BIM integrated digital twin framework for improving data visualization

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Abstract

The use of Building Information Modeling (BIM) methodology in Facility Management (FM) has become increasingly important due to its potential to improve data visualization and decision-making processes. Digital twins, a virtual replica of a physical building, can be integrated with BIM to provide FM with more detailed and easy-to-analyze information. This study presents a BIM integrated digital twin framework for improving data visualization, and a case study implementation of a digital twin using Autodesk Forge to showcase indoor air quality data provided by a sensor in a room. Results show that the implementation of a digital twin through sensor integration has a great potential to improve the efficiency and effectiveness of facility managers in their daily activities. The continuous information provided by the digital twin can help facility managers make informed and proactive decisions to ensure occupant safety, well-being, and energy efficiency of the building.

Resumen

El uso de la metodología de Modelado de Información de la Construcción (BIM, por sus siglas en inglés) en el Facility Management (FM) se ha vuelto cada vez más importante debido a su potencial para mejorar la visualización de datos y los procesos de toma de decisiones. Los gemelos digitales, una réplica virtual de un edificio físico, se pueden integrar con BIM para proporcionar al FM información más detallada y fácil de analizar. Este estudio presenta un marco de trabajo de gemelos digitales integrados con BIM para mejorar la visualización de datos, y un caso de estudio de implementación de un gemelo digital utilizando Autodesk Forge para mostrar los datos de calidad del aire interior proporcionados por un sensor en una habitación. Los resultados muestran que la implementación de un gemelo digital a través de la integración de sensores tiene un gran potencial para mejorar la eficiencia y efectividad de los facility managers en sus actividades diarias. La información continua proporcionada por el gemelo digital puede ayudar a los facility managers a tomar decisiones informadas y proactivas para garantizar la seguridad, el bienestar y la eficiencia energética de los ocupantes del edificio.

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AECO	Architecture, Engineering, Construction & Operations
BIM	Building Information Modeling
DT	Digital Twins
FM	Facility Management
FMM	Facility Maintenance Management
O&M	Operation and Maintenance
IoT)	Internet of Things
ML	Machine learning
AI	Artificial intelligence
API	Application Programming Interface
URN	Uniform Resource Name
CMMS	Computerized Maintenance Management Systems
JS	JavaScript
SDGs	Sustainable Development Goals
GWP	Global warming potential

Chapter 1

Introduction

The O&M (operation and maintenance) stage is one of the most important phases in the life cycle of a project. During this phase, the continuous management and maintenance of the building or facility is carried out, in order to ensure that it functions efficiently and safely. Proper management of the O&M stage can have a significant impact on the long-term profitability of the project, as adequate maintenance can prolong the lifespan of the building and reduce repair and replacement costs [1]. In this context, facility managers play a key role in O&M stage management. Facility managers are responsible for managing and maintaining facilities and buildings, and their work is essential to ensuring the proper functioning of the building or facility throughout its entire lifespan. Among their tasks are preventive and corrective maintenance, management of service contracts, and control of costs and budgets. Additionally, they are also responsible for managing the safety, health, and well-being of the people who use the building or facility. One of the costs with the highest percentage in the life cycle of a project is the operation and maintenance (O&M) phase [2]. It is therefore a phase where the importance of facility management activities is high [3].

One of the fundamental tools for managing the O&M phase is the BIM methodology. Building Information Modeling (BIM) is a digital representation of a building's physical and functional characteristics, which can be used to manage the building throughout its lifecycle. In O&M for facility management, BIM can be used for a range of tasks, such as space management, energy analysis, maintenance scheduling, and asset management. BIM enables facility managers to have a comprehensive view of the building's components, systems, and performance, which can help them make informed decisions and optimize the building's operation and maintenance. An important example of the improvements that are being worked on, in which BIM technology is involved, is in the occupants comfort of buildings [4], since it greatly affects the productivity of the people who use it. To improve comfort, the way to quantify it with ranges has also been studied, such as quantifying the indoor air quality [5]. However, one of the main problems with BIM is the lack of real-time data and the challenge of storing and accessing large amounts of data. BIM is often seen as a static model that is created during the design phase and is not updated frequently during the building's lifecycle. This can cause difficulty in managing FM tasks efficiently, as facility managers may not have access to up-to-date information about the building's condition and performance. As a result, there is a need for better integration

of real-time data into BIM and for more effective data management strategies to support FM tasks.

To address this problem, one improvement that can be introduced is digital twins. Digital twins are a virtual representation of a building or system in real-time [6]. They are used to analyze and predict the behavior of systems and their interactions in the physical world. In the BIM methodology, the building information model is used to create a digital twin of the building, which allows facility managers to monitor the building's performance and carry out maintenance and management tasks more efficiently. Facility managers can use digital twins for a variety of tasks, such as simulating different scenarios and predicting outcomes before implementing changes in the real world. Digital twins can also help facility managers plan for preventive maintenance tasks and make informed decisions to reduce the risk of system failures. The benefits of digital twins are numerous. They offer greater efficiency in facility management, allowing facility managers to make informed decisions and plan maintenance more effectively. Additionally, they can improve communication and collaboration among maintenance teams, as well as reduce downtime and increase workplace safety. With the BIM methodology, projects can be created, planned and built, but through the use of IoT, digital twins can be achieved, integrating and connecting different project data, being able to show the behavior of DTs in different scenarios.

1.1 Objective

The main objective of the thesis is to develop a digital twin for improving data visualization. This digital twin will be evaluated in a case study. This case study will be a room in the building TR5 of the school of industrial, aerospace and audiovisual engineering of terrassa (ESEIAAT).

1.2 Scope

The scope of the thesis has the following deliverables:

- A review of BIM in the facility managers acivities.

- A review of how the digital twins are implemented in the BIM technology.

- Digital twin framework development using a BIM model.

- Data integration in the digital twin framework.

- Analyze the result of the digital twin in the case study.

1.3 Requirements

The requirements of this thesis are the following:

- Use the tool Autodesk Forge for develop the digital twin.

- A revit file needs to be used to the BIM model.

- Make the development scalable, so that it can be used for more rooms in the building.

1.4 Standards

The proposed digital twin will have to comply the following standards and regulations, regarding technical, economic and legal specifications and restrictions.

- ISO 41001:2018: Facility Management - Management System. This standard establishes the requirements for a Facility Management management system that allows an organization to develop and implement a Facility Management policy, objectives, and processes that consider the needs of all interested parties.

- ISO 50001:2018: Energy Management Systems. This standard establishes the requirements for an energy management system that allows an organization to improve its energy performance, including energy efficiency, energy use and consumption, and the reduction of greenhouse gas emissions.

- ISO 55000:2014: Asset Management. This standard provides a framework for asset management, including the management of real estate assets.

- ISO 9001:2015: Quality Management Systems. This standard establishes the requirements for a quality management system that allows an organization to demonstrate its ability to provide products and services that meet customer requirements and applicable legal and regulatory requirements.

- ISO 14001:2015: Environmental Management Systems. This standard establishes the requirements for an environmental management system that allows an organization to improve its environmental performance, including pollution prevention, sustainable resource use, and the mitigation of adverse environmental impacts.

- ISO 45001:2018: Occupational Health and Safety Management Systems. This standard establishes the requirements for an occupational health and safety management system that allows an organization to provide a safe and healthy work environment for its employees and other interested parties.

1.5 Justification

The justification for the thesis is rooted in the growing need for facility managers to have access to accurate and real-time data to effectively maintain their buildings. As building systems become increasingly complex and there is a need for sustainability and energy efficiency, facility managers require detailed information on the performance and behavior of their buildings' systems.

The integration of digital twins into the BIM methodology provides a unique opportunity to create a virtual representation of a building that can simulate different scenarios and predict the behavior of the building's systems. This enables facility managers to make informed decisions and plan preventative maintenance to avoid potential system failures.

The case study of implementing a digital twin in a building room serves as a practical example of the potential

benefits of using digital twins for maintenance tasks. By creating a digital twin of a building room and monitoring its behavior, it demonstrates how facility managers can utilize this technology to identify potential issues before they occur, optimize system performance, and reduce energy consumption.

Overall, the study and case study contribute to advancing the field of building maintenance and provide valuable insights for facility managers looking to improve their maintenance strategies. By integrating digital twins into BIM methodologies, facility managers can leverage the power of data visualization to make informed decisions that improve the overall performance and sustainability of their buildings.

Chapter 2

State of the art

Prior to the investigation, it has been necessary to learn about the facility management, BIM, digital twins, and the relationship between them. Also know about how their evolution has been and what expectations there are for the future. For this, a literature review has been made on the recent publications on the use of digital twins and the BIM methodology in the facility managers activities. This section analyses three areas that are related to the core of the proposed research. These include: (1) Facility management, (2) Building Information Modelling and the benefits for the facility managers, (3) Digital Twins technologies in the facility management activities.

2.1 Facility management

Facility Management (FM) is the integration of processes within an organisation to maintain and develop the agreed services which support and improve the effectiveness of its primary activities (UNI EN 15221-1:2011, "Facility Management—Part 1: Terms and definitions").

The market of Facility Management is significantly growing in the last ten years with a general tendency to increasingly integrated services, longer-term contracts, and expansion of the strategic activities [7].

The responsibilities of a Facility Manager are to manage and plan a more efficient, human and productive work environment [8]. Facility Management is the comprehensive management of infrastructures and services in the company, with the aim of optimizing spaces and resources for the best development of professional activity so that the company can focus on the main business or "core business". [8]

Increasingly, companies are aware that the maintenance and effective management of their resources are critical factors for achieving their objectives [9]. In addition, the value that issues such as the work environment or health in the company have gained today has greatly boosted the importance and need to have these professionals in organizations. [9]

The benefits of using facility management in a company are clear and transparent communication between the demand and the party that provides the service, improvements in performance and the reduction of costs

of an organization, reduction of conflicts between internal service providers and external services, greater integration and coordination of all services, greater knowledge and information on service levels and their costs, improves the efficiency of the main activities and management processes and also, thanks to your preventive approach, extends the useful life of the building and the facilities [10].

