Learning material
Intro section

Document history

Date	Action	Author
2023-06-19	Document created based on previous decisions	Erling
2023-06-20	Some updates	Erling
2023-09-06	Section 3.4. Smartization has been added	Meinhardt
2023-09-28	Updating 3.4. Smartization	Meinhardt
2023-09-28	Discussed in partner editing meeting	Several /E as editor)
2023-10-23	Updating Metodology	Cristina
2024-03-06	Updated (started but not completed) on ch 1 the outcome and goals	Erling
2024-03-13	Previous version copied to folder OldVersions, before removing “outgoing text” in this version, mainly Ch 1 (Goals) and Ch2 (Digital Twin)	Erling
2024-03-14	1) I have tried to remove the PR terms, using Sections A,B,C and D instead 2) Also tried to reorder the chapters to have two data capture sections first (originally termed PR2 and PR4) and then the two other (PR3 and PR5) afterwards 3) Numbering the exercises using “global IDs”, with leading letter A-D pointing to main sections, and a following “I’ for intro exercise and a number. Please check if I have succeeded.	Erling
2024-03-20	Added more on intro exercise for viewing geometry – still more to do here.	Erling
2024-03-20	Rewritten the information security chapter	Erling
2024-04-10	Updated fig 1, replaced use of term Course with Learning material.	Erling

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2024-04-11	Pasted inn valuable text from PR2 document, into new Ch 2.2 here. To be decided if it will remain here, or stay in Pr2	Erling
2024-04-25	Some editing, incl adding figure text on the figures missing this.	Erling
2024-09-05	Added 4.6. Smartization Assignment	Meinhardt

Content

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1 Learning outcome

The outcome is divided into three parts: the first connected to the goals in the Erasmus+ funded project where the material is produced (the DigiLab/BE project), the second to the outcome of this intro section, and the third is the outcome of the whole learning material package.

1.1 The Digilab/BE project - Project goals

The goals of the project is found in the project report, and due to the rather general high level formulations, it is found of minor interest here.

1.2 Learning content and outcome

The goal of the DigiLab/BE LM (DigiLab/BE learning material) is to give an introduction to digital twins for the building and engineering (BE) sector.

The target group is pupils and students, having heard the term Digital Twin and want to know more, both on the possibilities it opens, and the technology involved.

The **DigiLab/BE LM** consists of several sections as shown in Figure 1.

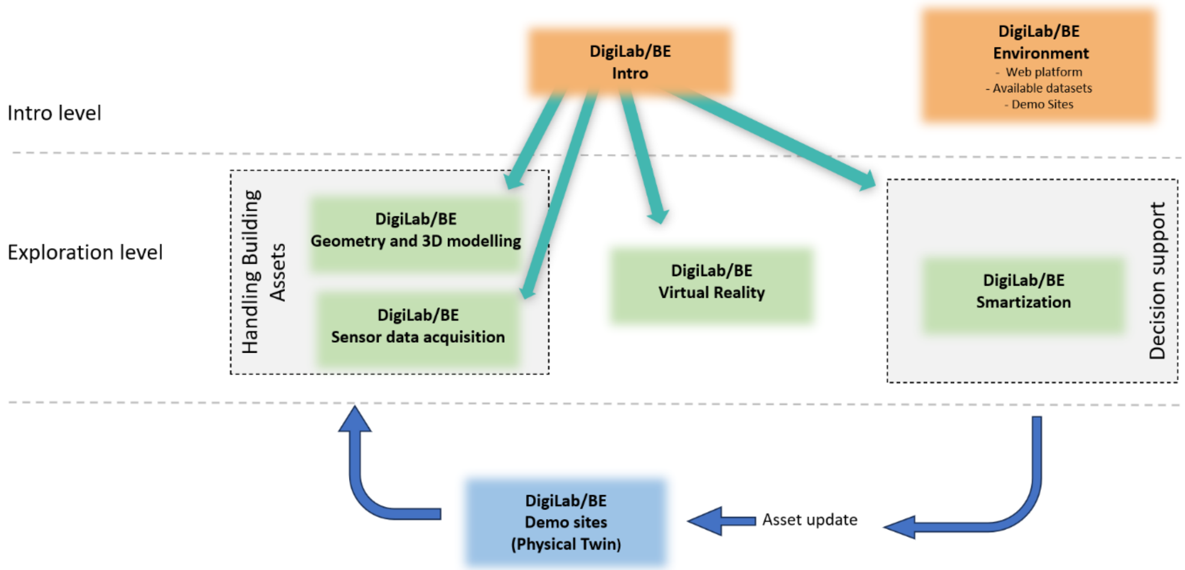

Figure 1 Learning material sections (orange and green boxes), use of the material (green arrows) and information flow (blue arrows) NB Names of sections need to be updated according

The **DigiLab/BE Intro** introduces the complete concept of Digital Twin, explained by overview text and examples. The examples use data from the two demo sites, one in Gjøvik/Norway, and one in Blanca, Spain.

Students are strongly recommended to start their digital twin journey in the DigiLab/BE Intro section. The students being inspired, can continue with the four more in-dept sections in data capture (**DigiLab/BE Geometry and 3D modelling** and **DigiLab/BE Sensor data acquisition**), the VR/Visualization section (**DigiLab/BE Virtual Reality**) and the section handling analysis and decision support (**DigiLab/BE Smartization**).

The **DigiLab/BE Platform** is the collection of supporting materials to the DigiLab/BE LM. The main purpose is to be a support to the DigiLab/BE LM However, it might also be used as supporting platform for continuing digital twin activities when/if the DigiLab/BE LM is not relevant.

The outcome:

- The **DigiLab/BE LM** will give you a practical introduction to the use cases, principles and technology used in digital twins, making you ready for further exploration of digital twins, either on your own or as part of an education.
- **DigiLab/BE Intro** will give you an introduction to digital twin for BE, sufficient for further learning using the four in-dept sections.

The outcomes for each of the four in-dept sections are found in each section.

1.3 Learning outcome from this Intro section

In this introductory section, we aim to provide students with a foundational understanding of the significance of digital twins in 21st-century construction, along with insights into the creation process, its various stages, and levels of development.

Consequently, this section offers a comprehensive overview, equipping students with essential competencies essential for embarking on a digital twin project for a building, starting from scratch and at a basic level. This approach is taken not only for fostering their interest in the subject but also underscores the importance of expanding their knowledge to attain a higher level of expertise. Additionally, it allows educators to gain an understanding of the level of digital twin application in their classes and assess the possibility of either fully developing the project or approaching it from various paths or perspectives, depending on the subject matter to be taught.

1.4 Overview of the sections in the learning material (Digilab/BE LM)

The learning outcome is given in each of the sections. Here is an overview (1 sentence for each section):

- DigiLab/BE Introduction: As the title indicated, this is the needed introduction, with chapters as Introducing Digital Twins, Information Security Challenges for Digital Twins in addition to intro for each learning material sections. In this Intro section you will find needed presentations from the other four sections for understanding "the full picture" of DT, to be ready for diving into each of the four following sections.
- Data capture sections
    - **DigiLab/BE Geometry and 3D modelling (Section A)**: In this section, we will learn how to carry out data collection tasks using various tools such as a laser scanner to

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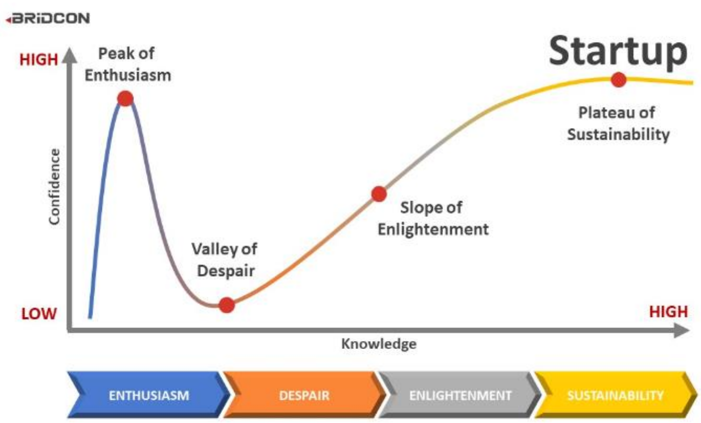
create 3D models. Additionally, we will study the basic digitization process of a building in order to obtain a digital twin.

  - **DigiLab/BE Sensor data acquisition (Section B)**: In this work section, students will learn how to assemble and install a variety of sensors to acquire information and display it in their digital twin.

- **DigiLab/BE Virtual Reality (Section C)**: At the end of the section students will be able to view 3D models generated by scanning in Virtual Reality, understand the process of remeshing and optimization and use VR environment for DI creation.
- **DigiLab/BE Smartization (Section D)**:

A warning on an unwanted outcome of this Intro section:

The **Dunning–Kruger effect** is a cognitive bias in which people with limited competence in a particular domain overestimate their abilities. It was first described by Justin Kruger and David Dunning in 1999.



After reading this intro section, might be you are on the Peak of Enthusiasm (see above). You are still not a digital twin expert, but are ready for continuing the journey in the exiting topic. Be careful not to quit the learning at the Valley of Despair, but follow up with learning material Sections A to D to start the learning slope to Plateau of Sustainability.

NB! Check property rights of figure, possibly Christina could make a figure designed for DigiLab.

2 Introducing Digital twins

2.1 On digital twins

In the current era of digitalization and Industry 4.0, digital twins have emerged as a pivotal concept. These virtual models, mirroring physical objects or systems in the digital realm, are bringing transformative changes across various sectors, including manufacturing and medicine. In this module, we will explore the process of developing digital twins, their usefulness, current status, and importance, as well as their applications in the construction sector.

Before diving into the full scope and advantages of digital twins, it is essential to comprehend what they are and how they differ from related concepts like BIM (Building Information Modeling).

BIM is a model-based methodology, pivotal for designing, constructing, and managing buildings or infrastructure. It facilitates the creation of comprehensive virtual models, with detailed data about construction elements such as geometry, physical properties, spatial relationships, and other pertinent attributes. The primary aim of BIM is to enhance collaboration, efficiency, and quality across the building lifecycle.

On the other hand, a digital twin represents a real-time digital replica of a physical asset, such as a building, infrastructure, or system. It integrates data from diverse sources, transcending the realms of design and construction. A digital twin emphasizes ongoing monitoring, simulation, and in-depth analysis of the physical asset. It is dynamically updated with real-time data, enabling a better understanding and decision-making based on the asset's operational performance.

In essence, while BIM focuses on creating and managing three-dimensional models for the design and construction of buildings, the digital twin goes beyond that and uses real-time data to simulate, monitor, and optimize the performance of a physical asset throughout its lifecycle. BIM is a fundamental part of creating the digital twin as it provides a solid and accurate database for its development and management. The digital twin, in turn, expands the capabilities of BIM enabling ongoing visualization and analysis of the asset's real-time performance.

In the following image, we can see the different stages of a digital twin, from a BIM-based virtual model to an autonomous digital twin.

