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**BIM to Digital Twin: A tool for  
Infrastructure Asset Management**

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# Abstract

Public entities face the challenge of improving the way infrastructure assets are managed. Recent legislative changes emphasize digitalization as the key to addressing this issue. In this context Digital Twin (DT) has emerged as a promising technology allowing for monitoring, analysis, and prediction of performance and maintenance needs. This thesis aims to test, through an actual case study (retaining wall on a category C road), a 5-layer system architecture for developing the Digital Twin, using as base the BIM model required by the current Italian regulation. The BIM model was developed following the guidelines provided by the contracting authority, and it was evolved into a DT following the 5-layer system architecture. The findings indicate that this architecture effectively guides the identification and creation of the Digital Twin's components, and the BIM model contains adequate information for the objective. It is evident that DT has a great potential for aiding in infrastructure asset management. A limitation in this thesis was that in absence of real Internet of Things (IOT) sensors, the data were simulated using a software application.

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# List of Acronyms:

- **AEC** - Architecture, Engineering, and Construction
- **AI** - Artificial Intelligence
- **API** - Application Programming Interface
- **AWS** - Amazon Web Services
- **BIM** - Building Information Modeling
- **CAD** - Computer-Aided Design
- **CIM** - City Information Modeling
- **DM** - Decreto Ministeriale
- **DT** - Digital Twin
- **GIS** - Geographic Information Systems
- **IoT** - Internet of Things
- **ISO** - International Organization for Standardization
- **LOD** - Level of Development
- **RFID** - Radio-Frequency Identification
- **UNI** - Ente Nazionale Italiano di Unificazione

# 1. Introduction

The backbone of a strong economy is a functioning, highly available, efficient and safe infrastructure [1]. Facing the challenge of aging transport network, public entities are increasingly focused on improving how these assets are managed. In recent years, the construction and infrastructure management sectors have experienced transformative changes due to the integration of digital technologies. Among these, the concept of "Digital Twin" has emerged as a revolutionary approach, offering a dynamic and real-time digital representation of physical assets. This technology facilitates monitoring, analysis, and optimization of infrastructure, thus significantly aiding owners in managing their assets throughout their lifecycle. The advent of Building Information Modelling (BIM) has played a pivotal role in this transformation, providing a foundational platform for creating detailed digital replicas of physical buildings and infrastructure.

In Italy, an important push towards the digitalization of infrastructure management has been led by policymakers, underlined by the enactment of the Decreto Ministeriale 560/2017 also known as "*Decreto Baratonò*". This decree, a landmark in the adoption of Building Information Modelling (BIM) across the Italian construction sector, outlines a phased approach towards the mandatory use of BIM for public works projects. Starting from January 1, 2019, the decree has set forth a timeline for the gradual implementation of BIM, mandating its use for complex works with varying thresholds of contract value over several years, culminating in its obligatory application for all public works contracts over 1 million € by January 1, 2025. This has necessitated Italian construction firms to significantly ramp up their digital capabilities, both in terms of technology and skills. As a direct consequence, companies across the sector are now investing more in digital tools and training, focusing on BIM technologies to ensure compliance.

The objective of this thesis is to test, through an actual case study, a 5-layer system architecture for developing the Digital Twin, using as base the BIM model required by the current Italian regulation. This process aims to simulate the process of developing a DT and to determine if the information contained in the BIM model is adequate for the task.

This thesis is structured into six chapters. The second chapter provides theoretical background information and discusses some state-of-the-art applications of DT in Infrastructure Asset Management. The third chapter explains the methodology, while the fourth chapter applies this methodology to an actual case study. The fifth chapter presents the results of the work, and the sixth chapter offers the conclusions.

## 2. State-of-the-art

This chapter aims to explain how DTs have come to be used in Infrastructure Asset Management. It provides an overview of important concepts such as BIM and DT, as well as significant policy developments regarding digitalisation in construction. State-of-the-art applications of DT in Infrastructure Asset Management are presented, along with identification of the key enabling technologies.

### 2.1 BIM

For purposes of this thesis, Building Information Model and the Building Information Modelling (both referred to as BIM) are defined as follows:

*“A Building Information **Model** is a digital representation of physical and functional characteristics of a facility. [2]”*

*“Building Information **Modelling** is a method that is based on a building model containing any information about the construction. In addition to the contents of the 3D object-based models, this is information such as specifications, building elements specifications, economy and programmes. [3].”*

BIM is not a simple application of CAD and 3D techniques, it is a system of organizing the right people and information together effectively and efficiently, while giving support to them with certain defined processes and technology [4].