The origin of FM dates to the early 1980s, when there was an increase in outsourcing with FM services, beginning in sectors such as cleaning or food. It was at the end of the decade when it began to expand to other industrial sectors [11]. At the beginning of the century, companies began to make use of FM for business process outsourcing and waste management. The current objective of facility managers is to focus on workplace change management and risk mitigation to increase the value of customer service. [11]
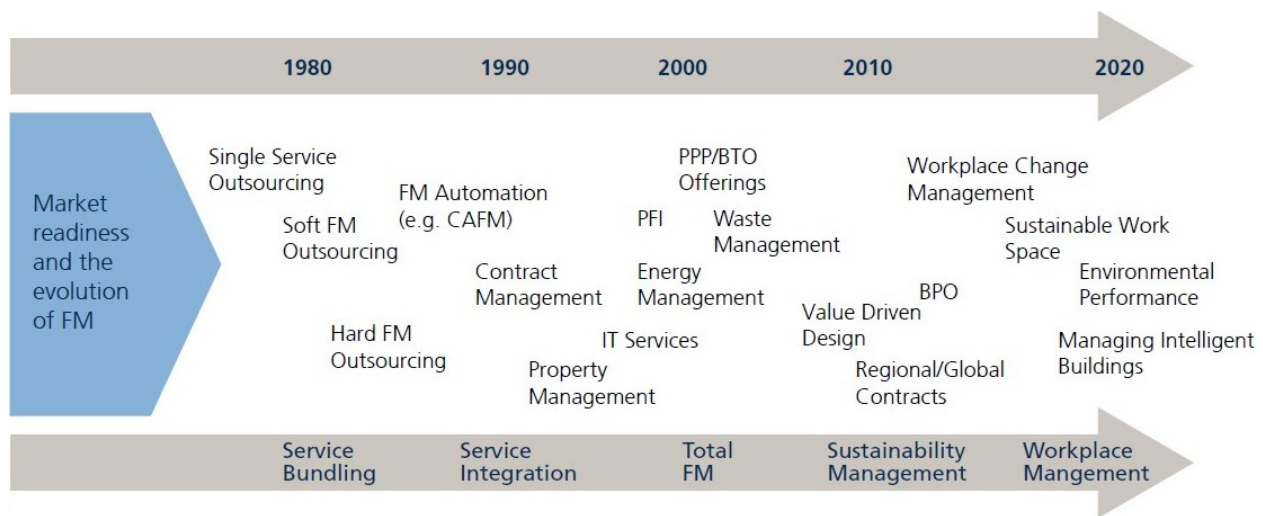

Figure 2.1: . Market readiness and the evolution of FM (Source: [11]])

2.2 Building Information Modelling

Building Information Modelling (BIM) is the holistic process of creating and managing information for a built asset. This technology is based on the use of digital representation technologies of three-dimensional structures. [3]

Figure 2.2: . BIM Drivers (Source: [3])

BIM has the ability to provide better documentation, improved collaboration and work flexibility, and updated information through the building life cycle.[12]

The main applications of BIM are the following: [12]

- Have a 3D visualization of the project.

- Have an estimate of the costs of the project.

- Planning of all phases of the project.

- Collision and interference detection.

- Support for facilities management tasks.

With what was explained above, the BIM methodology allows to have some benefits when it comes to having feedback in all the processes of a project, allowing to reduce operational costs and energy consumption. [13]

Within the BIM methodology, a differentiation can be made by dimensions: 3D, 4D, 5D, 6D and 7D [14]. Not all authors agree on the definition of these dimensions, so the definitions of Fernández, Ríos, & Marreros (2016) will be used here. According to these authors [14], BIM 3D refers to the integration of architecture, structure and facilities. BIM 4D implies adding the construction tasks of the model and the corresponding work schedule, so that a simulation of the construction process is achieved. BIM 5D adds up the costs and allows you to match the model to your budget. BIM 6D refers to the inclusion of sustainability elements, such as energy analysis, water consumption and others. Finally, BIM 7D involves integrating the use phase, that is, everything related to FM. [14]
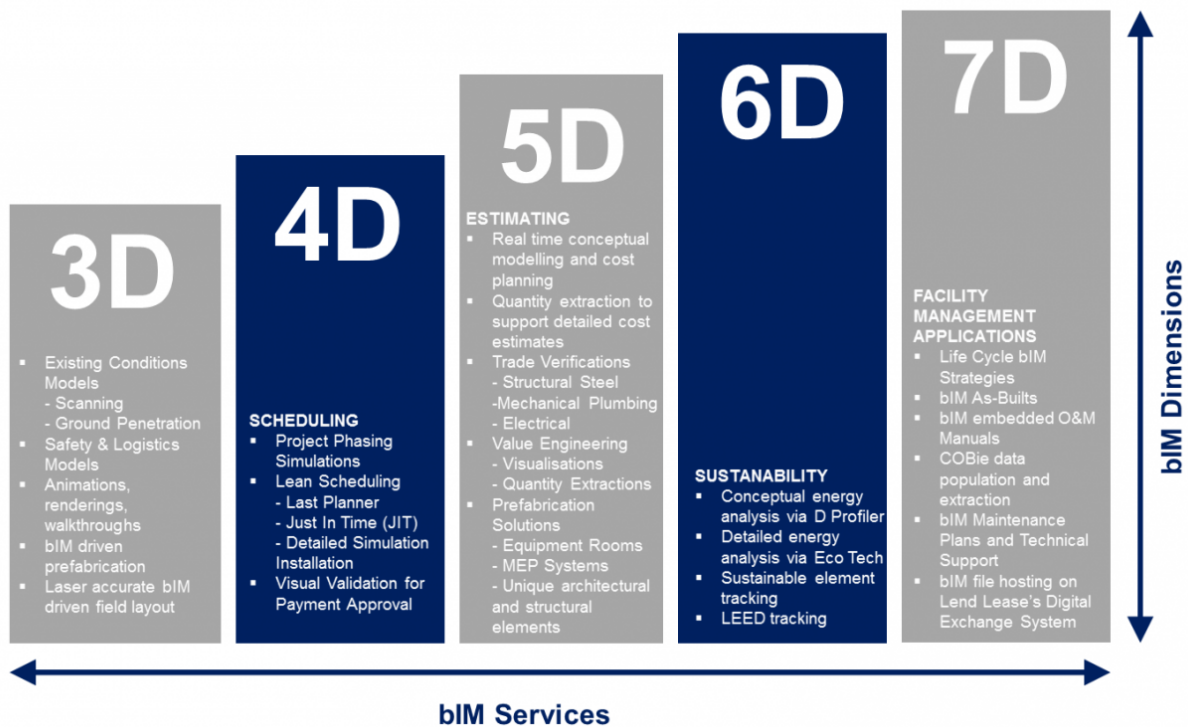
Figure 2.3: . BIM Dimensions (Source: [15]])

The benefits of using BIM will depend on the dimension in which you are working, although the main advantage, regardless of the dimension, is better information management. This methodology allows everyone involved in a project to have all the information they need without having to go through third parties.

Another advantage of BIM is being able to coordinate data from multiple systems during the Operation & Maintenance phase, which, as explained in the introduction, is one of the most expensive phases of a project. This makes it possible to optimize the maintenance of the different equipment and systems of the building, allowing the visualization of the information, speeding up the decisions regarding this maintenance, minimizing these tasks in time.[16]

With a BIM model and a viewer, we can digitally move around the building and create a digital twin with which to redesign processes to simulate possible behaviours until we have the desired result before creating it in production. [17]

The use of this technology allows management of building data throughout its life cycle and in real time. The main objective is to optimize time and resources in all stages of the life cycle (design, construction, maintenance and dismantling). [17]

Benefits of using BIM in FM include providing "as-is" information and enabling Facility Managers to work on information using a single source of data, overcoming all the issues deriving from the sources' fragmentation [18] . Moreover, it helps the FM team to optimize building operation strategies and supports decision-making on FM activities to improve building performance.

The software used for BIM exhibits features such as interoperability between applications, easy visualisation and cost effectiveness. Autodesk Inc. is one of the leaders in providing the innovative BIM software suite. The BIM software suite generally encompasses solutions for various objectives such as architecture, sustainability, structures, MEP, construction and facilities management in the overall project lifecycle. [3]

The software programs most used in the market are: [3]

- Autodesk Revit structure.

- Graphisoft ArchiCAD.

- Nemetschek Allplan architecture.

- Bentley facilities.

- Tekla structures.

2.3 Digital Twins technologies in the facility management activities.

The CIRP Encyclopedia of Production Engineering define a digital twin with the following expression [19]: "A digital twin is a digital representation of a unique active product (real device, object, machine, service, or intangible asset) or unique product service system (a system consisting of a product and a related service) that comprises its selected characteristics, properties, conditions, and behaviors through models, information, and data within a single or even across multiple life cycle phases." So, a digital twin is a digital representation of a physical object, process or service, which simulates their behavior.

Physical objects are sometimes equipped with many sensors in charge of collecting data about their status in real time, their working conditions or their position. All this data must be analysed and processed to recreate the digital model [20].
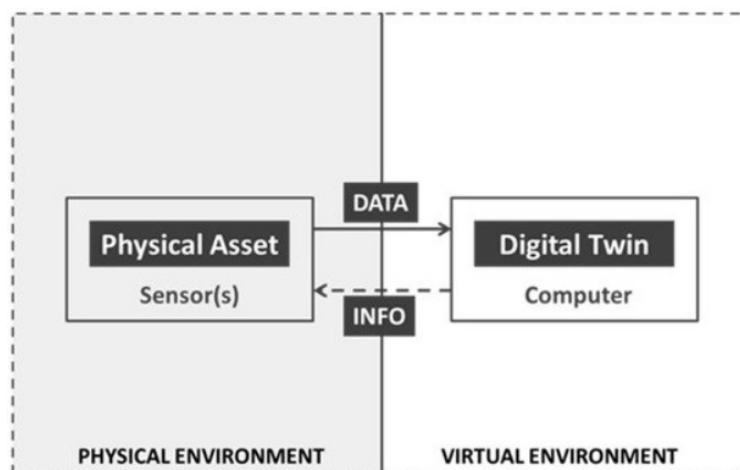

Figure 2.4: . Digital twin technology and its relation with a physical asset (Source:[20])

Despite the fact that at the end of the 1960s NASA began to create virtual replicas for the Apollo program, the concept of the digital twin did not arrive until 2002, when Michael Grieves presented the essential parts of a digital twin model: the real object, the virtual object, and the gathering and processing of data between the physical asset and the digital replica [21] . Grieves initially referred to it as a "conceptual ideal for product life cycle management." [21].

Digital twins can be useful to observe in real time the information of certain parameters, such as vibration, temperature, humidity... where, for example, alerts can be created for certain levels [22]. Its use to visualize historical data is also interesting, in order to carry out analyzes of certain behaviors. Another interesting use is in preventive maintenance, where the data from the digital twin can be integrated with the CMMS platform [22].