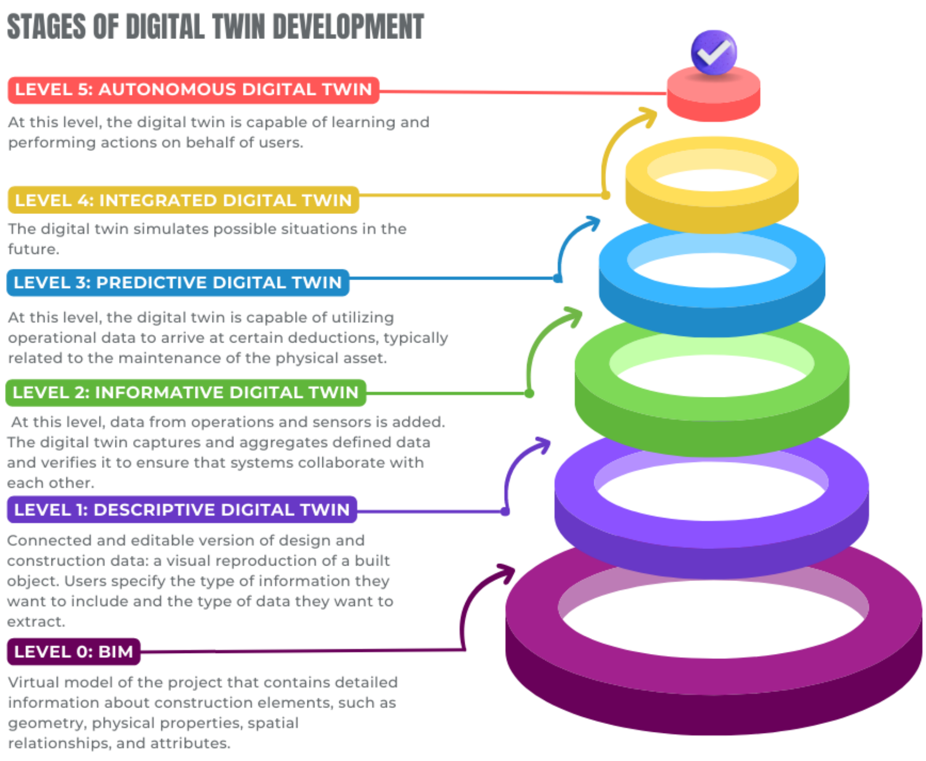


Figure 2 Stages of a digital twin development

Utility and current status of Digital Twins

The utility of digital twins lies in their ability to provide an accurate virtual representation of physical objects or complex systems. This capability allows for testing, simulation, and analysis within a virtual environment before implementing a real application. This approach is crucial in reducing costs, mitigating risks, and improving decision-making processes.

At present, digital twins are experiencing significant growth, and their adoption is accelerating in various sectors. As technology advances, they become more sophisticated and realistic, allowing for greater precision and more advanced applications.

Importance of studying Digital Twins

Studying digital twins is crucial for several reasons:

- Technological advancement: Digital twins are a fast-changing technology. Learning about them keeps us updated on the latest developments and helps us use their potential in different areas.
- Innovation and competitiveness: Digital twins bring new chances for creativity and improvements in many sectors. By studying them, we can find new areas to use them, come up with new solutions, and keep up with the fast-paced business world.
- Customized solutions: Digital twins can be tailored to meet specific needs. Understanding them helps us learn how to use them effectively to tackle unique challenges in various fields.
- Social and environmental impact: Digital twins can help with important social and environmental problems, like making better use of resources, managing energy efficiently, and creating healthcare that fits each person. Studying them helps us find ways to solve these important issues.

2.2 Planning

2.2.1 Assessment of existing conditions

Clear objectives are the essential starting point when planning the creation of a digital twin. A digital twin is a virtual replica of a physical object or system used for various purposes, such as simulations, performance analysis, and informed decision-making. Clearly defining why a digital twin is being created, is a fundamental step that influences the entire process and determines its success.

First and foremost, it is crucial to consider the purpose of your digital twin. Are you looking to simulate the performance of a product, optimize an industrial process, or enhance decision-making within your organization? These are just examples of the various uses of digital twins. Each objective requires a specific focus and planning.

If your goal is to simulate the performance of a product, like a vehicle or an electronic device, your digital twin must replicate all the features and behaviours of the real product. This enables virtual testing, identification of potential issues, and making improvements before production. Performance simulation is essential in industries such as automotive, aerospace, and consumer electronics, among others.

When aiming to optimize an industrial process, the digital twin becomes an invaluable tool. You can model a production line, a manufacturing plant, or even an entire supply chain. With real-time data and simulations, you can identify bottlenecks, enhance efficiency, and reduce costs. Process optimization is crucial in manufacturing and logistics industries.

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Another common objective of digital twins is to enhance decision-making. Organizations can create digital twins of their operations, systems, or assets to gain a clearer and more detailed insight into their functioning. This allows making informed decisions based on accurate and up-to-date data. Digital twins are also useful in asset management, urban planning, and infrastructure administration.

Having well-defined objectives not only guides the purpose of your digital twin but also influences the decisions made throughout the development process. From data collection to technology selection and digital twin validation, each step is designed to align with the established objectives. Furthermore, this clarity in objectives facilitates communication among team members, which is crucial in interdisciplinary projects.

Clear objectives also aid in assessing the project's success once the digital twin is completed. You can measure its effectiveness based on how it contributes to achieving the predefined objectives. For instance, if the goal was to optimize an industrial process, and the digital twin successfully reduces production time and costs significantly, then you would consider the project a success.

In summary, the definition of clear objectives when creating a digital twin is essential to guide the process, make informed decisions, and measure success. Objectives determine the digital twin's purpose and guide the entire development process, from data collection to validation and implementation. Clarity in objectives ensures that the digital twin becomes an effective and valuable tool for its intended purposes, whether it's simulation, optimization, or decision-making.

As we will see next, in this project, two digital twins have been developed. In the following section, we will determine the objectives and the level of development that our digital twins will have.

2.2.2 Determine objectives and qualities

The qualities/properties of a digital twin vary depending on its level of development and its specific application (the purpose or use case it is designed for). Some of the key qualities/properties of a digital twin include:

1. ***Accurate Representation***: A digital twin should be an accurate and faithful representation of the object, system, or process it models. It should accurately reflect its geometry, behavior, and state.
2. ***Real-time Interaction***: Dynamic digital twins should be capable of real-time interaction with the real object they represent. This involves the ability to receive real-time data and adjust their representation accordingly.
3. ***Simulation Capability***: Digital twins can be used to simulate different scenarios and evaluate how changes or decisions would impact the operation or performance of the object or system.
4. ***Prediction and Anticipation***: Advanced digital twins are capable of predicting the future behavior of the object or system and anticipating potential issues or needs.
5. ***Connectivity and Communication***: Digital twins can be connected to sensors and real-world systems to gather real-time data and communicate with other systems and devices.
6. ***Real-time Updates***: They should be capable of real-time updates as the real object or system they represent changes, allowing for continuous monitoring.
7. ***Analysis and Decision-Making***: Digital twins can analyze data and assist in decision-making, and advanced digital twins can even make decisions autonomously.
8. ***Scalability***: They should be adaptable and scalable to represent more complex or larger objects or systems.
9. ***Integration with Advanced Technologies***: Digital twins can benefit from technologies like artificial intelligence, machine learning, and Big Data to enhance their predictive and analytical capabilities.

10. ***Collaboration and Optimization***: Digital twins can facilitate collaboration between different systems and teams and optimize processes and operations.

When designing a digital twin, the needed functionality and "score" for each of the properties listed above must be specified considering the intended use. Examples:

- Scalabilty and real time interactions are two important aspects of digital twins. But for some use cases these aspects might be irrelevant, and thus no need for implementation.
- The higher requirement to the geometrical accuracy and level of details, the higher the cost for creating and maintenance the digital twin. For cost-effective implementations, the digital twin requirements/specifications must be adapted to the wanted outcome of the digital twin.

2.2.3 Major levels of digital twins

(Source for this chapter:

- https://bim2vr.es/blog-construccion-digital-gemelo-digital-grados-madurez/)

Based on its degree of digitization, we can classify a digital twin model into five major levels. These range from the simplest systems capable of recreating buildings based on real project data to the most advanced ones that can make decisions and execute them in the physical world autonomously.

1. Descriptive Twin

The most basic level of a digital twin allows us to virtually recreate our design using real project data. Additionally, this model can be edited in real-time to stay up-to-date in response to potential changes in reality. Thanks to current technologies, it is possible to provide immersive and hyper-realistic results based on virtual reality systems.

2. Informative Twin

The second level goes a step further by incorporating a layer of connectivity that links the virtual model with the physical world. This process can be done manually (by inputting data into the digital environment) or automated through sensors. In this way, the digital twin can acquire, verify, and manage operational and sensory information to facilitate collaboration among different systems. As in the previous case, data is updated in real-time to allow continuous monitoring of processes and project status.

3. Predictive Twin

At this third level, the digital twin can leverage all the data it has access to and transform it into knowledge to anticipate project needs or potential setbacks. In other words, it can not only connect to data sources but also extract and process data to reach certain conclusions. For example, it can carry out predictive maintenance actions for a building, have operational protocols, or applicable cost calculations during construction, and more.

4. Integrated Twin

In the penultimate stage of maturity, the model offers simulations of possible future scenarios or situations that require complex responses. At this point, the twin gains the ability to learn and provide data-driven responses. It can rely on the input of humans who introduce specific response models, as well as its own capacity for machine learning through advanced algorithm systems.

5. Autonomous Twin

Finally, there will come a time when technology allows for the creation of collaborative environments where digital twins not only assist humans in decision-making but are capable of making decisions themselves and applying them directly in a real-world setting. To do so, they conduct real-time simulations based on data from multiple sources, such as information from sensors, historical trends, and more. At this level, the use of technologies such as artificial intelligence (AI), Big Data, and machine learning becomes especially important.

Gelernter, David Hillel (1991). Mirror Worlds: o el día en que el software pone el universo en una caja de zapatos: cómo sucederá y qué significará. Oxford; New York: Oxford University Press

Grieves, M., Sistemas de productos virtualmente inteligentes: gemelos digitales y físicos, en Ingeniería de sistemas complejos: teoría y práctica, S. Flumerfelt, et al., Editores. 2019, Instituto Americano de Aeronáutica y Astronáutica

https://www.digitaltwinconsortium.org/

https://www.buildingsmart.org/digital-twins/

The digital twins developed for the demo sites in this project virtually represent buildings that exist in reality. Moreover, sensors are installed to acquire data related to the environment around them. With this information, what do you think is the level of development of these digital twins?

2.3 Methodology

This DigiLab/BE LM is designed to help students gain skills in creating digital twins using a variety of technologies. It emphasizes active participation and applying knowledge to real-world projects, enabling students to gain a deeper, hands-on understanding of the subject.

The learning material is divided into four main modules, each focusing on different aspects of the practical creation and virtualization of a digital twin.

Section A: Building Digital Twin

This module provides a comprehensive learning approach, focusing on data capture through photogrammetry and 3D scanning, followed by the creation of 3D models. Students will engage in both theoretical learning and practical exercises, ensuring a solid foundation in managing the data flow critical for 3D model creation.

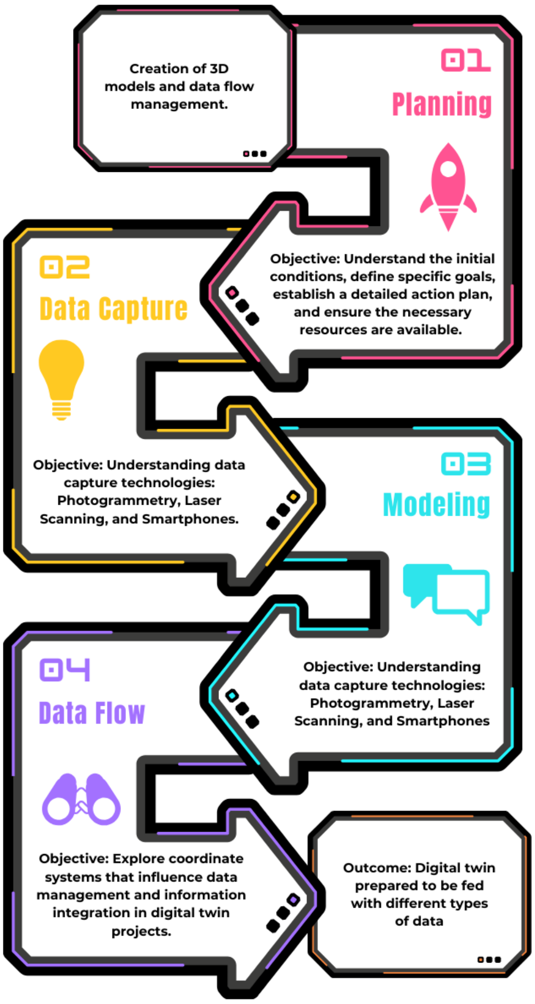


Figure 3 Steps in creating a digital twin for geometry and 3D modelling

Section B: Updating digital twin with dynamic data

In this module, students will explore how to select and install sensors in project demonstrators. The learning material includes images and videos for better understanding. Students will gain independence in assembling the entire system, connecting it to an IoT platform, and managing data storage for later visualization.

Section C: Virtual Training

This module is designed to develop proficiency in creating content and generating digital twins within the realm of Virtual Reality (VR). The module is structured to impart practical skills in key areas such as 3D visualization, point cloud manipulation, and mesh recording and simplification. These skills are particularly relevant to construction engineering and architectural applications.

