define the place they want while the property industry flexes to their requirements. Sophisticated digital twins that match available space with tenant desires would be needed for such a venture.

10. PROVIDING LEASING SIMULATIONS

Digital twins can track and manage leasing activities to optimize portfolios and identify opportunities for growth. For example, a leasing simulator with multiple tenancies could consider: demand for space across a portfolio; supply of new and expiring leases available in areas of interest; and risk factors associated with the economy, changing work patterns, and the impacts of natural disasters like the pandemic. By analyzing market conditions, the simulator could provide early warnings about market issues, offer insights that accelerate decision making, and identify opportunities to reduce operational costs.

CONCLUSION

Digital twins are transforming the way the property and real estate industry undertakes placemaking by optimizing performance and efficiency, enhancing tenant experiences, and providing more sustainable outcomes. These improvements offer exciting ways to enhance revenue streams by rethinking the value of place via the application of digital twins. In the coming years, the opportunities to integrate digital twins that generate new revenue streams for the property and real estate industry will increase rapidly. Increased revenues will come from new products and services that leverage experiences in ways yet to be imagined.

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