Grand View Research says that the global digital twin market size was valued at USD 7.48 billion in 2021 and is projected to grow at a compound annual growth rate (CAGR) of 39.1% from 2022 to 2030 [23].
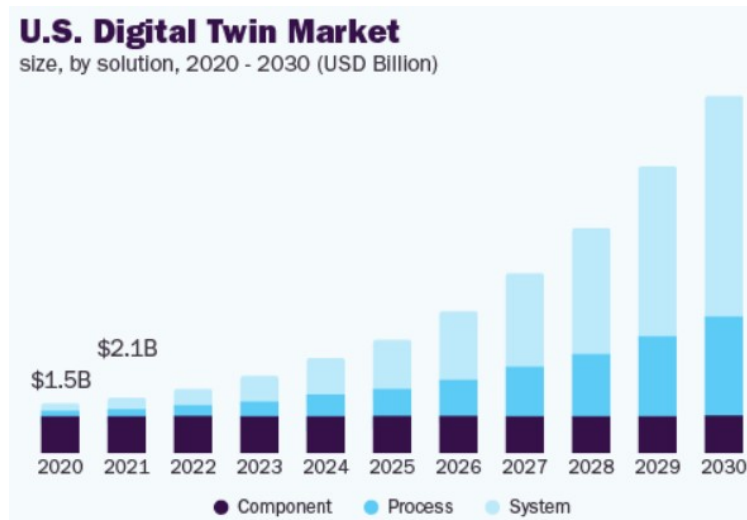

Figure 2.5: . U.S Digital Twin Market (Source: [23])

In 2021, the segments where digital twins have been used the most are, encompassing more than 19% of the total, the transport and automotive. The increase in these sectors may be due to the growth of simulations to be able to implement new technologies for electric vehicles [23]. Digital twins also facilitate the adoption of data provided by the vehicle, being able to reduce costs and improve supply chain operations. Other segments to highlight are telecommunications, manufacturing and healthcare & Life Sciences [23].
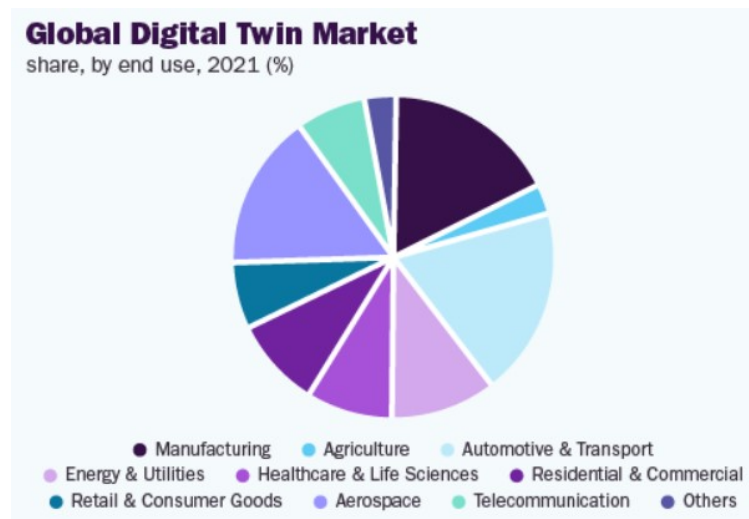
Figure 2.6: . Global Digital Twin Market (Source: [23])

The key market players in digital twin market are the followings [24]:

- General Electric.

- Microsoft

- Siemens

- Amazon Web Services.

- ANSYS

- Dassault Systèmes

- PTC

Four of these seven companies are from North America. North America has the largest share of the digital twin market, and it is expected to do so for the next few years [24].

Digital twins have the ability to improve work efficiency during the Operation and Maintenance phase in different fields of application [25].

Currently, work is being done to integrate DT technologies within the connection between FM and BIM. One of the main reasons for making this use is to have the physical assets mapped on a centralized platform to be able to analyze their conditions and status in real time. The technologies currently used to achieve these objectives are: [25]

- Smart sensors.

- Internet of Things (IoT) equipment.

- Machine learning (ML).

- Artificial intelligence (AI).

- Blockchain.

- Big data analytics.

The visualization is achieved through a 3D model generated by the BIM process and the real-time status is obtained from the information collected and transmitted by the intelligent sensors located in the building [26]. Thanks to the dynamic learning produced by the use of ML and AI, the deficiencies that the BIM methodology may have in the management of life cycle assets are compensated. Using machine learning and artificial intelligence, the digital twin uses real-time data to virtually represent how a building works, where it may require maintenance, and how it might respond to different scenarios [25].

Thus, the digital twin makes it possible to digitally "test" certain scenarios in the workplace before implementation in real life. Instead of spending hours upon hours weighing the benefits of the change in the workplace before it is physically installed, the FM can jump to any point in time within the buildings life cycle and tailor aspects to help understand the probable results, allowing to understand the impact of the decisions before they are physically made [25].

The digital twin concept revolves around the connection between the physical and digital versions of a building [27]. The digital replica exactly reflects the model of the physical version in terms of design and construction and represents, in digital terms, all the services of the building; lighting, air conditioning, mechanical and electrical installations, controls and commissioning at all times [28]. This digital duplicate can help us understand how buildings work and how we can manage and design them more efficiently. But not only does it provide us with information during construction, but it can also be used to understand why a building does not behave as it should [29].

Chapter 3

Methodology

In order to develop the present thesis, the following methodology has been followed (it has been summarised in Figure 3.1).

The first step is to prepare the cloud-based platform to host the digital twin information and utilize its available application programming interfaces (APIs). At this step, it is necessary to configure the credentials and select the APIs that will be used to access and process the collected data. An API is an application programming interface that allows different applications to interact with each other. In this case, APIs are used to access the data stored in the cloud and process it to build the digital twin model.

To upload information to the cloud and build the digital twin, it is necessary to use an API platform, which is a tool that allows the execution of APIs from the cloud-based platform. First, a bucket is created through the API platform, which is a cloud-based data storage container used to store and organize files. Second, the building information is uploaded to the bucket created in this platform. The building information is structured in a Building Information Modeling (BIM) format, and the file containing it must be tailored to the specific cloud-based platform used.

Therefore, after uploading the file to the bucket, the next step is to use the API that is used for to transform the file into a format that the cloud-based platform can understand. To facilitate the data transfer, it is essential to translate the BIM model into a format that is compatible with the cloud-based platform. This step is critical in ensuring that the data is transferred seamlessly and without any errors, can be read and processed correctly, and later consulted as needed.

Once the building information has been uploaded to the cloud-based platform, the development of the digital twin can begin. This involves creating a project where a frontend interface will be built to display the model of the building along with its associated information. To accomplish this, the application hosted in the cloud-based platform will be called using web services, allowing the frontend to retrieve the necessary data from the BIM model. The frontend will display this data in a way that is intuitive and easy to understand, allowing users to interact with the digital twin and access its functionality. This step is crucial in the development of the digital twin, as it enables users to visualize and understand the building information in a

way that is both informative and engaging.

Once the development is finished, with the digital twin prepared to receive and display the information, the next step is to integrate the data provided by the sensor into the digital twin. This process involves the real-time acquisition and recording of sensor data, including information about the physical environment such as temperature, humidity, and C02. Sensors are devices that can detect and measure physical changes in the environment around them, such as temperature, humidity, and others. Sensors convert these measurements into electrical signals that can be used to collect data and control systems. The sensor will be used to collect the necessary data to display it in the digital twin, reflecting the current situation of the physical environment in real-time. In order to carry it out, it is necessary to previously process the data provided by the sensor to have it in the format readable by the development done. When the sensor data is in the correct format in the project, the next step is to transmit the information to the cloud-based platform to include it in the model. This information must be associated with the room of the building to which it refers in order to be able to map the visualization in the model correctly.

Finally, once the digital twin has already been developed and is in operation, its functionality and its results will be analyzed. An assessment of the strengths and weaknesses of the digital twin will be made, analyzing whether their proposed objectives have been achieved.
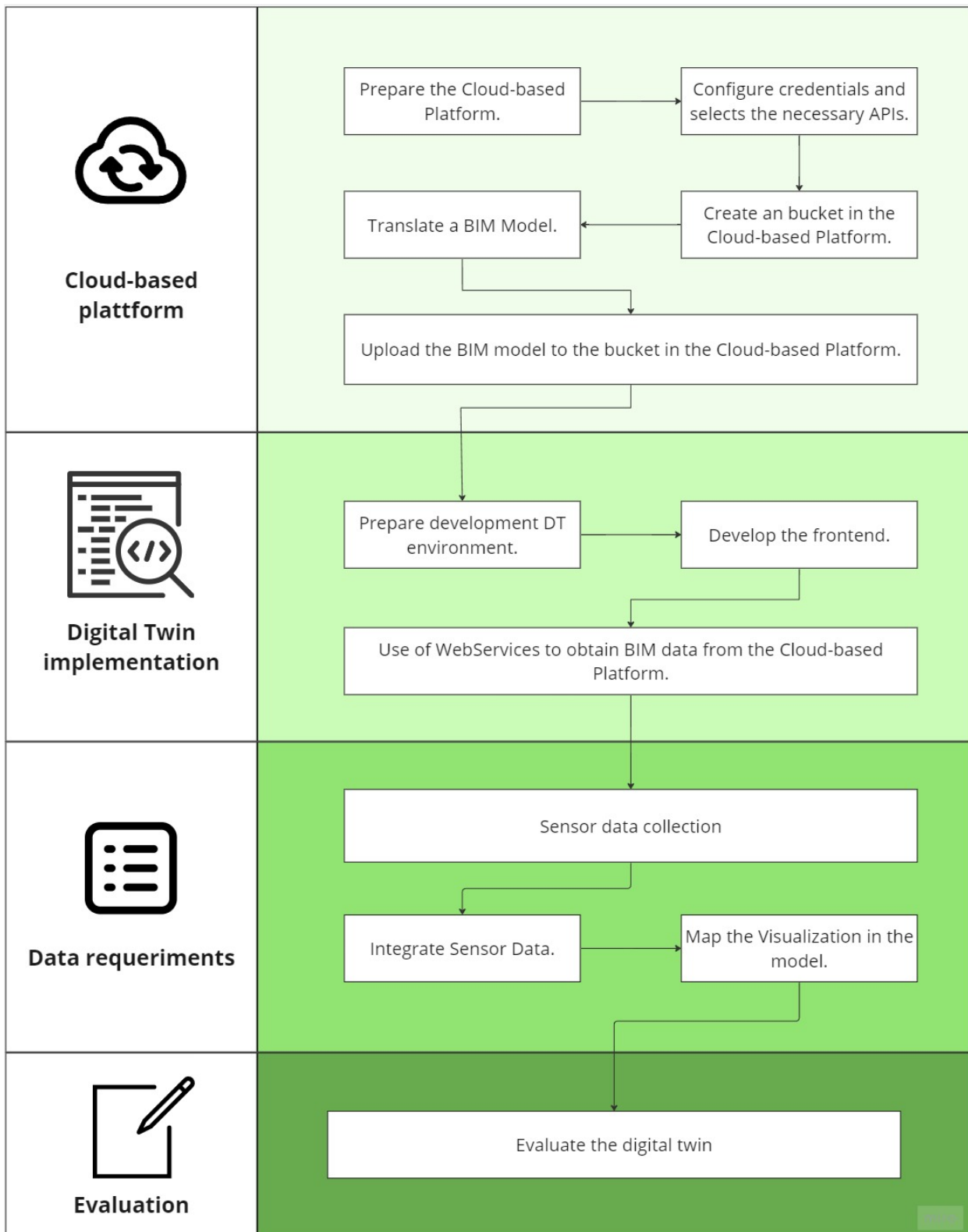
Figure 3.1: Flow chart of the methodology followed in the study.