Section D: Smartization of digital twin

2.4 Standards and Regulations

Implementing BIM (Building Information Modeling) technology in digital twins is guided by various standards and regulations, both nationally and internationally. These regulatory frameworks and technical guidelines ensure the quality, compatibility and interoperability of BIM models and associated information.

As the construction industry rapidly shifts from traditional design approaches to digitalization, there is a growing imperative to develop and establish BIM standards [1]. The absence of standardized procedures and shared methodologies has led to confusion when it comes to the definition of BIM-related processes. Standardization bodies are working towards creating a unified framework for BIM standards, methodologies, and data exchange.

Two leading standardization bodies regarding BIM are the “International Organization for Standardization” especially the Technical Committee 59/Subcommitee 13 (ISO/TC 59/SC 13 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)) and the “European Committee for Standardization” with technical committee 442 (CEN/TC 442 - BUILDING INFORMATION MODELLING (BIM)). **CEN/TC 442** serves as a European committee dedicated to establishing Standardization in the field of structured semantic life-cycle information for the built environment. The committee will develop a structured set of standards, specifications and reports which specify methodologies to define, describe, exchange, monitor, record and securely handle asset data, semantics and processes with links to geospatial and other external data [3].

Outlined below you can find a selection of the regulations and standards frequently adopted:

- **ISO 19650** is a meticulous and comprehensive series of standards that serves as a guide for the effective management of Building Information Modeling (BIM) data. This series covers the full spectrum of an asset's lifecycle, offering insightful recommendations for critical aspects of information management, including seamless data exchange, documentation practices, vigilant version control mechanisms, and robust organizational strategies. Important issue in the ISO19650-family is defining responsible actors, and definng requirements to the digital twin. Four kinds of requirements are identified: Organizational requirements (OIR), project requirements (PIR), asset requirements (AIR) and exchange requirements (EIR). [2]
- **ISO 12911:2023** establishes a framework for providing specifications for the internal commissioning and implementation of building information modelling (BIM) during both delivery and operational phases. It identifies a structured approach so as to encourage clarity during development, management and checking processes for use by organizations that develop and apply these specifications. [4]
- **ISO 16739-1:2018,** widely recognized as IFC (Industry Foundation Classes), delivers a neutral and open specification essential for interoperability among various software applications in building construction. It facilitates a comprehensive range of processes throughout the building lifecycle, promoting seamless data sharing and collaborative efforts among different stakeholders. This standard plays a key role in ensuring effective communication and integration across the various phases of construction and facility management.

Countries like Norway, Finland, Denmark [5], and Spain [6] have also made strides in BIM standardization, aiming to enhance collaboration, information exchange, and BIM implementation at various levels:

- **Norway** has actively contributed to the evolution of openBIM standards and has been involved in integrating the 3D facet of BIM into public projects since 2010. In 2013, Statsbygg introduced the "BIM Manual" to outline its requirements for IFC-compatible BIM. The Statsbygg Building Information Modelling Manual (SBM) has been positioned as the best approach for BIM implementation in Norway's Architecture, Engineering, and Construction (AEC) sector.
- **Finland** stands out as a pioneering force in incorporating BIM technologies within its construction sector. Starting in 2007, Senate Properties published the BIM requirements. In 2012, the Common BIM Requirement (COBIM) series was introduced to offer updated and detailed modeling guidelines across 13 releases. On the other hand, buildingSMART Finland introduced InfraBIM requirements in 2015 to expedite infrastructure sector digitalization.
- **Denmark** has acquired substantial practical expertise in the application of BIM in construction projects over the last years. Since 2011, BIM adoption has been compulsory for all local and regional projects in Denmark, exceeding a budget of 2.7 million Euros.
- **Spain** had some pioneering in the implementations of BIM by institutions and public administrations since 2009. The year 2014 marked the release of the first Spanish BIM guidelines, known as the UBIM guidelines (by buildingSMART Spain). In 2018, BIM became mandatory for the design and construction phases of public infrastructure projects exceeding €2 million.

2.5 Digital twin benefits: Use cases, roles, stages

2.5.1 Use cases

Digital twin use cases can be categorized as follows:

- Executive cases: These involve support for the establishment and maintenance of a physical asset, often focusing on the BIM aspects.
- Owner cases: These provide support to the asset's owner, typically a decision-maker, focusing on aspects like the asset's economic performance.
- Users' cases: This category offers information to the users of the asset, aiding in navigation and access to services like check-in, security, gates, and amenities such as toilets, shops, and restaurants.
- Public authorities' cases: These use cases involve providing information to public authorities regarding legal certificates and permissions.

It's important to note that these categories often overlap. For instance, a digital twin for an airport could be utilized across all these categories, but the information presented would differ based on the user's needs:

- The owner should focus on the economic aspects of the airport, such as revenues, costs, and investments.
- Building and maintenance workers would primarily concentrate on the technical properties of the airport, like infrastructure maintenance, repairs, and upgrades.

- The general users, such as travelers, would be interested in navigation through the airport, including finding check-in counters, security checks, gates, and information about traveler services like toilets, duty-free shops, and restaurants.

Overloading certain users with too much information might lead to confusion or misuse, while not providing enough information could result in dissatisfaction and the need to seek information from other sources.

At present, sectors like engineering and manufacturing are using digital twins for creating accurate virtual representations and simulations of operational processes (Mohosen A., 2023). Digital twins in these sectors are employed for operations tracking, transportation maintenance, remote assistance, asset visualization, and customized design.

The potential of digital twin technology spans a wide array of industries, including automotive, aerospace, construction, agriculture, mining, utilities, retail, healthcare, military, natural resources, and public safety. The technology's versatility and utility have garnered significant interest from both academia and industry professionals, with a growing body of literature and commercial applications emerging worldwide.

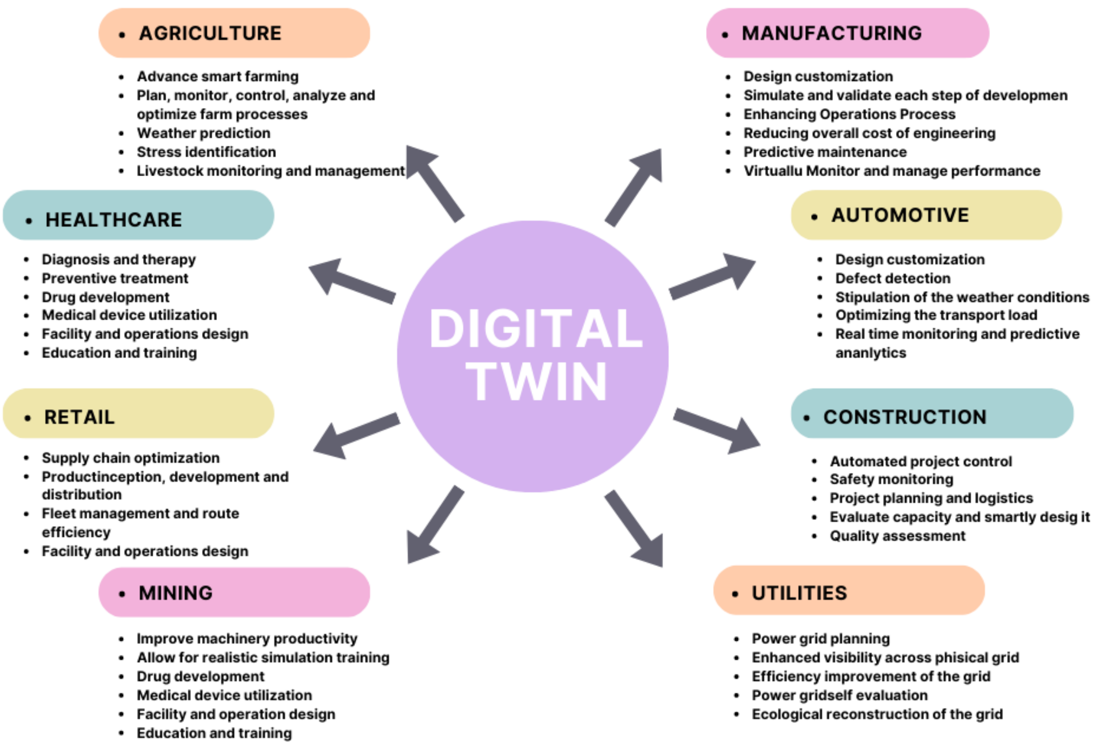


Figure 4 Digital twin application sectors

Questions to think about:

- Is it more effective to consider the information related to an airport as a single digital twin supporting all use case categories, or is it better to have separate digital twins for each use case?

- What are the advantages and disadvantages of each approach?

2.5.2 Roles

In the realm of digital twins, a variety of user roles can be identified, defined by their responsibilities and tasks in relation to the digital twin. These roles vary depending on the type of digital twin. Commonly, the following types of users are involved:

- Owner/manager: Responsible for strategic decision-making and oversight, focusing on business objectives and maximizing the asset's value represented by the digital twin.
- Digital Twin operator: Handles direct interaction with the digital twin, accessing real-time information and performing data-driven tasks and simulations.
- Designer/developer: Involved in creating and maintaining the digital twin, including developing virtual models, integrating data, and ensuring accuracy and functionality.
- Domain engineer: An expert in the field of the asset or system represented, contributing specialized knowledge to ensure the digital twin accurately mirrors the real-world counterpart.
- End user/Information user: Individuals that utilize the digital twin's information or services for their own purposes, ranging from executives to field workers, using it for decision-making, planning, and optimization.

To illustrate how these roles manifest in different contexts, let's examine specific user roles across a range of digital twin applications. Each application showcases the varied and specialized roles necessary to fully leverage the capabilities of digital twins:

Application 1: Smart Cities

- Urban planner: Uses the digital twin for city design and simulation, optimizing traffic, infrastructure, and resource management.
- Utilities administrator: Monitors and controls public services like water, waste, and lighting via the digital twin.

Application 2: Training and Simulation

- Virtual instructor: Develops and conducts training and simulations within the digital twin.
- Student: Engages in training and simulations within the digital twin for hands-on experience and knowledge.

Application 3: Energy Efficiency Optimization

- Energy specialist: Analyzes and optimizes energy consumption in the digital twin, identifying improvement areas.
- Resource manager: Makes data-driven decisions based on digital twin information to optimize energy resource use and reduce environmental impact.

Application 4: Maintenance and Repair

- Maintenance technician: Monitors status and performs preventive maintenance in the digital twin for optimal operation of physical assets.

- Diagnostic specialist: Analyzes monitoring data from the digital twin to detect and diagnose potential issues.
- Asset manager: Plans and schedules maintenance tasks in the digital twin, optimizing asset lifespan and performance.

Application 5: Process Optimization

- Process engineer: Models and simulates industrial processes in the digital twin for efficiency and productivity improvements.
- Operational data analyst: Collects and analyzes real-time data from the digital twin to inform process optimization decisions.
- Production supervisor: Monitors and controls production within the digital twin to ensure efficient workflow and minimize downtime.

Application 6: Product Design and Development

- Product designer: Responsible for creating and optimizing product design within the digital twin.
- Test engineer: Conducts virtual simulations and tests to validate product performance and functionality.
- Market data analyst: Analyzes market data to improve product design and marketing strategies.