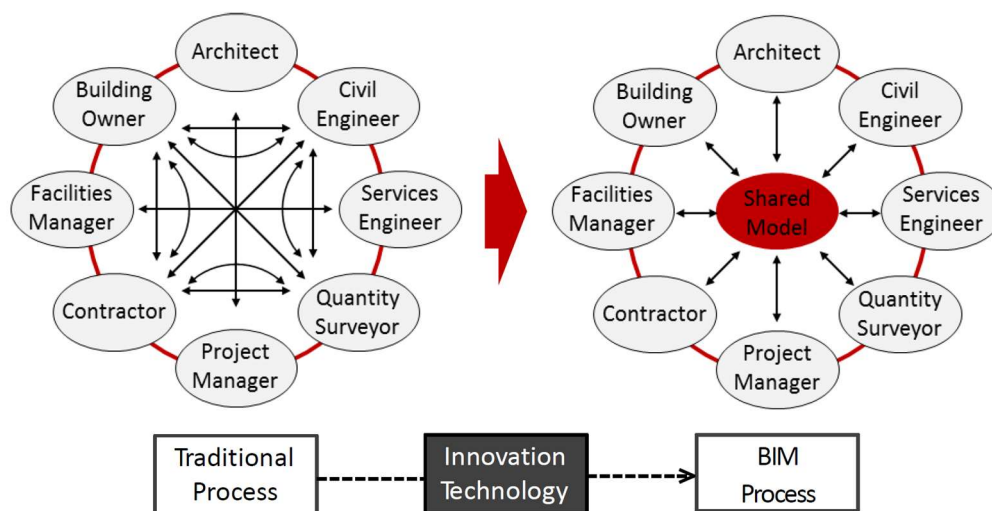
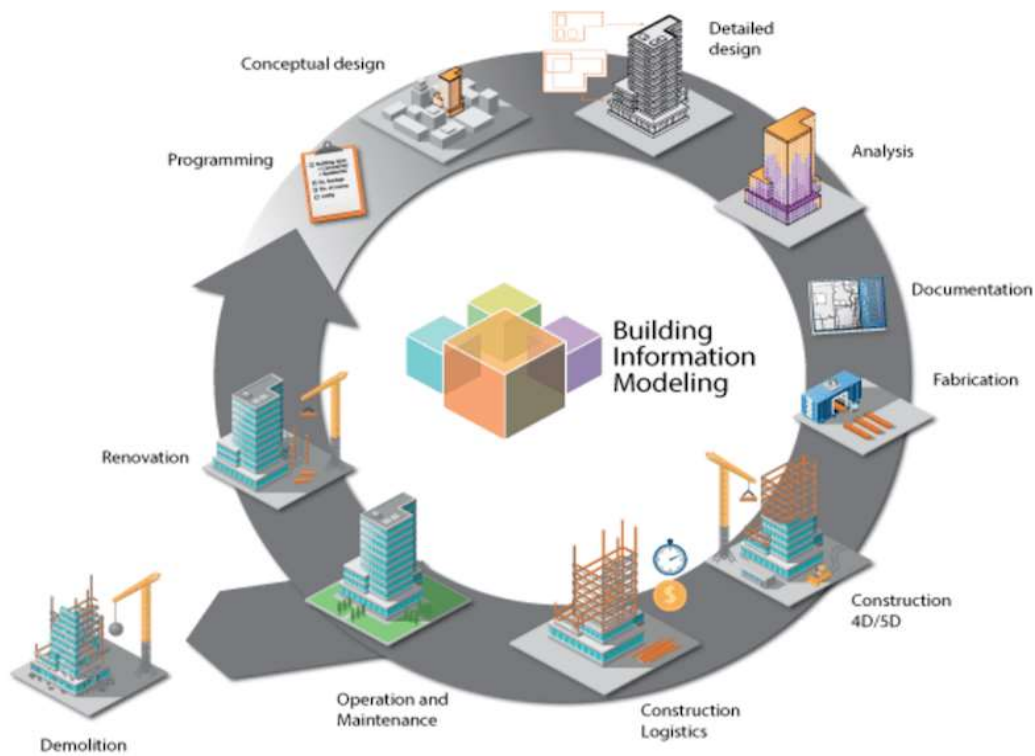


Figure 1. CAD vs. BIM process [5]

Building Information Modeling (BIM) is designed for application across the entire lifecycle of an asset, spanning from the initial planning and design stages through to the conclusion of its operational life. This holistic approach ensures that BIM serves not only as a tool during the construction phase but also supports the ongoing management, maintenance, and eventual decommissioning of the asset.