Chapter 4

Implementation of the digital twin in TR5 ESEIAAT building

4.1 Introduction

The case study of the thesis is based on the implementation of a digital twin for a room in the building TR5 of the school of industrial, aerospace and audiovisual engineering of terrassa (ESEIAAT). In order to evaluate the framework created, the data sensor and the model are integrated and visualized in a dashboard.

Figure 4.1 displays a real image of the TR5 building, whereas Figure 4.2 presents the digital model.
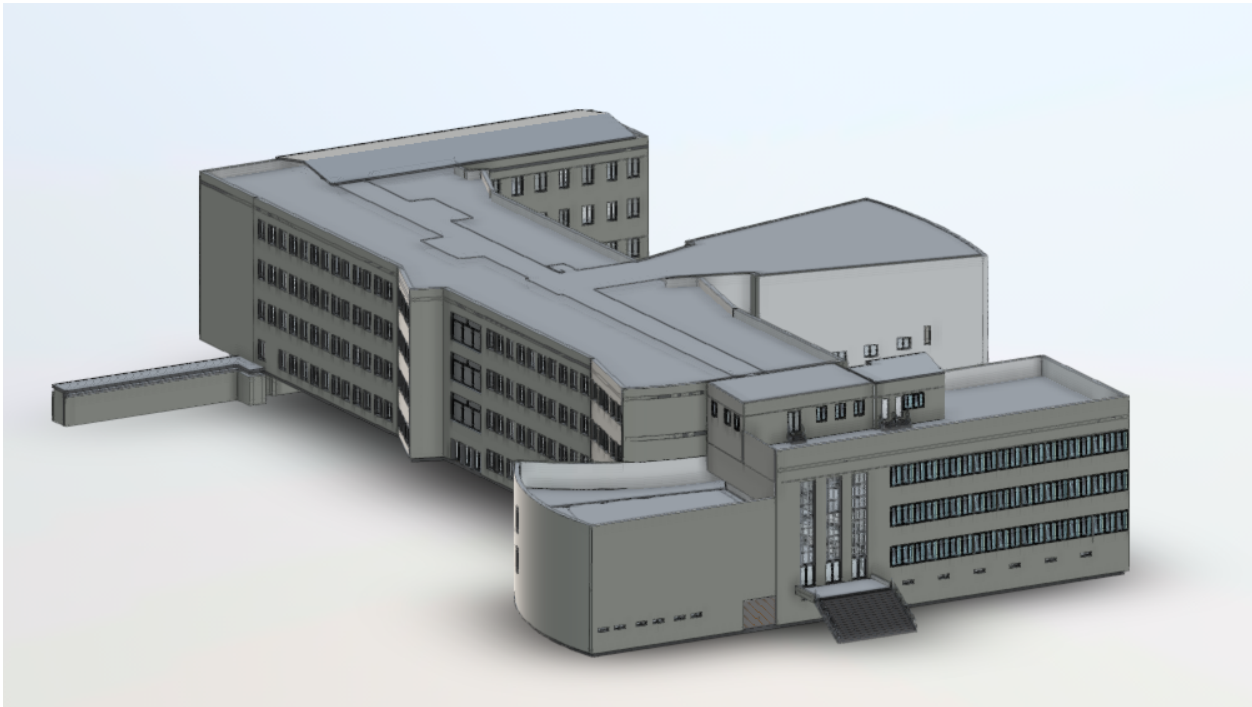

Figure 4.1: TR5 ESEIAAT building

Figure 4.2: TR5 ESEIAAT building model

4.2 Cloud-based Platform

In order to carry out this case study, the technology used is Autodesk Forge, that is an Autodesk's cloud development platform that makes web service APIs you can use to build innovative cloud-powered applications. The project in which these web service APIs will be called will be created in node.js.

To prepare the development environment, we will first start by creating an autodesk account. Once the account has been created, the next step is to create an Autodesk Forge app within this account, so that we can configure our development with the app's credentials, and be able to consume its APIs. These credentials are the Client ID and the Client Secret. The Client ID is the code that identifies the app and the Client Secret is the password.

Once the Autodesk Forge app is created, the next step is to be able to store the 3D model of the TR5 building in this application. To do this, the Forge platform allows you to create buckets. Buckets are arbitrary spaces created by applications and used to store objects for later retrieval. In our case, we store the file where the TR5 building is modeled.

The 3D model of the TR5 building is in a revit file. To create the bucket to which you want to associate and associate it, we will do it using the Postman tool. Postman is an API platform for building and using APIs. We use this tool to be able to communicate with Autodesk and be able to upload our file and translate it. To do this, the following methods will be used:

- POST: is used to send information to a server and create a new resource.

- GET: is used to retrieve information from the server, usually to read or retrieve existing resources.

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- PUT: is used to update an existing resource on the server.

1. POST https://developer.api.autodesk.com/authentication/v1/authenticate

   It is used to authenticate, for this the first thing to do is provide the client_id and the client_secret as input parameters.

2. POST https://developer.api.autodesk.com/oss/v2/buckets

   Once we have the token, the next step is to create a bucket, for this we must provide a name (bucketKey) so that it can be created and identified.

3. GET https://developer.api.autodesk.com/oss/v2/buckets/ ossBucketKey/objects/ossSourceFileObjectKey /signeds3upload?minutesExpiration=5

   The next step is to get the signed URL.

4. PUT ContentUploadSignedURL

   When we have the signed URL, we can upload the revit file.

5. POST https://developer.api.autodesk.com/oss/v2/buckets/ossBucketKey/objects/ossSourceFileObjectKey/ signeds3upload

   Once we have the upload file, we can finish associating it with the created bucket.

6. POST https://developer.api.autodesk.com/modelderivative/v2/designdata/job

   Finally, we have to translate the source file to SVF, so that it can be displayed correctly.

7. GET https://developer.api.autodesk.com/modelderivative/v2/designdata/{{t7_url_safe_urn_of_source}}/manifest

   With this call we can obtain the status of the upload and check that the translation has been done correctly.

4.3 Digital Twin Implementation

When the Autodesk Forge application has been created with the bucket containing the building model, the next step is to start creating the project where we will create the digital twin. The development environment will be VSCODE, and it will be programmed in node.js.

Node.js is an open source, cross-platform JavaScript execution environment used to develop scalable server-side and network applications. In order to start the project, you have to download and install node.js on the computer where you will work on the development. Visual Studio Code is a streamlined code editor with support for development operations like debugging, task running, and version control. To create and edit the development code, the visual studio code will be used.

To begin developing the code for the digital twin, the first thing that was done was to clone the repository of the Autodesk project template on which we will work. Once we have it cloned, the next step is to install all the dependencies with the "npm install" command.

The next step is to create the ".env" file inside the folder "server". In this file you will find the information regarding the credentials of the forge application, the bucket where the model is located and its URN, the environment where the application is (in this case it is local) and the sensor data source and format of these data.

Among the several folders that the project has, one of them is the "client". This folder is where the files related to the frontend are located. Inside is the folder "config", where the sensor styles are configured, where the types of data it provides (temperature, humidity and co2) and the color gradient that will appear based on its value are indicated.

Another folder inside client is "pages". In this folder are the js and jsx files. JSX is a JavaScript syntax extension that allows us to mix JS and HTML while js is a plain text file that contains Javascript scripts. The files in this folder refer to the visualization and design of the screens.

In this folder, the "ThesisApp.jsx" file has been created, where the information of the BIM model is recovered, later the sensor information is recovered, this information is included within the model and the BaseApp function is called within the file "BaseApp.jsx".

To generate the model surfaces, and to include the sensor information, the functions stored in the "DataHelper.js" file are called in "ThesisApp.jsx" for this purpose. This file is located within the "pages" folder. The Datahelper class references the Autodesk.DataVisualization extension in order to generate the visualization.

In the file "DataHelper.js" the function generateSurfaceShadingData is called. This function assigns customer-defined devices to rooms based on their 3D space positions and each room's bounding box, then generates hierarchical shading data based on the assignment. The inputs that this function has are:

- devices: The sensors to be assigned to loaded rooms.

- levels: Optional. The level-to-rooms map. If none is supplied, one will be generated internally.

- nodeName: Optional. Name of the node whose immediate child nodes are to be retrieved. If this parameter is not supplied, or if it is an empty string, then the default value "Rooms" will be used. In our case, since we have the file in Spanish, this input must be "Habitaciones".

In case we had more screens, it would be created inside the "pages" folder and it would be called inside the app.js file inside the router. In our case, we simply only have a screen where we will show all the information we want (BIM model of the building, and the information of the sensor inside a room), therefore in the router that is inside the app.js file, only we have ThesisApp.

Another folder that we have to modify is the "gateways" folder, which is located inside the server folder. The information regarding the sensor is stored in this folder. Inside the gateways folder, we must create the csv folder, where we will enter the csv where the sensor information is located. This csv must have the same name as the sensor to which it will refer. For example, if the sensor name is "AAA", the csv must be "AAA.csv". Its structure has to be the same as the one specified in the ".env" file.

In gateways we also have the "synthetic-data" folder, where we have the following json files:

- Device-models.json: indicates the properties that the sensors of our model have (the information it offers, the unit of this information and its minimum and maximum range).

- Devices.json: this file indicates the sensors used by the model, what information it offers and in what position it is located. To know the coordinates of the room where we want to place the sensor, one option is to make a console.log of the SurfaceShadingData object, which is where this information is stored. In this object, one of the arrays (SurfaceShadingGroup) will be the floor where the room is located ("Third Floor_DD"), and a subarray will be all the rooms on the floor (SurfaceShadingNode). We look for the SurfaceShadingNode of the room where we want to locate the sensor (Hamid's Office 306 [564238]) and look at the maximum and minimum bounds.

In Figure 4.3, the information stored in the SurfaceShadingData object is displayed, where the information related to the room where the information is displayed in the digital twin has been underlined.

Figure 4.3: SurfaceShadingData object

Once we have the coordinates, we can create the JSON object of the sensor. This JSON is shown in Figure 4.4.