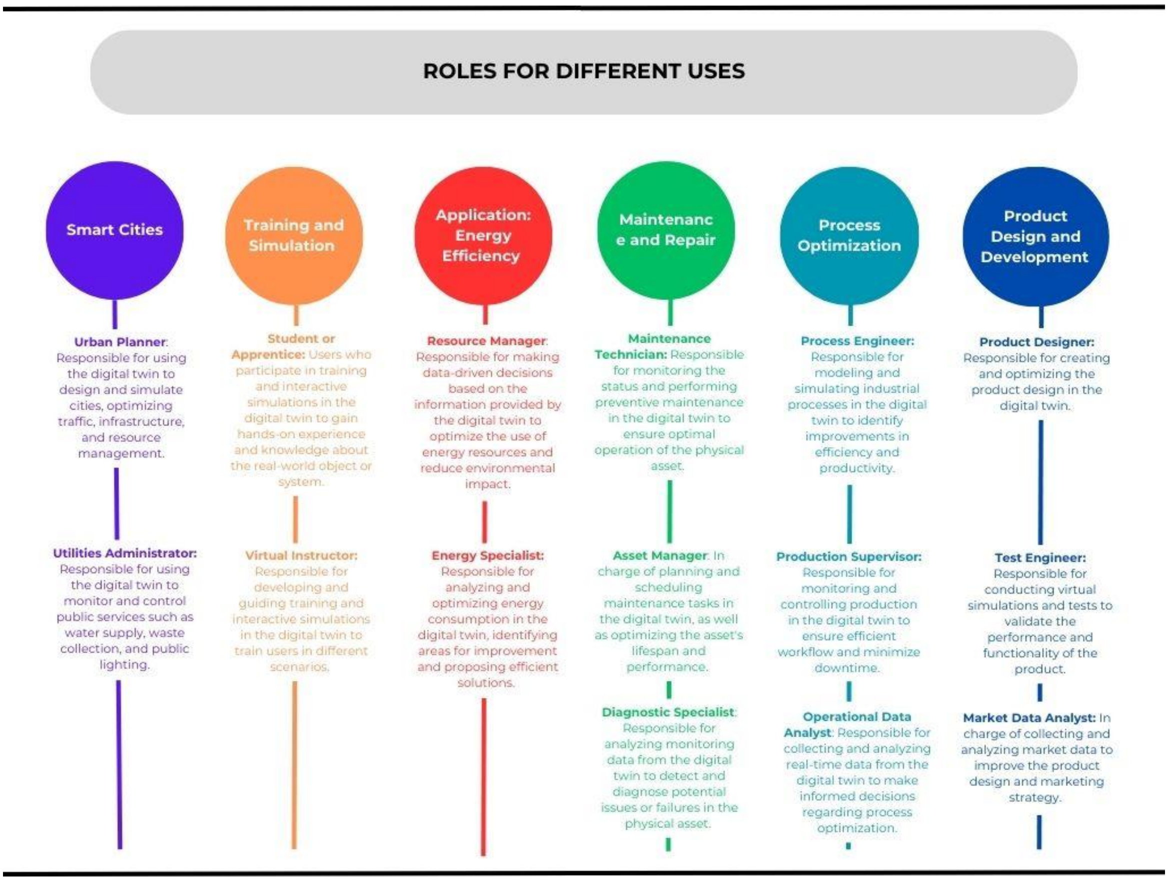


Figure 5 Digital twin roles

Please note that the examples provided in Figure 5 Digital twin roles are only for illustrative purposes, and the specific roles and their responsibilities may vary depending on the context and application of the digital twin.

2.5.3 Stages

While the stages in a building process focus on creating the physical counterpart, the development of digital twins, although related, follows a distinct set of steps. These stages, which can vary depending on the specific context and application, typically include:

- Goal Definition: This initial stage involves establishing the objectives and requirements of the digital twin. Key considerations include determining which aspects of the object or system will be replicated, the functionalities needed, and the expected outcomes.
- Data Acquisition: Essential data is gathered to construct and maintain the digital twin. This data encompasses design specifications, real-time operational data, historical records, sensor readings, and any other pertinent information about the object or system.
- Virtual Model Creation: In this phase, a virtual model representing the object or system is developed. This process entails creating a detailed and accurate digital replica that mirrors the physical attributes, behaviors, and interactions of the real-world counterpart.
- Data Integration: The collected data is then integrated into the virtual model. This step involves organizing and merging the data coherently with the virtual model, ensuring a complete and precise representation of the object or system.
- Validation and Calibration: At this stage, the digital twin undergoes validation and calibration using reference data and tests. The aim is to compare the digital twin's performance with the actual object or system, verifying its reliability and accuracy.
- Implementation and Deployment: Finally, the digital twin is set up on an appropriate platform or environment for use. This may include software configurations, setting up IT infrastructure, and other components necessary for the digital twin's operation and accessibility.

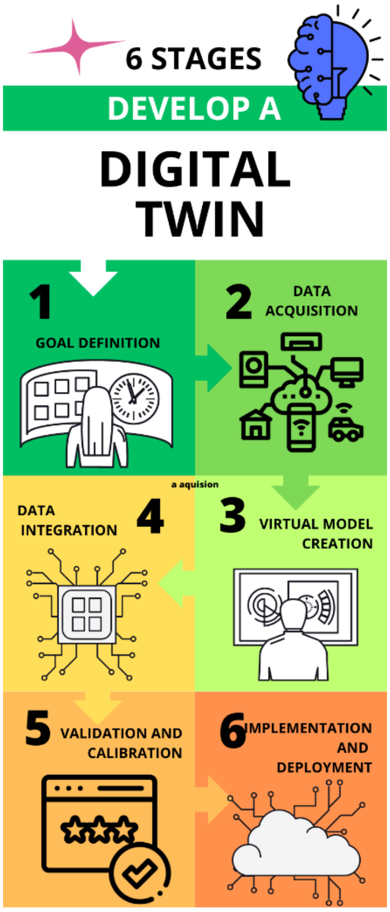


Figure 6

Remember: If you enjoy reading more about basic concepts of digital twins, visit the "Additional Readings" section, where you can find books, articles, and reference websites.

2.6 Computer tools

The creation of a digital twin for a building is a process that utilizes a range of computer tools and technologies. From initial data collection through 3D scanning and photogrammetry to the final stages of data integration, visualization, and analysis, each tool plays a critical role in developing a precise and detailed virtual representation of a real-world structure.

3D Scanning

3D scanning measures and captures the three-dimensional shape and size of an object or space. For buildings, this involves 3D laser scanners like the Leica BLK360, FARO Focus, and Trimble TX8. These devices emit lasers that reflect off the building's surfaces, allowing the scanner to calculate distances and shapes. The collected data points are then used to create an accurate 3D digital model of the building and its surroundings.

BLK 360

FARO Focus

Trimble TX8

Figure 7 Example of laser scanners from Leica, Faro and Trimble

Photogrammetry

Photogrammetry uses photographs to capture 3D information. It involves taking multiple photos of a building from various angles. Software such as Agisoft Metashape, RealityCapture, and Pix4D analyzes these images to identify common points and spatially position them, resulting in a 3D model of the building. Drones, like the Mavic Air 2, are often used for aerial image capture.

Modeling and design

Computer-Aided Design (CAD) tools like AutoCAD, SolidWorks, and Fusion 360 are used to create three-dimensional models of the physical objects in the digital twin.

3D modeling software such as Blender, SketchUp, and Rhino are essential for generating detailed and realistic models.

Data acquisition and sensorization

Sensors, including accelerometers, cameras, thermometers, and flow meters, collect environmental data for the digital twin.

Internet of Things (IoT) technology, with platforms like Arduino, Raspberry Pi, and Node-RED, facilitates the connectivity and communication of devices and sensors with the digital twin.

Virtual reality

Virtual reality is simulation of the virtual world by using virtual reality headsets such as Meta Quest 3. Virtual worlds and interactions are generally created with game engines such as Unity and Unreal Engine.

Erasmus+
This project is funded by the European Union.

Meta Quest 3 | Unity (game engine) | Unreal Engine

Figure 8 Example on game engins

Data visualization and analysis

Visualization tools like Tableau, Power BI, and Grafana graphically represent the digital twin data in an understandable format.

Data analysis tools like Python (using libraries such as NumPy, Pandas, and Matplotlib) and R help in extracting insights and performing statistical analysis of the collected data.

Communication and collaboration

Platforms like Slack, Microsoft Teams, and Trello are invaluable for facilitating communication and teamwork. These platforms provide an integrated environment for discussions, project management, and information sharing among developers and stakeholders, enhancing the collaborative process in digital twin development.

Applications like Speckle are critical for real-time data and model sharing between different applications and users. They enable interoperability and efficient collaboration in digital twin projects, ensuring seamless data exchange and synchronization.

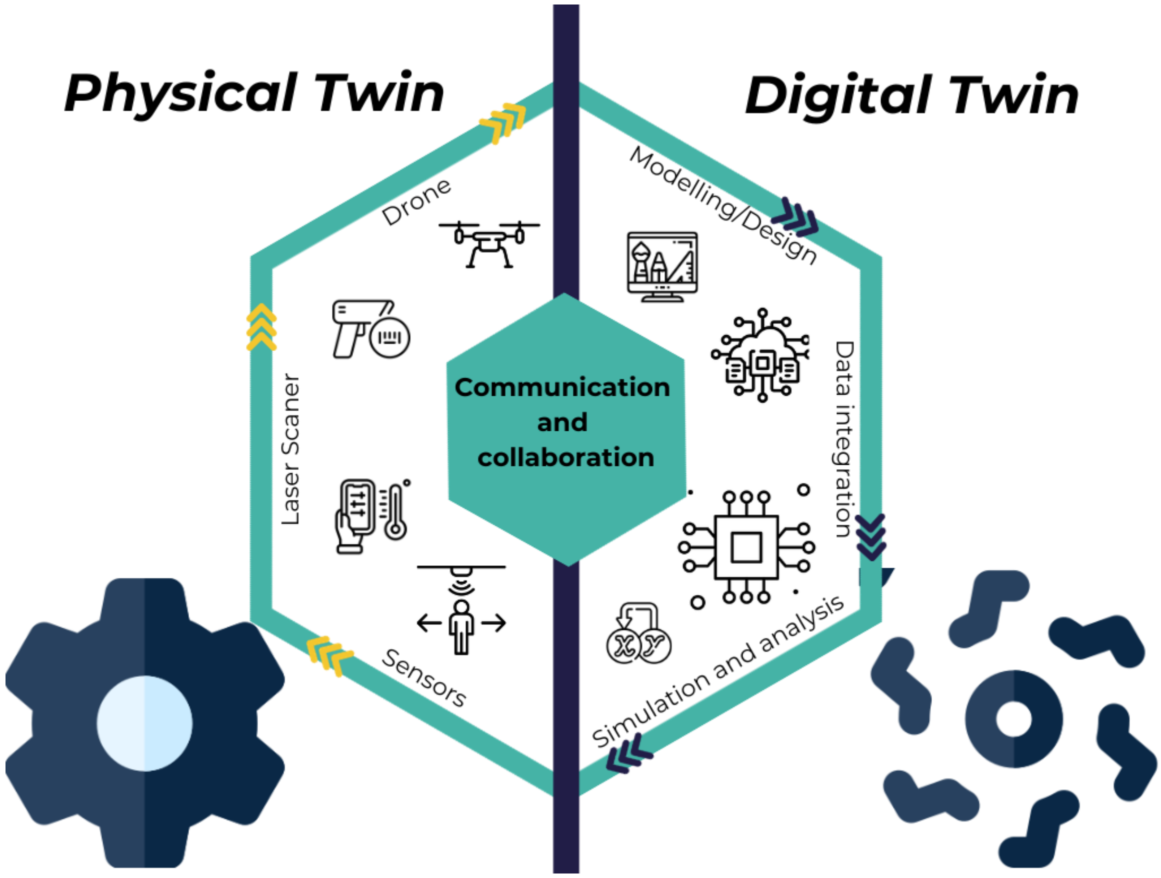


Figure 9 Physical vs. digital twins

2.7 Knowledge

Creating a digital twin is a multidisciplinary process that requires knowledge from various fields. The complexity and industry application of the digital twin dictate the specific areas of expertise needed. Collaboration across different disciplines is crucial in this process. Let's examine the key knowledge areas and skills essential for constructing a digital twin:

Domain Expertise

Understanding the specific environment of the physical object is crucial. This includes knowledge of relevant characteristics such as materials, energy, and potential interactions with other environmental elements. For the purposes of our learning material, we focus on buildings used for educational purposes, as demonstrated in our case studies (demo sites) in Spain and Norway.

3D Modeling

Proficiency in 3D modeling tools and techniques is vital to create a virtual representation of the physical object. This encompasses geometry, textures, and rendering techniques.

IoT and Sensors

A thorough understanding of Internet of Things (IoT) technologies is required, along with skills in integrating sensors and devices to gather real-time data from the physical object.

Data Management and Cloud Computing

Familiarity with methods of data collection, storage, and management is necessary. This includes processing sensor data, historical information, and other relevant data sources. Knowledge of cloud computing platforms and services is important for hosting and processing data and simulations associated with the digital twin.

