Bentley Education

Campus Digital Twin Guide

Part 3: Developing a campus digital twin strategy

Revision History

Date	Revision No.	Summary of changes
xx.xx.2025	V.1.0	First issue

Please email ***stefan.mordue@bentley.com*** with comments, feedback and suggestions.

Part 3: Developing a campus digital twin strategy

Introduction

This part of the Bentley Campus Digital Twin guide provides a series of steps and tasks designed to help you create, manage, and utilize a campus digital twin tailored to your institution's specific needs and goals. The ultimate aim of Part 3 is to support you in developing a clear, actionable strategy that defines why you are undertaking the project, what it should achieve, how it will be delivered, and when key milestones will take place.

The framework introduced here is structured around three core stages: planning, implementation, and enhancing and/or scaling the campus digital twin. Each stage includes guidance, prompts, and examples to help you make informed decisions, allocate resources, and adapt your approach over time.

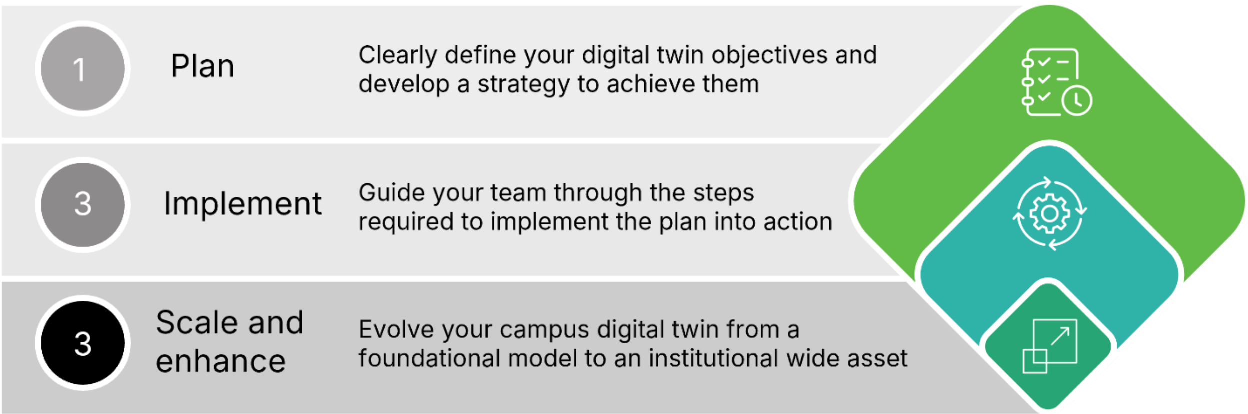
Whether you are building a prototype or formalizing a long-term program, this section will help ensure that your digital twin strategy is purposeful, practical, and aligned with your institution's wider objectives.

Getting started

The digital twin journey for any university typically begins with a gentle learning curve. Bentley Education's Campus Digital Twin Framework offers a series of steps and tasks designed to help you create, manage, and utilize a digital twin tailored to your institution's specific needs and goals. By following these guidelines and practical steps, your institution can develop a digital twin that not only enhances educational and research opportunities but also supports campus planning and sustainability efforts.

Whether you're starting with a small-scale pilot or planning a more extensive deployment, the Campus Digital Twin Framework provides a stage-by-stage overview that can be implemented by students and faculty.

The framework is divided into three main stages:



Stage 1: Plan will help your institution to clearly define your digital twin objectives and develop a strategy to achieve them. In this stage, you will define your objectives through an initial use case, which will help you to determine scope and data inputs. It provides the overarching context for what you aim to achieve and sets the direction for the project. The outputs of this stage are a high-level roadmap, which guides you toward achieving the strategy, and an implementation plan, which provides a detailed, actionable framework for executing the roadmap.

In addition to planning for the development of the twin, this stage will involve planning for its ongoing operation, including maintenance considerations. Maintenance is an ongoing process that is key to keeping the digital twin accurate and up to date, ensuring data quality and incorporating new information and technologies over time. Regular updates and monitoring allow the twin to adapt to changing campus needs and remain aligned with institutional goals.

Stage 2: Implement guides your team through the steps required to put this implementation plan into action. You will now design and develop an initial campus digital twin using iTwin Capture Modeler and OpenCities Planner as part of your wider technology architecture. The stage output is the creation of 3D reality mesh models using iTwin Capture Modeler. Following this, information is imported and connected to OpenCities Planner, creating a geotagged and located iModel that forms the basis of a static digital twin.

Stage 3: Scale and enhance helps you to evolve your campus digital twin from a foundational model to a dynamic, scalable, and institution wide asset. At this stage, you can enhance your campus digital twin by integrating real-time sensor data and developing tailored applications using platforms such as iTwin IoT and the iTwin Platform. Incorporating dynamic, live data significantly increases the twin's accuracy and functionality, enabling more responsive decision-making and deeper operational insights.

You may also start to consider adding to the fidelity of the twin and include additional use cases. This could involve incorporating more detailed data layers, such as high-resolution 3D models, advanced analytics, and predictive maintenance algorithms. By expanding the scope and sophistication of your digital twin, you can address a wider range of operational challenges and optimize various aspects of campus management, from energy efficiency to space utilization and beyond.

Scaling the digital twin involves expanding its use to new areas, departments, or campuses. This could include integrating advanced analytics, machine learning tools, or additional real-time sensors to enhance its functionality and scope. Continuous improvement through user feedback and performance assessments helps refine the digital twin and maximize its impact. The goal of this stage is to create a resilient, evolving digital twin that supports innovation, operational efficiency, and sustainability while delivering long-term value to your institution.

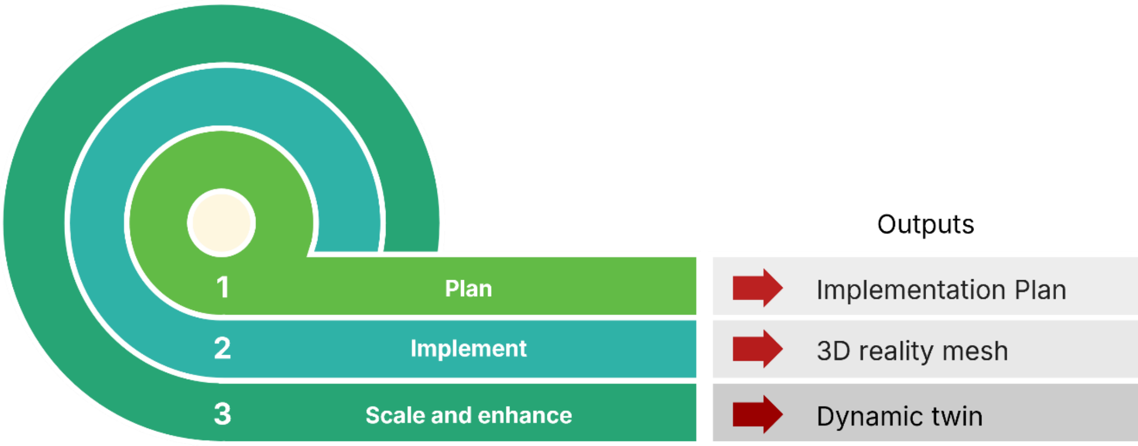
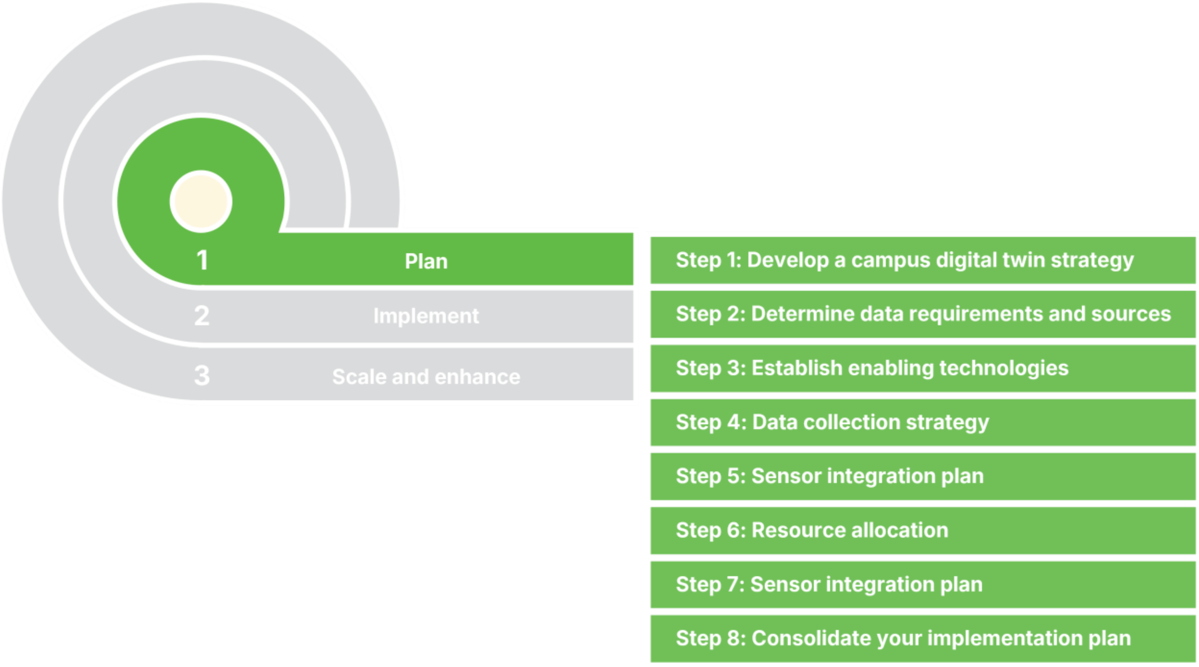


Figure 1: 3 Stage framework

Stage 1: Planning your campus digital twin

If you've used Bentley software before, you may be excited to jump into developing a campus digital twin. For others, this prospect may sound daunting. In order to create a valuable, viable digital twin, we encourage you to first define your "why": what it is that the university wants to achieve by participating in the Campus Digital Twin Initiative. Defining your objectives early will help smooth your implementation of technology and processes in Stages 2 and 3 of the project.



Step 1: Develop a campus digital twin strategy

This first milestone in developing your campus digital twin strategy will help define what you want to achieve and why. Your objectives should consider the short-term, medium-term, and long-term goals you may have and which aspect of your campus operations, teaching, research, or infrastructure is most critical for producing timely results and impact.

In the context of your campus digital twin, a "use case" is a specific scenario that outlines how the digital twin technology can be applied to solve real-world problems or enhance processes within a university setting. Adopting a maturity model approach means that the use cases for your campus digital twin can change over time as you increase its sophistication and scope. Your objectives will be guided by the use case(s) that you want to influence at each stage of maturity.

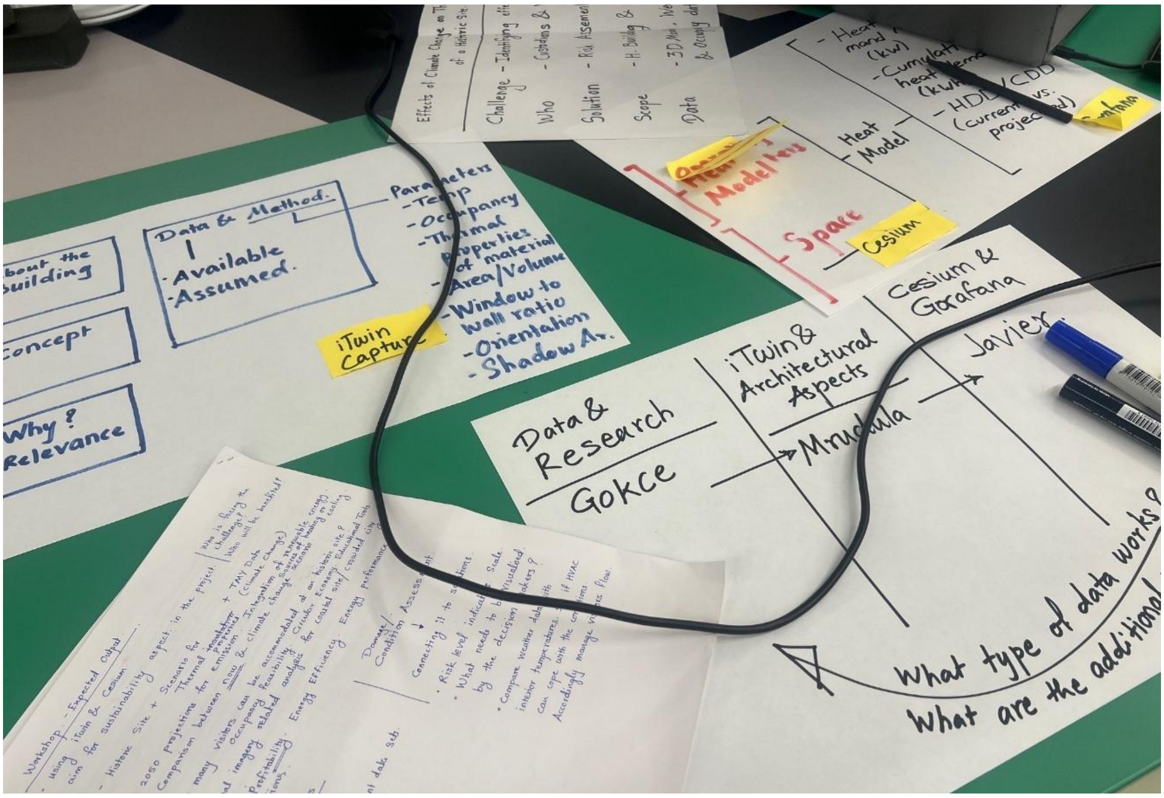


Figure 2: Strategy development

Reminder: You are striving to develop an achievable campus digital twin. While there may be many things you want to achieve using digital twin technology, you should not feel that you need to achieve them all immediately with your initial twin. Digital twin projects are dynamic: the scope and scale of your project can change over time. For your campus digital twin project to be achievable, you may wish to start with a few key assets or buildings and scale up at a later date.

To help determine your goals and outcomes, consider these questions:

- What is the use case or cases?
  - How might these use cases evolve over time?
- What immediate goal would be most valuable for your institution (e.g., knowledge and innovation, operational efficiency, social value)?
  - What longer-term goals must this project achieve to continue being allocated resources (e.g., time, money)?
- In what stage or stages of the building life cycle will the digital twin be implemented? (E.g., are you creating existing assets, mapping new construction, or a combination of both?)
- What is the smallest scale at which your initial digital twin could be implemented in order to achieve value?
  - What do you want your digital twin to capture and at what level of fidelity? Are you interested in the city, the campus as a whole, areas of campus,

buildings, or building components (such as a floor, room, or technical system such as the HVAC system)?.

- How will performance be defined and measured?
  - In what ways can the campus digital twin support both tracking and delivering those outcomes?
- What do you need your digital twin to be capable of doing?
- What data will we need?
  - What data do we already have?
  - How will we acquire the rest of the data we need?
- Who will lead and champion the project?
- What resources do you have, including human time/effort, financial resource, or technological support?

During Step 1, this strategy is not intended to be prescriptive or provide granular details of your digital requirements. Instead, your primary aim is to set out a clear campus digital twin vision, direction, and high-level pathway for how this can be achieved. This strategy should enable an initial project lead to gain crucial support from your faculty and buy-in from the wider university.

Define your headline campus digital twin strategy plan

To begin drafting a strategy for your campus digital twin, consider how and where you might incorporate this project either once you have developed the initial digital twin or further down the road.

- Do you want to use this digital twin to facilitate learning, labs, or projects within certain courses or modules? This may include the development of projects and assignments that leverage the twin's capabilities to allow students to explore and analyze real world scenarios in a controlled digital environment.
- Do you want to use this digital twin to facilitate research or thought leadership in a particular area of study? This may include postgraduate researchers or faculty using the digital twin to explore new theories and develop forward-thinking research practices that facilitate cross-departmental and interdisciplinary research. Consider how the campus digital twin could be used to support research initiatives, particularly for projects that require simulation, modeling, or real-time data analysis.
- Do you want to streamline university operations or support individuals using your campus for social purposes? Are you open to sharing your digital twin to external agencies (e.g., emergency services) or the public (e.g., publishing some or all of the digital twin for open-access use through your website)? The campus digital twin can become a valuable tool to create interactive and hands-on experiences

to facilitate student or community engagement, but this may require you to consider engaging with other organizations or specific regulatory bodies.

The way you answer these questions will help you start to consider the roadmap for your digital twin and how it may add value to your university in the short- and long-term. You can use **Appendix 1: Headline campus digital twin strategy template** to help you articulate a high-level overview of your strategy.

Define your initial objectives and use cases

Now, you should focus on the first milestone in your journey. What initial value proposition should you focus on to create your initial digital twin and progress towards your overarching objectives?

For example, say your long-term roadmap seeks to increase operational efficiency. Your initial digital twin will focus on one area of this complex objective, such as space management. This specific scenario or application is referred to as your use case. Your chosen use case is where the digital twin technology will be employed to achieve a particular objective, solve a problem, or enhance operations.

Remember, a digital twin is inherently designed to provide sustainable outcomes. This means that your strategy should be developed with the intent that your digital twin will be iterated upon regularly as you learn new insights and evolve over time alongside your campus resources and student populations.

Use cases can be varied and should reflect your unique context and goals. While operational drivers like efficiency or cost savings are valid and frequently referenced throughout this guide, it's important to remember that the Bentley Campus Digital Twin Initiative is primarily about education: using the digital twin as a learning tool to support teaching, research, and institutional development. The initiative, and the resulting iTwin asset (a digital twin built using Bentley software), is provided for educational purposes only and must not be used for commercial gain. As you shape your approach, take time to explore a range of educational and institutional use cases, considering how different objectives might involve various areas of your campus, buildings, or assets. While 3D visualization and real-time sensor integration often grab attention, many institutions find the most day-to-day value comes from integrating non-graphical data, such as maintenance logs, inspection reports, compliance records, and equipment metadata into the digital twin. A well-structured twin doesn't just show what something looks like or how it is behaving in real time; it can help to answer critical business questions by connecting diverse data sources in context. For example, a digital twin could serve as a single view of truth, helping you answer questions such as:

- "This room is overheating. Has this happened before?"
- "When was the HVAC last serviced?"

- “Do we need to replace the unit, or can we repair it?”

This level of insight comes from building a semantic, queryable data model around the twin, where operational, engineering, and planning data are all connected.

Once you have identified your initial digital twin use case, you should define the specific benefit or benefits that you want to derive from implementing that use case and how it will serve your overall goals. You can explore some potential ways of using campus digital twins in **Appendix 2: Examples of campus digital twin use cases and associated benefits**.

Once you have reflected on your goals and potential use cases, you may find it helpful to prioritize where to start. If you are weighing multiple options, try using **Appendix 3: Use case prioritization grid**. It offers a simple scoring system to help assess which use case aligns best with your strategy, data readiness, and institutional capacity.

Project phases

A use case is not necessarily confined to a single phase of a project life cycle. The campus digital twin can be effectively integrated across all stages of the building or site life cycle, providing value throughout the entire process. Think about what stages of the life cycle the digital twin use case(s) will cover, considering future expansion.

For example, consider how a use case focused on emergency response and safety can evolve throughout the life cycle of a building. During the design phase, this digital twin could be used to simulate potential emergency scenarios (such as fires or active shooter situations). In this way, the digital twin might be used to help with spatial planning and optimizing the campus layout for safety (e.g., placement of fire alarms, sprinklers, emergency lighting, muster points) or for compliance and regulation testing (ensuring the design meets relevant codes and standards).

During the building or construction stage, the digital twin can be used for the quality assurance testing of safety provisions (verifying evacuation routes and emergency access points are built as designed) or for training construction teams on safety protocols and emergency procedures specific to the campus.

In the post-construction or operation phase, the campus digital twin becomes an essential component of real-time emergency management. It can integrate with IoT devices and sensors to monitor the campus for signs of emergencies, such as fires or hazardous material leaks, and provide immediate alerts to relevant authorities. Should an incident occur, the digital twin supports detailed analysis, helping to refine future emergency plans and improve campus safety continuously.

Scope and scale

Consider the level of digital twin maturity and sophistication that reflects the appropriate level of capability, integration, and impact that you are trying to achieve. This will range from basic descriptive models to fully autonomous systems capable of optimizing and controlling their physical counterparts. Digital twin maturity is typically presented as each level building upon the previous one, leading to progressively greater benefits and capabilities.

There are several taxonomies used to describe the level of maturity of digital twins:

- Madni et al. (2019) outline a progression from pre-digital twin to digital twin, adaptive digital twin, and intelligent digital twin, highlighting increasing levels of sophistication and capability.
- Fuller et al. (2020) categorize the levels of data integration into digital model, digital shadow, and digital twin, emphasizing the depth of data connectivity and interaction. Deng et al. (2021) present a taxonomy that traces the evolution from building information modeling (BIM) to digital twin, passing through stages like BIM-supported simulation, BIM with sensors, and BIM with artificial intelligence.
- Agrawal et al. (2023) introduce classifications based on the level of automation and autonomy, ranging from dream and ambitious projects to more conditional and quick-win implementations. They also differentiate between non-routine and routine autonomy and support, reflecting the operational complexity and decision-making capabilities of the digital twin.

These frameworks collectively provide a comprehensive view of how digital twins can evolve, integrating more advanced technologies and data analytics to enhance their functionality and impact. The choice of taxonomy depends on the specific goals, resources, and context of the digital twin project.

The level of digital twin maturity will include balancing the scope of the project with the available resources, time, and team skill sets. For teaching purposes, a smaller-scale or focused digital twin may be more practical and effective at helping students to understand the principles, while a twin created for operational or knowledge-creation research purposes may be more extensive.

To help determine your appropriate scale and scope, consider the following broad levels of sophistication.

Level 1: Basic descriptive digital twin

- **Characteristics:** A basic descriptive digital twin is primarily a static digital representation of the physical entity. It includes basic data and visualization tools to describe the current state of the physical object. Users can view and monitor the system but cannot interact with it or predict future behaviors. At this level of sophistication, twins are usually limited in scope and functionality and are often used for specific, isolated use cases.

- **Data sources:** Basic data collection from a few sensors or manual data entry

Level 2: Connected digital twin

- **Characteristics:** This is an enhanced digital twin with better integration of data from multiple sources. Real-time data collection allows it to reflect current conditions accurately. Connected digital twins can provide insights into the performance and status of the physical asset through dashboards and visualizations.
- **Data sources:** Multiple sensors and IoT devices providing continuous data streams

Level 3: Informed digital twin

- **Characteristics:** An informed digital twin is integrated with advanced data analytics and visualization tools. The system can provide insights and recommendations based on data analysis.
- **Data sources:** Comprehensive data integration from diverse sources, including historical and real-time data

Level 4: Predictive digital twin

- **Characteristics:** A predictive digital twin uses advanced, predictive analytics and machine learning to forecast future states and outcomes. It can simulate different scenarios and provide optimization suggestions.
- **Data sources:** Fully integrated data ecosystem, leveraging machine learning and AI for predictions

Level 5: Autonomous digital twin

- **Characteristics:** Autonomous digital twins have a fully integrated data ecosystem, leveraging machine learning and AI for predictions. A twin at this level of sophistication is capable of fully autonomous data collection and processing with AI-driven decision-making.
- **Data sources:** Continuous data feeds from a wide range of IoT devices, legacy systems, AI models, and external data sources—fully automated and dynamically integrated

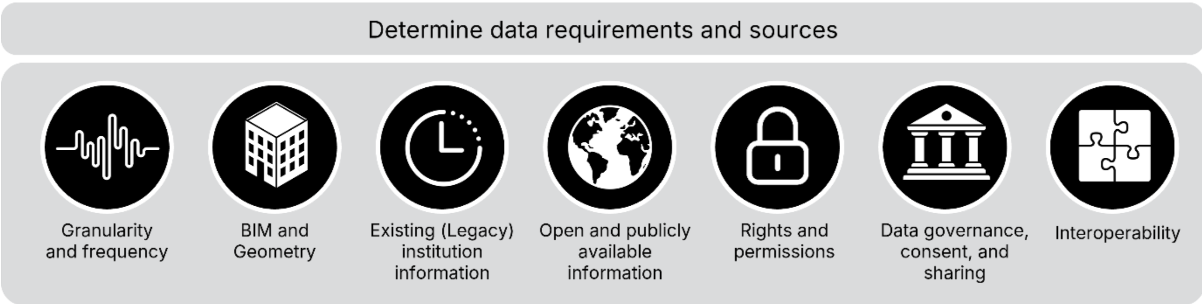
In reality, a campus digital twin may not fall distinctly into one category of sophistication. You may have certain data sources or sensors which are easier to integrate and others which require a more manual process and are influenced by factors such as data quality and integration, computing power, and cloud infrastructure. These elements may mean that your digital twin is primarily "connected", but may have an element that still remains "basic" or is able to be "informed".