*Figure 2. BIM Life cycle [6]*

According to UNI 11337 there are different dimensions of BIM:

- **3D BIM:** This is the most basic dimension, focusing on three-dimensional geometric and spatial representation of the physical characteristics of a building or infrastructure. It provides detailed digital representations of the building's physical and functional characteristics.
- **4D BIM:** Adds the element of time to 3D BIM, allowing for the visualization and management of construction schedules and project timelines. It helps in planning the sequence of construction activities, identifying potential conflicts, and optimizing the construction process.
- **5D BIM:** Integrates cost information with the 3D model, facilitating budgetary and cost management throughout the project lifecycle. This dimension allows for the estimation and tracking of costs based on the digital model's data, supporting more accurate and dynamic cost management.

- **6D BIM**: Focuses on the sustainability aspects and energy efficiency of a building. This dimension is used to analyze environmental impacts, perform energy consumption simulations, and design more sustainable and efficient buildings by incorporating environmental data into the BIM model.
- **7D BIM**: Concerns itself with facility management and operation, using the information within the BIM model to support maintenance and asset management over the building's life cycle.

Another important concept in the BIM process is that of Level of Development (LOD). LOD provides a framework for specifying the precision and content of BIM models at various stages of the project's life cycle. This term is widely recognized in BIM practices globally, including in standards set by organizations such as the American Institute of Architects (AIA), the British Standards Institution (BSI), and the International Organization for Standardization (ISO). It is also integral to the Italian standards for BIM, particularly within the UNI 11337, which defines LOD as follows [7]:

*“The Level of Development (LOD) of the digital objects that make up the models defines the quantity and quality of their information content and is functional to the achievement of the objectives of the phases (and stages) of the process and the uses and objectives of the model they refer to.”*

In UNI 11337, LOD is described for different categories (new construction, restoration interventions, territorial and infrastructure interventions, construction site). The particular category important to this thesis is “territorial and infrastructure interventions” and the LOD is defined as follows:

- **LOD A** - The entities are graphically represented through a two-dimensional geometric schema. The quantitative and qualitative characteristics (performance, size, shape, location, cost, etc.) are indicative and can be statistically assumed by other models.
- **LOD B** - The entities are graphically represented through an elementary three-dimensional geometric system. The quantitative and qualitative characteristics (performance, dimensions, shape, location, cost, etc.) are approximate.
- **LOD C** - The entities are graphically virtualized through a defined three-dimensional geometric system. The main quantitative and qualitative characteristics (performance, dimensions, shape, location, cost, etc.) are defined.
- **LOD D** - The entities are graphically virtualized through a detailed three-dimensional geometric system. The quantitative and qualitative characteristics (performance, dimensions, shape, location, cost, etc.) are detailed.
- **LOD E** - The entities are graphically virtualized through a specific three-dimensional geometric system. The quantitative and qualitative

characteristics (performance, dimensions, shape, location, cost, etc.) are specific to a single production system.

- **LOD F** - The objects express the virtualization verified on-site of the three-dimensional geometric system as executed/constructed (as-built). The quantitative and qualitative characteristics (performance, dimensions, shape, location, cost, etc.) are specific to the production system used.
- **LOD G** - The objects express the updated virtualization of the actual state of an entity at a defined time. It's a historicized representation of the lifespan of an updated three-dimensional geometric system compared to what was originally executed/constructed. The quantitative and qualitative characteristics (performance, dimensions, shape, location, cost, etc.) are updated with respect to the life cycle and a previous actual state. The level of wear/decay is defined.