Cybersecurity

Awareness of security measures to protect the digital twin and the associated data from potential cyber threats.

Data Analysis and simulation

Analytical skills are needed to interpret data collected from various sources, identify patterns, trends, and anomalies that may emerge. The ability to simulate the behavior of the physical object using mathematical models and simulations is also critical. This might include physics simulations, predictive modeling, and dynamic analysis.

For more complex projects, additional skills in areas like software development, machine learning, or artificial intelligence may be required.

> **Remember**: Strong communication skills are essential for collaborating with multidisciplinary teams and conveying insights from the digital twin

3 Digital twin aspects covered in Digilab/BE

As explained in previous chapters, the purposes users want to cover by creating a digital twin are very broad and involves numerous aspects. In this learning material four of the aspects are covered, each aspect has it own section in the learning material. In this chapter you will find a short introduction to each of the aspects. To learn more on each of the aspects the learning material section for the aspect should be studied.

Examples of aspect not covered by the learning material are control of the physical twin, e.g. switching on and off light based on sensor input.

3.1 Building digital twin

Geometry and structure are fundamental elements when creating a digital twin, as they form the visual and functional foundation of the virtual model. Precisely representing the shape and arrangement of components is essential to achieve an effective correspondence between the digital twin and the physical object it represents.

The starting point in building a digital twin is capturing the physical site into digital form. The most common way is to capture a point cloud. Two main methods are used: Photogrammetry (taking multiple, overlapping photos of the site and process the photos to create point clouds) and Laser scanning (directly measuring point on the site using laser beams).

3D modeling is an essential part of constructing a digital twin, as it serves as the foundation upon which a three-dimensional virtual representation of the physical object is created. A point cloud is usually the input dataset. The process of 3D modeling involves the creation and manipulation of digital objects in three dimensions, allowing for the capture of both the shape and detailed structure of the real object. The following image depicts a detailed outline of the process of creating a 3D model. As mentioned earlier, there are points that are not covered in this LM section.

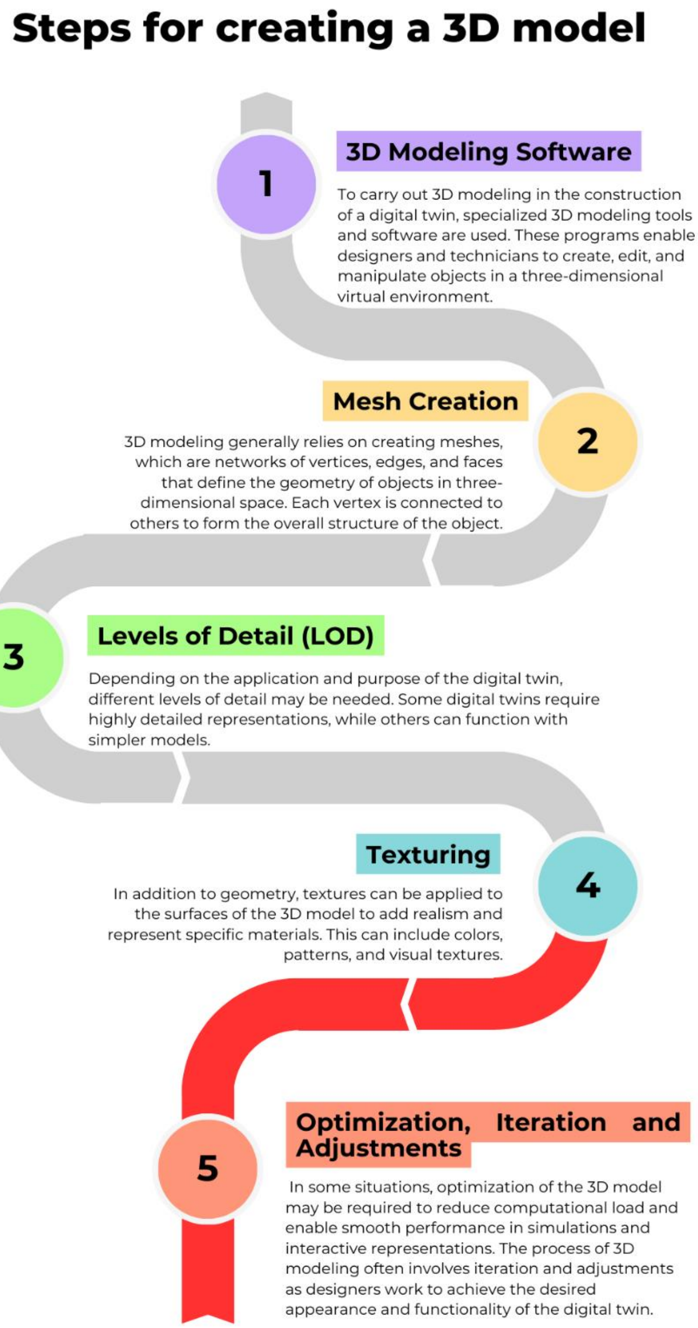


Figure 10 Steps for creating a 3D model

3.2 Dynamic updating

Dynamic updating in Digital Twins involves continuously adding real-time data into the virtual model. This process is key to keeping the digital twin current and functional.

With dynamic updates, Digital Twins can gather real-time data from sensors, IoT devices, and other sources. This means organizations can track how their physical assets or systems are performing at any moment.

One of the major advantages of dynamically updated digital twins is the ability for remote monitoring and control. Users can get real-time updates and alerts from anywhere, making it easier to manage assets no matter where they are.

Here's a look at the kinds of dynamic data we may use, depending on the application:

- Environmental Data: Includes information about surrounding conditions, like light, air quality, and temperature, which are essential for understanding the environment in which the asset operates.
- Position Data: Tracks location and movement, useful for simulating trajectories and movements.
- Status Data: Provides updates on the current state of components, such as whether equipment is on/off or if doors are open/closed.
- Energy Consumption Data: Records resource usage for efficiency analysis.

The process of dynamically updating a digital twin encompasses several steps, each crucial for ensuring the accuracy of the digital twin:

- Installing Sensors and IoT Devices: Placing these on the physical object to collect the necessary data.
- Data Communication: Establishing pathways for data transfer from the sensors to the digital twin system.
- Data Processing: Converting raw data into a usable format for analysis and application.
- Platform Integration: Incorporating this processed data into the digital twin platform.
- Visual Representation: Using various tools to display this data on the digital twin interface, such as interactive charts and graphs.

3.3 VR/AR/XR

Virtual Reality (VR) and Augmented Reality (AR) can be combined with Digital Twins to enhance the user experience and provide a more interactive environment. Here are some examples of how VR and AR can be used with digital twins:

1. Visualization and Exploration: VR and AR can be used to visualize and explore digital twins in a three-dimensional space. Users can wear VR headsets or use AR-enabled devices to interact with the virtual representation of the physical object or system. This allows them to navigate through the digital twin, inspect different components, and gain a better understanding of its structure and functionality.

2. Training and Simulation: VR and AR can provide realistic training and simulation environments based on digital twins. For complex systems or processes, such as industrial machinery or medical procedures, users can practice and learn in a safe virtual environment

that mimics the real-world conditions. This enables them to acquire hands-on experience and develop skills without the risk of damaging physical assets or endangering themselves.

3. Collaboration: VR and AR can facilitate collaboration among a team working with Digital Twins. Models from the different locations can be combined into one visualization tool.

4. Data Visualization and Measurements VR and AR can transform complex data from Digital Twins into intuitive visual representations. In a VR environment or with use of AR interfaces, users can explore data visualizations, simulations, or measurements associated with the Digital Twin.

3.4 Smartization

A Digital Twin can make a building more intelligent by creating a virtual replica of the physical building and using real-time data, simulations, and advanced analytics to enhance its operational efficiency, safety, and overall performance, as shown in figure XX. To describe this phenomenon, DigiLab uses the terminology "Smartization".

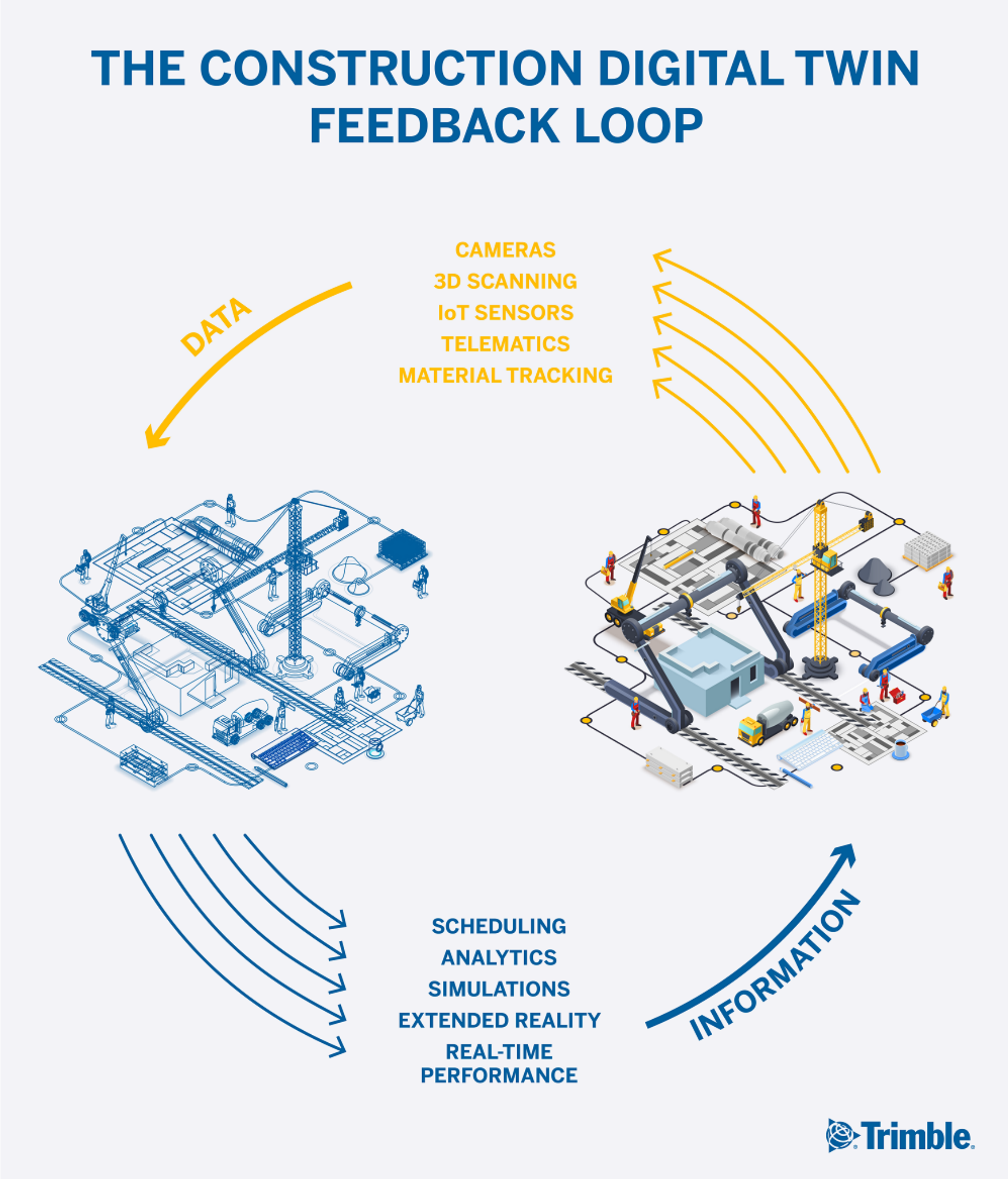


Figure 11 From https://constructible.trimble.com/construction-industry/what-are-digital-twins

3.4.1 The capabilities of a Digital Twin

While "Smartization" may be a term used by DigiLab to describe the capabilities of Digital Twins in construction, it's not a widely recognized term in the field. In research and industry discussions related to Digital Twins and their analytical and forecasting capabilities, you'll often come across more established and commonly used terminology. Here are some terms that are more commonly used:

Real-time Monitoring: As described in section 3.4 “Dynamic Updating” a Digital Twins continuously collect data from sensors placed throughout the building. These sensors can monitor various parameters like temperature, humidity, occupancy, energy consumption, and more. By analyzing this data in real-time, users e.g., building managers can gain insights into the building's current state and performance.