As access to technology progresses, it may become easier to integrate, predict, or autonomize elements of a twin using machine learning, AI, and advanced analytics.

While the key aim for a specific digital twin must be to attain sophistication that directly affects your organization's goal, the overarching goal of the digital twin concept is to help organizations and individuals transition from document-reliant to data-informed decision-making.

Step 2: Determine data requirements and sources

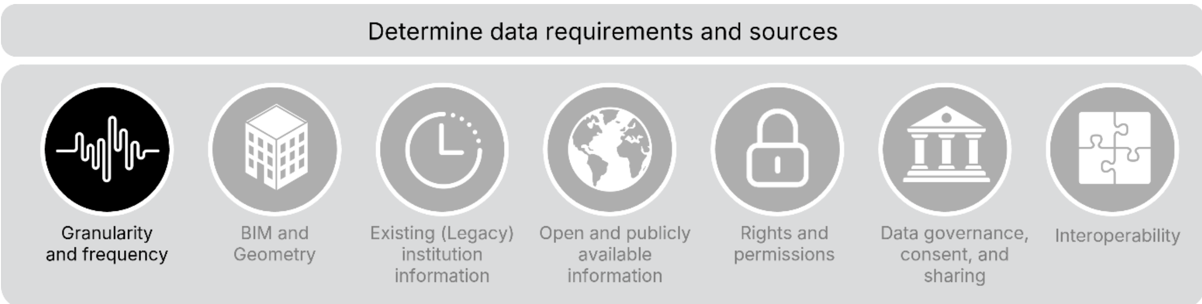
Once you've defined your digital twin's value proposition and initial use case(s), the next step is to determine the data and information required to fulfil it.



This will typically include the following:

- **Spatial data:** Floor plans, site layouts, building dimensions
- **Condition data:** Structural integrity, maintenance records, condition assessments
- **Real-time data**: Sensor readings
- **Utility data**: Gas/water/electricity usage and consumption, waste collection schedules
- **Operational data:** HVAC systems, energy consumption, occupancy data
- **Documentation:** Operations and maintenance (O&M) manuals, building codes, compliance documents

Granularity and frequency



It is important to remember that the campus digital twin is about exploration and experimentation. Therefore, it may be unrealistic to try and gather detailed information about every building or asset immediately. During the planning stage, you should start to consider what you have access to or where you might seek out the necessary information, but you do not need to assign data at this stage.

We recommend identifying one or two key buildings or teaching blocks (e.g., wings of a building or areas of campus) as a good starting point. You can either:

- plan your initial digital twin based on the data you have known access to and meets your use case
- identify a few (1–3) data points most relevant to your goals and commit to finding or building this dataset.

Granularity

Whichever method you choose, consider the granularity of information, such as the level of detail or resolution at which the data is captured and represented in the twin together with what it is to be used for. Higher granularity means more detailed data, while lower granularity means more generalized or aggregated data. For example, if the digital twin is used for detailed structural analysis or precise energy modeling, highly granular data (e.g., detailed 3D models, specific material properties) is essential. Conversely, for broader planning tasks, such as space utilization analysis, lower granularity data (e.g., floor plans, occupancy rates) may suffice.

If your digital twin is focused specifically on the use case of improving energy efficiency, you may need to collect high-granularity data that provides you with daily, hourly, or even real-time energy consumptions of individual HVAC units. If your digital twin is more broadly focused on operational efficiency, low-granularity data about monthly energy consumption per building may be enough to help you with trend analysis and broad insights.

For example, your existing data might be at any of the following levels:

- Campus level: Broad, aggregated data for holistic campus management and high-level decision-making
- Building level: Detailed data on individual buildings for operational efficiency and building-specific management
- Building component level: Highly detailed data on specific components for precise maintenance, monitoring, and optimization

For examples of types of data at each of these levels of granularity, see **Appendix 4: Granularity of data examples**.

In addition to granularity of specific data, ask yourself, “How can I find or clean the data I have to the appropriate level?” If your organization is collecting data at a different granularity than you need, you will want to ensure your implementation plan accounts for improved data collection or a way to clean and sort existing data for your purpose.

Frequency

Frequency refers to how often data is captured, updated, or refreshed within the digital twin. High-frequency data is updated more frequently (e.g., real-time sensor data), whereas low-frequency data may be updated periodically or only when changes occur. While applications such as energy management or occupancy tracking may require high frequency data collection (e.g., every 15 minutes), some use cases, such as trend analysis or historical performance reviews, may not require real-time data to provide valuable insights.

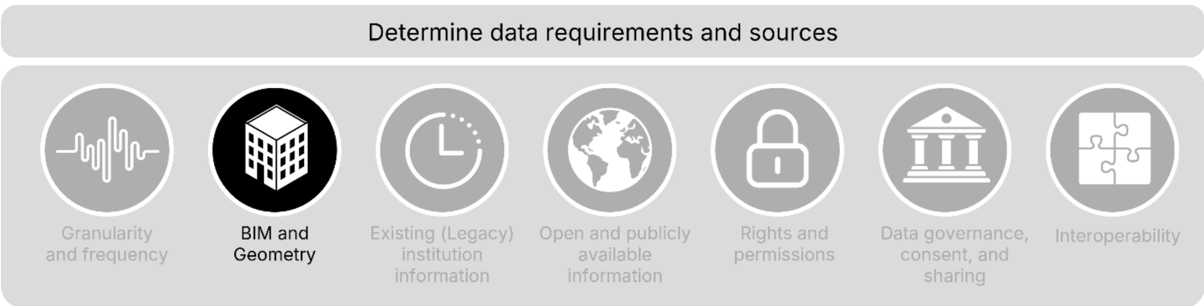
Choosing appropriate granularity and frequency

While it may be tempting to seek out high-granularity, high-frequency data where possible, this can (at times) work against your ability to achieve value quickly. Highly granular or frequent data might be manageable for a small area but could become overwhelming when scaling up to an entire campus. The more data you have, the more hardware you need and more effort you have to put into supporting and maintaining that infrastructure.

However, this also depends on the refresh model you use. For example, an event-based refresh model can maintain high fidelity to the physical entity because only the content of the latest event is posted to the twin. In contrast, extracting, transforming, and loading-based updates can become bottlenecks and require high levels of throughput over time.

During the planning stage, it is important that you prioritize data collection against your goals and decide whether to maintain the same granularity across all areas or vary it based on the importance and usage of different spaces.

BIM and geometry



While BIM models can enable your use case, they are not essential for a system to qualify as a digital twin. If your focus is on legacy assets, you are unlikely to have any form of data-rich models. If you are considering procuring a 3D model, ensure that the purpose of the information is known and that an appropriate level of geometry is specified.

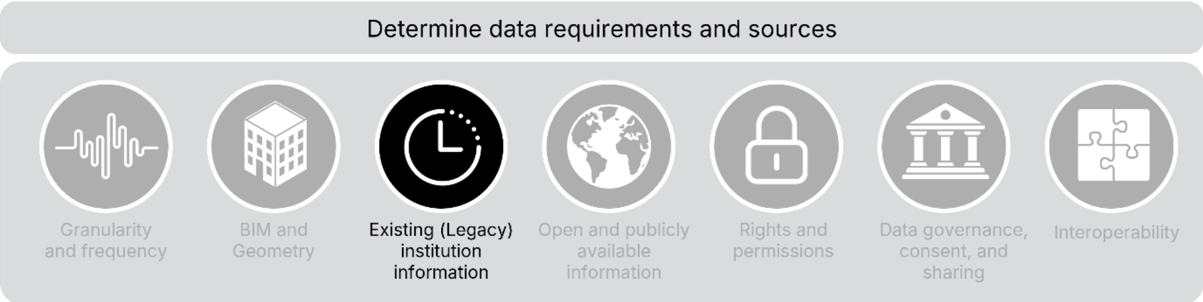
Additionally, think about the periodic updates due to maintenance or expansion activities. Maintaining an accurate 3D BIM model is attractive and useful but can be complex and maintenance-intensive unless you build that aspect into your day-to-day activities. For example, for every modification to the physical entity, there has to be an equivalent effort to keep the model(s) in sync.

Consider from the outset which domains are to be modelled, such as architecture, MEP, and structural. Also, think about your expectations from BIM: are you only interested in geometry, or do you require attributes as well? In many cases, attributes take additional effort but can be added into a future scope plan to enrich the digital twin.

Because of the use case requirements, typically a large-scale digital twin (such as a smart campus) can remain valuable with less stringent data accuracy and precision. Alternatively, a digital twin of an individual building or asset is typically more appropriate for a more granular use case. Geometric tolerance for objects within a campus is typically broader than what is required for building structure during the construction and in-use phases. This tolerance means that it is possible to use a wider variety of equipment that can be more affordable for data collection.

Traditional measured surveys work well for spaces with simple geometry, low volume, or straightforward topography. Although highly accurate, they tend to be more expensive due to equipment costs, processing time, and slower on-site data capture. You may wish to consider this type of survey to supplement or extend already existing technical 2D data that is deemed sufficient.

Existing (legacy) institution information



With an understanding of what information you need, next, you should turn your attention to establishing what information you already have, how it can be accessed, and in what form it exists. With this established you can then begin to consider any gaps and what new information and data needs to be acquired during implementation. Universities are typically long-established campuses that already have an array of existing digital records and follow years of construction projects, which can serve as initial base information. This might include CAD files and building information models (BIM) as well as physical drawings and printed documents, which may need digitization. (BIM can encompass as-designed/as-built models and 3D models used for visualization, among others). In these instances, you will need to engage the university's estates or facilities departments as stakeholders or the department(s) responsible for the curation of records management. These individuals can help you locate the information, provide helpful context to these resources, and grant you the necessary permissions and access rights.

Tip: If the university has undertaken recent building projects, the original suppliers of information, such as architects or contractors, may be able to provide access to the original handover information. In some cases, information might exist that was not handed over at the end of a project.

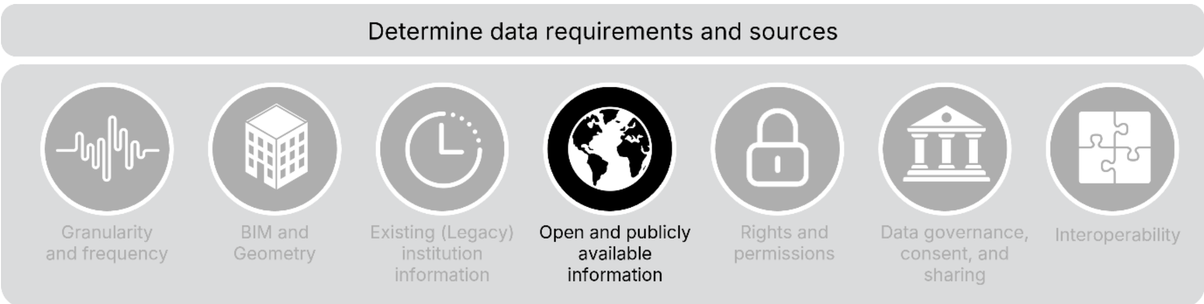
GIS data traditionally provides a 2D representation of geographic features, such as roads, grassy areas, or utility lines, often stored in vector formats like DWG files. While GIS is a valuable tool for mapping and analyzing spatial data, its limitations in depth and elevation representation can present challenges, particularly for underground features like pipes, cables, and tunnels.

Modern GIS platforms, such as Bentley OpenCities Map, increasingly support 3D modeling and data integration to address these gaps. These tools can incorporate supplementary data from technologies like lidar, ground-penetrating radar (GPR), or BIM to provide accurate subsurface details, including depth and elevation.

In many cases, GIS data includes attribute information that helps classify and distinguish between different features, such as roadways, vegetation, or utility types (e.g., water pipes vs. electrical cables). However, this information is often stored as metadata or within layered datasets, and its level of detail depends on the source and quality of the data. For example, underground utilities may be represented as simple lines or polygons, requiring additional context or georeferencing to achieve higher accuracy.

By combining GIS with advanced technologies and 3D capabilities, a campus digital twin can offer more robust and detailed spatial insights, supporting operations, planning, and decision-making.

Open and publicly available information



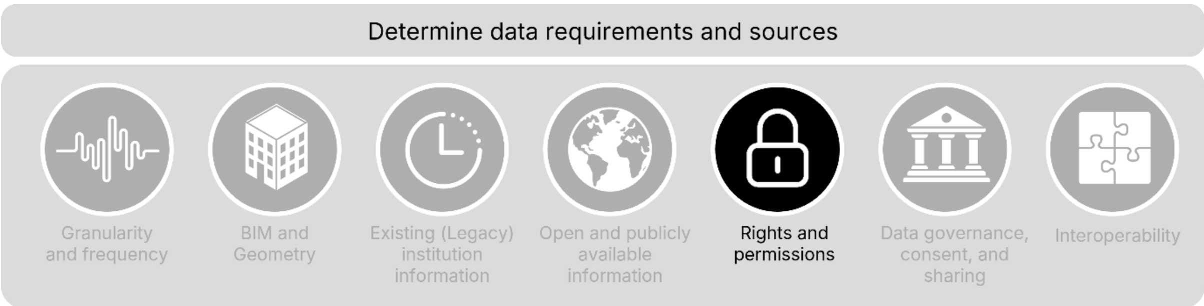
Leveraging existing internal data is a valuable way to engage with stakeholders and get wider buy-in to your project. However, internal data is not the only source of legacy information that you can obtain to support your digital twin.

Open-source data (i.e., data that is freely available for anyone to use, modify, and share) or publicly available data can significantly enhance the richness and accuracy of your model while reducing the need for extensive generative data collection.

These data sources can provide valuable information on various aspects of the campus and how a campus works within its social surroundings, helping to create a more comprehensive and functional digital twin. Open-source data can offer critical information that might otherwise be difficult or costly to obtain using primary data collection. It also ensures that your digital twin is built on reliable, verified sources and can integrate seamlessly with broader smart city initiatives to provide symbiosis and align with sustainable infrastructure initiatives happening elsewhere. As with any publicly-available and adaptable source, ensure you verify the credibility of this data and check for updates regularly as you may not control the source of this data.

For an example of open data sources that could support your campus digital twin see **Appendix 5: Open data source examples.**

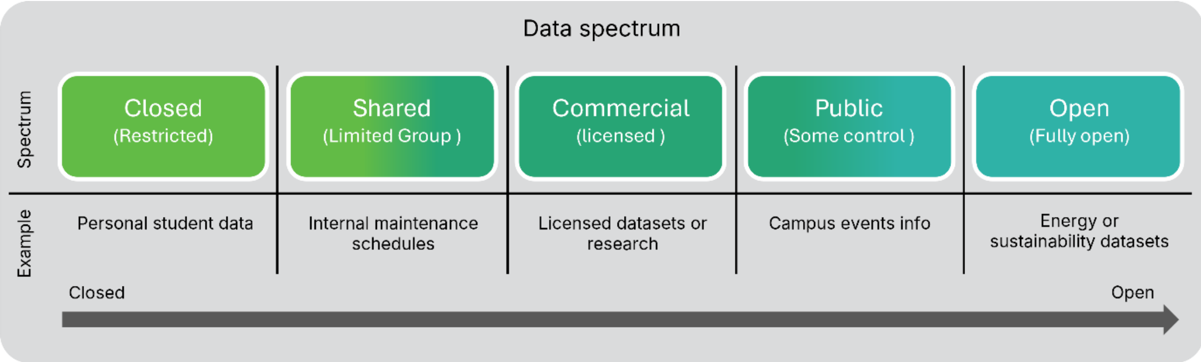
Rights and permissions



As a data-rich asset, managing data rights and permissions for data attached to your campus digital twin is critical to ensure legal compliance, data security, and ethical use. These considerations involve understanding:

- who owns the data
- who has access to the data
- how data can be used or shared.

The Open Data Institute (ODI) provides an approach for understanding the different types of data called the “data spectrum” and categorizes data permissions based on a dataset’s level of openness. The spectrum ranges from closed to open data, guiding users on how data can be accessed, shared, and used. It categorizes data into five types, which are described below.



Closed data

Closed data is restricted and can only be accessed by the owner or specific authorized individuals. Some campus data (such as security systems, personal data from student or staff records, and research data) may be classified as closed.

This data must be handled with strict privacy and security controls to prevent unauthorized access. Ensure compliance with regulations such as GDPR in Europe for handling personal or sensitive data.

Shared data

Shared data is data that is shared between specific groups, such as within an organization or with select external partners. Certain data (like campus maintenance schedules, infrastructure plans, or utility usage) may be shared within specific groups (e.g., facilities management, energy providers).

Define clear data-sharing agreements to ensure that sensitive data remains protected while allowing collaboration for campus management.

Commercial data

Commercial data is accessible under a license or for a fee. A university might license data to or from third parties, for example, subscribing to third-party demographic data or selling anonymized research outputs.

Public data

Public data is available to anyone but may have some access controls or restrictions on how it can be used. Some campus data (such as general information about campus layouts, services, or events) can be made available to the public. However, this data might still have restrictions on how it can be used.

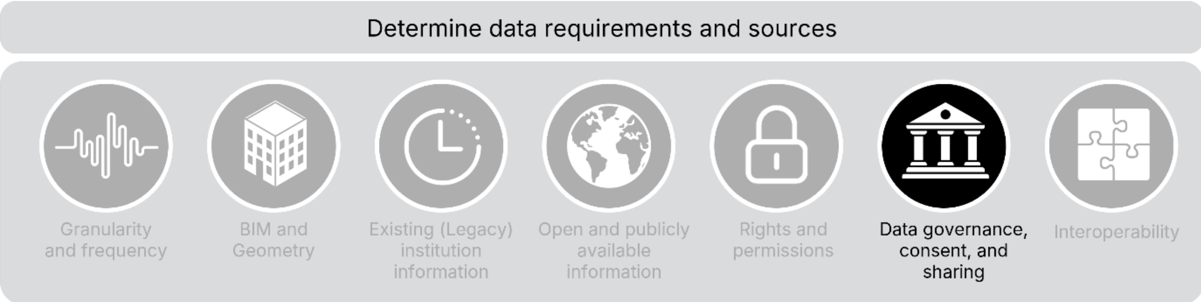
Make sure you balance transparency with security, ensuring that public data does not compromise safety or privacy.

Open data

Open data is freely available for anyone to access, use, and share without restrictions. Open data could include anonymized datasets related to sustainability efforts, energy usage, or student research outcomes that can be shared with the public or research communities. Ensure that data is properly anonymized to protect individuals while contributing to broader societal benefits like research and innovation.

For an overview of the key actions you should consider when managing data in your campus digital twin, including ownership, licensing, compliance, and ethical use, see **Appendix 6: Data rights and permissions considerations**.

Data governance, consent, and sharing



While securing appropriate rights, permissions, and consent is vital, ensuring the reliability, accuracy, and ongoing integrity of the data is equally important. Alongside managing rights and permissions, it is essential to establish responsible practices for collecting, using, and sharing data associated with the campus digital twin. This not only ensures legal compliance but also builds trust among stakeholders and reinforces ethical standards.

Informed consent

Where data involves personally identifiable information (PII), such as student or staff movement, occupancy patterns, or Wi-Fi tracking, it is important to obtain informed consent. Individuals must be aware of what data is being collected, how it will be used, and their rights regarding that data.

Data sharing agreements

When campus data is shared with third parties, such as technology partners, researchers, or government agencies, formal data sharing agreements should be established. These agreements must define access rights, permitted uses, security measures, compliance with data protection regulations (such as the General Data Protection Regulation), and obligations regarding retention or deletion.

Privacy and security compliance

All personal or sensitive data must be processed in accordance with relevant legislation, such as the General Data Protection Regulation (GDPR) in Europe. This includes safeguarding data against unauthorized access, ensuring data minimization, and establishing procedures for managing data subject rights.

You can use **Appendix 7: Sample data use consent form template** to support you in obtaining informed consent for the use of personal data in your campus digital twin and **Appendix 8: Sample data sharing agreement template** to support responsible data sharing with third parties. **Note:** The sample templates provided are for illustrative purposes only and do not constitute legal advice. Institutions should seek appropriate legal review before adapting or using these materials.

Reliability of information

Assessing the reliability of information involves evaluating its provenance, accuracy, timeliness, and suitability to identify gaps or inconsistencies. Data collected, particularly from public or legacy sources, may not reflect recent alterations, refurbishments, or maintenance activities. For example, rooms may have been divided or repurposed without being updated in existing datasets. Cross-checking against recent utility or condition surveys can help fill these gaps and improve accuracy.

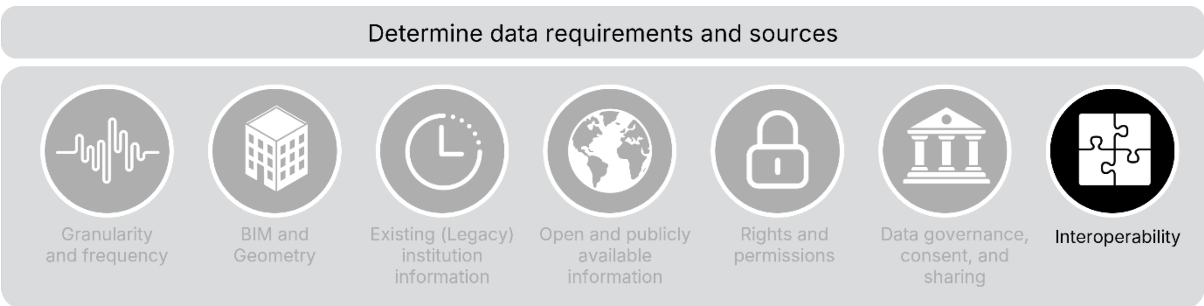
Data governance becomes relevant here. Establishing a systemic process for ensuring data is accurate, timely, and relevant is crucial. This includes defining who is responsible for data updates, setting protocols for regular data validation, and prioritizing trusted sources.

Data completeness and consistency are also key. Ensure all required data points are present, and reconcile discrepancies between datasets, such as variations in dimensions between GIS maps and BIM models. Missing metadata or documentation, such as source details or collection dates, can reduce confidence in the data.

Another critical factor is the format and transformation of data. Converting between file formats (e.g., CAD to GIS) can lead to data loss or corruption, such as missing attributes, geometric distortions, or loss of metadata. Using validation tools or QA/QC methods can help identify and address these issues.

Finally, consider temporal relevance and update protocols. Stale data can undermine decision-making, so regular updates and clear version tracking are essential. Define who is responsible for ensuring that data reflects the latest changes, and prioritize trusted sources to maintain reliability over time.

Interoperability



In **Stage 2: Implement**, you will need to go through the process of ensuring your data is interoperable, meaning it is able to operate with different networks or systems, tools, or platforms to exchange, use, and process data across different file formats seamlessly. It is about ensuring that the data in one format can be understood and manipulated by other systems or platforms without requiring significant manual adjustments or loss of information. Interoperability involves Open Standards, APIs, and the ability to federate data from different systems. Data interoperability is essential for the continuous evolution and success of a campus digital twin, supporting its ability to scale and adapt to changing needs and technologies.