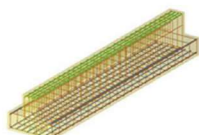
LOD A	LOD B	LOD C	LOD D
			
<b>Geometria</b> Elemento strutturale lineare orizzontale o pseudo-orizzontale rappresentato mediante un simbolo 2D.	<b>Geometria</b> Elemento strutturale lineare orizzontale o pseudo-orizzontale rappresentato mediante un solido di estrusione abbozzato.	<b>Geometria</b> Elemento strutturale lineare orizzontale o pseudo-orizzontale rappresentato mediante un solido avente dimensioni calcolate secondo la normativa tecnica.	<b>Geometria</b> Elemento strutturale lineare orizzontale o pseudo-orizzontale rappresentato mediante un solido avente dimensioni pari alle dimensioni reali. Sono modellate tutte le armature in posizione corretta.
<b>Oggetto</b> Simboli grafici 2D	<b>Oggetto</b> Solido 3D	<b>Oggetto</b> Solido 3D complesso	<b>Oggetto</b> Solidi 3D complessi
<b>Caratteristiche</b> - Posizionamento di massima	<b>Caratteristiche</b> - Materiali ipotizzabili - Incidenza di armatura standard	<b>Caratteristiche</b> - Materiali da calcolo - Incidenza di armatura calcolata	<b>Caratteristiche</b> - Armature 3D - Dettagli costruttivi

Figure 3. Example LOD according to UNI 11337 (1)

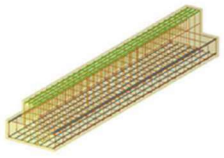
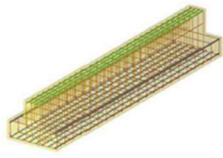
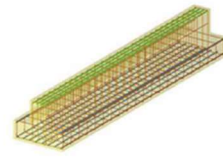
LOD E	LOD F	LOD G
		
<b>Geometria</b> Elemento strutturale lineare orizzontale o pseudo-orizzontale rappresentato mediante un solido avente dimensioni pari alle dimensioni reali. Sono incluse tutte le armature in posizione corretta, i dati specifici del fornitore dei materiali e delle armature e la gestione dei getti.	<b>Geometria</b> Come LOD E (rilievo di quanto eseguito).	<b>Geometria</b> Nuovi interventi: Come LOD F (con aggiornamenti) Manutenzione e gestione su elementi esistenti: Come LOD C o D (a partire da).
<b>Oggetto</b> Solidi 3D complessi	<b>Oggetto</b> Solidi 3D complessi	<b>Oggetto</b> Solidi 3D complessi
<b>Caratteristiche</b> <ul style="list-style-type: none"> <li>- Gestione dei getti</li> <li>- Liste di piegatura ferri</li> <li>- Eventuale produzione prefabbricata gabbie di armatura</li> </ul>	<b>Caratteristiche</b> <ul style="list-style-type: none"> <li>- Certificati di collaudo</li> <li>- Piano di manutenzione</li> </ul>	<b>Caratteristiche</b> <ul style="list-style-type: none"> <li>- Data di manutenzione/sostituzione</li> <li>- Soggetto manutentore</li> <li>- Tipologia di intervento</li> </ul>

Figure 4. Example LOD according to UNI 11337 (2)


## 2.2 BIM Mandates in Europe

While the construction sector is a key driver of the overall economy, it faces numerous challenges relating to inter alia competitiveness, labour shortage, resource efficiency and especially productivity [8]. Digitalisation of the construction sector is increasingly recognised as a potential game changer for the sector [9]. The European Commission has thus supported, promoted and developed several policies and initiatives aiming to foster the digitalisation in the construction sector [8]. These include inter alia the Strategy for the sustainable competitiveness of the construction sector and its enterprises (2012), the EU BIM Task Group and the EU Digital Construction platform [8]. The digitalisation of the construction sector is also integrated in other policy areas such as the EU directive on Public Procurement (2014), which promotes the use of Building Information Modelling in construction project [8].