Predictive Analytics: In the high-end version Digital Twins use historical data and machine learning algorithms to predict future events and performance trends. For example, they can forecast when equipment is likely to fail, when maintenance is required, or when energy usage patterns might change. This enables proactive decision-making and minimizes downtime.

Some examples of predictive analytics are Energy Efficiency, Space Utilization, Maintenance and Repairs , Security and Safety and Remote Management.

Energy Efficiency: By monitoring and analyzing energy consumption patterns, Digital Twins can optimize HVAC systems, lighting, and other energy-intensive components. They can adjust settings based on real-time conditions, weather forecasts, and occupancy levels to reduce energy waste and lower operational costs.

Space Utilization: Digital Twins can track how spaces within a building are used. By analyzing occupancy data, they can optimize room allocations, seating arrangements, and meeting schedules to maximize space utilization and improve employee productivity.

Maintenance and Repairs: Predictive maintenance is a significant advantage of Digital Twins. They can detect when equipment is approaching the end of its lifecycle or showing signs of wear and tear. This information helps maintenance teams schedule repairs and replacements before a breakdown occurs, reducing downtime and costly emergency repairs.

Security and Safety: Digital Twins can incorporate security systems and fire safety simulations. They can monitor security camera feeds, access control systems, and fire alarm data to identify anomalies or potential threats in real-time, enhancing the safety and security of the building and its occupants.

Remote Management: Building managers can access the Digital Twin remotely, allowing them to monitor and control building operations from anywhere. This is particularly useful for large or geographically dispersed facilities.

Simulation and Modeling: Digital Twins often involve creating detailed simulations or models of physical assets or processes. These models can be used for various analytical purposes, including predicting how changes or disruptions might impact a construction project or maintenance and repairs. As apposed to predictive analysis that are based on historical data, a prediction can be created based on a simulation or a model.

The “smartization” of a Digital Twin offers Data-Driven Decision Making, Scenario Testing and Lifecycle Management:

Data-Driven Decision Making: By providing a comprehensive view of the building's performance and operations, Digital Twins enable data-driven decision-making. Building managers can optimize resources, reduce operational costs, and improve overall efficiency based on insights derived from the virtual replica.

Scenario Testing: Digital Twins allow for "what-if" scenario testing. Managers can simulate changes in building configurations, energy-saving strategies, or emergency response plans to evaluate their impact before implementing them in the physical building.

Lifecycle Management: Digital Twins are valuable throughout a building's entire lifecycle, from design and construction to operation and maintenance. They ensure that the building is built and operated as efficiently as possible while also providing insights for future renovations and upgrades.

In summary, Digital Twins make buildings more intelligent by harnessing data, simulations, and analytics to optimize operations, enhance energy efficiency, improve safety and security, and enable data-driven decision-making. They provide a holistic view of the building's performance and enable proactive management to create more efficient, cost-effective, and sustainable structures.

3.4.2 Evaluation of the Indoor Environment

Our Project

4 Examples and exercises

An important part of Digilab is to provide users with suitable examples on how digital twins can be created and used. The examples are connected to two physical locations, two demo sites, one in Norway and one I Spain. The example data is provided in three levels:

- **Level 1 exercises: Just viewing.** This is what follows in this chapter. The goal is to get a first impression what is included in the DigiLab/BE aspects of Digital twin.

- **Level 2 exercises: Working with defined exercises on the demo site data.** The goal for this level is twofold:
    - Be able to adopt the demo site data to your own applications
    - Be able to set up your own digital twin

  The exercises are found in the sections A, B, C and D

- **Level 3 activities: Adopting the demo site data complete to your own project.** The goal for this is to provide proper open example datasets for people wanting to test own principles and methods in own learning and research activities. According to these goals, there are no Level 3 exercises available, these you have to define yourself.

4.1 Exercise Ii1: Getting familiar with the demo sites

A short walk-through of the demo site documentation.

An important part of DigiLab/BE is the demo sites. The demo sites are used throughout the learning material. It is useful to spend some time getting familiar with the resources available.

Steps	Content
Goal	Have a first meeting with the demo sites
Method	Reading the available documentation on the demo sites
Needed computer	One with internet connection
Needed data	Text documents with demo site descriptions
Needed software	Web browser with capabilities of showing PDF-files
User instructions	Steps: - From the main menu of the learning material, select the Demo Site option, and find documentation on two demo sites:

	○ The NTNU/Smaragd building ○ The IES Segura Valley/Blanca building - Click into the documentation, and for each demo site try to find answers on the user questions below
User questions	The questions: 1. Where is the demo site located? Imagine you want to take a trip to the demo sites, describe the steps of the trip as a suitable level of details. 2. What kind of building is the demo site? 3. Which rooms in the demo site building are included in the demo site? 4. What kind of data describes the 3D model of the digital twin 5. What kind od sensors are installed
Video support (not produced yet, added when the DemoSite material are more stable)	Two videos are available (as least planned) - A walk-trough of the documentation NTNU/Smaragd - A walk-trough of the documentation Blanca/IES Segura Valley

4.2 Viewing demo sites geometry

The demo sites have available data in three different versions, two kind of files to be downloaded (IFC and Revit) and one API using Speckle.

4.2.1 Exercise Ai1: Viewing demo site buildings using IFC

In this exercise, software Solibri is used, to have a 3d view of the demo site buildings.

Steps	Content
Goal	Viewing the demo site geometry IFC-files using the open version of Solibri
Needed computer	A PC with MS Windows operating system
Needed data	IFC-files downloaded from demo site repositories, either Demo Site Norway or Demo Site Spain, or both (one at a time) File links: - http://speckle.it.ntnu.no:7070/DemoSite_NorwaySmaragd/IFC/20221020_S_building_local_rev1.ifc - http://speckle.it.ntnu.no:7070/DemoSite_SpainBlanca/IFC/IES_Valle_del_Segura.ifc
Needed software	Many open software solutions are available for viewing IFC-files. Here the open version of Solibri, Solibri Anywhere is selected. The software can be downloaded from https://www.solibri.com/download Solibri sign in needed: Before downloading, you have to sign up at the Solibri web site. To do so, you need an email address and a phone number. There is no fee for this sign in. You have to log in to your Solibri account every time you want to use the Solibri Anywhere software. This will require that you use a computer with internet connection.
User instructions	Steps: - Download, install and open the software - Download the selected IFC file - Open the IFC file using the Solibri/Open command

	- Explore the content of the file
Video support (not produced yet)	Show the video of instructor going through the exercise
Reflections	Questions to be conciders during and after the practical work: - What is the content of the data set? - Are there any details you miss? (considering your selected use case)

4.2.2 Exercise Ai2: Viewing demo site buildings using Revit

Steps	Content
Goal	Viewing the demo site geometry revit-files using the open version of Autodesk Revit
Needed computer	A PC with MS Windows operating system
Needed data	The Revit files downloaded from demo site repositories, either Demo Site Norway or Demo Site Spain, or both (one at a time) File links: - http://speckle.it.ntnu.no:7070/DemoSite_NorwaySmaragd/RevitFile/20221020_S_building_rev1.rvt - http://speckle.it.ntnu.no:7070/DemoSite_SpainBlanca/RevitFile/IES_Valle_del_Segura.rvt *NB! Revit project files are connected to versions of the software. Might be needed to upgrade to current version, an automated function within Revit.*
Needed software	Many open software solutions are available for viewing IFC-files. Here the open version of Autodesk Revit. The software is available from https://viewer.autodesk.com/ *You also need a Autodesk account to use this, created on the Autodesk site.*
User instructions	Steps: - Log in to the Autodesk Viewer at https://viewer.autodesk.com/ - Download the revit file from the demo site repository - ??
Video support	Show the video of instructor going through the exercise
Reflections	

4.2.3 Exercise Ai3: Viewing demo sites buildings using the Speckle API/web-site

Steps	Content
	Exercise not ready yet!! Must have demo site on default Speckle server, NTNU-server “invite-only” so far
Goal	Viewing the demo site using the Speckle API

Needed computer	A PC with MS Windows operating system
Needed data	Access to the DigiLab/Be Speckle server, either Demo Site Norway or Demo Site Spain, or both (one at a time) *Access info for NTNU-Speckle server needed*
Needed software	The Manager for Speckle software is available by choosing the download option from https://speckle.systems/ You also need a Speckle login, can be created for free following links in Speckle Manager. Using the ***Speckle Manager***, it is possible to log into a ***Speckle Account***. This Speckle account will give access to a ***Speckle Server***, and makes is possible to view data available on this server. The Speckle Viewer is a pure viewer, where it is only possible to view data. For further use and manipulation of the data, you need software with Speckle connector installed. More on this on https://speckle.systems/features/connectors/ *Need to find out more how to create just-view-users to Speckle Server. Users might have the limited view-access to projects/datasets, but they still are "full users" on the server, and can create own projects. The Speckle Server user role "guest" are not active in the NTNU-Speckle server.*
User instructions	Steps: - From the Speckle Manager, open the Accounts, and log into the wanted Speckle Account. - Select the wanted Project and dataset
Video support	Show the video of instructor going through the exercise
Reflections	

4.3 Access to sensor data

4.3.1 Exercise Bi1: Accessing sensor data via ThingSpeak website

Content

In this exercise, you will learn how to access and explore sensor data from a real scenario, the IES Valle del Segura high school in Spain, using the ThingSpeak platform. ThingSpeak offers public access to sensor data along with interactive tools for effective visualization. Additionally, the platform provides the functionality to download recent data, giving you the flexibility to analyze it in different formats.

Prerequisites

No other prerequisites are needed besides Internet access.

User guide

Accessing data

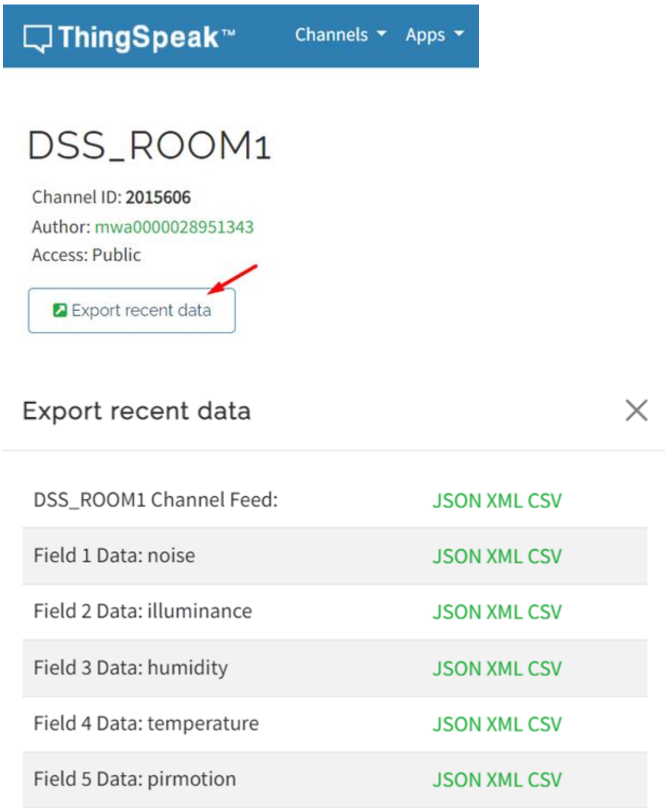
Open your web browser and go to https://thingspeak.com/channels/2015606. This channel stores the data from one of the Arduino devices placed in Spain.

Data Interaction

Explore the different graphs to view data collected in the last few hours. Observe the trends and patterns in the sensor readings.

Exporting data

Utilize the 'Export recent data' feature on ThingSpeak to download the data in different formats for further analysis. For example, you can export the data as a .csv file.



4.3.2 Exercise Bi2: Accessing sensor data via ThingSpeak API

Content

This exercise is about retrieving data from the ThingSpeak platform using its API. You will learn to construct and execute API requests to access real-time sensor data, and understand the response format. This skill is crucial for integrating IoT data into digital applications or projects.

Prerequisites

Basic understanding of APIs.