During the planning stage, you should begin to consider what file formats (i.e., the specific ways that data is encoded for storage in a digital file) to request or that are most interoperable with any institution-specific technical requirements. File formats define how information is structured and what kind of data it contains, such as geometries, attributes, and metadata.

Bentley software, particularly OpenCities Planner, is designed to promote interoperability by enabling data from multiple systems, platforms, and file formats to be integrated and used within a cohesive digital twin environment. The platform supports stakeholder engagement and decision-making by allowing seamless integration of GIS, CAD, and reality data into accessible 3D city models. The following are some of the areas that Bentley software addresses to help you plan for interoperability are.

Open standards

Campus digital twins are most valuable when built on open data ecosystems. This openness allows institutions to integrate diverse tools, adapt to new technologies, and avoid vendor lock-in. Bentley iTwin uses open data standards like Industry Foundation Classes (IFC), which is crucial for building information modeling (BIM). IFC ensures that data from various BIM tools can be integrated into a cohesive digital twin without being locked into proprietary formats.

Data federation

Rather than converting all data into a single format, OpenCities Planner supports data federation, which allows various datasets to coexist within the platform. Data from different sources—like BIM, GIS, IoT sensors, and reality models (e.g., from photogrammetry or lidar)—can be accessed and visualized together without needing to merge or convert everything into one file type.

This approach also applies to non-graphical data, such as disparate engineering and maintenance data sources. This helps universities bring together diverse data sources for more comprehensive campus management.

APIs and SDKs for custom integrations

The Bentley iTwin API (application programming interface) and SDK (software development kit) allow developers to create custom applications or workflows that can extend the capabilities of the digital twin. This is particularly useful for universities that want to develop bespoke tools for their campus or integrate the twin with existing systems (e.g., energy management or smart building solutions). These APIs also enable interoperability with external platforms such as ArcGIS or SAP, which might be used for campus operations.

Integration with IoT and real-time data

iTwin IoT facilitates the integration of real-time sensor data from IoT devices across the campus. This interoperability allows the digital twin to update dynamically as conditions (such as energy use, occupancy levels, or environmental conditions) change.

IoT devices across different vendors and platforms can be integrated using Bentley's solutions, ensuring that sensor data is accessible and usable regardless of the technology provider.

Visualization and collaboration

With OpenCities Planner, different stakeholders can view and interact with the digital twin through a web-based platform, ensuring accessibility and collaboration regardless of the tools they typically use. This cloud-based approach means that data from multiple sources and formats can be visualized and explored in a single, integrated environment.

Geographic information system (GIS) integration

iTwin supports integration with GIS (such as Esri's ArcGIS), allowing for the seamless use of geospatial data alongside BIM and IoT data. This interoperability is important for campus planning, as geospatial data often plays a critical role in managing infrastructure and land use.

Versioning and data lineage

The iTwin Platform tracks changes to iModel-based BIM data over time, ensuring that all stakeholders are working from the latest information. This traceability ensures that as data evolves, it can still interact with other data sources correctly, maintaining interoperability across different project phases and departments. It is equally important to apply similar versioning and data lineage practices to non-iModel data to ensure consistency and interoperability across all data types.

File formats

OpenCities Planner supports a wide range of file formats for visualizing and presenting digital twin content in an interactive, web-based environment. It is designed to handle 3D models, geospatial data, and reality capture content from various sources, making it well-suited for communicating complex information to stakeholders.

Some of the key file formats supported (directly or via-processing) include:

- BIM and CAD formats: IFC, DGN, DWG, RVT (via conversion)
- 3D modeling formats: OBJ, 3DS, FBX, STL, SKP (sketchUp), DAE (Collada)
- Geospatial formats: SHP, KML, GeoJSON
- Point cloud and reality capture formats: LAS, LAZ, E57 (typically converted to 3D Tiles)
- Other formats: JT, VUE, SKP (via conversion)

Step 3: Establish enabling technologies

Now that you understand the types of information and data needed for a campus digital twin, the next step is to create an implementation plan that ensures your technology architecture is open, interoperable, and scalable. "Technology architecture" refers to the various technologies, systems, and components that interact to support the digital twin. Your implementation plan is like a blueprint, detailing how the selection and integration of hardware, software, networking, data management, and security solutions will enable the effective creation, operation, and evolution of the digital twin.

Bentley recognizes the value of infrastructure digital twins will come through technology integration; no single organization or technology solution will solve all the problems in a vacuum. The Bentley iTwin Platform was designed to facilitate interoperability by acting as a central integration layer, while tools like OpenCities Planner and iTwin IoT provide specialized capabilities for visualization and live data streaming.

The quickest way to get your campus digitally established is by using a few core Bentley components. These comprise **iTwin Capture Modeler** and **OpenCities Planner**. As your digital twin gains more maturity, **iTwin IoT** can also be deployed to enhance the digital twin by adding a dynamic, real-time dimension to it, transforming it from a static model into a living representation of the campus, while those wishing to develop their own apps should consider the **iTwins Platform**.

We explore the workflows in more detail later. Below is a high-level overview of key information you need to know.

Create the data—iTwin Capture Modeler

Bentley iTwin Capture Modeler serves as the critical first step in developing a campus digital twin by accurately capturing reality data through technologies like drones and laser scanners. This detailed data provides a precise 3D model of the campus, ensuring that the digital twin is a true reflection of the physical environment. The captured data includes everything from buildings to infrastructure and landscapes, creating a comprehensive foundation for the digital twin. The outcome of this is a 3D reality mesh.

iTwin Capture Modeler's versatility allows you to seamlessly reconstruct subjects of various scales, ranging from centimeters to kilometers, photographed from the ground or from the air. There is no limit in the precision of the resulting 3D model other than the resolution of the input photographs and camera parameters (such as focal length and sensor size).

Find out more here.

Consolidate the data—OpenCities Planner

Once this reality data is captured and processed, it flows into OpenCities Planner, where it is integrated with data from other sources, such as engineering data, documents, maintenance records, work orders, IoT sensors, BIM and CAD files. OpenCities Planner then uses this aggregated data to create a unified and interactive view of the campus, where information and data is tagged and located. OpenCities Planner allows stakeholders to visualize and explore the digital twin in an interactive 3D environment, supporting insights into campus operations and infrastructure through integrated, up-to-date data.

The integration of iTwin Capture Modeler and OpenCities Planner ensures that the digital twin is visually rich and geographically accurate, providing a clear and interactive representation of the campus. OpenCities Planner uses high-fidelity models from iTwin Capture Modeler to support planning, stakeholder communication, and informed decision-making. While it does not perform real-time monitoring or advanced analytics natively, it serves as an effective platform for presenting up-to-date data and visual scenarios to support campus development and management.

The resulting campus digital twin can be shared using a URL link, simplifying the process of engaging with the twin and making it an effective tool for collaboration, education, and stakeholder communication.

Find out more here.

Feed the twin—iTwin IoT

As the next step in the development of a campus digital twin, iTwin IoT plays a crucial role in bringing dynamic, real-time data into the digital model. Once the static data—like buildings and infrastructure—is accurately captured and integrated through iTwin Capture and OpenCities Planner, iTwin IoT adds a layer of live information. This includes data on environmental conditions, energy usage, occupancy, and other operational parameters that are constantly changing. For example, sensors installed across the campus can provide continuous updates on temperature, humidity, air quality, and occupancy levels in different buildings.

Find out more here.

Enhance the twin—iTwin Platform

The iTwin Platform is an open, scalable, vendor-agnostic cloud platform designed to enable the creation, visualization, and management of digital twins. It serves as the foundational technology for developing digital twin applications. While the iTwin Experience is aimed at end-users who need to interact with and analyze digital twins, the iTwin Platform offers a suite of APIs, services, and tools that developers and integrators can use to build custom applications tailored to specific needs. For example, a university might use the iTwin Platform to develop a custom app for monitoring energy usage across campus buildings, integrating data from IoT sensors, and generating reports.

Find out more here.

Legacy systems

The university may already have components in place that are capturing huge amounts of real-time data as part of your existing technology stack, such as intelligent building control systems or asset sensors. For example, you may already collect data through security cameras; door sensors enabled by institutional ID access; fire or carbon monoxide sensors; library, space, or technology asset management; or smart lighting data.

You should assess the data you identified from Step 2 against your campus's legacy systems and determine its current compatibility with Bentley products. To assess compatibility, focus on identifying the type of data and file formats generated (e.g., DWG, RVT, IFC, GIS data).

Digital twin technology architecture

To manage complexity and ensure scalability, digital twin systems are typically structured into distinct architectural layers, each with defined roles and interfaces. In this sense, "layers" refers to a distinct level or component of the overall system that performs specific functions and interacts with other layers to achieve the overall objective of the digital twin. Bentley's iTwin capabilities can help you organize and manage how these layers interact to enable data collection, transition processing, and visualization.

These layers are typically organized to manage the complexity of the system and ensure that the digital twin operates efficiently and effectively. Take some time to sketch or map out your proposed digital twin architecture and how the various layers come together.

There is no single path to creating a digital twin. Each university's technology ecosystem will look different, depending upon its starting point, technical capabilities (such as in-house coding expertise), and the specific goals it aims to achieve.

Common layers

The following are some of the common layers found in digital twin system architectures.

Hardware layer

The hardware layer, consisting of essential physical infrastructure and devices for data collection and communication, serves as the backbone of the digital twin. University campuses typically rely on high-speed LAN, WAN, and wireless gateways to facilitate seamless connectivity between sensors, servers, and user devices. IoT devices such as environmental sensors, occupancy trackers, and utility meters play a critical role in capturing real-time data, while reality capture technologies—including drones, cameras, and lidar systems—provide detailed spatial information.

Many universities already possess legacy systems, such as intelligent building controls, security cameras, and smart lighting, which can be integrated into the digital twin architecture to enhance its operational scope and effectiveness.

API (third-party)

APIs act as a critical integration layer, enabling the digital twin to connect seamlessly with external platforms and datasets. Standard APIs are used to interface with building management systems (e.g., BACnet), GIS tools (e.g., ArcGIS API), and IoT protocols (e.g., MQTT or CoAP). These interfaces ensure smooth data exchange and interoperability across systems.

Additionally, open data integration brings in valuable external datasets, such as weather information, traffic conditions, and geospatial resources to enrich the twin's functionality. For bespoke requirements, custom APIs allow universities to connect proprietary tools and platforms, ensuring that the digital twin aligns with specific institutional needs.

Middleware (university servers)

Middleware serves as the intermediary layer that bridges hardware and higher-level systems, ensuring seamless communication and data processing. It manages the transformation of raw data from sensors and other devices into standardized formats that can be utilized by the digital twin. This layer also handles data exchange between IoT devices, building management systems, and university-specific tools such as learning management or facilities software.

By enabling interoperability between legacy and modern systems, middleware ensures the smooth operation of the digital twin and its ability to adapt to future technological changes.

Aggregation and storage

This layer focuses on collecting, organizing, and storing data to provide both real-time insights and long-term analytics. Real-time data is streamed from IoT devices, sensors, and campus systems into the digital twin, where it is aggregated into a unified dataset. Historical data storage allows for trend analysis, predictive modeling, and operational planning, offering valuable insights into campus performance over time.

Universities can manage data through layered repositories, with specific departments handling updates for each layer, such as annual aerial imagery or real-time IoT feeds. This structured approach ensures the digital twin remains comprehensive and up to date.

Evaluation and calculation (university servers)

University servers handle the processing and analysis of aggregated data, enabling actionable insights and operational improvements. Advanced analytics engines perform tasks such as trend analysis, anomaly detection, and scenario simulations. AI and machine learning capabilities allow for predictive maintenance, resource optimization, and the modeling of future campus scenarios.

By balancing data granularity, this layer ensures efficiency. For instance, highly detailed data might be used for structural analysis, while broader, less granular data supports campus-wide energy management or space utilization efforts.

Geometrical and visual representation

The geometrical and visual representation layer provides a detailed and dynamic view of the campus through advanced modeling techniques. This includes 3D reality meshes and point clouds created using drones, lidar, or photogrammetry, which offer precise spatial representations. BIM models add further detail, covering architectural, structural, and system-specific aspects of campus buildings. Dynamic overlays of real-time data on these models enable users to interact with and explore the digital twin.

This layer can begin with basic representations and progressively incorporate advanced elements such as IoT data and predictive analytics for a richer, more functional model.

Tabular data visualization

Tabular data visualization complements the graphical elements of the digital twin by providing simplified access to information that is not inherently visual. This layer includes dashboards that display key metrics—such as energy consumption, occupancy rates, and maintenance schedules—in real time.

Reports and charts summarize historical trends and predictive insights, offering a clear overview for decision-making. Customizable views ensure that different stakeholders, such as facilities managers, researchers, or administrators, can access data tailored to their specific needs, enhancing usability and operational efficiency.

Integration

Integration is essential for connecting the digital twin with external systems and tools to expand its capabilities and functionality. Digital twin platforms like iTwin provide a robust foundation for data integration, advanced analysis, and visualization. Visualization tools such as OpenCities Planner or Unity enhance the twin's graphical and simulation capabilities. Additionally, integration with systems like GIS tools, energy management platforms, and smart building software ensures the twin is a central hub for campus operations.

Modular design principles ensure compatibility with existing systems and facilitate future expansions as new needs arise.

User interface layer

The user interface layer provides an intuitive, accessible entry point for stakeholders to interact with the digital twin. Web-based portals allow users to visualize and manage campus systems from any browser, while mobile applications enable on-the-go monitoring and control. Immersive technologies like AR and VR enhance user engagement, making it possible to explore campus scenarios in a hands-on, interactive way.

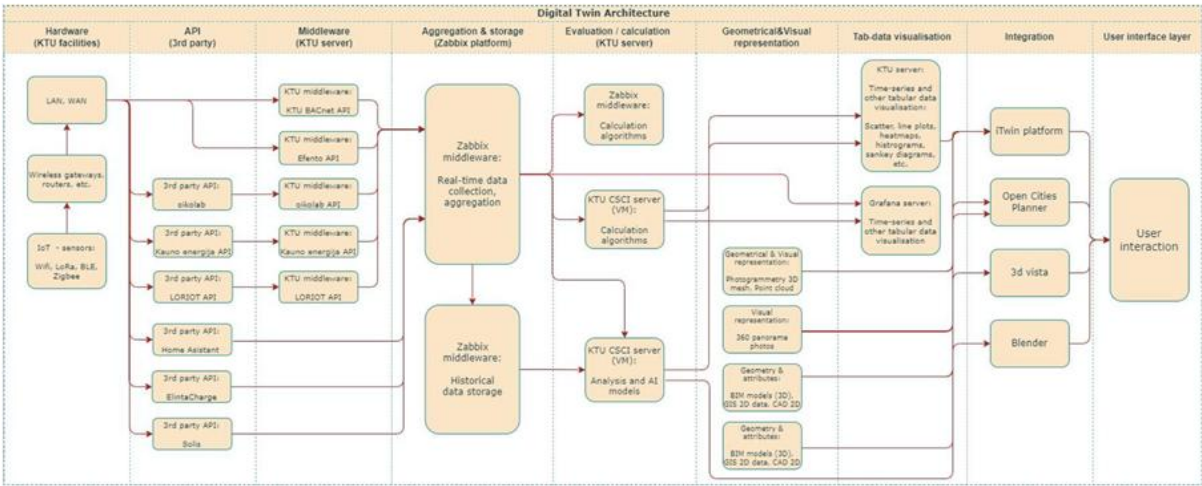
Role-based access ensures that each stakeholder, from students and faculty to administrators and facilities teams, receives customized views and controls relevant to their roles, fostering effective use and collaboration.

Example – Dublin City University (DCU)

DCU used a low-cost capture workflow to build out the geometrical layer of its campus digital twin. LiDAR-enabled smartphones, combined with apps like Polycam and iTwin Capture, were used to generate 3D meshes of buildings, rooms, and external objects. These were processed into BIM-compatible models and visualized through platforms such as OpenCities Planner and Unreal Engine, enabling integration with other system layers. The approach demonstrates how spatial accuracy and visual depth can be achieved without high-end scanning hardware. See **appendix 17** for more details.

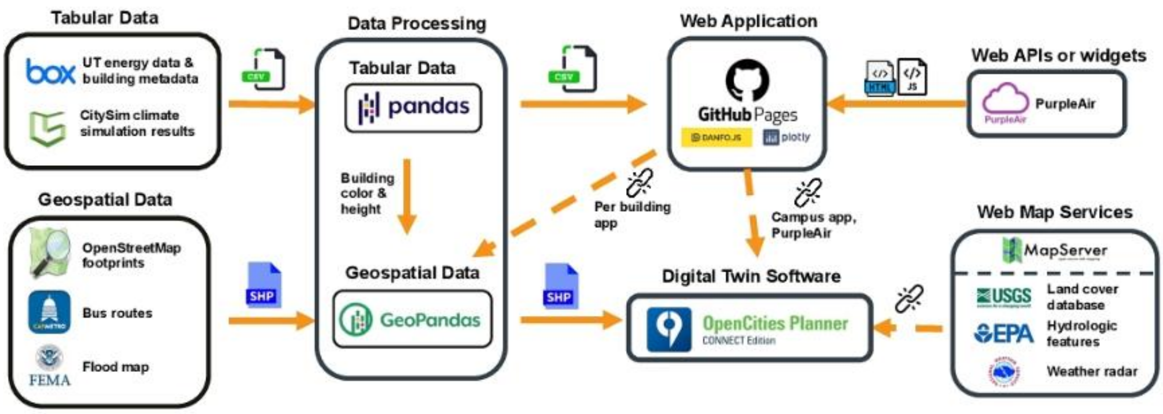
Example – Kaunas University of Technology

KTU developed a full-stack campus digital twin by integrating IoT sensors (via WiFi, LoRa, BLE, Zigbee), third-party APIs (e.g., Solis, Efento), and its own middleware. Real-time and historical data is aggregated using Zabbix and analyzed using AI models running on university servers. The twin combines photogrammetry, 3D meshes, BIM, and GIS data, visualized through OpenCities Planner and 3D Vista. Dashboards built with Grafana display live metrics, enabling both operational monitoring and predictive planning. See **appendix 18** for more details.



Example: University of Texas at Austin

UTwin, a campus-scale digital twin at the University of Texas at Austin, integrates building energy data, air quality metrics, and geospatial sources (e.g., building footprints from OpenStreetMap) into OpenCities Planner. It combines tabular and shapefile data processed using Python libraries such as Pandas (and Danfo.js in the browser) and is shared through a public-facing web app hosted via GitHub Pages. Its strength lies in data integration, lightweight processing, and live web deployment, rather than in high-fidelity geometry or advanced 3D modelling.



Where does Bentley come in?

iTwin Capture creates the foundation for the digital twin by transforming data from reality capture devices like drones, lidar, and cameras into precise 3D models. These models provide an accurate representation of the campus and serve as the base for integrating additional data layers.

The **iTwin Platform** acts as the backbone of the digital twin, aggregating data from BIM models, GIS systems, and IoT sensors into a unified, accessible environment. Using open standards like IFC and GeoJSON, it ensures seamless interoperability between systems and tools, enabling a comprehensive view of campus operations.

iTwin IoT connects real-time data sources, streaming updates from energy meters, environmental sensors, and occupancy trackers directly into the digital twin. This enables dynamic insights, such as live energy usage or space utilization, to be reflected instantly for immediate decision-making.

OpenCities Planner serves as a web based platform for visualizing and sharing the digital twin in an interactive 3D environment. It enables stakeholders to explore models, overlay contextual data, and collaborate easily via a simple URL, supporting planning, communication, and engagement across the campus.

Together, these tools form a flexible and open ecosystem, enabling universities to design, scale, and evolve digital twins tailored to their goals, infrastructure, and data maturity: iTwin Capture generates the models, iTwin Platform integrates and manages data, iTwin IoT keeps it live, and OpenCities Planner makes it accessible and interactive. This combination empowers universities to create, scale, and optimize their digital twins with ease.

You can use **Appendix 9: Digital twin architecture planning template** to help you structure your thinking and document key decisions when planning your digital twin architecture.

Step 4: Data collection strategy

Now that you have an understanding of what information currently exists, it is inevitable that you will need to fill in any gaps in data and information. You should plan your data collection approach considering the types of data you need. Ensure that your strategy addresses ethical considerations, such as data privacy and security.

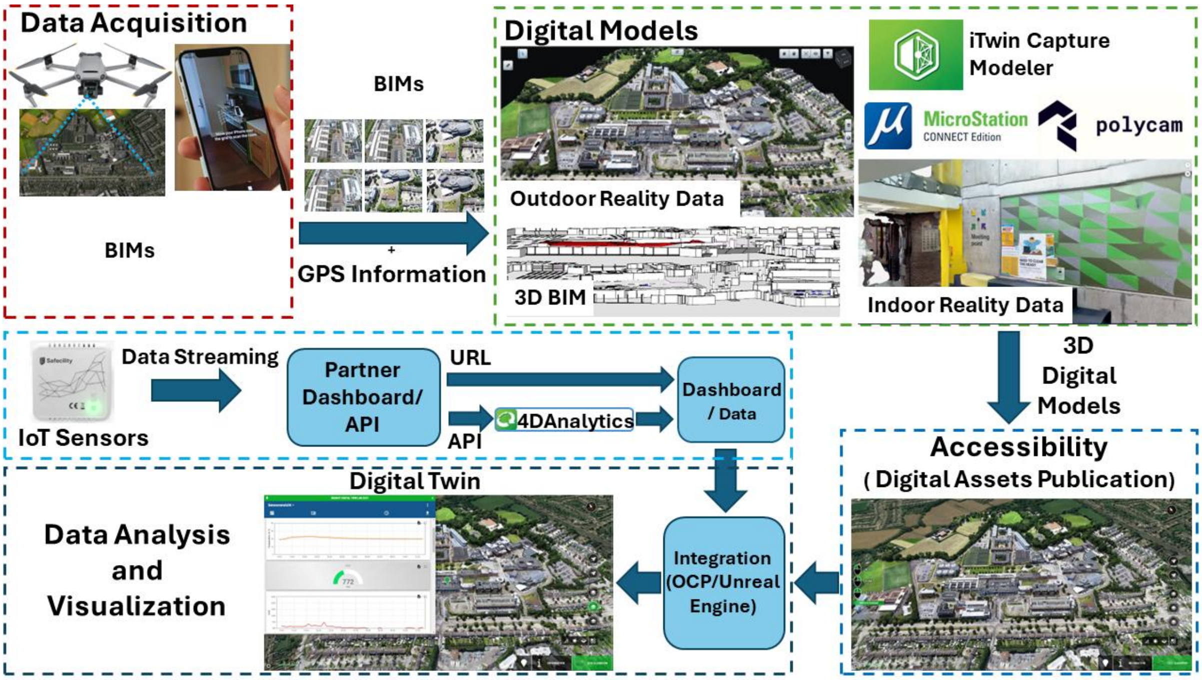


Figure 3: End-to-end digital twin methodology fo integrating drone, handheld LiDAr, and BIM data for indoor and outdoor environment - DCU

Data capture

Data and information capture can be aimed to address information gaps (such as missing or incomplete documents, drawings, reports, certificates, or surveys) and data gaps, such as missing or incomplete data within asset management systems. Information can be further broken down into non-graphical and graphical information. In addition to gaps in non-graphical information, there may also be gaps where paper documents and other analogue formats still need to be digitized.

There are a variety of methods that universities should consider for data capture. These may include procuring the services of a third party or, in some cases, undertaking data capture yourself. When choosing which data capture methods to employ, it is important to choose techniques that are appropriate to your university's requirements and budget.