Figure 4.4: JSON sensor

To make sure that the sensor has been correctly located inside the model, we can also check it from SurfaceShadingData once the generateSurfaceShadingData function has been executed, since within the SurfaceShadingNode of the room where we have located the sensor an array must appear inside shadingPoints with the position and the data that we have reported in the json of the sensor. In figure 4.5, it is shown that the sensor information has already been introduced into the object.

Figure 4.5: SurfaceShadingData object with sensor information

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4.4   Data Requeriments

Once we have the project ready to display the BIM model, the next step is to integrate the sensor data into the model. For it, the first step is to collect temperature, humidity and CO2 information provided by a sensor located in the room in a csv. In Figure 4.6, an example of the data obtained by the sensor is shown. These data include the number and time of acquisition, levels of CO2 and CO, humidity, air temperature, pressure, and temperatures. This CSV file can be updated and the data will be visualized in real-time.

	A	B	C	D	E	F	G	H	I	J	K	L
1	n.	AdquisiciÃ³n	CO2 (ppm)	CO (ppm)	RH (%)	T1 (C)	Patm (hPa)	DP (C)	AH (g/m3)	MR (g/kg)	Tw (C)	H (kJ/kg)
2	0	12/11/2020 8:05	428	0	69	14,4	989	8,8	8,6	7	11,3	32,2
3	1	12/11/2020 8:06	436	0	69	14,4	989	8,8	8,6	7	11,3	32,2
4	2	12/11/2020 8:07	437	0	69	14,3	989	8,7	8,5	7	11,2	32
5	3	12/11/2020 8:08	439	0	68,7	14,4	989	8,8	8,5	7	11,3	32,1
6	4	12/11/2020 8:09	441	0	68	14,5	989	8,7	8,5	7	11,3	32,1
7	5	12/11/2020 8:10	436	0	67,5	14,5	989	8,6	8,4	6,9	11,2	32,1
8	6	12/11/2020 8:11	435	0	67,8	14,5	989	8,7	8,5	7	11,3	32,1
9	7	12/11/2020 8:12	436	0	68,1	14,4	989	8,6	8,4	6,9	11,2	32
10	8	12/11/2020 8:13	432	0	68,3	14,4	989	8,7	8,5	7	11,3	32,1
11	9	12/11/2020 8:14	436	0	68,3	14,4	989	8,7	8,5	7	11,3	32,1
12	10	12/11/2020 8:15	443	0	67,3	14,6	989	8,6	8,4	6,9	11,3	32,2
13	11	12/11/2020 8:16	447	0	65,8	14,8	989	8,5	8,4	6,9	11,4	32,4
14	12	12/11/2020 8:17	450	0	64,4	15,1	989	8,5	8,3	6,9	11,5	32,5
15	13	12/11/2020 8:18	449	0	63,3	15,3	989	8,4	8,3	6,9	11,6	32,7
16	14	12/11/2020 8:19	449	0	62,4	15,5	989	8,4	8,3	6,8	11,6	32,9
17	15	12/11/2020 8:20	449	0	61,7	15,7	989	8,4	8,3	6,9	11,7	33,1
18	16	12/11/2020 8:21	452	0	61,2	15,9	989	8,5	8,3	6,9	11,8	33,3
19	17	12/11/2020 8:22	449	0	61	16	989	8,5	8,3	6,9	11,9	33,5
20	18	12/11/2020 8:23	445	0	61,3	16	989	8,6	8,4	6,9	11,9	33,6
21	19	12/11/2020 8:24	442	0	61,3	16,1	989	8,7	8,4	7	12	33,8
22	20	12/11/2020 8:25	443	0	61,5	16,1	989	8,7	8,4	7	12	33,9
23	21	12/11/2020 8:26	441	0	61,4	16,1	989	8,8	8,4	7	12	33,9

Figure 4.6: Experimentation Data Collected

The next step is to process this information so that it has the correct structure and format so that the code can read it and retrieve the values.

An Excel macro was used to follow the steps and ensure the correct structure. First, unnecessary data columns were removed to improve efficiency. Next, the date and time format was changed to match the digital twin's requirements. To ensure compatibility, the CSV delimiter was changed from " " to ";". Additionally, the decimal separator was updated from "," to ".". Finally, trailing zeros were added to all values to maintain consistent decimal precision throughout the dataset.

Figure 4.7 displays the resulting output.

```
 1    time;Temperature;Humidity;CO₂
 2    2020-11-12T08:05:00.000Z;14.400000000000000;69.00;428.00
 3    2020-11-12T08:06:00.000Z;14.400000000000000;69.00;436.00
 4    2020-11-12T08:07:00.000Z;14.300000000000000;69.00;437.00
 5    2020-11-12T08:08:00.000Z;14.400000000000000;68.70;439.00
 6    2020-11-12T08:09:00.000Z;14.500000000000000;68.00;441.00
 7    2020-11-12T08:10:00.000Z;14.500000000000000;67.50;436.00
 8    2020-11-12T08:11:00.000Z;14.500000000000000;67.80;435.00
 9    2020-11-12T08:12:00.000Z;14.400000000000000;68.10;436.00
10    2020-11-12T08:13:00.000Z;14.400000000000000;68.30;432.00
11    2020-11-12T08:14:00.000Z;14.400000000000000;68.30;436.00
12    2020-11-12T08:15:00.000Z;14.600000000000000;67.30;443.00
13    2020-11-12T08:16:00.000Z;14.800000000000000;65.80;447.00
14    2020-11-12T08:17:00.000Z;15.100000000000000;64.40;450.00
15    2020-11-12T08:18:00.000Z;15.300000000000000;63.30;449.00
16    2020-11-12T08:19:00.000Z;15.500000000000000;62.40;449.00
```

Figure 4.7: Experimentation Data Collected with the correct format

Once we have the data in the correct format, the next step is to save it in a csv. The name of this csv must be that of the sensor. In this case, the sensor is called "HamidsOfficeSensor", so the file name will be "HamidsOfficeSensor.csv" and it will be saved in the folder "server/gateways/csv/". Also, it is necessary to add in the "devices.json" file, the json of this sensor with the structure explained in the previous chapter.

4.5 Results

Once the development has been completed, the result is a dashboard where the digital twin and all the information it provides can be viewed. The dashboard result can be seen in figure 4.8:
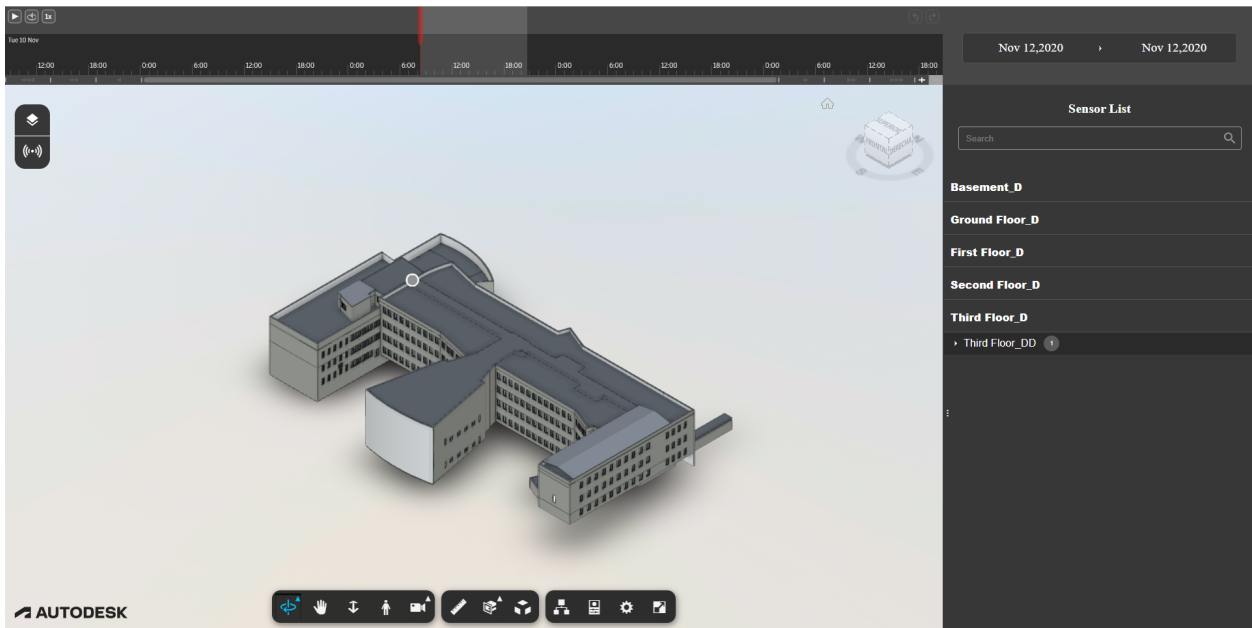
Figure 4.8: Dashboard Digital Twin.

In figure 4.9 some numbers can be seen which refer to:

1. Controls to set the digital twin view type, pan, zoom, explode the model, hide and show components.

2. In these buttons the floor that is displayed can be selected, show or hide the sensors. Also the type of heatmap (geometry or planar) can be selected.

3. Play, loop and play speed buttons.

4. Time bar where it indicates when the information is being displayed and where it is possible to select and move to view the information at the desired time.

5. Indicates the first and last day of sensor data.

6. Digital Twin visualization.

7. Sensor List. For each floor, the sensors that are integrated into the digital twin are shown. By clicking on a sensor, the visualization of the digital twin is placed in its position.

Figure 4.9: Main Points Digital Twin.