(Optional) Basic understanding of JSON or xml formats.

User guide

Understanding the ThingSpeak API

Gain knowledge about the ThingSpeak API and how it works for accessing channel data.

Review the resource: https://www.mathworks.com/help/thingspeak/read-data-from-channel.html

Constructing the API request

Format: https://api.thingspeak.com/channels/<channel_id>/feeds.<format>

Replace <channel_id> with the ThingSpeak channel ID and <format> with the desired data format (.json, .xml, .csv).

Making an HTTP request

Use a web browser to send a request to your constructed URL. For example:

- Browser: https://api.thingspeak.com/channels/2015606/feeds.json?results=2

Interpreting data

Examine the response to understand its structure and key components, such as "channel," "feeds," and different "fields."

Using query parameters *(Optional)*

Try adding query parameters to refine your data request, like specific time filters.

Example for date interval and timezone:

https://api.thingspeak.com/channels/2015606/feeds.json?start=2023-09-15T00:00:00Z&end=2023-09-15T23:59:59Z&timezone=Europe/Madrid

* Remember, specifying your timezone is important to get data in your required date format; otherwise, it defaults to UTC.

4.4 Digital twin in game engine

4.4.1 Exercise Ci1 : Sensordata visualization tool

Content

This exercise uses a visualization tool developed in Unity, to visualize sensordata in a BIM-model. To accomplish this, the tool implements the IFC-based BIM-models developed in PR2, as well as sensordata from PR4. Data analysis results from PR5 could also be visualized using this tool if the data structure matches the specifications.

Architecture

To incorporate the different aspects of a digital twin, the visualization tool retrieves information from different sources. BIM models are streamed using Speckle's Unity connector. Live sensordata is retrieved using HTTP2 clients developed in C#, that retrieves API responses from ThingSpeak and Arduino Cloud. Time series data was downloaded manually from the Arduino Cloud (Possibly retrieved using API calls "soon").

Installation and user guide

System Requirements: Some of the processes can be demanding, and load times wary based on system specifications. If the minimum requirements below are met, it should be possible to run the application.

Operating system	Windows 64-bit
Memory	6GB RAM
Storage	2GB available disk space
Network	Internet connection

Download: The visualization tool can be downloaded from Teams - Digilab - PR3 - Files - Sensordata visualization tool - Visualization V0.3.zip. After downloading, un-zip the folder, and run the executable "Visualization V0.3" to start the visualization tool.

Navigating the menu: The menu can be navigated by using the mouse cursor to click the buttons. Any greyed-out buttons are disabled and are meant as placeholders for possible future functionality to be added. The "Main Menu" button located in every scene will return the user to the starting screen, where "Close program" can be pressed to exit the application. From the main menu the "Start" button will redirect the user to a menu for selecting a BIM-model to view. By first pressing "Template" the user can then select to view the demo site from Norway or the demo site from Spain. When the "Norway" or "Spain" button is pressed, the user will have to wait for the BIM-models to be loaded and wait time will wary based on the computer's specifications.

Viewing live sensordata: When one of the demo sites is opened, live sensordata will be displayed as colored rooms in the building. To get a better view of the sensordata the transparency of the building can be adjusted using the "transparency slider" in the bottom left corner. To view different live measurements, the dropdown menu in the top left corner can be used to select different variables. The currently active color scale is displayed in the bottom right corner, alongside the corresponding minimum and maximum values.

Loading time series: While viewing the Norwegian demo site, time series can be visualized by pressing the "Time series" button in the top right corner. This will open a series of menus where CSV-files downloaded from the Arduino cloud can be viewed by pressing the "CSV" button and then the "Arduino" button. This will show the directory path for the folder where the time series are stored, and where more time series folders can be added. The dropdown menu can be used to select which time series folder to load. If more time series folders are added, the "Refresh" button can be used to update the dropdown menu options. When the desired time series folder has been selected, the "Load" button can be pressed, and the user will have to wait depending on the size of the time series selected. When the time series are loaded, information about date, time and number of measurements will be displayed. The "Play" button can then be pressed to generate the colored timelines for the time series data, and the user will have to wait depending on the amount of data.

Viewing time series: To view the data in the BIM-model, there is a play and pause button. The "Speed" dropdown menu can be used to determine the duration each measurement is displayed. The "Interval" dropdown menu can be used to determine how frequent data is retrieved from the time series and specifies the number of measurements that is skipped. There are four rows in the colored timeline, one for each sensor. Any white segments in the timeline indicates missing measurements in the time series data. As when viewing the live sensor data, the dropdown menu in the top left can be used to change variables, and the color scale in the bottom right displays the minimum and maximum values.

Reflections and discussions

Questions to help users to use and learn from the exercise:

- Live sensor data:
  - How many sensors are active?
  - How many rooms have sensors in them?
  - What is being measured?
  - What is the minimum and maximum values visualized?
- Time series data:
  - What is the frequency of measurements?
    - Has the frequency changed during the available data sets?
  - Are there any gaps in the datasets where measurements are missing?
    - What could be the cause of this?

4.5 Smartization

In this section, you will have the opportunity to interact with live and historical data from three different sensors located at the NTNU demo site. The tool you will be using is developed in Power BI and made accessible to you via an API. Currently, the data is refreshed manually by us, the tool's creators; however, using Power Automate, we can configure automatic updates at chosen intervals. This capability allows Power BI to effectively visualize data for a digital twin.

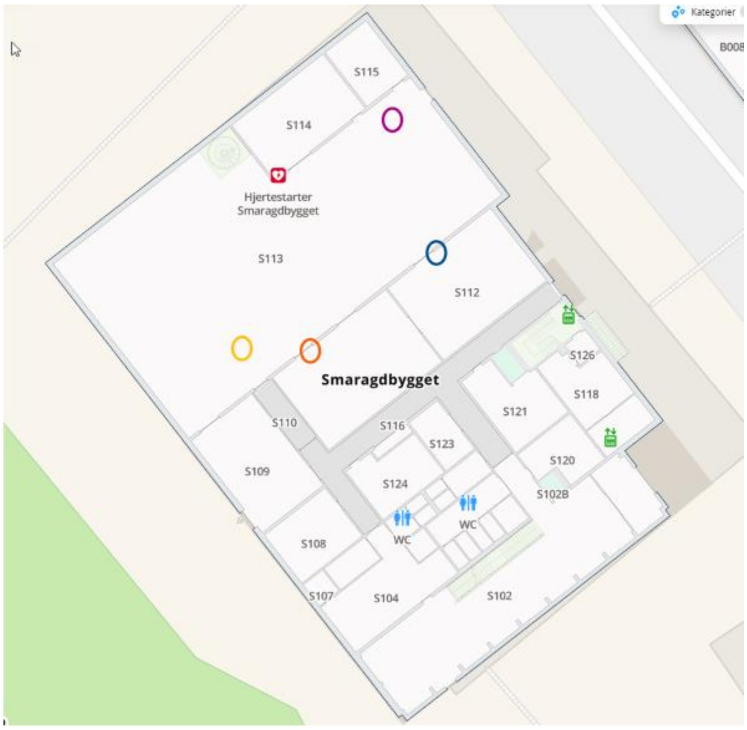
After completing this exercise, if you are interested in learning more about setting up data visualizations in Power BI, you are encouraged to explore the smartization module of the learning material (PR5 – Smartization). Additionally, this section covers how to use Revit in conjunction with Dynamo to create a Digital Twin.

Exercise Di1:

The DemoSite has (for the time being) 4 Arduino units (Things) with 7 sensors connected to each.

The things are:

Thing ID	Room #	Installation date	Room name	
DSN_Digilab01	S111	2023-11-09	Målelaboratorium	O
DSN_Digilab02	S112	2023-11-16	3D printer lab	O
DSN_Digilab03	S113	2023-11-09	Hall	O
DSN_Digilab04	S114	2023-11-09	Mekanisk verksted	O



The raw data and the visualization in Power BI can be accessed from the following API'S.

DSN_Digilab01:

Raw data:
http://speckle.it.ntnu.no:3000/temp_outside_device_view?thing_name=in.(DSN_Digilab01)
&order=measurement_time.desc&limit=200

Power BI:

https://app.powerbi.com/view?r=eyJrIjoiZGVmYTBjOTctNmFjZC00YWYyLTgyZDQtMjhlOWVh
YmM4NjhlIiwidCI6ImQ2MzM4OTk3LTIxNGEtNGY5Mi1iYTc1LTAzOTdmMTBhODRjYyIsImMiOj
h9

DSN_Digilab02:

Raw data:
http://speckle.it.ntnu.no:3000/temp_outside_device_view?thing_name=in.(DSN_Digilab02)&order=measurement_time.desc&limit=200

Power BI:

https://app.powerbi.com/view?r=eyJrIjoiZjY4MjRhZDAtYzliNC00NDJmLWI1NDEtOWE1OTU4OTU1N2EyIiwidCI6ImQ2MzM4OTk3LTIxNGEtNGY5Mi1iYTc1LTAzOTdmMTBhODRjYyIsImMiOjh9

DSN_Digilab03:

Raw data:
http://speckle.it.ntnu.no:3000/temp_outside_device_view?thing_name=in.(DSN_Digilab03)&order=measurement_time.desc&limit=200

Power BI:
https://app.powerbi.com/view?r=eyJrIjoiODU5ZGFlZjYtZGMxYy00NjQ4LWFiMzktZTVlMzViNDY3YzIzIiwidCI6ImQ2MzM4OTk3LTIxNGEtNGY5Mi1iYTc1LTAzOTdmMTBhODRjYyIsImMiOjh9

DSN_Digilab04:

Raw data:
http://speckle.it.ntnu.no:3000/temp_outside_device_view?thing_name=in.(DSN_Digilab04)&order=measurement_time.desc&limit=200

Power BI:

https://app.powerbi.com/view?r=eyJrIjoiOTU0YTljNzYtYmQzYy00NjBjLTk0NTYtYmRlYjQ2ODUxZWExIiwidCI6ImQ2MzM4OTk3LTIxNGEtNGY5Mi1iYTc1LTAzOTdmMTBhODRjYyIsImMiOjh9

VIDEO: 4.6. Power Bi - Intro Section

Questions/tasks:

(1) Try opening a Raw Data API and Power BI API for the same Room. Consider how the visualization improves your understanding of the data?
(2) In one or several of the Power BI API(s), try investigating the Page 1,2 and 3, and can get any meaning full information through the visualization.
(3) Can you think of any other measurements that would be interesting to visualize in PowerBI? Elaborate on how it would help the decision making of a user.
(4) In general, elaborate on how Vizualization of data can improve the data-driven decision-making.

5 Digital twins in an (information) security perspective

In all cases where information is available, there is also a chance for misuse. This is also the case for digital information in general and digital twins in special.

Digital twins need a physical twin (at least a planned one) to have a purpose. Then security issues must be extended from just information security to object security.

5.1 Introduction on information security for digital twins

Important motivation for establishing a digital twin of some kind of physical things is to spread the information of existence of something (the physical twin), and in addition make it easier to explore and maintain the thing.

- (possibly the typical DT understanding) Establish a better environment for maintaining the thing, e.g. indoor climate in a building.
    - One digital twin with one user for each physical twin
- Be able to perform digital simulations for improved design and operations, e.g. evacuation and rescue routine design and planning
    - Several digital twins with several purposes, with multiple users, and possibly still no physical twin, just a planned one
- Make a physical thing more available for instance for training, e.g. digital training before physical use of a laboratory or a vehicle.
    - Several digital twins with multiple users for each physical twin

General information security is mainly connected to challenges with the information itself. Important aspects are often divided in three:

- Computer security
- Data security
- Network security

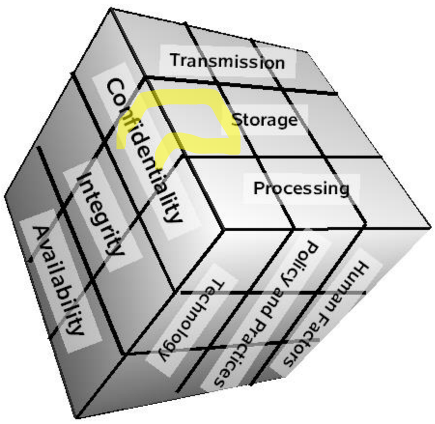


Figure 12 The McCumber Cube for information security analysis (Source: Wikipedia)

5.2 The McCumber Cube, also termed CNSS security model

In USA CNSS (the Committee on National Security Systems) has published documents and regulations on information security. They also have published a security model with three dimensions/Key goals, also known as the McCumber Cube, named after John McCumber who created this model in 1991. Each side of the cube represents one aspect of information security:

- Key goals/Desired goals:
    - Confidentiality
    - Integrity
    - Availability

- Safeguards/Security Countermeasures:
    - Policy,
    - Education/Awareness,
    - Technology
- Information States:
    - Storage,
    - Processing,
    - Transmission

Each sub-cube in this 3x3x3 cube can be viewed as representing the 27 different combinations of the three aspects with their 3 sub-aspects. One example of using the cube: The sub-cube marked yellow in the Figure 12 represents the Goal/Confidentiality aspect combined with State/Storage and

Reflection: Select two other sub-cubes of the McCrumber Cube and give examples on security actions represented with the selected sub-cube.