Typically, there are two types of data acquisition:

- **Acquisition of new data:** This process may involve capturing data about new or existing assets. For example, new data is generated and exchanged during the design and construction process of a new build or renovation project, for example, this can include 3D models, asset registers, and commissioning data.
- **Acquisition of existing (legacy) data:** This process involves identifying and extracting information that already exists about an existing asset. Legacy information may be unstructured, incomplete, or not yet digitized. This type of information may be available and retrievable from a central data repository,

discs, or ring binder, or it may not be available at all or may be of low quality and inaccurate

A university campus is likely to consist mostly of existing assets and will require an approach that is an appropriate and proportionate blend of acquisition methods. This might comprise a blend of data capture techniques, such as measured surveys and condition reports, 2D topographical, 3D digital scans, photogrammetry and/or other proprietary tools and hybrid systems.

In addition to one-time data capture, universities may also benefit from ongoing or periodic data acquisition, particularly when real-time insights are required. This could include installing sensors to monitor occupancy, temperature, or energy usage.

For capturing geometrical data, it's crucial to select a method that balances cost, efficiency, speed, and accuracy for your project or building. Where legacy information may be of low quality or accuracy, you may choose to capture new data or to retain the data with limitations as long as those limitations are accurately signposted. The option you choose will depend on your data requirements and whether your digital twin use case will require that data to be accurate or merely catalogued for future updates.

Reality modeling

Perhaps the quickest means to develop the campus digital twin is via reality capture modeling. This involves employing methods like photogrammetry and 3D laser scanning to develop a detailed digital model, known as a reality model. These methods are especially practical in busy environments such as a university campus setting.

This document isn’t intended to be an in-depth guide on the different capture techniques; however, it is important to have an understanding of the broad concepts and the difference between lidar and photogrammetry within the context of iTwin Capture software to leverage its full capabilities.

Figure 4: Drone-generated reality mesh of DCU's Glasnevin campus. This was processed using Bentley's iTwin Capture Modeler, providing a detailed and georeferenced base layer for further integration

Photogrammetry

Photogrammetry uses photographs to measure distances and create 3D models. It involves capturing multiple overlapping images of an object or landscape from different angles. The images are processed within iTwin Capture Modeler, which identifies common points between them to construct the 3D shape of the objects or terrain.

Photogrammetry typically relies on cameras mounted on drones, airplanes, or other platforms. It requires good lighting and clear visibility, as it relies on the quality and clarity of the images taken.

Photogrammetry can be categorized into four methods:

- Satellite photogrammetry
- Aerial photogrammetry (e.g., photographs taken from an aircraft)
- UAV (unmanned aerial vehicle) photogrammetry (e.g., aerial photographs taken from a drone)
- Terrestrial photogrammetry

Each method offers varying levels of detail and coverage, from large-scale city mapping to detailed building-level documentation. Satellite and aerial photogrammetry are best suited for broad, city-scale applications, while UAV and terrestrial methods provide more detailed, close-range data, especially for individual buildings or specific structures.

3D scanning: Lidar (light detection and ranging)

3D laser scanning, commonly known as lidar, uses laser beams to capture the physical environment and create a "point cloud model": a dense collection of data points that forms a digital replica of the scanned area.

This technology can be classified into four methods:

- Aerial 3D laser scanning
- Autonomous 3D laser scanning
- Terrestrial 3D laser scanning
- Handheld 3D laser scanning

Each lidar method varies in its application. As with photogrammetry methods, aerial and autonomous scanning are suitable for large-scale city environments, while terrestrial and handheld scanning provide high levels of detail for smaller areas or specific objects.

3D scanning is highly accurate, especially in measuring elevation and distance. It can capture fine details and is particularly effective in environments with complex structures or where precise measurements are needed. Lidar can detect small features on the ground, such as vegetation, buildings, and small terrain variations, even under canopy cover.

Hybrid approach

Photogrammetry is typically quicker in the reality capture process and the processing time to produce 3D mesh models when compared to 3D laser scanning. It also tends to be less expensive than 3D laser scanning, especially for large-scale projects, as it primarily relies on standard digital cameras and drones. However, while photogrammetry provides good visual detail, it may not achieve the same level of geometric accuracy as 3D laser scanning, particularly for complex or intricate structures.

Lidar is versatile and can be used both indoors and outdoors, making it suitable for capturing detailed models of campus buildings, including interiors, mechanical systems, and structural elements.

Often, the most effective strategy for developing a campus digital twin is to combine both methods to varying extents. Photogrammetry can be used to capture the broader campus environment, while 3D laser scanning can focus on detailed, high-precision areas such as building interiors or a single piece of critical infrastructure.

By combining photogrammetry and 3D laser scanning data, iTwin Capture generates a **reality mesh** that is both visually detailed and geometrically precise. This hybrid approach ensures that the reality mesh not only looks accurate but also corresponds closely to the physical dimensions and structures of the real-world environment.

In some instances, you may even consider enhancing visual quality, by retouching reality meshes using software such as Unreal Engine.

Figure 5: The Smart DCU team enhanced visual quality by retouching reality meshes using Unreal Engine, to help improve vegetation, furnishing and recognizable features.

Choosing a combination of tools

Drones offer flexibility and broad coverage. Ground-based cameras provide detailed visuals. Lidar scanners deliver high precision. Specialized multi-directional systems ensure comprehensive coverage of complex environments. By strategically combining these technologies, you can ensure that your digital twin is accurate, detailed, and fit for its intended purpose.

Drones (unmanned aerial vehicles—UAVs)

Drones are highly effective for capturing large outdoor areas, such as campus grounds, building exteriors, and hard-to-reach locations like rooftops and towers. Equipped with cameras or lidar sensors, drones can collect two types of data: high-resolution images for photogrammetry or point clouds for precise measurements using lidar.

Drones offer a flexible and cost-effective way to gather data quickly over large areas. However, factors like weather conditions, flight permissions, and battery life must be considered. While ideal for exteriors, drones are typically less suited for indoor environments due to space constraints and limited GPS reception.

Figure 6: Drone demonstration

When capturing data with a drone, it is strongly recommended to use a flight planning application to optimize flight paths and ensure thorough data collection. Additionally, drone operation often requires a license, depending on the regulations in your country. Be sure to familiarize yourself with local laws, which may include rules about flying over populated areas, maintaining a specific distance from structures, and adhering to maximum altitude limits.

Figure 7: Drone flight planning

Drone survey best practice tips

- **Plan a structured flight path** using apps like DJI Ground Station Pro. Grid or lawnmower paths ensure consistent coverage.
- **Aim for 70-85% overlap** between images (both front and side) to ensure full coverage and successful 3D reconstruction
- **Adjust altitude based on site size and required detail**. Lower altitudes offer better resolution but increase flight time and data volume.
- **Fly during cloudy or overcast conditions** to reduce glare from white surfaces or glass.
- **Minimize risk and comply with local regulations**, avoid flying over people or in restricted airspace, and follow licensing requirements
- **Bring spare batteries if surveying** large areas

For example flight parameters used in a real world campus survey (including resolution, altitude, overlap, and duration), see **Appendix 17: Smart DCU Case Study.**

Cameras

iTwin Capture Modeler supports a wide range of cameras, including mobile phones, compact digital, DSLR, fisheye, photogrammetric and multi-camera systems. It can even process still photographs or extracted video frames from digital video cameras. iTwin Capture Modeler natively supports photographs in JPEG and TIFF formats. It can also read some of the more common RAW formats.

Remember that you do not always require high-end equipment. For example, you could use a handheld smart phone camera, but you may need more photos than if you were using a high end DSLR camera. (The more megapixels captured in a single image, the fewer photos you need to achieve high-quality results.)

A handheld camera allows you to easily capture images from underneath objects, something a drone cannot do. However, handheld devices cannot capture aerial images of roofs, as they are limited to what is visible from the ground.

Capturing indoor spaces and objects

Indoor spaces and smaller campus objects can be captured quickly using consumer-grade devices such as the iPhone 14 Pro Max and apps like Polycam. These tools allow you to create 3D meshes or basic BIMs of rooms and objects with minimal setup.

For detailed guidance, including specific techniques for rooms, furniture, and objects of interest, see **Appendix 17: Smart DCU Case Study.**

Tool selection

Selecting the right tool for each capture and integration task is essential to achieving a practical and scalable campus digital twin. The images below illustrate how different tools and capture methods were combined across Smart DCU's digital twin project.

- Outdoors were captured via drone photogrammetry using iTwin Capture Modeler
- Indoor spaces and objects were modeled using Polycam on an iPhone 14 Pro Max
- Buildings were visualized and refined in Twinmotion
- All models were ultimately integrated using OpenCities Planner and Unreal Engine

This layered workflow allowed DCU to build and scale the campus digital twin incrementally, using tools appropriate for each task. A detailed breakdown of the tool selection is provided in Appendix 17.

Lessons learned: Tips from real campus projects

As you plan and execute your digital twin data collection strategy, keep these practical insights in mind, based on real-world university implementations:

- Cloudy days are best for drone capture: Overcast conditions reduce glare, especially on white surfaces or glass.
- Glass and vegetation do not scan well: These surfaces often produce distorted meshes. Consider replacing them with high-quality 3D assets.
- Use photogrammetry for small, detailed objects: Items such as furniture scan better with photos only (not LiDAR).
- Collapse large BIM files by material before import into Twinmotion to improve performance and simplify editing.
- Scan in modules: Capture rooms, buildings, and objects separately, then integrate them in stages. This avoids overwhelming your team or tools.
- Start with what you have: Legacy drawings, handheld cameras, and basic photogrammetry apps are often enough to begin.

For extended insights, see the detailed breakdown in **Appendix 17: Smart DCU Case Study.**

Appendix 10: Data collection checklist provides a handy checklist of things to consider when assessing your data needs, locating legacy information, and planning new data capture activities for your campus digital twin.

To help you plan and organize your data collection activities, consider using a data collection checklist with four key areas:

1. **Identify the data you need:** Define what is required to support your digital twin use case. Consider including:
    - 3D campus models (indoor/outdoor
    - IoT sensor feeds (occupancy, temperature, energy use)
    - BIM files for buildings
    - GIS and map data
2. **Assign responsibilities and define sources:** Clarify who will collect, manage, or supply each dataset, and where the data will come from.
    - Internal departments (e.g. estates, I.T., research office)
    - External partners (e.g. IoT vendors, consultants)
    - Existing systems (e.g. BIM servers, GIS portals, databases)
3. **Capture and process data:** Use the appropriate tools and methods to collect and convert data into usable formats for your digital twin:
    - Drone surveys and photogrammetry
    - LiDAr and handheld scanners
    - BIM models (New or converted from floor plans)
    - Sensor integrations and live data APIs
4. **Document formats, storage, and access:** Record key information such as file types, storage locations, owners, access rights, and update responsibilities.

To help you record how your data is formatted, stored and accessed, use **Appendix 11 Data documentation and management template**. This doesn't have to be overly complex, but having a clear record of what data you are collecting, in what formats, and who is responsible for it will save time and reduce risks.

Step 5: Sensor integration plan

A well-thought-out sensor integration plan is essential for creating a dynamic digital twin that evolves with real-time data, rather than remaining a static 3D model. High-end sensors provide greater accuracy, but they are not always necessary. You can begin with lower-cost sensors for proof-of-concept projects that can deliver meaningful insights with minimal investment, such as monitoring temperature, occupancy, or energy consumption. Assess existing campus sensors and focus on areas with modern infrastructure to build a foundation before expanding to older systems.

Types of sensors

Sensors used in smart university applications can be broadly categorized as follows.

- **Fixed sensors:** Installed in permanent locations, these sensors provide consistent and reliable data due to their stable position. Examples include environmental sensors for monitoring conditions like temperature, humidity, and air quality, as well as noise sensors for tracking sound levels in designated areas.
- **Equipment-based sensors:** Integrated directly with machinery or systems, these sensors focus on monitoring operational performance. Common examples include energy sensors attached to HVAC systems for tracking power consumption or system efficiency.
- **Handheld sensors:** These portable devices allow for flexible, on-demand data collection by users. Tools such as handheld laser scanners and cameras are ideal for capturing spatial or visual data in areas that might not be accessible by stationary equipment.
- **Wearable sensors:** Designed to be worn by individuals, these sensors can track environmental factors like air quality or noise exposure and, in some cases, monitor user activity or movement within a space.
- **RFID sensors:** Passive RFID sensors are ideal for localization, tracking, and inventory management. They operate without a dedicated power source and are often used for applications like managing library books or IT equipment.

To achieve sustainability and long-term interoperability, select sensors that minimize energy consumption and align with open standards (e.g., MQTT, Zigbee, HTTP). These protocols ensure seamless data transmission and integration with platforms like Bentley iTwin. Consider operational factors such as battery life, wired vs. wireless connectivity, and compatibility with existing campus networks.

Case study: The Smart DCU team used different sensor types to capture environmental conditions. The figures below shows the WIA dashboard tracking 40 sensors across rooms and HiDatai's edge-based system using computer vision. These contrasting examples illustrate the flexibility of integrating various technologies.

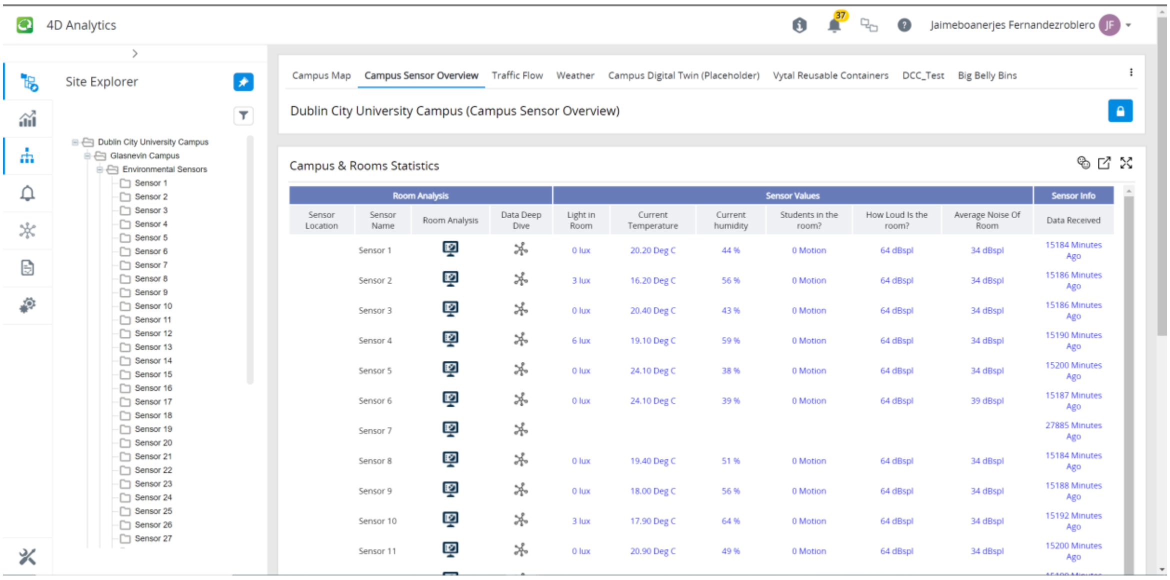


Figure 8: WIA dashboard showing data from 40 sensors across DCU campus tracking temperature, light, humidity, occupancy, and noise levels

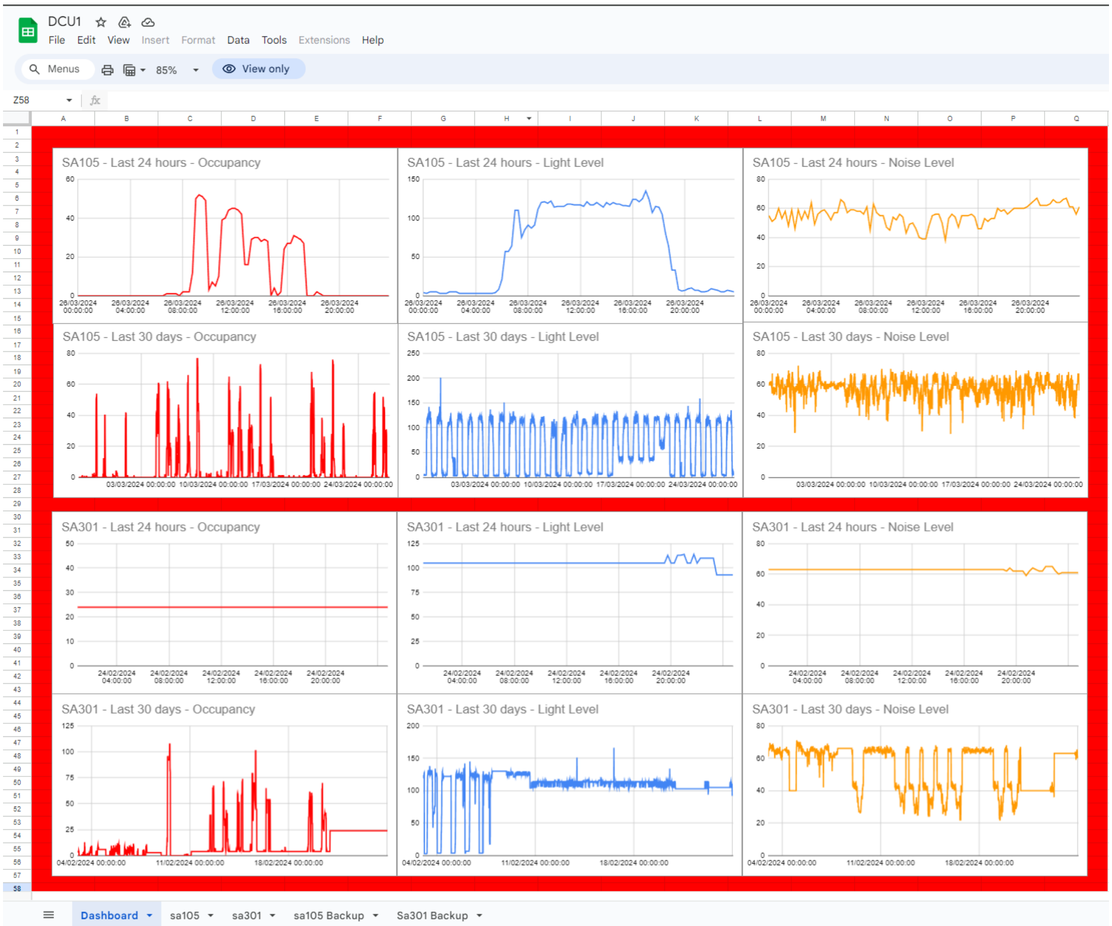


Figure 9: HiDatai dashboard using edge-based computer vision sensors to monitor occupancy, illumination, and noise in selected rooms

Key considerations for sensors

- **Start small:** Focus on critical areas or use cases, such as energy consumption or air quality in high-traffic areas. Expand incrementally, adding sensors as funding becomes available.
- **Centralized data collection:** Use platforms like Bentley iTwin to aggregate and manage data from all sensors.
- **Real-time data flow:** Define appropriate update intervals for real-time data transmission based on specific use cases.
- **Smart data sampling:** Avoid indiscriminate deployment; instead, target areas of high impact and optimize data frequency to reduce costs without compromising insights.
- **Connectivity:** Match network needs to campus size, using LPWAN (e.g., LoRaWAN) for large areas or Wi-Fi for shorter-range applications.
- **Data privacy and security**: Ensure compliance with privacy regulations, and protect transmissions with encryption.
- **Energy efficiency:** Use battery-powered sensors where possible, and prioritize multi-function devices to maximize value.

Appendix 12: Sensor integration plan template provides guidance and considerations you can use to help in your sensor integration planning.

Step 6: Resource allocation

Proper planning and distribution of resources can help avoid bottlenecks, ensure project sustainability, and maximize the digital twin's impact. In your implementation plan, you need to consider the resources you will need during the active project development, but you should also consider the resources that will ensure your digital twin has the necessary resources throughout its life cycle, even after your initial twin is launched.

Human resources

It is important to have a champion for the digital twin that will lead and drive the initiative forward. Equally, effective digital twins rely on the input and skills of a team in order to develop a valuable twin and ensure that the twin’s value is embedded into day-to-day operations for your use case.

As the project champion, you will be responsible for ensuring visibility for this initiative and clearly expressing what your digital twin is trying to achieve, what it is to be used for, why the university needs one, and who is going to use it.

Regular meetings and clear documentation can help keep the project on track and ensure that everyone is aligned with the project goals. It is likely that there will be human resource changes over the course of the project; therefore, it is recommended to get the objectives and scope in a written format.

Sustainability and maintenance

You should also consider resources that will be required for the ongoing maintenance of the digital twin. Remember that strategies are "living documents", and you will often discover additional maintenance needs throughout the course of development. Don't worry if this list is not exhaustive in the planning phase or if you have blind spots. Where possible, attempt to identify maintenance needs early and clearly document your unknowns or assumptions, providing space for yourself to update these needs as you learn throughout the process.

This section of your plan may also identify potential future resources that would be required for scaling a digital twin but not required for the initial implementation. Maintenance needs might include software updates, data refreshes, and hardware maintenance. Allocate resources to ensure that the digital twin remains functional and relevant over time. Actively planning for future expansion will enable you to keep these considerations in mind so that future iterations will not require a complete overhaul of the initial twin but can be planned sympathetically with the initial design.

Time resources

As with any development, digital twins are at risk of scope creep as you involve multiple perspectives and because technology evolves quickly, even over the span of several months or a year. Try to develop a realistic timeline that includes all phases of the project, from planning and data collection to implementation and testing.

Ensure that you allocate sufficient time for each stage, keeping in mind potential delays or unforeseen challenges. Reasonable buffer time should be included in plans as this will help you stay on track through natural delays like unforeseen complications or even sickness or holiday leave within the team.

Set clear milestones to track progress and ensure that these are communicated and regularly assessed. Milestones could include the completion of data collection, the initial reality mesh model, the import into iTwin Experience, and the integration of real-time or custom applications.

Grants and academic partnerships

Collaborate with academic departments such as engineering or computer science departments, for example, to build sensor systems as part of student projects or research initiatives. This can reduce costs while providing hands-on experience for students. Look for government grants related to sustainability, smart city development, or educational innovation that might fund sensor installations.

Step 7: Create campus digital twin roadmap

A clear and practical roadmap is essential to outline the steps needed to achieve your digital twin goals. It should detail the key phases, activities, and milestones, starting with planning and data collection, moving to initial deployment, and scaling up to full campus integration and additional use cases.

Your roadmap should include a timeline that sets out short-, medium-, and long-term goals. Key milestones might include completing a prototype, integrating data, or deploying your first use case. Early phases should focus on quick wins that demonstrate value and build support for the project.

Engaging stakeholders at each stage is vital to ensure alignment across departments, students, and external partners.

Clearly allocate the necessary resources, such as staff time, technology, and budget, and include plans for training as the project expands. It's important to identify potential risks, such as challenges with data quality or technical issues, and plan how to address them. The roadmap should also be flexible enough to adapt to new technologies or changing priorities while staying aligned with the university's broader goals, such as sustainability or research excellence.

Consider breaking the roadmap into key themes, such as structure and technologies (approach), compliance and management (governance), managing change (change), and updating and integrating data (data capture). Align these with the three stages in this guide—planning, implementation, and scaling and enhancement—and fit the timeline to the university calendar to make it realistic and actionable.

Anticipating risks and planning for success

Remember that developing a digital twin is an iterative process that involves diverse inputs and dependencies. To improve your chances of success, it's important to anticipate and mitigate common challenges early. The table below summarizes key risks you may encounter during planning and delivery, with suggested mitigation strategies.

Risk	Description	Mitigation strategy
Data quality issues	Inaccurate, incomplete, or outdated data reduces twin effectiveness.	Conduct data audits early. Prioritize high-quality sources. Use staged rollouts with validation checkpoints.