Figure 4.10 shows the room where the case study was carried out, with the information provided by the sensor. In the sensor list, the data provided by the sensor can be observed in real-time on the floor where it is located.
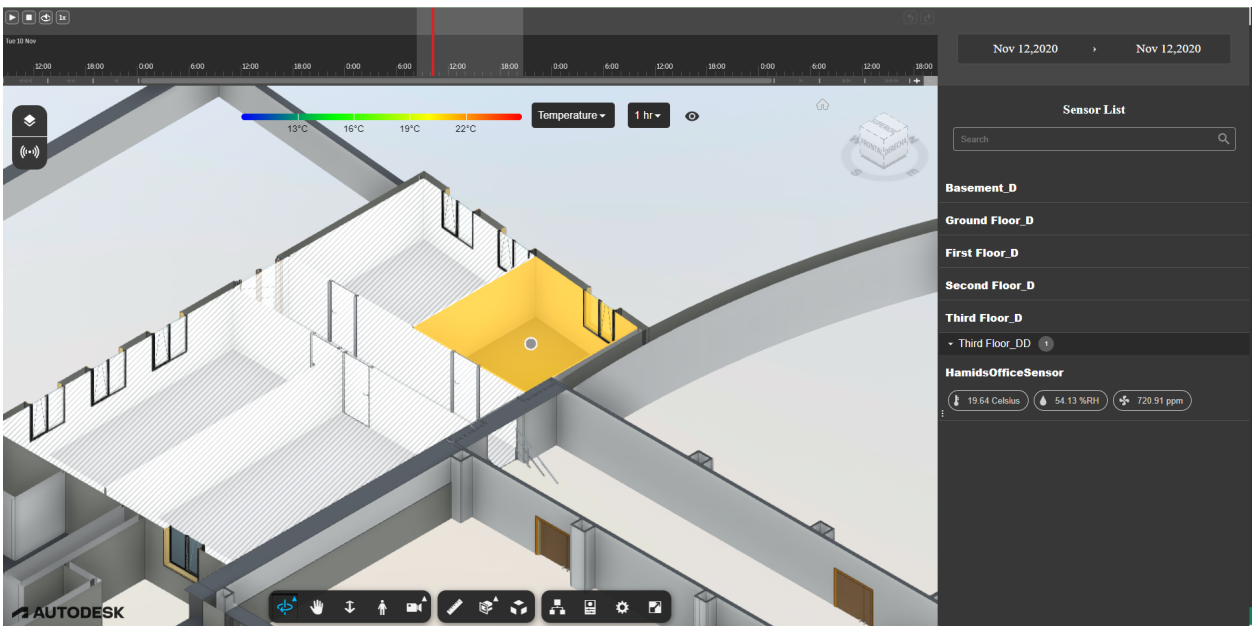
Figure 4.10: Sensor Case study.

Figure 4.11 shows that if the pointer is placed over the sensor in the visualization, the data associated with the sensor is displayed. The displayed information includes both real-time data and a historical graph.
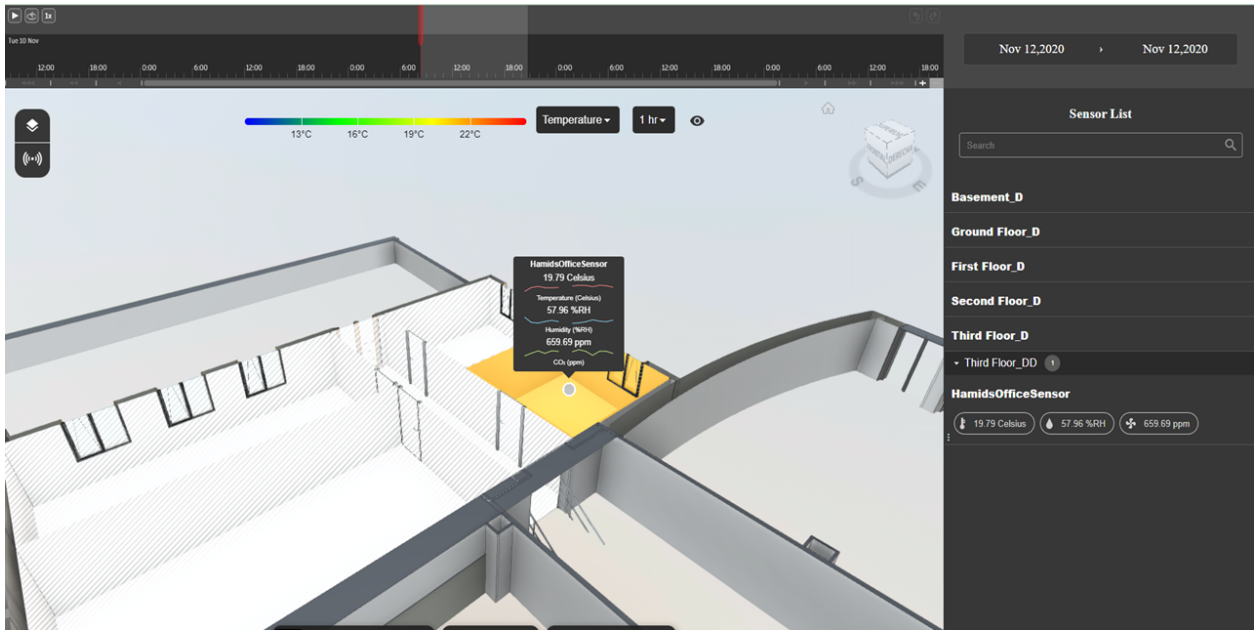
Figure 4.11: Pointer over Sensor.

Also if the sensor in the list is clicked, this information is displayed on the right side of the dashboard. This information is shown in Figure 4.12.
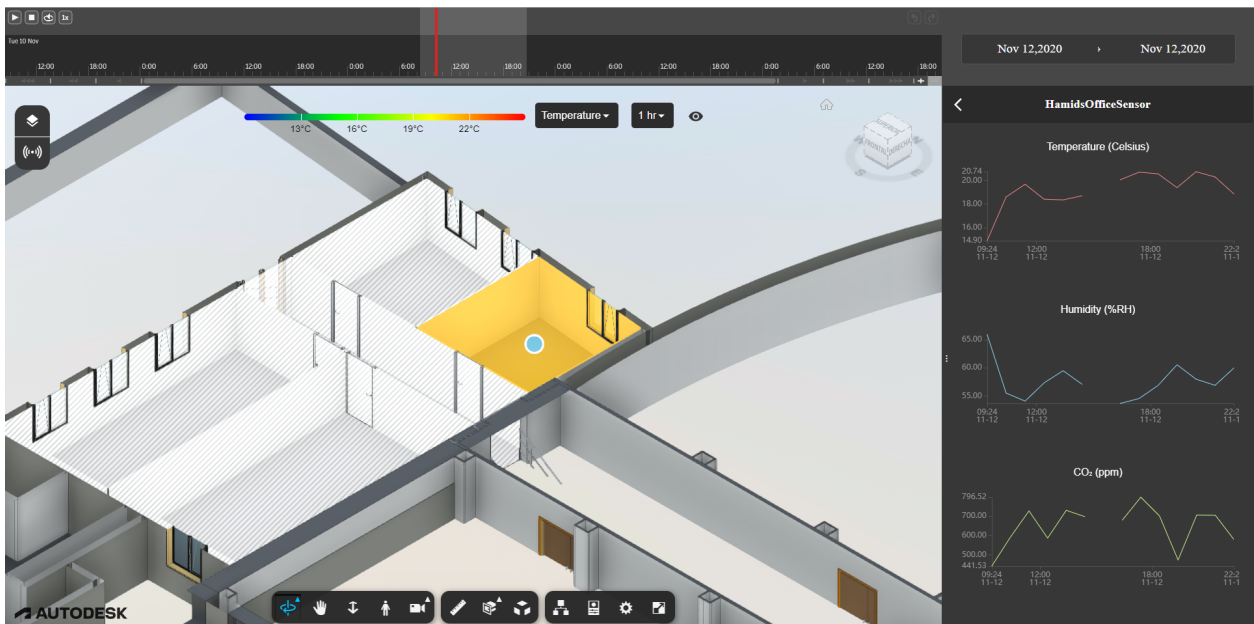
Figure 4.12: Sensor Data Case study.

At the top of the digital twin display is a gradient bar. The type of data to be displayed can be selected from this gradient bar. The default data is the temperature.
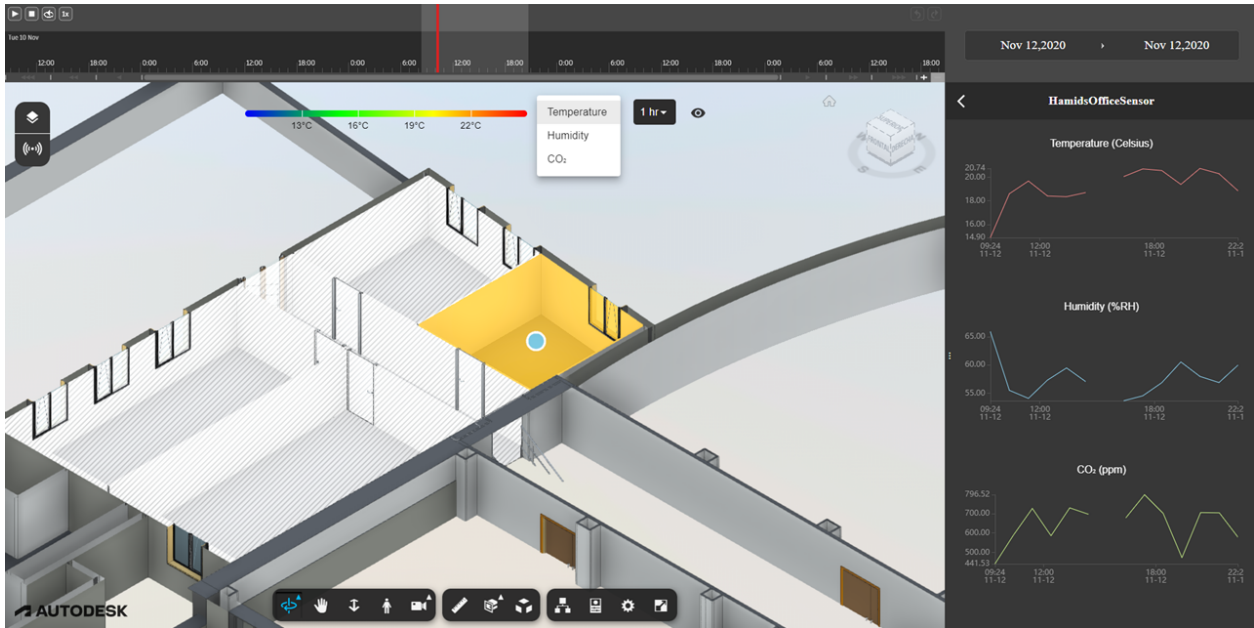
Figure 4.13: Temperature visualization.