Safeguard/Technology, and will hold security actions where technology is used to ensure confidentiality of the stored information. This can be the use of access technology to ensure only authorized access to the digital twin information.

Additional reading on information security is found in **¡Error! No se encuentra el origen de la referencia.**.

5.3 Combining information security with object security

The security aspects to be considered for a digital twin is not just data, but also the “twin connection” to the physical twin:

- The security to the physical twin itself.
    - Is the thing commonly available/accessible, or is a special a permission needed to get access to the thing?
    - Are there security aspects connected to the physical twin itself? Examples: need for protections against damage (relevant for museum objects)? Can misuse cause injury to users (relevant for laboratory equipment)
    - Does the owner agree that knowledge connected to the thing is spread?
    - What level of details are needed/wanted/allowed considering use cases of the DT ?
- The security of the digital twin
    - Do the data properly describe the physical twin
    - Are the data quality ok, information integrity ok)
    - Are the dataset maintained in a proper way, and in accordance with the security aspects of the thing
- Access to the digital twin
    - Proper access control needed

5.4 General security aspects to consider when handling digital twins

In the life cycle of digital twins security issues must be considered. In this chapter we have structures questions to be discussed based on the phases of the digital twin

5.4.1 Digital twin planning phase

Questions to be considered:

1. Security aspects connected to the physical installation. It is important to identify the security challenges to the physical asset/installation.
2. Information from the physical asset planned included in the digital twin.
3. Security aspects of the digital twin itself. Considerations needed to ensure that the digital twin information is correct, and the possible sensors are working according to plans

5.4.2 Digital Twin Set-up/data capture phase

Questions to be considered:

1. Do the persons involved in the work have the needed knowledge and permissions for access?
2. Is the content of the digital data captured limited to what is planned?

5.4.3 Digital Twin Operational phase

Questions to be considered:

1. For static data: Are the data as they should be? Need for update?
2. For dynamic data: Are the sensors working as they should?
3. For data access: Are the access regime working as planned?

5.4.4 Digital Twin Shut-down phase

Questions:

1. Are the whole content of the digital twin properly deleted?
2. Are all the data access points properly closed down?

5.5 Demo sites as security cases: The security aspects connected to the demo sites

In this learning material, two demo sites are set up. The goal is to have publicly available data, accessible for the whole world.

The security considerations are explained below.

5.5.1 Planning

Only publicly available buildings and rooms are selected. That means it will be possible for (close to) everybody to capture similar data as in the digital twin themselves. However, it is still a question how to protect equipment, to avoid dangerous materials and/or expensive assets to be stolen/removed.

The sensors are selected to avoid (the majority of) GDPR related issues, especially connected to information where individuals can be identified.

5.5.2 Setup and data capture

The sensors are set up and the scanning is performed in cooperation with responsible personnel of the buildings and rooms, ensuring no security conflicts.

5.5.3 Operational phase

The static content of the digital twin is stored on servers set up according to the partners security regime. This should ensure that the content remain unchanged and available for the public.

The dynamic sensor readings content of the digital twin are ensures for correctness by regularly inspecting the sensors and protecting the sensors from unauthorized changing of setup. The dynamic sensors time serious readings are kept on secure servers with publicly available APIs.

A remaining challenge might be to prevent users legally downloading digital twin content to modify/falsify the content and publish is in other sources as valid information on the buildings and rooms.

5.5.4 Shut-down phase

This is not considered as a security challenge, no further actions taken.

5.6 Information security reflections for readers

The following questions is meant for reflection:

- Are the security considerations related to setting up the demo sites (see 5.5 above) sufficient for this kid of publicly available digital twins?
- What could be information security the consequences of adding a camera to the set of sensors?

6 Digital Twin Intro / Discussion questions

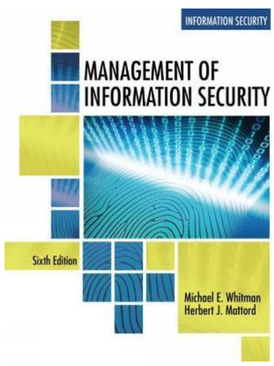
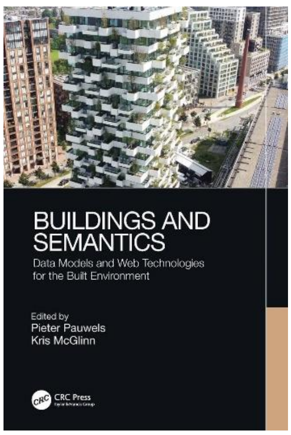
After passing through the chapters in this section, here are some questions useful to spend some time to answer:

- Think of one digital twin you might be interested in creating.
  - What is the purpose you want to achieve?
  - What technologies and tools are necessary to develop and manage the digital twin?
  - Who are the users of the digital twin?
  - What are the benefits for each group of identified users?
  - How should the users get in contact with the digital twin?
  - Can you imagine there might be misuse of the digital twin?
    - What kind of misuse?
    - How should the chances for misuse be reduced?

7 References

Here are the references used in this section.

7.1 Text books

	Mattord Herbert, Whitman Michael: **Management of Information Security** Sixth edition, 2018, Cengate **ISBN** 9781337405713 **Comments:** More than 700 pages of academic text, useful for master students want to dive deep into the topic.
	Pieter Pauwels, Kris McGlinn **Buildings and Semantics - Data Models and Web Technologies for the Built Environment** 1st Edition, 2022, Routledge/Taylor&Francis group ISBN 9781032023120 **Comments:** Selected content (Book Preview) available from https://www.routledge.com/Buildings-and-Semantics-Data-Models-and-Web-Technologies-for-the-Built/Pauwels-McGlinn/p/book/9781032023120
	Qiuchen Lu, Xiang Xie, Ajith Kumar Parlikad, Jennifer Schooling and Michael Pitt: **Digital Twins in the Built Environment: Fundamentals, principles and applications** 2022, ICE Virtual Library **eISBN:** 978-0-7277-6581-9 | **ISBN:** 978-0-7277-6580-2 **Comments:** Three chapters of this book is free, can be accessed from https://www.icevirtuallibrary.com/doi/book/10.1680/dtbe.65802

7.2 Articles

https://doi.org/10.1088/1755-1315/410/1/012073	C. Panteli et al., 'Overview of BIM integration into the Construction Sector in European Member States and European Union Acquis', IOP Conf. Ser.: Earth Environ. Sci., vol. 410, no. 1, p. 012073, Jan. 2020
https://doi.org/10.3390/buildings11120594	A. Pérez-García, N. Martín-Dorta, and J. Á. Aranda, 'BIM Requirements in the Spanish Public Tender—Analysis of Adoption in Construction Contracts', Buildings, vol. 11, no. 12, p. 594, Nov. 2021

7.3 WEB sites

https://www.cnss.gov/cnss/	US Committee on National Security Systems Here CNSS has published important documents om Security in general and Information security in special. (a bit complicated to find relevant, easily understandable content)
https://en.wikipedia.org/wiki/McCumber_cube	The McCumber Cube, framework for establishing and evaluation of information security programs.
https://www.netskope.com/blog/the-security-implications-of-a-digital-twin	The Security Implications of A Digital Twin Visited 2023-06-19
https://en.wikipedia.org/wiki/General_Data_Protection_Regulation	General Data Protection Regulation Visited 2023-06-26
https://www.iso.org/standard/68078.html	ISO 19650 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling

https://www.iso.org/standard/79692.html	ISO 12911:2023 - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) - Framework for specification of BIM implementation
https://www.bimspot.io/blogs/bim-adoption-nordic-countries/	BIM Adoption in Nordic Countries,

8 Terminology

8.1 Glossary

	Explanation	Reference
asset		
demo site	Term to describe the two established example sites in the Digilab/BE project: One in IES Segura Valley, Spain, and one in NTNU Gjøvik, Norway. Name of demo sites used in the learning material: • Demo Site Norway (Demo Site NTNU-Smaragd) • Demo Site Spain	
Digital Twin	A digital representation of a real-world physical entity, process, or system that enables monitoring, analysis, and simulation to optimize its performance.	
Internet of Things	A network of interconnected physical devices and objects that are embedded with sensors, software, and other technologies to exchange data and information.	
Cybersecurity	Measures and practices designed to protect computer systems, networks, and data from digital attacks and unauthorized access.	

8.2 Abbreviations

	Explanation	Reference
BIM	BIM stands for Building Information Modeling. It is a process that involves creating and managing a digital representation of a building or infrastructure project.	

Erasmus+
This project is funded by the European Union.

	BIM models contain information about various aspects of the project, including architectural, structural, and mechanical details.	
DT	Digital Twin	
STEM	STEM stands for Science, Technology, Engineering, and Mathematics. It refers to an interdisciplinary approach to education that integrates these four disciplines to foster critical thinking, problem-solving skills, and innovation. Source: https://en.wikipedia.org/wiki/Science,_technology,_engineering,_and_mathematics	
AEC	AEC stands for Architecture, Engineering, and Construction. It represents a collective term for industries related to the design, construction, and management of built structures and environments.	
IoT	IoT stands for the Internet of Things. It refers to the network of physical objects or "things" embedded with sensors, software, and other technologies to collect and exchange data over the internet.	
IT	IT stands for Information Technology. It encompasses the use of computers, software, networks, and electronic systems for managing and processing information.	
FAQs	FAQs stands for Frequently Asked Questions. It refers to a list of common questions and their answers to provide quick information to users.	
API	API stands for Application Programming Interface. It defines protocols and tools for building software applications by specifying how different software components should interact.	
CAD	CAD stands for Computer-Aided Design. It involves using computer software to create detailed designs and technical drawings for various purposes, such as architecture, engineering, and manufacturing.	
AI	AI stands for Artificial Intelligence. It refers to the development of computer systems that can perform tasks that typically require human intelligence, such as problem-solving, learning, and decision-making.	
VR	VR stands for Virtual Reality. It is a technology that immerses users in a computer-generated environment, often through the use of specialized headsets.	
AR	AR stands for Augmented Reality. It overlays digital information, such as images or data, onto the real-world environment, typically viewed through a smartphone or AR glasses.	
UI	UI stands for User Interface. It refers to the visual elements and design through which users interact with software, websites, or applications.	
UX	UX stands for User Experience. It encompasses the overall experience and satisfaction that users have while interacting with a product, system, or service.	

SME	SME stands for Subject Matter Expert. It refers to an individual who has in-depth knowledge and expertise in a specific field or domain.	
KPI	KPI stands for Key Performance Indicator. It is a measurable value that indicates how effectively an organization or individual is achieving specific objectives or goals.	
R&D	R&D stands for Research and Development. It involves the systematic process of creating new products, technologies, or knowledge through experimentation and innovation.	
ML	ML stands for Machine Learning. It is a subset of AI that involves the development of algorithms that allow computers to learn and make predictions based on data without explicit programming.	
DL	DL stands for Deep Learning. It is a specialized form of machine learning that uses artificial neural networks to model and solve complex problems.	
CNSS	Committee for National Security Systems, USA	www.cnss.gov
GDPR	General Data Protection Regulation. A regulation in EU law on data protection and privacy for individuals within the European Union and the European Economic Area.	https://gdpr-info.eu/

Erasmus+
This project is funded by the European Union.