Lack of stakeholder buy-in	Teams may not see the value or may fear additional workload.	Engage stakeholders early; use visuals and demos; highlight specific benefits per role.
Underestimating skills or resources	The institution may lack the required capacity or expertise.	Assess internal skills up front. Define realistic scope. Identify opportunities for upskilling or external support.
Fragmented effort	Without coordination, teams may create disconnected models or initiatives.	Establish a cross-functional team and regular alignment meetings. Promote reuse of models and data.
Technology fatigue or burnout	Over-reliance on one champion or tool can cause progress to stall.	Distribute responsibility. Build a network of contributors. Plan for long-term institutional support

For an example of a campus digital twin roadmap, see **Appendix 13: Campus digital twin roadmap example**.

Step 8: Consolidate your implementation plan

As you work through the previous steps, you have been acquiring the information needed to articulate your strategy. In the final step of the planning process, you should consolidate and synthesize the details from your existing high-level strategy and roadmap into a comprehensive, actionable plan.

This step is not about creating an entirely new plan but rather about integrating and elaborating on the components outlined in your headline strategy and roadmap. By consolidating this information, you ensure that all aspects of the project are aligned, detailed, and ready for execution.

This consolidation process includes the following actions:

- **Detailing specific actions:** Breaking down high-level objectives into specific, actionable tasks
- **Assigning responsibilities:** Clearly defining roles and responsibilities for each task to ensure accountability
- **Establishing timelines:** Setting realistic deadlines and milestones to track progress effectively
- **Allocating resources:** Identifying and assigning the necessary resources, including budget, personnel, and technology
- **Defining metrics:** Establishing key performance indicators (KPIs) to measure success and inform adjustments as needed
- **Developing a modification plan:** Outlining procedures for updating and modifying the digital twin, establishing version control and data lineage practices, and defining roles and responsibilities for managing changes

By elaborating on these elements, the implementation plan becomes a practical guide that translates strategic goals into operational steps, facilitating seamless collaboration and effective communication among stakeholders.

Modification plan

To ensure the digital twin remains a valuable and accurate representation of the campus, it is crucial to consider as part of your implementation plan how you will approach and handle changes and modifications. This modification plan should outline the procedures for updating and modifying the digital twin, ensuring that all changes are meticulously tracked and documented.

By maintaining up-to-date information, the digital twin can continue to provide reliable insights and support informed decision-making. Regular updates and modifications are essential to reflect the evolving conditions and requirements of the campus, thereby enhancing the digital twin's effectiveness and ensuring it remains a dynamic tool for operational efficiency and strategic planning.

See **Appendix 14: Digital twin modification plan template** for support in developing a modification plan for your campus digital twin

Summary and key takeaways

With a clear strategy and well-defined objectives in place, you are now ready to move forward to **Stage 2: Implement**. This next stage will guide you through the practical steps required to bring your campus digital twin to life. This phase will leverage the insights and plans developed in the planning stage to support its focus on designing and developing the initial digital twin using Bentley's iTwin Capture Modeler and OpenCities Planner.

Stage 2: Implementing the campus digital twin

With a clear strategy and implementation plan in place, you are now in a position to get your campus digital twin underway.

Step 1: Download Bentley software

Your first task is to head to the Bentley education portal to download the software. **See Appendix 15: Access Bentley software** for full details of this process.

About iTwin Capture Modeler

iTwin Capture Modeler automatically reconstructs objects, buildings, and man-made or natural landmarks from imagery or lidar datasets. It allows the production of high-resolution 3D meshes as well as the generation of point clouds, digital surface models (DSM), and true orthophotos.

Download of software and installation

iTwin Capture Modeler does not require administrator rights to run; however, you must have administrator rights to install the application. To make sure you have the latest version, check for updates with the Connection Client or go to connect.bentley.com and log in to gain access to the installer downloads. (If you have not done so before, you will need to register on the website when prompted.) Once you have downloaded the installer, simply double-click on the downloaded package, and follow the installation instructions.

To install the software from the Bentley Education Portal, please refer to the instructions here. You can also follow the steps in our YouTube video, which has all the instructions for teaching staff and students on how to download any Bentley desktop application available on the Bentley Education Portal.

Please note that the following is a mandatory step: Update your profile under the dashboard section with the required fields. You need to be logged in and have an updated profile to access the product download.

In case of any questions feel free to check the FAQ page by clicking here.

Please refer the following link to download iTwin Capture Modeler:
education.bentley.com/ProductLine/iTwin Products

Step 2: Understand iTwin Capture Modeler's high-level process

Now that you have iTwin Capture Modeler installed, you should now turn your attention to understanding the high-level process. iTwin Capture Modeler takes as its input a set of digital photographs of a static subject, taken from different viewpoints. Various additional input data may be provided: camera properties (focal length, sensor size, principal point, lens distortion), positions of photos (GPS), rotations of photos (INS), control points.

Without manual intervention and within a few minutes/hours of computation time depending on the size of the input data, iTwin Capture Modeler outputs a high resolution textured triangular mesh. The output 3D mesh constitutes an accurate visual and geometric approximation of the parts of the subject adequately covered by input photographs.

Step 2.1: Data acquisition

Your starting point will be data acquisition with iTwin Capture Modeler. Start by capturing the necessary raw data. This will typically involve using drones, cameras, or lidar scanners to create detailed 3D models of your campus assets.

Follow best practices to ensure high-quality data acquisition, which is critical for creating an accurate and reliable digital twin. For example, ensure sufficient overlap between images (typically 60– 80%).

Imagery dataset: Photo/video acquisition guidelines

Overlap

Each part of the subject should be photographed from at least three distinct—but not radically different—viewpoints. The overlap between consecutive photographs should typically exceed two thirds. Different viewpoints of the same part of the subject should be less than 15 degrees apart.

For simple subjects, you can achieve this by taking approximately 30–50 evenly spaced photographs all around the subject. For aerial photography, a longitudinal overlap of

80% and lateral overlap of 50% or more are recommended. You may, however, prepare a flight plan for more systematic acquisitions.

Camera models

iTwin Capture Modeler supports a wide range of cameras: mobile phone, compact digital, DSLR, fisheye, photogrammetric, and multi-camera systems. Although iTwin Capture Modeler does not require a minimum camera resolution, a higher resolution camera allows acquisition of a subject at a given precision with fewer photographs, and thus more quickly, than a lower resolution camera.

Focal length

Using a fixed focal length throughout the acquisition process is recommended. To achieve a non-uniform projected pixel size, vary the distance to the subject. Avoid digital zoom.

Exposure

Select exposure settings that will avoid the motion blur, defocus, noise, and over- or under-exposure that can seriously alter 3D reconstruction. Turning off optical or digital image stabilization is recommended.

Photo retouching

Before inputting photographs into iTwin Capture Modeler, do not manipulate them by resizing, cropping, rotating, denoising, sharpening or adjusting brightness, contrast, saturation, or hue. Make sure to deactivate your camera's auto-rotate feature.

Photogroups

For optimal precision and performance, iTwin Capture Modeler must group all photos taken by the same physical camera with identical focal length and dimensions (identical interior orientation) in one photogroup.

Masks

A mask can be associated to a photo to cause specific parts of the image (e.g., moving obstacles, reflections) to be ignored in the workflow. A valid mask is a black and white TIFF image with the same dimensions as the photo.

Step 2.2: Input data file formats

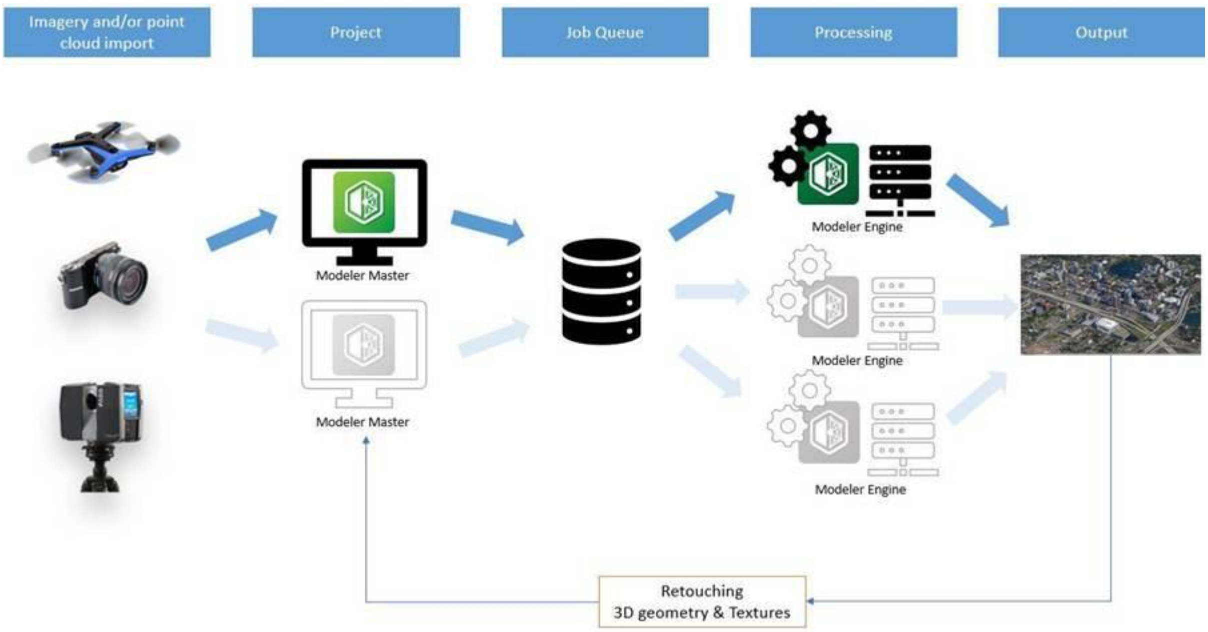
iTwin Capture Modeler natively supports photographs in JPEG and TIFF formats. It can also read some of the more common RAW formats. iTwin Capture Modeler uses Exif metadata if present. iTwin Capture Modeler can also import frames from video files and supports several common point cloud formats able to store scan positions.

Step 2.3: Positioning data

iTwin Capture Modeler also natively supports several types of positioning data, including GPS tags and control points, and can import potentially any other positioning data through position/rotation import or complete block import.

Control points should be used whenever you need better-than-GPS georeferencing accuracy or whenever you want to eliminate long-range geometric distortion caused by numerical error accumulation across the subject's extent. Georeferencing requires a minimum of three control points.

Step 2.4: Data import into iTwin Capture Modeler



The two main iTwin Capture Modeler modules are iTwin Capture Modeler Master and iTwin Capture Modeler Engine. They follow a master–worker architecture.

iTwin Capture Modeler Master is the master module of iTwin Capture Modeler. Through a graphical user interface, it allows you to define input data and processing settings, submit processing tasks, monitor the progress of these tasks, visualize their results, etc. iTwin Capture Modeler Master does not perform the processing tasks; instead, it decomposes jobs into elementary tasks, which it submits to a job queue.

iTwin Capture Modeler Engine is the worker module of iTwin Capture Modeler. It runs on a computer in the background, without user interaction. When idle, iTwin Capture Modeler Engine takes the next available tasks in the queue, depending on its priority and date of submission and executes it. A job usually consists of processing aerotriangulation or 3D reconstruction using various computationally intensive algorithms (KeyPoint).

iTwin Capture Desktop Viewer is iTwin Capture's free lightweight visualization module. It is optimized for iTwin Capture Modeler 's native format, which handles level-of-detail, paging, and streaming, thus allowing visualization of terabytes of 3D data, locally or online, with a smooth frame rate. You can also use it to display the different production results.

After collecting images, import the dataset (images or point clouds) into Context Capture. During import, you will define your project parameters, such as the type of data being processed (aerial, terrestrial, or mixed), and select options related to how the data will be used in later stages. Therefore, it is important to ensure your datasets are well-organized before import for smooth processing.

This step is the transition from the acquisition phase to the processing phase, in which the software will automatically analyze the images and recognize common points to begin reconstructing the 3D model.

Step 2.5: Data processing

After importing the data, Context Capture begins aligning images, generating tie points, and moving through the various stages of 3D model creation, including dense point cloud generation, mesh creation, texture mapping, and georeferencing.

Image alignment and sparse point cloud generation

Context Capture automatically aligns the imported images by detecting tie points across overlapping images, creating a **sparse point cloud** that represents the general structure of the scene.

At this stage, if GPS data is embedded in the images or Ground Control Points (GCPs) are provided, Context Capture will use this information to align the data to real-world coordinates. Otherwise, the georeferencing can be manually inputted.

Georeferencing

An important aspect is to geolocate your information to ensure the 3D models generated from photographs or point clouds are accurately aligned with the real-world coordinate system. The process involves assigning known coordinates to images or point cloud data through Ground Control Points (GCPs) or GPS metadata embedded in the image files, ensuring that the final model is spatially accurate. (iTwin Capture Modeler can import potentially any other positioning data through position/rotation import or complete block import.)

These points allow iTwin Capture Modeler to transform the 3D model into the correct geographic coordinate system, such as UTM (Universal Transverse Mercator) or WGS84 (World Geodetic System 1984). Once aligned, the software applies transformations and ensures accuracy through residual error checking.

Dense point cloud and mesh generation

Next, iTwin Capture generates a detailed point cloud from the aligned images. The dense point cloud is then converted into a 3D mesh, which serves as the final visual representation of the scene.

iTwin Capture Modeler Master workflow

The iTwin Capture Modeler Master is the master module of iTwin Capture Modeler. Through a graphical user interface, it allows you to:

- import the datasets
- define the processing settings
- submit tasks
- monitor the progress of submitted tasks
- visualize results.

A project is organized along a tree structure. It contains items of different types, corresponding to each step of the workflow:

- **Project:** A project manages all data relative to a scene processed by iTwin Capture Modeler. It contains Capture items, which are one or several blocks as sub-items, and Analysis items, which are describing Feature Extraction and Ground Extraction jobs.
- **Block:** A block manages a set of input photos (or scans) and their properties (photo group properties: sensor size, focal length, principal point, lens distortion/pose: position, rotation), based on which one or several reconstructions can be created. These reconstructions are represented as sub-items of the block in the tree structure.
- **Reconstruction:** A reconstruction manages a 3D reconstruction framework (spatial reference system, region-of-interest, tiling, retouching, processing settings), based on which one or several productions can be launched. These productions are represented as sub-items of the reconstruction in the tree structure.
- **Production:** A production manages the generation of a 3D model with error feedback, progress monitoring, and notifications about updates of the underlying reconstruction.

Step 2.6: Review and edit the model

Before the digital twin is finalized, the data and models undergo validation and quality assurance checks. This step ensures that the models are accurate, aligned with existing datasets, and meet the required standards. Any discrepancies identified during this phase are corrected to maintain the integrity of the digital twin. While in most cases the automatically generated 3D model can be used as it is, you may need to consider retouching to fix occasionally geometric defects using third-party software.

Inspect the model: After the 3D reconstruction is done, examine the model for any errors or areas that need improvement. Use the viewing tools in Context Capture to rotate, zoom, and explore your model.

Edit if necessary: Context Capture provides tools to clean up the model, remove unwanted elements, or refine certain areas. You can also add control points or adjust settings if some parts of the model need tweaking.

Step 2.7: Export your model

The final step in the iTwin Capture workflow is publishing the digital twin for use by various stakeholders. The digital twin can be accessed through OpenCities Planner, where it can be visualized, explored, and used for decision-making.

Once you're satisfied with the model, you can export it in various formats (e.g., OBJ, FBX, 3MX) depending on how you plan to use it. Export the model by selecting "Export" and choosing the desired format and resolution.

The next step would be to take the 3D mesh model into the iTwin Environment, and this would require selecting the right output file format. To complete this step, select "Production Definition" and, from the Format dropdown, select OpenCities Planner LOD tree export format. Please refer to the following link to check the remaining steps:https://help.opencitiesplanner.bentley.com/index.html@p=4160.html

To get access to OCP and Creating Instance, contact the Bentley Education team at educationsupport@bentley.com

Step 3: Building the digital twin in OpenCities Planner

OpenCities Planner

OpenCities Planner is a visualization platform for web, mobile, and showroom experiences. You can do many things with it, but primarily it is great for visualizing terrain, reality models, and 3D city models in combination with GIS and design data.

Contact the Bentley Education Support team to get invited to an instance:

ContactUs - education-bentley

https://bentleysystems.service-now.com/community?id=kb_article_view&sysparm_article=KB0107919

When your Instance has been activated, you can invite other people to projects and datasets that you create and configure.

Figure 10: Real-time dashboard embeded in OpenCities Planner

OpenCities Planner UI

The OpenCities Planner (OCP) interface consists of two main parts: the project view and the editor. The project view is what a public user or a team member sees when a project is shared with them. It is the presentation interface of a project. The content is prepared and configured in the editor interface. The editor interface also embeds the project view.

Using terrain, reality, and 3D city models

OCP can handle massive terrains, reality models, and 3D city models. There are also built-in OpenStreetMap and Bing maps that you can use directly for your projects.

If you want to upload your own terrain, reality, and 3D city models, you do so using the DataManager tool accessible from the Editor.

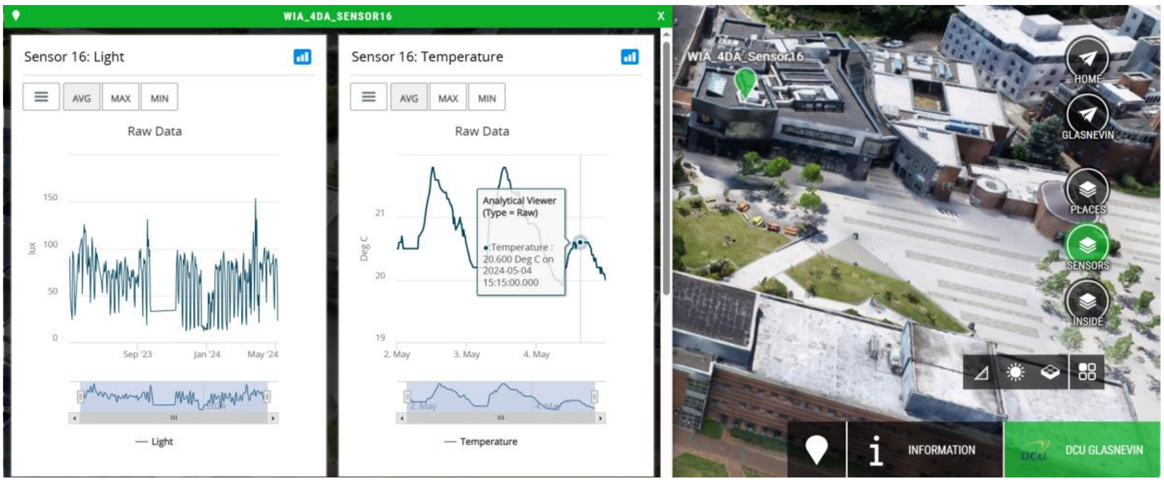


Figure 11: OpenCities Planner integrating real time sensor from WIA

Preparing content

The project editor supports uploading 3D models, images, text, documents, vector data, using WMS-services and more.

It is important to consider the target audience of your project. If you are preparing a project for public users, then your content needs to be optimized for consumption over the internet and possible for low-end devices and computers to use.

Creating, sharing, and publishing projects

Projects are created using the editor interface and can consist of all the content types that OpenCities Planner supports. Each project can include its own set of Team members and can create an individual URL if the project is published.

Please refer the following link for all the FAQs, tutorials, references, webinars, and blogs: https://help.opencitiesplanner.bentley.com/index.html

OpenCities Planner

Preparing your data for OpenCities Planner

Before uploading content to OpenCities Planner, ensure your models and datasets are optimized for browser-based viewing. This typically involves:

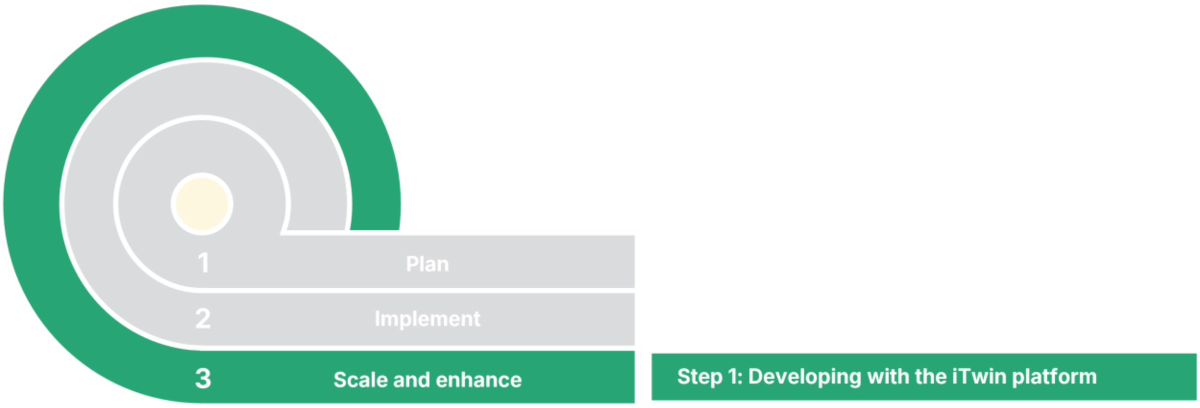
- Exporting 3D models in CityGML, KML, OBJ, or Cesium 3D Tiles format
- Using vector or raster GIS formats such as GeoJSON, Shapefiles, or WMS/WFS layers
- Compressing and simplifying complex models where needed for performance

Where possible, avoid merging datasets into single large files, instead, maintain a modular structure and link them via the project editor. OpenCities Planner supports data layering and metadata tagging, allowing federated viewing of multiple sources without permanent conversion.

Stage 3: Scaling and enhancing your campus digital twin

Integrating iTwin IoT for advanced applications

As your digital twin evolves, consider incorporating iTwin IoT to add real-time data streams from IoT devices across the campus. This integration enables dynamic analysis and monitoring, providing valuable insights for research and enhancing the educational experience.

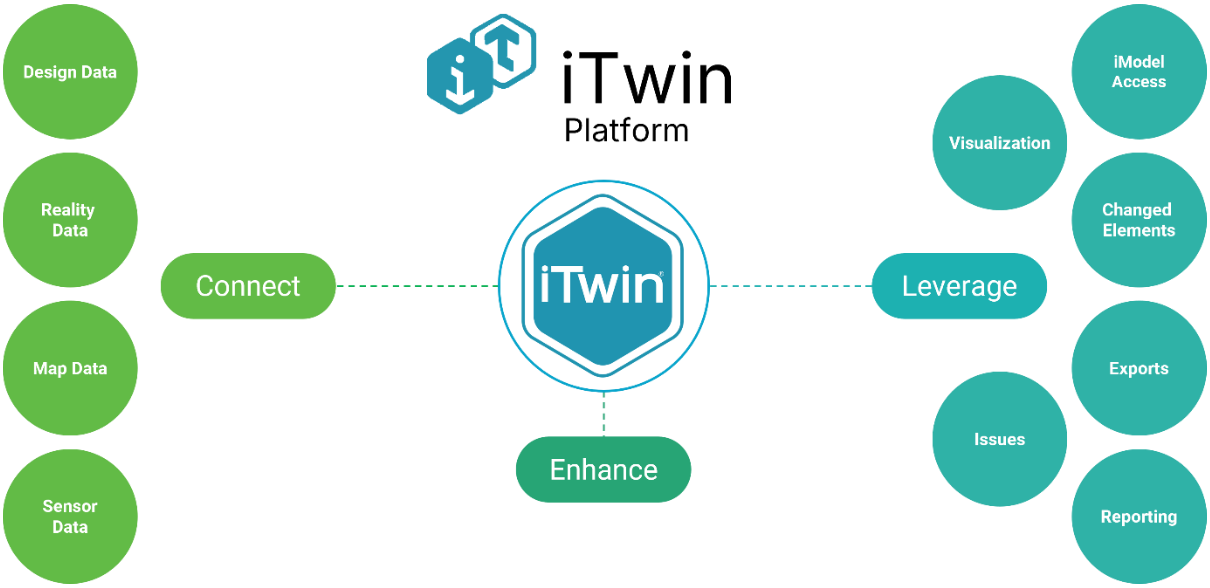


Developing with the iTwin Platform

If your project requires custom tools or applications, the iTwin Platform offers a development environment for creating these enhancements. This platform supports the creation of specialized features tailored to your institution's specific needs, further expanding the capabilities of your digital twin.