The figure 4.14 shows the humidity data. It can be observed that the color gradient is different to distinguish it when changing the data type.
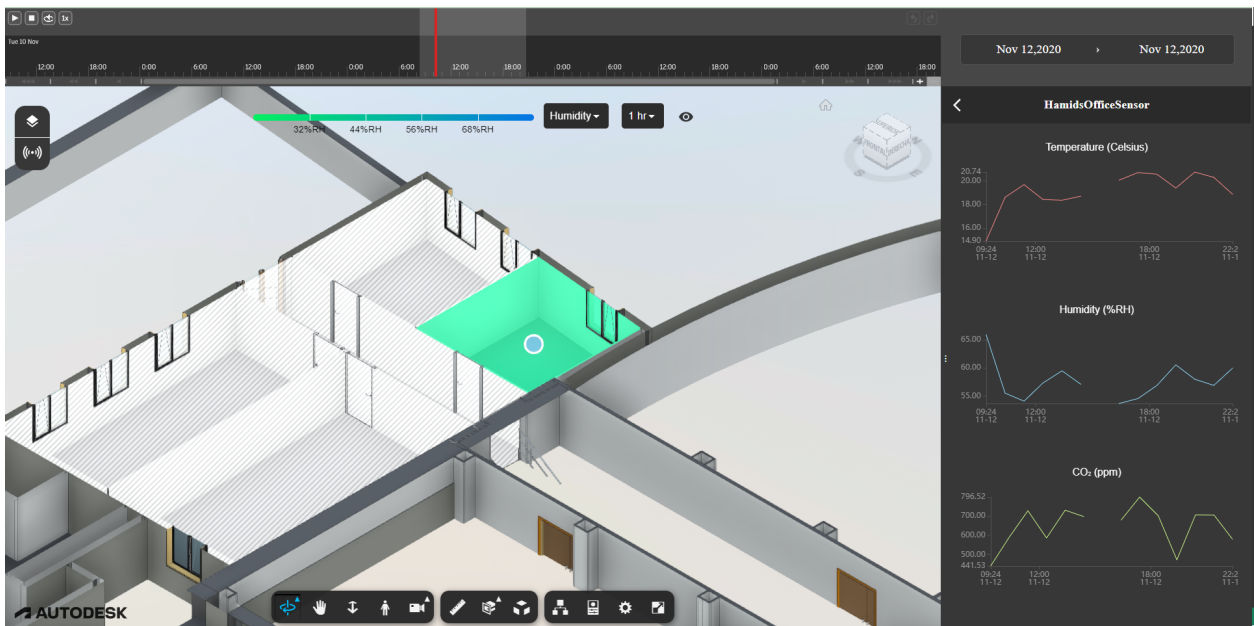
Figure 4.14: Humidity visualization.

Finally, figure 4.14 shows the C02 data.
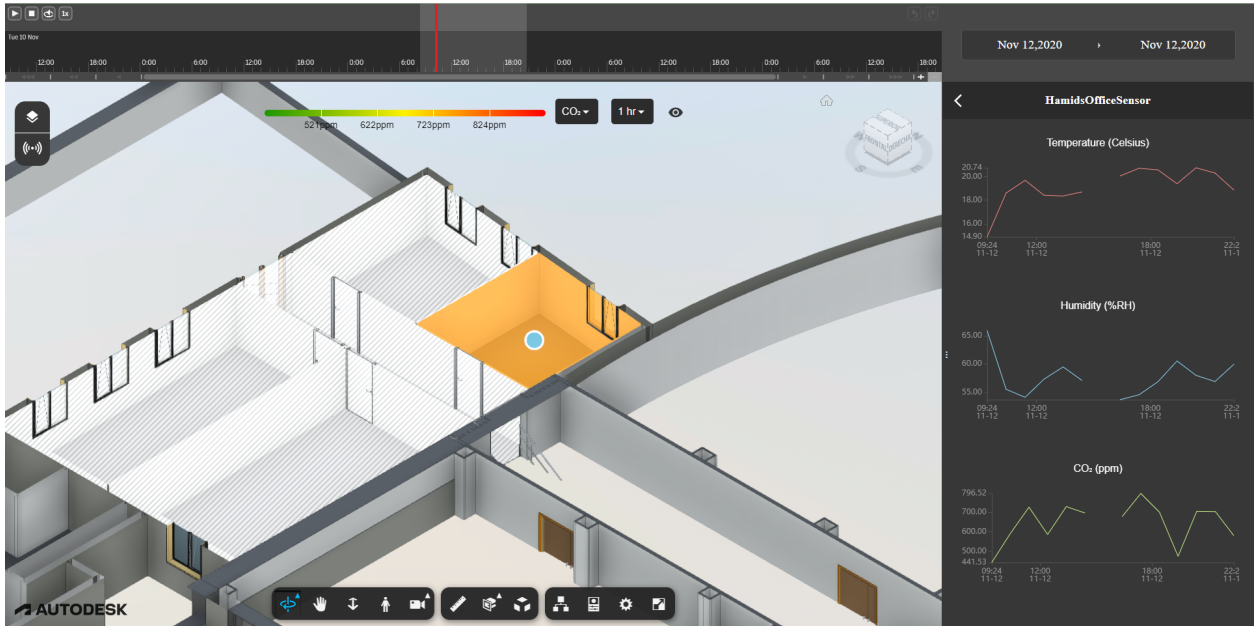
Figure 4.15: C02 visualization.

Chapter 5

Evaluation

The proposed digital twin can enhance the efficiency and effectiveness of FMMs in their daily tasks. With the help of the dashboard that displays the digital twin with all the information collected by the sensor, it allows for easy capturing and analysis of this information, directly visualizing the representation of the building, making this analysis much more intuitive.

In this section, an evaluation is presented on the impact of using digital twins on FM tasks, carried out from two perspectives. Firstly, the effect of replacing manual inspections with the use of digital twins is analyzed. Secondly, the improvements that would be obtained by using both digital twins and computerized maintenance management systems (CMMS) are examined.

5.1 Inspections

Actually, facility managers typically conduct manual inspections to review various equipment and systems, including HVAC, electrical, plumbing, and security systems. Facility managers can also perform visual inspections to detect problems such as water leaks, cracks in walls, or damage to the roof. In addition, they can perform safety inspections to ensure that buildings comply with safety codes and regulations.

In comparing digital twins with the manual inspections performed by facility managers for building maintenance, it is evident that digital twins present some important advantages in various aspects.

In terms of accuracy, in the case study it has been shown that the digital twins provide a precise and detailed picture of the building, which allows for more accurate problem identification and informed decision-making. On the other hand, manual inspections can be subjective and limited by the lack of precise measuring tools, which can lead to diagnostic errors and wrong decisions.

Regarding efficiency, digital twins allow for instant access to information, which saves time and resources compared to manual inspections. Manual inspections can be a laborious and time-consuming process, especially in large buildings. Additionally, digital twins can be updated in real-time, meaning facility managers can make informed decisions in real-time.

In terms of coverage, digital twins allow for complete coverage of the building, including hard-to-reach areas, which can prevent hidden or undetected problems in manual inspections. Manual inspections may overlook hidden or hard-to-reach areas, which can result in undetected problems.

With the digital twin developed in the case study, it can be verified that through this technology, all information from the environment provided by sensors is displayed on a dashboard, allowing for a reduction in the number of manual inspections required if more rooms in the building were to be scaled up.

Finally, digital twins offer the possibility to simulate different scenarios and evaluate the effects of design changes before their implementation, which is not possible with manual inspections. This means that facility managers can anticipate the effects of design changes and make informed decisions before they are implemented.

While digital twins can be costly to implement, long-term costs may be lower than those of manual inspections, as they can reduce the need for manual inspections and enable more efficient and preventive maintenance. In conclusion, digital twins offer a significant advantage over manual inspections for building maintenance, and their adoption can be beneficial for both facility managers and building owners.

Aspects	Proposed Case Study Solution	Manual Inspections
Accuracy	Provides precise and detailed information, allowing for accurate problem identification and informed decision-making.	Can be subjective and limited by lack of precise measuring tools, which can lead to diagnostic errors and wrong decisions.
Efficiency	Allows for instant access to information, saving time and resources compared to manual inspections. Can be updated in real-time, enabling informed decisions.	Can be laborious and time-consuming, especially in large buildings.
Coverage	Provides complete coverage of the building, including hard-to-reach areas, preventing hidden or undetected problems.	May overlook hidden or hard-to-reach areas, resulting in undetected problems.
Simulation	Offers the possibility to simulate different scenarios and evaluate the effects of design changes before implementation.	Not possible with manual inspections.
Cost	Costly to implement, but long-term costs may be lower than those of manual inspections, as they can reduce the need for manual inspections and enable more efficient and preventive maintenance.	Cost of labor and time-intensive inspections.

Table 5.1: Comparison between DT and manual inspections.

5.2 Maintenance Management

Another tool that can be used to compare DTs and analyze the impact of including the use of digital twins in FM tasks are Computerized Maintenance Management Systems (CMMS). CMMS, also known as Maintenance Management Systems, are tools used by facility managers to schedule and perform preventive and corrective maintenance in buildings. These systems allow users to track scheduled maintenance, repairs, associated costs, as well as providing analysis tools to improve maintenance efficiency.

Regarding the accuracy and detail of information, CMMS can provide detailed information about maintenance and repair history, but do not provide a detailed visual representation of the building. Regarding task efficiency, CMMS allows facility managers to schedule preventive and corrective maintenance and track work progress. However, digital twins allow instant access to information, which can save even more time and resources.

Another important factor is that CMMS focus on scheduled maintenance and repair of existing problems, while digital twins allow for complete coverage of the building, including hard-to-reach areas. This allows for identification and solution of problems throughout the building, even those that have not yet manifested.

Facility managers can use the digital twin and CMMS together to schedule and perform preventive and corrective maintenance more efficiently and effectively.

First, digital twins can help facility managers identify critical areas of the building that require more frequent and detailed maintenance. This is achieved through modeling and simulating scenarios in which areas prone to failures and recurring problems can be detected. Facility managers can use this information to schedule preventive maintenance in those critical areas using CMMS.

Second, digital twins can also be used to improve corrective maintenance planning. In case of a failure or problem, facility managers can use the digital twin to identify the exact location of the problem and obtain detailed information about the affected equipment or system. They can then use CMMS to schedule and assign specific repair tasks and track them to completion.

Additionally, the digital twin can help facility managers track maintenance activities and monitor building performance in real-time. Information collected through CMMS, such as maintenance data and failure records, can be added to the digital twin to provide a complete overview of the building's status and detect problems at an early stage before they become major issues.

In the case of the building evaluated in the case study of the thesis, which uses the CMMS called Archibus, referred to as "Facil" by the UPC [30], the developed digital twin could be used in a complementary way to provide additional support to maintenance tasks, given all the benefits explained above.

Therefore, the digital twin would not replace CMMS but rather be an added value, improving the information that this software can provide. The combination of digital twins and CMMS can provide a comprehensive solution for building maintenance, allowing facility managers to schedule and perform preventive and corrective maintenance more efficiently and effectively.

Chapter 6

Discussion of the solution

The following section presents a discussion of the solution, analyzing all the benefits that using digital twins can offer in facility managers' activities.

Firstly, an important point to analyze is air quality monitoring. It is a critical task for facility managers, as the air people breathe while working or living in a building can significantly affect their health and well-being. Air quality can be affected by many factors, such as ventilation, the presence of pollutants, and the control of humidity and temperature. By monitoring a building's air quality, facility managers can take measures to improve it, thereby enhancing the well-being of people inside. Currently, facility managers can monitor a building's air quality using a variety of tools and techniques, such as sensors, air quality monitors, on-site air quality evaluations by specialists, and more. While these tools are effective at detecting and measuring air quality, they do not provide a complete picture of the building and its systems. This is where the use of the digital twin comes into play.