Utilize Bentley's iTwin API to develop custom applications tailored to specific university needs. Examples include energy management dashboards, environmental monitoring tools, or space utilization trackers. If the university uses existing platforms like ArcGIS for geospatial data or SAP for asset management, integrate these systems with the digital twin for a seamless flow of information.

The iTwin Platform enables you to build, manage, and grow your digital twin solutions with iTwin Platform APIs and services.



iTwin Platform

Getting started with iTwin

1. This quick start is intended to help you get started with using iTwin Platform visualization components. In this walk-through, you will be introduced to the iTwin Viewer, a customizable viewer that offers basic tooling and widgets for viewing an infrastructure digital twin and can be further extended with iTwin.js extensions.

   Get Started! - Tutorials | iTwin Platform

2. This tutorial will take you through the first steps of customizing your **iTwin Web Viewer**. First, you will learn **how to add a new user interface component**. Later, you will **customize that component** to change the background color of your viewer.
   Customizing the iTwin Viewer - "The Basics" - Tutorials | iTwin Platform

3. This tutorial takes widgets from the sample showcase and adds them to your iTwin Viewer using the uiProviders prop.

   Adding showcase widgets to your iTwin Viewer - Tutorials | iTwin Platform

Once you have completed the iTwin Getting Started walk-through, this section guides you through setting up your digital twin application so that it is visible to iTwin Platform services. Once completed, you are ready to begin working with your iTwin.
Quickstart - Web and Service Apps - Tutorials | iTwin Platform

Courses

Our courses will get you familiar with important concepts related to the iTwin Platform. Also, completing courses will prepare you to take our accreditation tests. Upon completing each test, you will receive a badge attesting to your accomplishment.

Courses | iTwin Platform

1. Introduction to the iTwin Platform (entry-level)
2. The Synchronization API
3. Grouping and Mapping

Documentation

For all iTwin documents, please refer to the links below.

APIs | iTwin Platform

1. **Administration:** Administration | iTwin Platform
   Manage the users, projects, and organizations that interact with your iTwin.
2. **Digital twin management:** Digital Twin Management | iTwin Platform
   Access and integrate data from both Bentley and third-party repositories.
3. **Reality capture:** Reality Capture | iTwin Platform
   Create, manage, analyze, and share reality data such as photos, point clouds, and meshes.
4. **Reporting:** Overview - Reporting | iTwin Platform
   The Reporting API is a tool for aggregating digital twin data from multiple sources into one unified format and place. With the Reporting API, consuming your data through business intelligence applications such as Power BI or your own custom-built application is dramatically simplified.
5. **Carbon calculation:** Overview - Carbon Calculation | iTwin Platform
   Our Carbon Calculation APIs provide integrations for your digital twins into a variety of software tools, provided by both third parties and Bentley Systems, to assist with environmental impact calculations such as life cycle assessments (LCA) or embodied carbon estimations (EPD).
6. **Review:** Review | iTwin Platform
   Collaborate with the project team to manage issues, exchanges, and design reviews.
7. **Synchronization and exports:** Synchronization & Exports | iTwin Platform
   Transform engineering data from native design formats to web-viewable iTwins.
8. **Validation:** Validation | iTwin Platform
   Detect geometry clashes.
9. **Visualization:** APIs | iTwin Platform
   View and interact with your iTwin in a web browser using Bentley cloud services.

10. **Workflow automation:** Workflow Automation | iTwin Platform
    Subscribe to iTwin events to receive notifications and trigger actions in your applications.

References

Agrawal, A., Thiel, R., Jain, P., Singh, V., and Fischer, M., (2023), ‘Digital Twin: Where do humans fit in?’, Automation in Construction, 149, DOI:10.1016/j.autcon.2023.104749, https://www.sciencedirect.com/science/article/abs/pii/S0926580523000092?via%3Dihub, accessed 15 May 2025.

Deng, Y., Cheng, J.C.P., and Anumba, C., (2021), ‘From BIM to Digital Twins: A systematic review of the evolution of digital twin technologies for the built environment’, ITcon, 26, DOI: 10.36680/j.itcon.2021.005, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/, https://www.itcon.org/papers/2021_05-SI-ITcon-Deng.pdf, accessed 15 May 2025.

Fuller, A., Fan, Z., Day, C., and Barlow, C., (2020), ‘Digital Twin: Enabling Technologies, Challenges and Open Research’, IEEE Access, 8, DOI: 10.1109/ACCESS.2020.2998358, https://ieeexplore.ieee.org/document/9103025, accessed 15 May 2025.

Madni, A., Madni, C., and Lucero, C., (2019), ‘Leveraging Digital Twin Technology in Model-Based Systems Engineering’, Systems, 7(1), https://www.mdpi.com/2079-8954/7/1/7, accessed 15 May 2025.

Appendices

Appendix 1: Headline campus digital twin strategy template

The example below is of a high-level campus digital twin strategy.

Headline campus digital twin strategy and vision	
< Insert a short high- level description of the campus digital twin strategy and vision for the project.> E.g., “Develop and implement a campus digital twin to monitor, analyze, and optimize the operational carbon footprint and indoor climate of KTU buildings, fostering sustainability, innovation, and enhanced campus efficiency. The vision is to create a dynamic, data-driven digital ecosystem that empowers Kaunas University of Technology to achieve carbon neutrality, improve resource efficiency, and advance education and research through actionable insights and innovative technology.”	
Objectives	
Short term	<Insert short- term objectives.> E.g., “Monitor operational carbon emissions and indoor climate across selected KTU campus buildings.”
Medium term	< Insert medium- term objectives.> E.g., “Expand monitoring to include real-time optimization of energy consumption and waste reduction strategies.”
Long term	<Insert long- term objectives.> E.g., “Use data insights to achieve carbon neutrality across the entire KTU campus by 2035.”
Use cases	
Primary use cases	<Insert primary use cases.> E.g., “Space utilization optimization to better allocate lecture halls and common areas based on real-time usage data”.
Goals	<Insert metrics or goals.> E.g., “Achieve a 20% increase in space utilization efficiency within the first year.”
Key stakeholders	< Insert key stakeholders.> E.g., “Facilities management team, academic scheduling department, IT services”.
Potential future use cases	<Insert potential future use cases.> E.g., “Real-time emergency response planning using the digital twin. Energy optimization by integrating IoT sensors for HVAC and lighting systems.”
Scope	
Initial scale	<Insert scale for initial twin, e.g., city- wide, entire campus, specific area of campus, building level, building component (e.g., HVAC system, specific room).>
Key assets/focus areas	<List specific assets or locations to include initially.> E.g., “Focus: MLAB and two high-energy-use campus buildings). Focus area includes HVAC systems, solar installations, waste management processes, and energy meters.”

Building life cycle stages	
Implementation stage(s)	<Insert relevant implementation stage(s), e.g., existing assets, new construction, combination.>
Data requirements	
Current data available	<Outline what data you already have access to. List out location if known.> E. g., “CAD files for building layouts, utility records, and historical energy usage reports. Location: Server [#]”
Data gaps	<Identify what data you still need.> E.eg., “Real-time occupancy data and IoT-enabled HVAC performance metrics”
Data acquisition plan	<Outline how you will collect or generate missing data.> E.g., “Use photogrammetry to create 3D models of interiors and install occupancy sensors in key areas. Retrofit additional sensors for missing parameters and establish protocols for waste data collection.”
Performance measurement	
Key metrics for success	<Insert key metrics, e.g., relating to energy consumption reduction, space utilization improvement, and note how the digital twin can support their measurement.> E.g., 20% reduction in operational carbon footprint within 5 years. 15% decrease in campus-wide waste generation. Campus digital twin will provide real-time dashboards for energy and waste data, enabling informed decision-making."
Maturity and sophistication	
Level	<Insert level of maturity and sophistication, e.g., static, bi-directional, predictive.>
Resources	
Project champion	<Insert name of person(s) that will lead the initiative.> E.g., “Dr. John Smith, Head of Sustainability”
Available resources	Human effort: <List available team members or departments.> E.g., “Energy efficiency team, IT specialists, and student interns” Financial: <List your budget.> E.g., “€200,000 grant funding from Horizon Europe” Technology: <Identify what tools, hardware, or software are available.> E.g., “IoT sensors, photogrammetry tools, and the Bentley iTwin platform”
Buy-in and support	
Plan	<Insert how will you will engage faculty, students, and staff.> E.g., “Involve students and researchers in data analysis and solution development. Share progress with the broader community through demonstrator projects and public dashboards.

Appendix 2: Examples of campus digital twin use cases and associated benefits

Campus space management	
Use case	Optimize the usage of lecture halls, classrooms, labs, and other facilities by monitoring occupancy levels, scheduling, and maintenance needs in real time. The digital twin can simulate different scheduling scenarios to maximize space utilization and reduce overcrowding.
Benefit	Increases efficiency in space usage, reduces scheduling conflicts, and minimizes the need for new construction
Energy management	
Use case	Monitor and manage energy consumption across the campus buildings. The digital twin can simulate energy usage under different conditions, such as varying weather patterns or changes in building occupancy, to optimize heating, cooling, power use (e.g., charging points), and lighting systems.
Benefit	Reduces energy costs, supports sustainability goals, and ensures a comfortable environment for students and staff
Emergency response and safety	
Use case	Use the digital twin to simulate emergency scenarios, such as fires, earthquakes, or active shooter situations. This helps in planning evacuation routes, optimizing emergency services deployment, and training staff and students in emergency procedures.
Benefit	Enhances campus safety, improves preparedness, and ensures quicker and more effective responses during real emergencies
Campus planning and development	
Use case	Support campus expansion or renovation projects by simulating the impact of new buildings, infrastructure changes, and landscape modifications. The digital twin can help planners visualize future scenarios and assess how changes will affect traffic flow, utility networks, and campus aesthetics.
Benefit	Enables data-informed decision-making in campus development, minimizing disruptions and helping to ensure that new projects meet long-term goals
Student experience enhancement	
Use case	Personalize student experiences by integrating the digital twin with campus services, such as navigation, event scheduling, and facility access. For example, students can receive real-time updates on the availability of study spaces, dining options, or gym facilities.
Benefit	Improves student satisfaction and engagement by providing convenient access to campus resources and information
Operational efficiency	
Use case	Monitor and manage the performance of campus infrastructure, including HVAC systems, water supply, and waste management. The digital twin can predict when maintenance is required, preventing unexpected breakdowns and reducing downtime.
Benefit	Extends the lifespan of campus assets, reduces maintenance costs, and ensures that the campus runs smoothly
Sustainability initiatives	

Use case	Track and model the environmental impact of campus activities, such as carbon emissions, water usage, and waste generation. The digital twin can simulate the effects of sustainability initiatives, like solar panel installations or waste reduction programs, to measure their effectiveness.
Benefit	Helps the university meet its sustainability goals, enhances its reputation as an eco-friendly institution, and engages the campus community in sustainability efforts
Smart campus integration	
Use case	Integrate various IoT devices and smart systems across the campus into the digital twin to create a smart campus ecosystem. This could include smart lighting, automated access control, and connected learning environments.
Benefit	Creates a more efficient, responsive, and interconnected campus environment that can adapt to the needs of students, faculty, and staff
Real-time collaboration and decision-making	
Use case	Provide a platform for different stakeholders, including administrators, faculty, and facility managers, to collaborate in real time using the digital twin. They can make informed decisions on campus operations, event planning, and resource allocation based on the virtual model.
Benefit	Facilitates quicker decision-making, improves collaboration, and ensures that decisions are based on accurate, up-to-date data
Health monitoring	
Use case	During health crises like the COVID-19 pandemic, the digital twin can be used to monitor and manage the health and safety of the campus population. This includes tracking occupancy levels, ensuring social distancing, and monitoring air quality in real time.
Benefit	Enhances health and safety protocols, reduces the spread of illness, and ensures compliance with health regulations
Facility accessibility management	
Use case	Use the digital twin to assess and improve accessibility across campus facilities, such as wheelchair ramps, elevators, and parking. It can also simulate changes to infrastructure for compliance with accessibility regulations.
Benefit	Enhances inclusivity, ensures compliance with accessibility standards, and improves campus navigation for all users
Event planning and management	
Use case	Simulate and optimize event logistics, including venue selection, crowd management, and resource allocation. The digital twin can predict the impact of large events on campus infrastructure and services.
Benefit	Reduces logistical challenges, minimizes disruptions to campus activities, and ensures successful event execution
Asset life cycle management	
Use case	Monitor the life cycle of campus assets, such as furniture, lab equipment, and IT infrastructure. The digital twin can track asset usage, maintenance schedules, and replacement timelines.
Benefit	Extends asset life, reduces replacement costs, and ensures that resources are available when needed
Transportation and mobility	

Use case	Analyze traffic flow, pedestrian movement, and public transportation usage on campus. The digital twin can optimize shuttle routes, parking availability, and bike-sharing programs.
Benefit	Reduces traffic congestion, improves accessibility, and enhances campus mobility
Alumni and donor engagement	
Use case	Showcase campus developments and sustainability initiatives through an interactive digital twin experience for alumni and donors.
Benefit	Strengthens alumni relationships, increases donor engagement, and promotes university achievements
Cultural heritage preservation	
Use case	Create 3D models of historic campus buildings and landmarks to preserve their cultural and architectural heritage.
Benefit	Protects legacy assets, supports educational initiatives, and showcases campus history to the community
Educational teaching and learning	
Use case	Use the digital twin as a hands-on learning platform for students across disciplines such as architecture, engineering, computer science, and environmental studies. It can support project-based learning, allowing students to explore real-world data, simulate scenarios, and contribute to live campus projects.
Benefit	Provides students with practical experience using industry tools, enhances employability, and supports interdisciplinary, experiential learning aligned with real-world challenges

Appendix 3: Use case prioritization grid

This matrix helps campus digital twin champions and teams assess and compare multiple candidate use cases to identify the best starting points, balancing strategic value with feasibility. It's designed to support informed decision-making and manage expectations around what's achievable early on.

Example: Creating a digital twin for monitoring indoor air quality across campus buildings

Criteria	Guiding questions	Notes	Score 1–5
Strategic alignment	How well does the use case support university priorities (e.g., Net Zero, digital transformation, student experience)?	Example: Supports environmental monitoring and health goals, but not directly tied to core teaching or digital strategies	E.g., 3
Stakeholder demand	Is there clear interest or a "pull" from users (e.g., estates, academics, students)?	Example: Some interest from sustainability teams, but low awareness or urgency from other stakeholders	E.g., 2
Data availability	Are the required data sources already available and accessible?	Example: Air quality sensors are not yet widely deployed; would require new installation and integration	E.g., 2
Technical feasibility	Can this be delivered with current tools, skills, or support (e.g., from Bentley Education)?	Example: Tools exist, but integration with environmental sensors is complex and would need external support	E.g., 2
Speed to implement	Can you deliver a protype or outcome within a reasonable timeline (e.g., 1–2 trimesters)?	Example: Sensor procurement and installation would delay progress; likely to exceed a trimester	E.g., 1
Potential for impact	Will it generate visible benefits or unlock further adoption?	Example: Long-term value for health and sustainability, but limited short-term visibility or engagement	E.g., 3
Scalability	Can it be extended or adapted to other departments, buildings, or use cases?	Example: Once sensors are installed, it could easily be expanded across campus	E.g., 4
Total score	<Add up the scores for each category and compare across candidate use cases>		E.g., 17/35

Scoring guide: 1 = Low, 3 = Moderate, 5 = High

Appendix 4: Granularity of data examples

Campus level: At the campus level, information is generally aggregated and provides a holistic view of the entire campus infrastructure. This level focuses on broad metrics and overall performance indicators. Examples might include:	
Geographic information system (GIS) data	Maps of the entire campus, including building locations, green spaces, roads, and utilities
Energy consumption	Total energy usage across the campus, broken down by building and energy source (e.g., electricity, gas, renewables)
Water usage	Aggregate water consumption data for the campus, including trends over time
Waste management	Data on waste generation and recycling efforts across the campus
Transportation and parking	Information on campus transportation systems, parking availability, EV charging points, and traffic flow patterns
Security and surveillance	Data from campus-wide security systems, including access control and surveillance cameras
Environmental monitoring	Air quality, noise levels, and other environmental metrics measured across the campus
Occupancy and utilization	Occupancy rates and space utilization metrics for different buildings and facilities on the campus
Pedestrian movements	Data on movements throughout the campus (incoming and outgoing) through different times of day

Building level At the building level, information becomes more detailed and specific to the operations and performance of individual buildings. This level focuses on building-specific metrics and systems. Examples might include:	
Structural information	Detailed architectural and structural models of the building, including floor plans and elevations
Building systems	Data on HVAC (heating, ventilation, and air conditioning) systems, elevators, lighting, and plumbing
Energy management	Energy consumption data broken down by system (e.g., lighting, HVAC) and time (e.g., daily, weekly)
Water usage	Water consumption data for the building, including usage by different systems (e.g., toilets, kitchens)
Maintenance records	Historical and scheduled maintenance data for building systems and components.
Indoor environmental quality	Indoor air quality, temperature, humidity, and lighting levels
Space utilization	Data on the usage of different areas within the building, such as offices, meeting rooms, and common areas, including as-planned/as-used space utilization (actual occupancy patterns)
Safety and security	Information on fire alarm systems, access control, and emergency exits

Building component level (e.g., product) At the building component level, information is highly detailed and specific to individual components or products within the building. This level focuses on the performance, condition, and life cycle of specific elements. Examples might include:	
Component specifications	Manufacturer details, model numbers, and technical specifications of components (e.g., HVAC units, lighting fixtures)
Performance data	Operational data for specific components, such as efficiency, power consumption, and output
Condition monitoring	Real-time data from sensors monitoring the condition of components (e.g., vibration, temperature, wear and tear)
Life cycle information	Information on the expected lifespan, warranty, and replacement schedules for components
Maintenance history	Detailed maintenance logs for individual components, including repairs, replacements, and upgrades
Failure rates and diagnostics	Data on failure rates, diagnostics, and fault detection for components
Integration with building systems	Information on how components are integrated with other building systems (e.g., HVAC integration with building automation systems)
User manuals and documentation	Digital copies of user manuals, installation guides, and technical documentation for components

Appendix 5: Open data sources examples

Geospatial data	
OpenStreetMap (OSM)	A collaborative project that provides free, editable maps of the world, OSM can offer detailed geospatial information about campus layouts, surrounding infrastructure, and local points of interest, which can be integrated into your digital twin for better spatial accuracy.
USGS National Map	In the United States, the U.S. Geological Survey provides a wealth of open geospatial data, including topography, hydrography, and land cover, which can be used to enhance the environmental context of your campus digital twin.
Ordnance Survey (OS) open data (UK)	The Ordnance Survey offers a range of open geospatial datasets that cover the UK. This includes topographic maps, administrative boundaries, and vector map data. These datasets can be integrated into your campus digital twin to provide accurate geographical context.
European Space Agency (ESA)	Copernicus Open Access Hub: Copernicus, the EU's Earth observation program, provides free access to satellite data. This data includes imagery for land monitoring, marine environment, atmosphere, and climate change. It can be particularly useful for analyzing environmental conditions around your campus.
Inspire Geoportal (EU)	The INSPIRE initiative by the European Union provides access to harmonized geospatial data across member states. This portal offers datasets on various themes, including land use, environmental monitoring, and natural risk zones, which can be incorporated into your digital twin.

Environmental data	
NASA Earth data	NASA offers a range of open datasets related to climate, weather, and environmental conditions. Incorporating this data can help simulate environmental impacts or analyze sustainability measures within your digital twin.
EPA air quality data	Available in many countries, air quality data from environmental protection agencies can be used to monitor and simulate air quality on campus, which is particularly useful for research focused on environmental health.
European Environment Agency (EEA) data and maps	The EEA offers various datasets related to environmental conditions across Europe, including air quality, climate data, and biodiversity information. These datasets can help integrate regional environmental insights into your campus digital twin.

Transportation and mobility data	
City or regional transportation authorities	Many cities provide open data on public transportation routes, schedules, and usage. This data can be integrated into your digital twin to simulate transportation flow and study mobility on and around the campus.
Google transit feed specification (GTFS)	A standard for public transportation schedules and associated geographic information, GTFS data can help you to model and analyze transportation systems as part of your campus digital twin.

Building and infrastructure data	
Local government building permits	In some regions, local governments provide open data on building permits and construction projects. This data can help in visualizing

	ongoing or planned construction around the campus, which might be relevant for long-term planning with your digital twin.
Energy usage data	Some universities or local governments release aggregated energy usage data, which can be used to model energy efficiency or simulate sustainability initiatives within the digital twin.

Demographic and socioeconomic data	
Census data	National census datasets can provide demographic information about the area surrounding the campus, which can be valuable for planning campus services and facilities within your digital twin.
World Bank open data	The World Bank offers global socioeconomic data that can provide context for international campuses or universities engaging in global research initiatives.

Appendix 6: Data rights and permissions considerations

This framework provides an organized overview of key actions for managing data in a campus digital twin, including ownership, licensing, compliance, and ethical use. It supports regulatory adherence, transparency, and trust among stakeholders while ensuring the digital twin operates effectively. Use this table as a practical reference for ongoing data management throughout the project life cycle.

Category	Key actions	Notes
Data ownership	Identify ownership of campus-related data (e.g., university, third-party contractors, students, staff).	Ownership may vary by data type, such as IoT sensor data, building information, or activities.
	Clarify ownership for different data categories.	Clearly defined ownership simplifies permissions and compliance.
Data licensing	Define licenses for campus data (e.g., open data for research, restricted use for internal purposes).	Use consistent licensing terms to align with institutional policies.
	Set terms for external access by researchers, students, or partners.	Ensure that licensing reflects data sensitivity and intended use.
Data access and permissions	Establish access levels for stakeholders (e.g., facilities managers, students, researchers).	Access should align with roles and responsibilities.
	Protect sensitive data, such as students' personal information or security details.	Use robust security protocols to prevent unauthorized access.
Data sharing agreements	Develop agreements for sharing data with external parties (e.g., government, research institutions).	Agreements should detail terms of use, access, and restrictions.
	Ensure compliance with laws like GDPR when sharing with third parties.	Regularly review agreements to ensure they remain current and compliant.
Compliance with data regulations	Ensure data collection complies with regulations like GDPR.	This includes obtaining consent for collecting personal or sensitive data.
	Train staff on compliance best practices and monitor adherence.	Ongoing reviews ensure alignment with updated regulations.
Data anonymization	Anonymize individual-related data (e.g., campus traffic patterns, student movement) before analysis or sharing.	Robust anonymization protects privacy and reduces risks.
	Regularly update anonymization techniques to adapt to emerging threats.	
Intellectual property (IP)	Clarify IP ownership for digital twin data (e.g., university vs. software providers).	Collaboration agreements should explicitly define IP rights.
	Address IP ownership for research outcomes associated with the digital twin.	

Ethical considerations	Communicate transparently how campus data will be used (e.g., monitoring, service improvement).	Regular communication builds trust among stakeholders.
	Monitor for misuse (e.g., intrusive surveillance) and enforce ethical standards.	
Data retention and deletion	Set policies for retaining different types of campus data (e.g., personal vs. operational data).	Include clear guidelines on data life cycle management.
	Establish protocols for securely deleting personal data when no longer needed.	Ensure secure and irreversible deletion processes.

Appendix 7: Sample data use consent form template

This template is provided for internal planning and educational purposes only. Please consult your institution's legal or data protection office before formal use.

1. Overview

We are collecting data as part of a project to improve campus operations through the use of a digital twin system. This may involve the use of occupancy data, environmental sensors, or location-based technologies. This form explains what data is being collected, how it will be used, and your rights.

2. Type of data

What data is being collected?

- ☐ Occupancy (e.g., presence in a room)
- ☐ Environmental (e.g., temperature, air quality)
- ☐ Wi-Fi or ID card check-ins (location activity)
- ☐ Other (please specify): ___________________________

3. Purpose of the data

What will the data be used for?

- ☐ Optimizing building usage and energy consumption
- ☐ Improving safety and accessibility
- ☐ Supporting teaching and research facility planning

4. How the data will be handled

- Data will be anonymized where possible.
- It will be stored securely in compliance with university data policies.
- It will not be shared with third parties without additional consent.
- You can request access to, correction of, or deletion of your data.

5. Your consent

Please confirm your understanding and consent by signing below.

I understand how my data will be used, and I consent to its use for the purposes described above.

Name: ______________________ Signature: ______________________

Date: ____________

6. Contact for questions

If you have questions or concerns, please contact:

Project contact name: ______________________

Email: ______________________ Phone: ______________________

Appendix 8: Sample data sharing agreement template

This template is provided for internal planning and educational purposes only. Please consult your institution's legal or data protection office before formal use.

1. Agreement overview

This data sharing agreement is made between:

- Disclosing party: ____
- Receiving party: ____

Date: ______________________

2. Purpose of data sharing

The purpose of this agreement is to enable the sharing of data to support the following:

- ❑ Digital Twin development
- ❑ Facilities management
- ❑ Academic research
- ❑ Sustainability or space optimization initiatives
- ❑ Other (please specify):

  ____

3. Description of data

Provide a summary of the data to be shared, including type, format, and sensitivity:

- Data type: ____
- Format: ____
- Frequency: One-time/Ongoing
- Sensitivity: Public/Internal/Confidential

4. Data handling and responsibilities

- Data will be used only for the agreed purpose.
- The receiving party will not share the data with any third party without permission.
- Both parties will comply with applicable data protection and privacy laws.
- Access to the data will be limited to authorized personnel.

5. Storage and security

- Data will be stored securely in accordance with institutional policies.
- Encryption and access controls should be applied where appropriate.

6. Duration and termination

This agreement is valid from ________________ to ________________.

Either party may terminate the agreement with written notice.

Upon termination, the receiving party will delete or return all data.

7. Signatures

Disclosing party representative:

Name: ____________________ Signature: ____________________

Date: ___________

Receiving party representative:

Name: ____________________ Signature: ____________________

Date: ___________

Appendix 9: Digital twin architecture planning template

This template is designed to help you structure your thinking and document key decisions when planning your digital twin architecture. Answer each question in detail.

System and technology readiness	
What hardware is needed to capture and manage different types of data (e.g., visual, numeric)?	Example: "Drones with high-resolution cameras for photogrammetry, LiDAR scanners, environmental sensors for air quality and temperature, and occupancy trackers"
Do you have sufficient servers, networking infrastructure (e.g., LAN, WAN, wireless gateways), and peripheral devices (e.g., VR headsets, graphics cards)?	Example: "Campus has sufficient LAN/WAN coverage, but wireless gateways need upgrading to handle IoT devices. Graphics cards will need an upgrade for 3D visualization."
Is your current hardware scalable to support future needs?	Example: "Current server setup allows for modular expansion, and the network architecture is cloud-compatible, enabling future integration of additional IoT devices and buildings without major overhauls."
Are there specific requirements for drones, sensors, or reality capture devices?	Example: "A Mavic 3 drone and Leica LiDAR scanner have been identified as optimal tools for reality capture."
Do you have a disaster recovery plan in place?	Example: "Existing IT disaster recovery plan is being updated to include IoT and digital twin-specific data recovery protocols"
Software and compatibility	
What additional software is required beyond Bentley CAD or iTwin software?	Example: "ArcGIS for geospatial data analysis"
Are there compatibility issues with existing systems (e.g., operating systems, licenses, security)?	Example: "Current licenses for Bentley are valid, but ArcGIS licenses need to be procured. Systems are compatible with current OS."
Can the software integrate with university systems like CRMs, LMSs, or timetabling platforms?	Example: "Integration is planned for the facilities management system, energy monitoring dashboards, and the LMS for academic use cases."
Are APIs available for seamless integration with third-party tools?	Example: "Bentley APIs will integrate BIM and GIS data, while IoT device protocols (MQTT) will connect sensors."
Data management	
Where will your data be stored (on-premises, cloud, hybrid)?	Example: "A hybrid solution is planned: real-time IoT data in the cloud and BIM/GIS data on-premises"
What are the storage limitations regarding quantity, duration, or access control?	Example: "Current storage is sufficient for the pilot phase but will require a 50% increase in capacity within three years."

Do you need to extend administrative rights to access certain data sources or systems?	Example: "Yes, facilities management and IT teams will need expanded access to building management and IoT systems."
How will you handle real-time data collection and long-term historical storage?	Example: "IoT data will stream to a cloud platform for real-time analysis, while historical data will be archived annually on on-premises servers."
Are there existing datasets (e.g., BIM models, GIS layers) you can leverage?	Examples: "Existing BIM models for 40% of campus buildings and a GIS map of the entire campus will be integrated into the digital twin."
Scalability and futureproofing	
Is the system designed to scale with future needs, such as adding new buildings or use cases?	Example: "Yes, modular architecture will allow for additional buildings and sensors to be added incrementally."
Does the architecture allow for modular upgrades or replacements?	Example: "Hardware and software choices prioritize modularity to enable smooth upgrades."
What are the long-term costs and ROI of scaling hardware and software?	Example: "Initial costs are high but expected to reduce maintenance costs by 20% annually and increase energy efficiency by 15%."
What is your plan for ongoing maintenance, training, and updates?	Example: "Dedicated budget for staff training and software updates will be allocated annually."
Privacy, security, and compliance	
How will you ensure compliance with regulations like GDPR?	Example: "All personal data will be anonymized, and access controls will restrict usage to authorized personnel."
What security measures (e.g., encryption, role-based access controls) are in place?	Example: "IoT data will be encrypted, and role-based access controls will be implemented for BIM and GIS data."
How will sensitive or personal data be safeguarded?	Example: "Security audits will be performed biannually, and sensitive data will be stored in secure, encrypted repositories."
What protocols are in place for managing cyber threats or breaches?	Example: "An incident response plan includes real-time alerts for data breaches and immediate action protocols."
Functional and operational requirements	
What prerequisites need to be addressed (e.g., software downloads, permissions)?	Example: "Bentley iTwin software and ArcGIS will be installed, with administrative permissions granted to the facilities team."
How will the digital twin integrate with building management, energy monitoring, or academic systems?	Example: "APIs will connect the twin with the building management system and energy dashboards; LMS integration is planned for teaching modules."
What training will be required for staff, and how will it be delivered?	Example: "Training for facilities and IT teams will include workshops and online modules. Faculty will receive a simplified user guide."
What key performance metrics or milestones will you use to evaluate success?	Example: "Metrics include reduced energy costs, improved space utilization, and integration with 80% of campus systems within two years."

Budget and cost-effectiveness	
What is the budget for hardware, software, and other resources?	Example: “£200,000 for hardware, £50,000 for software, and £20,000 for training and maintenance in the first year”
Is the return on investment (ROI) justified for new investments?	Example: “Yes, the digital twin is expected to save £40,000 annually through energy optimization and better facilities management.”
Are there cost-saving or funding opportunities, such as using existing infrastructure or applying for grants?	Example: “Existing BIM models and GIS maps reduce initial data acquisition costs by 25%. Grants for smart campus initiatives are being explored.”
How will you prioritize quick wins to demonstrate value early?	Example: “A pilot project on a single building will deliver early results, including energy savings and improved operational insights.”

Appendix 10: Data collection checklist

These checklists help universities assess their data needs, locate legacy information, and plan new data capture activities for their campus digital twin.

1. Data needs assessment checklist

- What is the purpose of this data collection (e.g., space planning, energy efficiency, maintenance)?
- Which buildings, zones, or systems are in scope?
- What data types are required?
  - ❑ Graphical (e.g., 2D plans, 3D models)
  - ❑ Non-graphical (e.g., condition reports, certificates)
  - ❑ Environmental or live data (e.g., temperature, CO_2)
- Do you already have this data?
  - If so, where is it stored?
  - Is the existing data up to date and accurate?
- Are there regulatory or compliance needs for this data?

2. Legacy data sourcing checklist

- Search digital repositories (SharePoint, network drives, CAFM, etc.)
- Review physical storage locations (e.g., ring binders, archive rooms)
- Identify key staff who might hold undocumented knowledge or files
- Check for the following:
  - ❑ Drawings (CAD, PDFs)
  - ❑ Asset registers or spreadsheets
  - ❑ Maintenance records
  - ❑ Fire safety or O&M manuals
- Assess each source for the following:
  - ❑ Accuracy
  - ❑ Completeness
  - ❑ Format (digital, paper, scanned)
- Tag legacy information with quality ratings (low/medium/high).
- Decide which of the following applies:
  - ❑ It is usable as-is.
  - ❑ It needs to be digitized.
  - ❑ It must it be recaptured.

3. New data capture planning checklist

- What are the information gaps?
- What is the required accuracy level? (e.g., general reference vs exact geometry)

- Which data collection method is most suitable?
    - ❑ Measured survey
    - ❑ 3D laser scan
    - ❑ Photogrammetry
    - ❑ Condition survey
    - ❑ Manual inspection/data entry
- Can this be done in-house, or do you need a third party?
- Do you have the required tools or equipment?
- Has a data privacy or ethics review been completed (if relevant)?
- How will the data be validated and stored?
- Are there cost or resource limitations?

Appendix 11: Data documentation and management

This template supports your Data Collection Checklist by helping you document formats, storage plans, and responsibilities for each dataset in your campus digital twin

1: Data overview	
Project name	Smart campus twin
Primary use case(s)	Inclusive design, room occupancy monitoring, facilities planning
Data owner(s)	Digital Twin Project Lead, Head of IT

2: Data types and formats			
Type of data	Source / tool	Formats	Volume estimate
Reality mesh (outdoor)	Drone + iTwin Capture Modeler	.obj, .3mx, .3dtiles	10–30 GB
Indoor scans (manual)	iPhone + Polycam	.obj, .gltf	1–5 GB per building
BIM models	Revit/ArchiCAD	.ifc, .rvt	500 MB – 2 GB each
IoT sensor data	WIA / HiData / CIVIC	.csv, .json, API URLs	10–50 MB/day
Maps and GIS layers	OpenStreetMap, local GIS	.shp, .geojson, .kml	1–5 GB
Dashboards/interfaces	OpenCities Planner, Unreal Engine	Web URL / .html	Hosted/cloud
Documentation/scripts	Internal/Shared	.docx, .pdf, .py	100 MB

3: Storage and backup		
Data Type	Storage Location & Backup Plan	Access Control
Raw drone images	University research drive, backed up weekly	Core project team only
Processed models	Cloud storage with auto-backup	Read-only for broader access
IoT data	Live stream from API, 4DA export weekly	Restricted by sensor type
Docs/scripts	GitLab or shared folder with version control	Team contributors
Data Type	Storage Location & Backup Plan	Access Control

4: Metadata and documentation	
Item	Plan / notes
Readme files	Describe content, version, usage, units, and contact person
Metadata standard used	DataCite or schema.org (if publishing openly)
Software documentation	Inline comments, install instructions, version info
Codebook for sensors	Spreadsheet describing variables, units, locations
User guides / training	PDF/Video explaining how to explore or update twin

5: Privacy, IP, and sharing	
Aspect	Plan

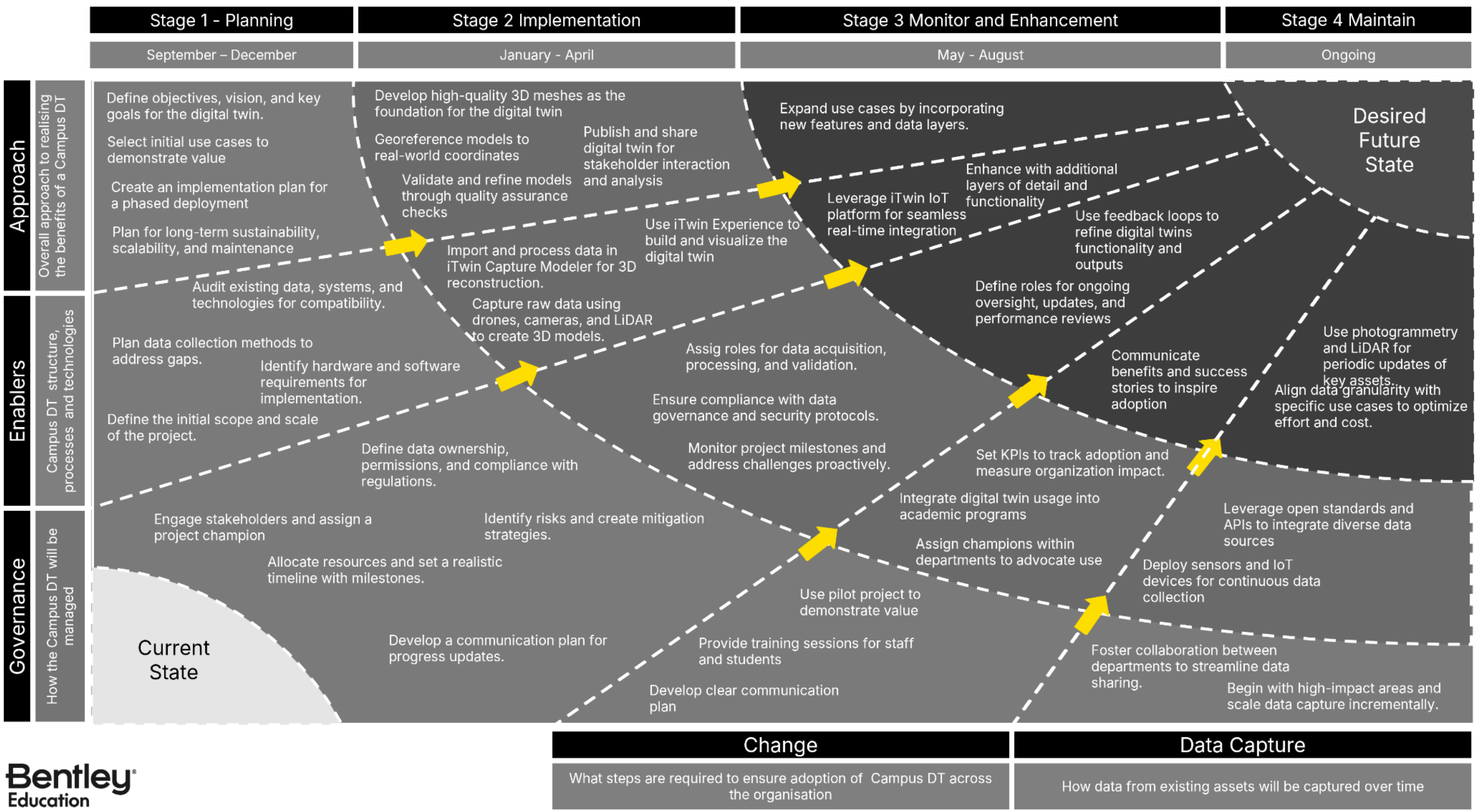
Personal data used?	Yes – anonymised room occupancy data only
GDPR compliance	Data stored securely, access limited, no identifiers
Open licensing	Creative Commons BY or similar for non-sensitive data
Where published?	Internal server; public models via OCP; data via 4TU
Embargo period?	6 months post-project to allow for publication

Appendix 12: Sensor integration plan template

This table provides guidance and consideration as part of your sensor integration planning.

Section	Purpose	Notes	Example
Project overview	Set the context for the project.	Define the project name, location, responsible team, and objective.	Smart Lecture Theatre Pilot Location: Building A, Room 101 Lead: Jane Smith, Estates Goal: Monitor CO_2 and occupancy in real time
Existing infrastructure	Check what systems or sensors already exist.	Note current sensors, platforms, and network/power availability.	Legacy BMS present. Wi-Fi available. No dedicated environmental sensors.
Sensor selection	Choose appropriate sensors based on your goals.	List sensor type, purpose, location, protocol, and power source.	Type: CO_2 sensor Purpose: Monitor air quality Location: Room 101 Protocol: MQTT Power source: Battery
Deployment plan	Plan installation steps and responsibilities.	Break down tasks, assign owners, and include deadlines.	Prep Wi-Fi – IT – 01/06 Install sensors – Estates – 05/06 Integrate with iTwin – Digital Twin Lead – 07/06
Data & connectivity	Ensure the data flow is reliable and accessible.	Define update frequency, protocol, platform, and dashboard visibility.	Every 10 minutes MQTT via Wi-Fi Platform: Bentley iTwin Dashboard: Power BI (Estates + H&S)
Privacy & security	Ensure compliance with data policies, and protect transmissions.	Note if data is personal, use of encryption, and policy checks.	Environmental only (no personal data) TLS 1.2 encryption GDPR reviewed
Maintenance plan	Ensure sensors stay functional and accurate.	Include tasks, frequency, and responsible team.	Battery check – Every 6 months – Estates Firmware updates – As needed – IT
Review & lessons learned	Reflect on the process and recommend improvements.	Document what went well, challenges faced, and lessons for next time.	Set-up was smooth. Wi-Fi config caused initial lag. Test network beforehand next time.

Appendix 13: Campus digital twin roadmap example



Stage 1 - Planning
September – December
Stage 2 Implementation
January - April
Stage 3 Monitor and Enhancement
May - August
Stage 4 Maintain
Ongoing
Approach
Overall approach to realising the benefits of a Campus DT
Enablers
Campus DT structure, processes and technologies
Governance
How the Campus DT will be managed
Define objectives, vision, and key goals for the digital twin.
Select initial use cases to demonstrate value
Create an implementation plan for a phased deployment
Plan for long-term sustainability, scalability, and maintenance
Audit existing data, systems, and technologies for compatibility.
Plan data collection methods to address gaps.
Identify hardware and software requirements for implementation.
Define the initial scope and scale of the project.
Engage stakeholders and assign a project champion
Allocate resources and set a realistic timeline with milestones.
Current State
Develop high-quality 3D meshes as the foundation for the digital twin
Georeference models to real-world coordinates
Publish and share digital twin for stakeholder interaction and analysis
Validate and refine models through quality assurance checks
Use iTwin Experience to build and visualize the digital twin
Import and process data in iTwin Capture Modeler for 3D reconstruction.
Capture raw data using drones, cameras, and LiDAR to create 3D models.
Define data ownership, permissions, and compliance with regulations.
Identify risks and create mitigation strategies.
Develop a communication plan for progress updates.
Expand use cases by incorporating new features and data layers.
Enhance with additional layers of detail and functionality
Leverage iTwin IoT platform for seamless real-time integration
Use feedback loops to refine digital twins functionality and outputs
Define roles for ongoing oversight, updates, and performance reviews
Assig roles for data acquisition, processing, and validation.
Ensure compliance with data governance and security protocols.
Monitor project milestones and address challenges proactively.
Communicate benefits and success stories to inspire adoption
Set KPIs to track adoption and measure organization impact.
Integrate digital twin usage into academic programs
Assign champions within departments to advocate use
Use pilot project to demonstrate value
Provide training sessions for staff and students
Develop clear communication plan
Desired Future State
Use photogrammetry and LiDAR for periodic updates of key assets.
Align data granularity with specific use cases to optimize effort and cost.
Leverage open standards and APIs to integrate diverse data sources
Deploy sensors and IoT devices for continuous data collection
Foster collaboration between departments to streamline data sharing.
Begin with high-impact areas and scale data capture incrementally.
Change
What steps are required to ensure adoption of Campus DT across the organisation
Data Capture
How data from existing assets will be captured over time

Appendix 14: Digital twin modification plan template

This template is designed to support universities in maintaining an accurate and up-to-date campus digital twin. It outlines basic steps to follow when changes happen on campus, such as new buildings, refurbishments, or system updates. The aim is to keep things clear, collaborative, and easy to manage.

As part of your modification plan, you will need to consider the following.

When the campus digital twin be updated?

For example, you might update it when:

- a new building or renovation is completed
- classrooms, labs, or offices are changed
- new equipment or systems are added
- sustainability or accessibility projects are carried out.

Who can request changes?

For example, this may be one or more of the following:

- Estates or Facilities team
- IT Services
- Academic or research staff
- Students (with staff approval)

How to approve changes

For example, the approval process might involve:

- one person (e.g., the digital twin lead) checking the request
- a small team reviewing the impact
- a group giving final approval if needed.

Making the change

- Update the digital twin using your usual software. (Ensure BIM data reflects design and construction updates. Conduct geospatial surveys to collect accurate data on new or altered physical features.)
- Apply changes to 3D models, GOS layers and live systems as needed.
- Keep track of which version was changed and when.
- Make sure someone checks that the update is accurate.

Keeping a record

- Ensure all updates are documented with appropriate tags, timestamps, and source information.
- Log the following each time a change is made:
  - Date of change
  - What changed and why
  - Who made and approved the change
  - Any impact on teaching, research, or operations

Tell people and train if needed

- Let staff or students know about big changes.
- Offer simple training if needed.
- Use Teams, email, or your intranet.

Check the twin regularly

- Schedule routine checks to verify the twin accurately reflects the physical environment
- Enable users to report issues or recommend improvements (e.g., via Teams, intranet, or feedback form).

This completed example shows how a modification plan could be used to record, approve and implement a significant change to the campus digital twin.

1: Change identification	
Element	Details
Trigger events	Renovation of the main library ground floor
Initiating stakeholders	Estates and Facilities teams
Change request format	Submitted via the university's CAFM system on 02/02/2025

2: Approval workflow		
Step	Responsible party	Notes
Initial review	Tom Jones, Digital Twin Champion	Confirmed relevance and data completeness
Impact/risk assessment	Tom Wright, Data Steward	Assessed compatibility with current BIM and GIS systems
Final approval	Campus Planning Committee	Approved at the March 2025 monthly meeting

3: Change implementation		
Item	Method or tool used	Notes
Data update protocol	iModel updated and synced with campus GIS system	Models validated against as-built drawings

Version control strategy	Stored in SharePoint with version tracking enabled	Old versions archived and tagged
Responsible party	Laura Chen, BIM Lead (Estates)	Completed update on 10/03/2025

4: Documentation and audit trail	
Element	Details
Date of change	10/03/2025
Description	Library ground floor layout updated to reflect new open-plan study zones
Rationale	To accommodate increasing student numbers and flexible group study needs
Submitted by	Sophie Adams, Head of Campus Development
Approved by	Campus Planning Committee
Affected systems	BIM model, campus wayfinding app, room booking system
Academic use impact	Updated layout supports extended library hours and accommodates 25% more students

5: Communication and training		
Activity	Description	Frequency
Stakeholder notification	Email sent to library staff, Estates, and IT	Once, post-update
User training	Quick-start guide for library team on new space booking interface	Single session provided
Student communication	Digital signage and student email newsletter update	One-time message in early March

6: Periodic review			
Activity	Frequency	Responsible role	Output
Digital twin accuracy audit	Quarterly	GIS analyst	Audit confirms layout reflects current use
Modification plan review	Annually	Digital twin governance team	Plan updated in March 2025 to reflect new stakeholder roles

Appendix 15: Access Bentley software

How do I access Bentley Software via the Education Portal?