The digital twin is a simulation tool that allows for the creation of a virtual replica of a building and its systems. By using this technology to monitor air quality, facility managers can obtain an accurate picture of the building's air quality, monitor its status, and take actions for its maintenance, control, and improvement. In the case study conducted, it has been demonstrated that the use of the digital twin allows for monitoring of temperature, humidity, and CO_2 levels, enabling immediate action when these levels fall outside the established ranges.

Also, the DTs offer simulation and prediction capabilities that other data analysis software lacks, which can help facility managers plan preventive maintenance and make informed decisions to reduce the risk of system failures. However, DTs require a large amount of data to build an accurate model of the building, which can be complex and time-consuming. The appropriate software choice depends on the specific needs and resources of the facility managers. By analyzing data collected from sensors, the digital twin can identify patterns and trends that suggest possible future issues. This enables facility managers to anticipate problems and take measures to avoid costly downtime and repairs, preventing future failures with associated costs and prolonged downtime. Thanks to this detection of potential errors, the use of this tool can reduce the

costs associated with HVAC maintenance and repair. There is also a reduction in the dedication of facility managers to data collection and analysis since the digital twin displays information in a clear and intuitive manner. The use of the digital twin can also improve a building's energy efficiency. By optimizing the use of HVAC systems, facility managers can reduce energy costs, improving energy efficiency.

Another benefit is that digital twins are a powerful tool for communication and collaboration among teams in an organization, as they can help teams work together more effectively and better understand how processes work in the organization. One way in which digital twins can improve communication and collaboration between teams is by providing a common platform for teams to work on, as this allows teams to share information more effectively and work together to solve problems. Additionally, digital twins can help teams better understand the processes and systems of the organization. By visualizing processes and systems on a digital platform, teams can see how they are interconnected and how they work together to achieve the organization's goals. This can help teams better understand the role they play in the organization and work together more effectively to achieve common goals. All of this can help an organization improve its overall performance and achieve its goals more effectively.

Therefore, the use of the digital twin for monitoring air quality in buildings can provide many benefits to facility managers. From early detection of problems to improved energy efficiency and reduced maintenance costs, this technology is a valuable tool for enhancing air quality and the well-being of people inside a building.

Also, digital twins can be a valuable tool to help facility managers comply with ISO regulations. For example, ISO 41001 establishes requirements for a Facility Management management system that enables an organization to develop and implement a Facility Management policy. Digital twins can help facility managers comply with this regulation by providing a virtual representation of the building that can be used to plan and optimize facility management. Similarly, digital twins can also be useful in complying with other ISO regulations, such as ISO 50001, which establishes requirements for an energy management system that enables an organization to improve its energy performance, including energy efficiency, energy use and consumption, and greenhouse gas emissions reduction. Digital twins can be used to simulate and optimize energy consumption and efficiency in building systems management, which can help organizations comply with the requirements of this regulation.

In conclusion, the use of digital twins for monitoring air quality in buildings can provide numerous benefits to facility managers. From early detection of problems to improved energy efficiency and reduced maintenance costs, this technology is a valuable tool for enhancing air quality and the well-being of people inside a building. Additionally, digital twins can aid facility managers in complying with ISO regulations and improve collaboration and information sharing within an organization.

Chapter 7

Budget summary and economic feasibility study

7.1 Budget summary

The total budget of the study is €65.726,51. For further details see the document Budget.

7.2 Economic feasibility study

The implementation of the digital twin for the university building room represents a significant investment. To determine the economic viability of the project, a cost-benefit analysis has been carried out, considering both the project costs and the expected benefits.

In technical terms, the use of Autodesk Forge has allowed the creation of an interactive 3D model of the room that can be used to simulate different configurations and make real-time changes.

In economic terms, it is expected that the use of the digital twin for the university building will result in long-term cost savings on energy and maintenance. The digital twin can also be used as a marketing tool to promote the university and attract potential students interested in technology.

Through the digital twin in the building, high consumptions could be detected. By monitoring the sensors installed in the building and through the digital twin, a high consumption could be defined as one that exceeds a predefined threshold or that is significantly higher than the average consumption for a certain period of time. It would also be necessary to define what constitutes a failure, which could be any situation that causes high consumption or affects the system's performance.

The cost of a failure that causes high consumption in the building can vary significantly depending on various factors, such as the nature of the failure, the duration of the failure, the type of system affected, and the cost of energy at the time the failure occurs.

In general, costs associated with a failure that causes high consumption could include:

- The cost of the energy consumed in excess during the duration of the failure.

- The cost of repairing or replacing the affected equipment.

- The cost of labor required to fix the failure.

Assuming a consumption of 1000 kW per hour, and a local electricity rate of 0,15 €/kWh, if there were a 2000 kW failure (1000 kW of normal consumption + 1000 kW of the failure), the cost of the failure would be equivalent to €750,00 (5 hours x 1000 kW x 0,15 €/kWh).

Therefore, estimating €750,00 per failure and assuming there are 20 failures per year, the cost would be 15,000€ annually. In section 7.1, an estimate of €65.726,51 has been made for the implementation of the digital twin, so the investment would begin to be profitable in the fourth year.

Chapter 8

Analysis and assessment of environmental and social implications

The implementation of the digital twin for the case study has an impact on the environment, both in terms of the energy used to create it and in terms of the energy efficiency of the room. In this section, a life cycle assessment (LCA) of the case study has been carried out. The scope of the assessment includes the entire life cycle of the digital twin, from the extraction of raw materials for the creation of the digital twin to the final disposal of the room at the end of its life.

8.1 Inventory Analysis

The inventory analysis includes the following stages:

- Raw material extraction: The creation of the digital twin requires the use of high-end computer equipment, which includes components such as an Intel Core i7 processor, 16 GB of RAM, and an NVIDIA GeForce RTX graphics card. The production of these components involves the extraction of raw materials such as metals and plastics, which have environmental impacts.

- Manufacturing: The production of the computer equipment, including the assembly of components and packaging, has environmental impacts, including energy consumption and greenhouse gas emissions.

- Transportation: The transportation of the computer equipment to the location where the digital twin is created also has environmental impacts, including energy consumption and greenhouse gas emissions.

- Use: The use of the digital twin in the university building room has an impact on energy consumption, including the energy used to power the computer equipment and the energy savings resulting from improved building performance.

- Disposal: At the end of its life, the computer equipment and the university building room must be disposed of, which has environmental impacts, including energy consumption and waste generation.

8.2 Impact Assessment

The Sustainable Development Goals (SDGs) are a set of 17 goals established by the United Nations (UN) in 2015 as part of the 2030 Agenda for Sustainable Development. The SDGs aim to address the most urgent global challenges, from extreme poverty to climate change, and promote a sustainable and inclusive future for all [31].

The impact assessment includes the following stages, which are related to some SDGs:

- Global warming potential (GWP): The creation of the digital twin has a significant impact on the project's carbon footprint due to the energy consumption and greenhouse gas emissions associated with the production and use of the computer equipment. The long-term use of the digital twin, however, contributes to reducing the energy consumption and therefore the carbon footprint of the university building room. Related SDGs: SDG 7: Affordable and Clean Energy, SDG 9: Industry, Innovation and Infrastructure, and SDG 13: Climate Action.

- Energy consumption: The creation and use of the digital twin has an impact on energy consumption, including the energy used to power the computer equipment and the energy savings resulting from improved building performance. Related SDGs: SDG 7: Affordable and Clean Energy, SDG 9: Industry, Innovation and Infrastructure, and SDG 11: Sustainable Cities and Communities.

- Resource depletion: The extraction of raw materials for the production of the computer equipment and the disposal of the equipment and the university building room at the end of their lives have an impact on resource depletion. Related SDGs: SDG 8: Decent Work and Economic Growth, SDG 9: Industry, Innovation and Infrastructure, and SDG 12: Responsible Consumption and Production.

8.3 Interpretation

The results of the LCA show that the implementation of the digital twin in the case study has a significant impact on the environment, particularly in terms of global warming potential and resource depletion. However, the long-term use of the digital twin can result in significant energy savings and contribute to reducing the carbon footprint of the university building.

To minimize the environmental impact of the implementation of a digital twin, it is recommended to use energy-efficient computer equipment and to dispose of the equipment and the university building at the end of their lives in an environmentally responsible manner.

Chapter 9

Conclusions

This study presents the implementation of a digital twin in a building, which integrates a sensor in a room to display data related to indoor air quality. The inclusion of this digital twin and BIM methodology in facility managers' activities has shown to provide more detailed and easily analyzable information. By creating a virtual replica of the building and its systems, facility managers can have a complete view of the building's state and make informed and proactive decisions.

Integrating sensors into the digital twin can further improve the accuracy and effectiveness of building system monitoring. By obtaining precise data on temperature, humidity, and CO_2 in a room, facility managers can detect and solve problems before they become major issues. The use of the Autodesk Forge platform for creating the digital twin has proven to be an effective and practical solution for implementing this technology in existing buildings. Integrating BIM technology with the cloud and web services has enabled easy collaboration and access to digital twin data, facilitating the creation of the project to develop the dashboard where the information from the case study conducted in this study is displayed.

The case study carried out in this thesis has the potential to benefit companies that manage tertiary buildings, such as commercial offices, retail spaces, and public buildings. The implementation of a digital twin can provide significant improvements in building performance and energy efficiency, resulting in cost savings and environmental benefits. The case study presents a scalable solution, allowing to increase the number of sensors connected to the Digital Twin. Also, once the dashboard development is completed, the implementation of this application to another building is relatively quick and easy to do.

Companies that manage tertiary buildings could use a digital twin to optimize building operations and maintenance, reduce energy consumption, and improve occupant comfort. For example, a digital twin could simulate the impact of different HVAC settings on energy consumption and adjust the building's systems accordingly. It could also predict and prevent equipment failures, optimize maintenance schedules, and improve indoor air quality.

In terms of the types of buildings that are optimal for digital twin implementation, those that are complex and have a large energy demand are particularly suitable. These could include high-rise commercial office

buildings, hospitals, universities, and data centers. However, digital twin technology can also be applied to smaller buildings, such as retail spaces and restaurants.

The evaluation of the work carried out in this thesis demonstrates that implementing a digital twin in a building by integrating sensors in a room has great potential to improve the efficiency and effectiveness of facility managers in their daily activities. By providing information at every moment about the building's state and its systems, facility managers can make informed and proactive decisions to ensure the safety, well-being, and energy efficiency of building occupants.

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