1. Visit the Bentley Education Portal and click on "Login" in the upper right-hand corner.
2. If you already have a Bentley account, log in with your email and password. If this is your first visit, click "Don't have an account? Register now." It's recommended to use your registered university or school email address. (If you do not have one, please refer to the instructions following this list.)
3. Provide your details on the "Create Your Account" page, and click "Create Account."
4. Once your account is created, return to the Bentley Education Portal and log in with your credentials.
5. Update your profile under the dashboard section with the required fields. You need to be logged in and have an updated profile to access product downloads.
6. Click on the "Software" section, and choose the software you want to access.
7. Accept the Terms of Service and Privacy Policy to proceed to the Software Downloads page.
8. For activation instructions, please refer to the following link: How to activate products under Subscription Entitlement Service.
9. If you have any questions, feel free to check the FAQ page: FAQ.

For users without a university or school email:

- If you are using a generic email address (e.g., @gmail.com or @yahoo.com), you will receive a pop-up message when you click on the "Software" section.
- Upload a clear and readable ID card (JPEG, JPG, or PNG format, less than 1 MB) that matches the details on your Bentley Education profile.
- Once your ID card is accepted, you will proceed to the Terms of Service and Privacy Policy page. After acceptance, you will reach the Software Downloads page.

Appendix 16: Useful resources

Getting started with Bentley Education

- Installing iTwin Capture - Downloading Bentley software for students and educators
  This is a short video showing how to create a profile on the Bentley Education portal and how to download and install Bentley software.

- Bentley Education Learning and Training - How to access the learning and training content on the Bentley Education Portal?
  This provides step-by-step guidance for navigating to the Bentley Education Training page and accessing learning resources, ideal for both new and returning users.

Reality modelling with iTwin Capture

- **Reality Modeling Workflows** (Video series)
  This is a five-part series introducing Bentley's reality modeling solution, iTwin Capture. Learn how to create 3D reality mesh models for use in design, construction, and operations.

- **Introduction to Reality Modeling**
  This provides an overview of how reality modeling is used across industries, from surveying and city-scale modeling to facilities management and construction progress tracking, using Bentley iTwin Capture.

- iTwin Capture knowledge base articles
  This is an official article with technical guidance and documentation on using iTwin Capture.

Additional learning resources

- Bentley Learn: 3 hour online training course
  This is an introductory course offering structured, self-paced training on Bentley tools including reality modeling.

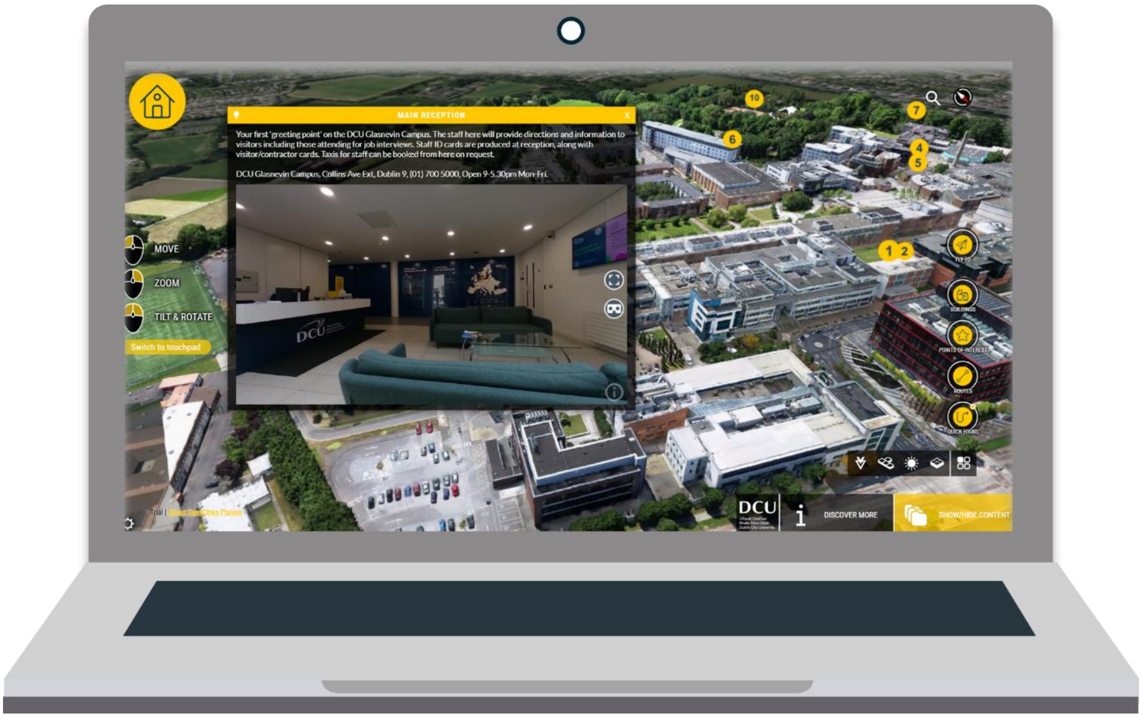
Appendix 17: Case Study – Smart DCU

Institution: Dublin City University

Partners: Insight Research Ireland Centre for Data Analytics,, Bentley Systems, Dublin City Council, Kaunas University of Technology

Focus: Supporting an Autism-Friendly campus through immersive digital twin integration

Bentley tools featured: iTwin Capture Modeler, OpenCities Planner, AssetWise 4D Analytics (4DA)



Overview

The Smart DCU example illustrates a modular, Bentley-enabled approach that can be adapted to suit an organisation's existing infrastructure, capabilities, and goals. The project demonstrates how a layered methodology, starting with photogrammetry, progressing through cloud-based visualisation, and integrating real-time data streams, can deliver meaningful outcomes, even without perfect data coverage.

DCU's goal was twofold: to enhance operational efficiency and to support its ambition to become the world's first autism-friendly university. With a user-first philosophy, particularly for neurodiverse students, the digital twin was designed to help users assess space suitability in real-time before physically entering a room.

Data Acquisition: Indoor and Outdoor Capture

The methodology used a combination of drone surveys, handheld photogrammetry, and available BIMs to model indoor and outdoor spaces.

Outdoor Capture

A DJI Mavic 2 Pro drone was flown over DCU's four campuses (Glasnevin, All Hallows, St. Patrick's, and Alpha) using DJI Ground Station Pro for automated, grid-based flight plans at 30–100 metres. This generated over 5,600 high-resolution geotagged images (e.g., 1,749 for Glasnevin), forming the base reality dataset for the digital twin.

The following drone flight parameters were used:

Drone flight parameters – DCU Campus survey					
Campus	Altitude (m)	Resolution (sm/px)	Overlap (f/s)	Flight time (mins)	Area (ha)
Glasnevin	60	1.4	70% / 70%	103	31.51
St. Patrick's	50	1.2	75% / 75%	53	7.06
All Hallows	42	1.0	80% / 80%	108	6.34
Alpha	47	1.1	85% / 85%	74	3.15

These values were generated using DJI Ground Station Pro flight planning software and a DJI Mavic 2 Pro. Overcast conditions were chosen to reduce glare.

Indoor Capture

For indoor environments, which drones can’t easily access, an iPhone 14 Pro Max equipped with LiDAR was used to take handheld photos. Polycam processed this imagery into 3D meshes, suitable for smaller rooms with standard lighting. However, for complex environments with glass, glossy surfaces, or high ceilings, this method proved less reliable.

Where available, 3D BIMs (such as those for the Polaris building) were incorporated directly. For older buildings with only 2D floorplans, a hybrid approach was used: Polycam-generated shell models were enhanced in Twinmotion, where missing objects and textures were manually added. For example, objects like sensory pods, student art, and furniture were modelled separately and placed into the space.

Category	Element	Description
Rooms	Tools used	iPhone 14 Pro Max + Polycam (LiDAR + image capture)
	Simple rooms	Quiet rooms and interfaith centres scanned handheld; Polycam produced textured 3D meshes or plain BIMs
	Complex rooms	Spaces with glass, glossy surfaces, or dense objects were scanned with Polycam to create shell models. Retouched in Twinmotion with manual edits

	Benefit	Method enabled realistic, semantically meaningful room models without requiring perfect scan conditions
Objects of interest	Approach	Small items with complex textures (e.g., Lego flowers, chess sets) captured using image-only photogrammetry
	Larger outdoor feature	Larger outdoor features (e.g., benches, the Labyrinth) scanned with both LiDAR and photos for full geometry + texture capture.
	Conditions	Photos taken from multiple angles and heights in uniform, soft lighting (ideally overcast conditions).
	Processing	Polycam auto-processed data and exported to formats such as OBJ and GLTF for use in Twinmotion and Unreal Engine.

Figure 12: Indoor rooms

Reality Modelling and Publishing

iTwin Capture Modeler was used to process drone imagery into textured 3D meshes and point clouds, exported in formats suitable for real-time rendering and integration.

For publishing and stakeholder engagement, OpenCities Planner provided a lightweight, browser-based interface. Digital twins could be accessed via simple URLs, and the platform supported the creation of Points of Interest (POIs), each of which could link to external dashboards, 360° images, or live sensor data. This proved especially useful for showcasing autism-friendly features such as quiet rooms and wellness areas.

Sensor Integration and Real-Time Monitoring

To make the twin dynamic, real-time IoT data was integrated using Bentley's 4D Analytics (4DA) platform. Data could be streamed directly or linked from third-party APIs and dashboards.

Sensors installed on campus included:

- **WIA:** 40 devices monitoring room occupancy, temperature, humidity, noise, and lighting

- **HiData:** 2 edge devices using computer vision to measure occupancy and environmental conditions
- **CIVIC:** Radar sensors at campus entrances tracking pedestrian, vehicle, and cyclist movement
- **Bigbelly:** Smart waste bins providing live waste collection data

Each sensor type had its own dashboard and API, but 4DA unified the data, allowing fusion and temporal analysis. For instance, sensor 16 in the U Building could display historical temperature, noise, or occupancy across selectable date ranges—useful for both students and facilities teams.

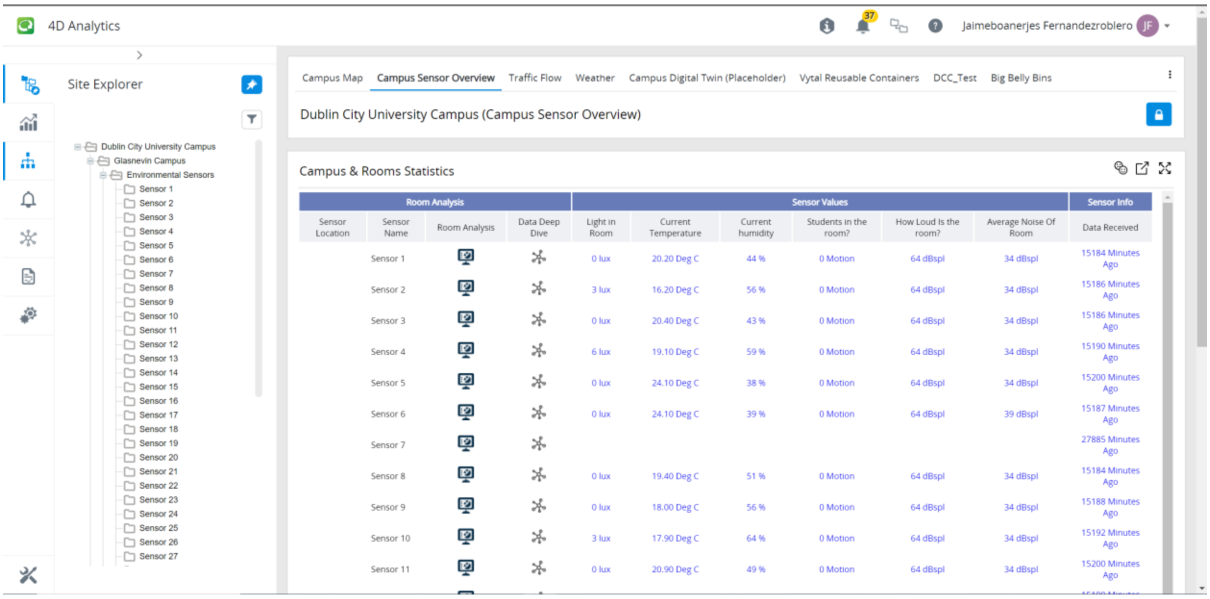


Figure 13: WIA: 40 sensors reporting light, temperature, humidity, room occupancy and noise level.

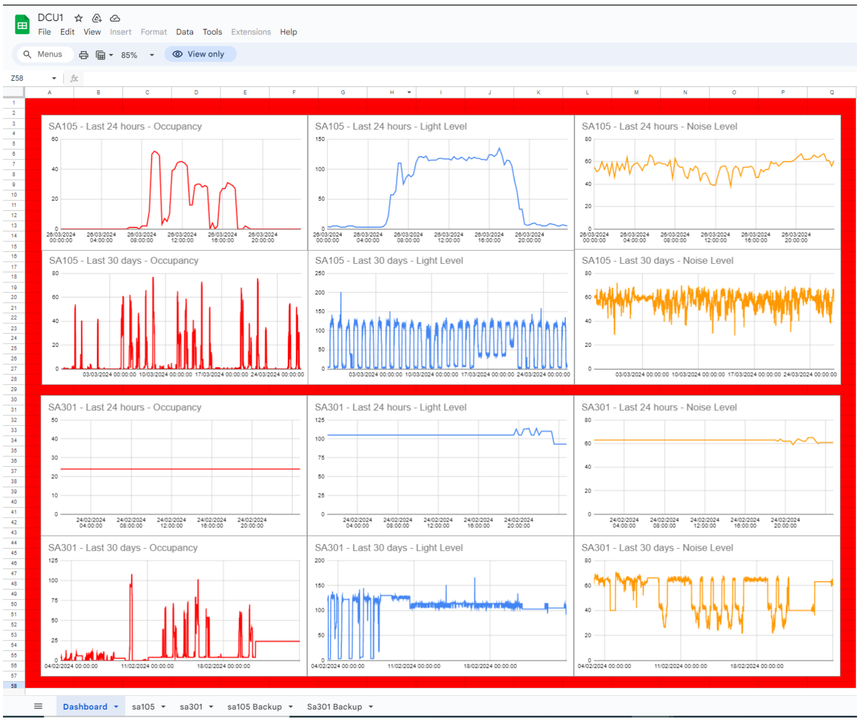


Figure 14: HiDatai: Two computer vision-based sensor reporting room occupancy, light and noise level

Data Visualisation and Accessibility

The team used different platforms for visualisation depending on the audience and goals:

- OpenCities Planner was used for rapid, low-barrier access via web browsers. POIs provided real-time context for users navigating the 3D model.
- Unreal Engine was explored for immersive digital experiences. The team developed interactive spaces such as the Interfaith Centre, Wellness Room, and the Polaris building with live IoT overlays. These were enhanced with realistic assets and textures using Twinmotion, and then deployed via Unreal Engine.
- For added accessibility, the team prototyped a wayfinding system: users could select a destination room, and a digital avatar would guide them via two modes, either showing a video-like path or allowing the user to follow the avatar themselves, like in a video game.

Tool selection and integration overview

The table below provides a quick reference for common campus modeling scenarios, reflecting a combination of Bentley and third-party tools as used in real-world implementations like Smart DCU. This layered approach ensures that each asset (whether a room, building, or object) is captured, refined, and integrated using the most appropriate method. Each workflow was tailored to the specific needs of the asset, balancing speed, accuracy, realism, and interoperability with Bentley tools.

Physical Assets	Data Collection	3D Modeling (Processing)	Library of Digital Assets	Type of Assets	Virtual Environment Integration
DCU Campus (Outdoors)	Drone Photography (DJI Mavic II PRO, DJI Ground Station Pro) 	iTwin Capture Modeler	Glasnevin, St. Patricks, All Hallows, Alpha	3D reality data meshes	
Rooms (Indoors)	Hand-held photos (Iphone 14 Pro Max)  48 Pix Cam. LiDAR Cam.	polycam	Interfaith Centre, Quiet Room	3D reality data meshes	OpenCities Planner Bentley
Buildings	BIMs (DCU)	Twinmotion	Polaris Building	3D realistic BIMs	
Complex Rooms (Indoor)	Plain 3D BIMs (Iphone 14 Pro Max)  48 Pix Cam. LiDAR Cam.	polycam Twinmotion	Wellness Room, Henry Grattan Entrance, U Building	3D realistic BIMs	UNREAL ENGINE
Objects of Interest	Hand-held photos (Iphone 14 Pro Max)  48 Pix Cam. LiDAR Cam.	polycam	E-Bikes, E-Scooters, Labyrinth, Benches, Lego flowers, Chess game, Bigbelly bins, Prayer furniture.	3D reality data meshes	

Challenges and Workarounds

- **Photogrammetry indoors** struggled with reflective surfaces, cluttered rooms, and large spaces. The team either modelled rooms empty or created a clean shell and manually placed digital objects.
- **Sensor placement** required university approval, highlighting the need for institutional support early on.
- **Visualization tools** varied in capability. OCP was ideal for quick publishing, but lacked native graphing; 4DA supported dashboards and integration but required configuration; Unreal offered immersive potential but came with higher complexity.
- Modeling vegetation and glass produced distorted meshes, even with LiDAR. Realistic replacements were added using high-fidelity assets from Twinmotion or Unreal Engine.

- Importing large BIM files (e.g., the Polaris building) caused performance issues in Twinmotion. Files were optimised by collapsing by material type to reduce system load while maintaining editability.
- Institutional buildings lacked consistent BIM or CAD records. Drone photogrammetry and mobile scans were used to fill gaps with new reality meshes.

Tips for Implementation

1. **Start with what you have:** Drone imagery and free tools like Polycam can go a long way.
2. **Use a layered approach:** Reality mesh → contextual data → real-time data → immersive experience.
3. **Combine formats:** Integrate BIMs where available and fill gaps with photogrammetry or modelling.
4. **Match tools to audiences:** Use OpenCities Planner for public access and Unreal Engine for deeper interaction.
5. **Build incrementally:** DCU started with a few key spaces—interfaith centres, quiet rooms, classrooms, before scaling.
6. **Prioritise inclusivity:** Design for neurodiverse users from the outset, not as an afterthought.
7. Optimise large BIMs: Collapse elements by material to improve usability in visualization tools.
8. **Scan in modules:** Capturing individual rooms or buildings reduces complexity and supports iteration.
9. **Replace complex materials digitally:** Use asset libraries to substitute vegetation and reflective surfaces when mesh quality is poor.
10. **Engage stakeholders early:** Secure approvals and access by involving estates, IT, and facilities teams from the start.

Appendix 18: Case Study – Kaunas University of Technology (KTU)

Institution: Kaunas University of Technology (KTU), Lithuania

Partners: Bentley Systems, Digital Construction, YIT Lietuva, Kauno Tiltai, Staticus, Inhus

Focus: Sustainability-driven digital twin for education, emissions reduction, and city-scale planning

Bentley tools featured: iTwin Capture Modeler, OpenCities Planner, iTwin Platform

Overview

Kaunas University of Technology's digital twin initiative, developed through its Centre for Smart Cities and Infrastructure, demonstrates how academic-industry collaboration can enable innovation in sustainable infrastructure and education. Originally developed as a campus-scale pilot, the twin has expanded to cover parts of Kaunas city and is used as both an emissions monitoring tool and a teaching platform.

Driven by Lithuania's goal of decarbonizing its building stock by 2050, the project integrates UAV-based photogrammetry, LiDAR, IoT streaming, and BIM to visualize and optimize building performance. The campus digital twin acts as a real-world sandbox to support CO_2 emissions reduction, smart infrastructure development, and digital skills transfer into industry.

Data Acquisition and Modelling

Reality Capture: The project began with the systematic capture of both exterior and interior spaces. UAV-based photogrammetry and terrestrial LiDAR were used to create reality meshes of campus buildings. These 3D datasets were later enriched with BIM models and mapping data to provide spatial and semantic context.

Model Use in Education: Students access these digital models to contextualize architectural and engineering designs. Several faculty members embed the twin into coursework, bridging theoretical content with hands-on experience.

Live IoT Integration

KTU has built a system that integrates IoT sensor data into the digital twin for real-time monitoring and feedback. These include:

- Air quality and human comfort indicators (temperature, humidity)
- Energy performance and production (e.g., photovoltaic outputs)

The aim is to create and monitor sustainability indicators to support long-term building performance optimization.

City Engagement and Expansion

Initially focused on campus buildings, the digital twin expanded into Kaunas city centre. The Centre for Smart Cities and Infrastructure is now advising the city on how to replicate the model at scale. While city authorities were initially hesitant, demonstrator projects have illustrated the benefits of using digital twins for urban planning.

Teaching Through Innovation

KTU's digital twin acts as an engine for digital skills development. Architecture and civil engineering students explore:

- Open standard modelling using IFC
- Safety analysis and infrastructure design
- Sustainability strategies and emissions analysis

Notably, the MLab prototyping building was built and analyzed using the digital twin. Students engaged in real-time design assessment, HVAC and utility integration, and safety modelling, applying classroom knowledge in a practical context.

Outcomes and Impact

- A dynamic 3D model of KTU's campus and Kaunas city centre
- Integration of IoT sensors for real-time sustainability monitoring

- Deployment in academic curricula for architecture and civil engineering
- Uptake of digital twin use by local government and developers
- Support for emissions reduction in line with EU building directives

Key Lessons

- Digital twins support both infrastructure and education goals simultaneously
- UAV photogrammetry and LiDAR offer scalable, accurate data capture
- Open standards like IFC enable model longevity and interoperability
- Live sensor data enhances model value and supports sustainability metrics
- Partnerships between industry and academia drive meaningful innovation

Appendix 19: Case Study – uTwin, University of Texas at Austin

Institution: University of Texas at Austin (UT Austin), United States

Partners: Texas Advanced Computing Center (TACC), UT Facilities, City of Austin, Bentley Systems

Focus: Data-driven urban digital twin for building performance, environmental planning, and public engagement

Bentley tools featured: OpenCities Planner

Overview

UTwin is a data-centric, campus-scale digital twin developed at the University of Texas at Austin. Designed to integrate a wide variety of datasets including environmental, infrastructural, and spatial information, UTwin provides a visual decision-support tool for researchers, students, and the public.

The twin is optimized for accessibility and performance rather than high-fidelity geometry, focusing on real-time data exploration and public communication. While initially created for research, the twin is now publicly accessible via a web interface using GitHub Pages, providing stakeholders a live view of metrics such as air quality, energy consumption, and flood risk.

Data Integration and Processing

Data Sources:

UTwin integrates data from:

- Building energy consumption datasets
- Air quality sensors across campus
- GIS layers for transportation, hydrology, and green infrastructure

Processing Tools:

Python libraries such as Pandas and GeoPandas were used to clean, standardize, and process shapefiles and tabular data. These datasets were uploaded into OpenCities Planner for map-based visualization.

Visualization and Deployment

OpenCities Planner served as the primary platform for building and sharing the twin. It supports the integration of:

- 3D models (simplified for browser use)
- Vector overlays and base maps
- Interactive Points of Interest (POIs) linking to external dashboards or documents

The final output is deployed as a public-facing web application, with optimized content delivery for low-bandwidth users and lower-spec devices. This ensures the tool remains inclusive and usable for diverse audiences.

Education and Public Engagement

UTwin was developed as both a research and communication tool. Its open-access format allows:

- Faculty and students to explore sustainability scenarios
- City planners to examine environmental risks in an academic sandbox
- Citizens to understand local air quality and building performance trends

It acts as a learning resource, enabling non-specialist users to engage with urban data in a meaningful way.

Outcomes and Impact

- Integration of live and historical datasets into an interactive platform
- Enhanced public understanding of energy use and environmental conditions

- Demonstrated a low-cost, replicable framework for urban-scale digital twins
- Reinforced UT Austin's leadership in civic digital innovation

Key Lessons

- Start with available data: Low-cost tools like Python and GitHub Pages can create powerful results
- Optimize for audience: Prioritize web performance and clarity over graphical fidelity
- Use open-source wherever possible: Maximize transparency and replicability
- Engage students and the public early: A twin is more impactful when it's shared