The EU BIM Task Group, comprising representatives from EU member states, has articulated a shared vision for Government BIM Programs aimed at transforming the construction sector. These programs aim to:

- Deliver greater value for public money: build more for the same
- Increase openness, fairness, competitiveness and productivity
- Stimulate innovation and growth in the construction and digital sectors
- Grow digital construction market for trading regionally and with the rest of the world

According to [10], BIM offers economic, environmental and social benefits across a range of different public stakeholders. The benefits are summarized in the table below:



		BUILT ASSETS		SECTORS	
		Delivery Phase	Use Phase	Construction	Digital
ECONOMIC		10% savings on time delivery	Lower maintenance costs Lower operations costs	Improve sector competitiveness Grow export capability	Grow digital services industry Digital single market
	ENVIRONMENTAL	Less site waste	Optimise operational energy use Assess whole life-cycle analysis	Resource efficiency Circular economy	Data infrastructure resource efficiency
SOCIAL		Higher standard of health and safety Improved public consultation and engagement	Improve social outcomes (e.g. patient care, pupil learning)	Cleaner and safer jobs in construction Attract next generation to the sector	Data Security Attract digital talent to construction

Figure 5. BIM benefits [10]



Following the directive, many countries have published BIM mandates. The following map shows the BIM adoption in Europe:

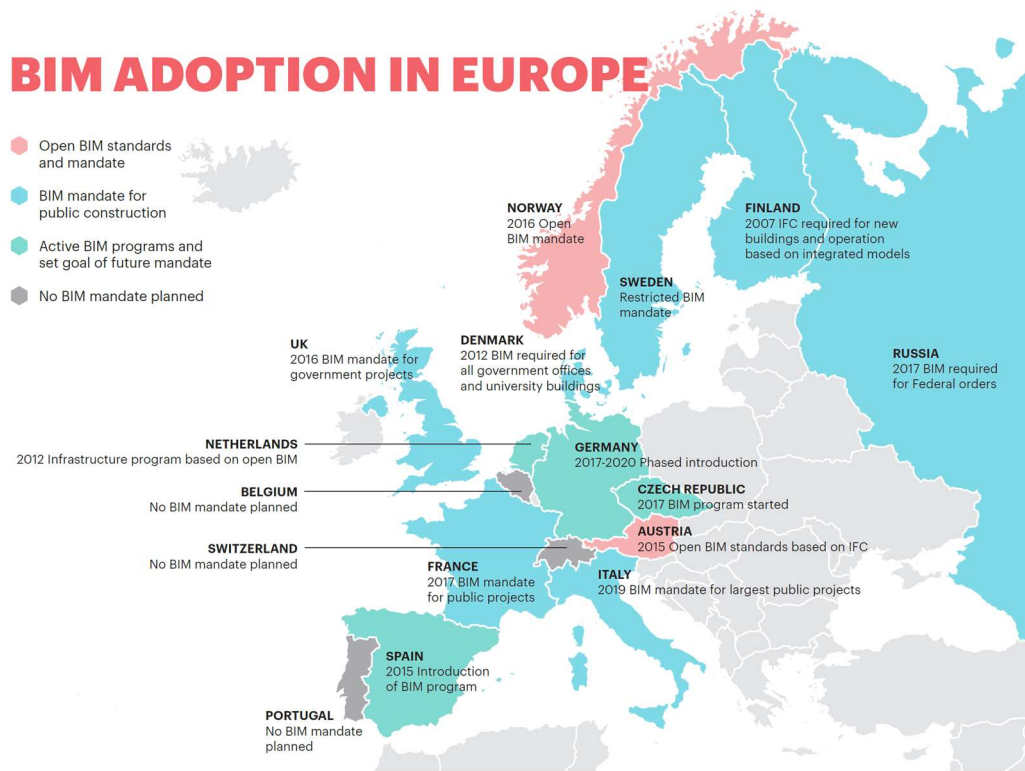


Figure 6. BIM adoption in Europe [11]

Italy is among the countries that have implemented a BIM mandate, underscored by the enactment of Decreto Ministeriale 560/2017. Further advancing digitalization, Italy has adopted the technical standards UNI 11337, serving as the national annex to ISO 19650-1-2:2019.

**DM 560/2017**, known as the Baratonno decree, stipulates a gradual introduction of the mandatory use of the BIM method for public procurement. Article 6 outlines the implementation timelines and associated costs of the works:

- From 1 January 2019 for all public works over 100 M euro
- From 1 January 2020 for all public works over 50 M euro
- From 1 January 2021 for all public works over 15 M euro
- From 1 January 2023 for all public works over 5.35 M euro
- From 1 January 2025 for all public works over 1 M euro

Article 3 of the Decree prescribes as preliminary requirements for contracting authorities the adoption of i) a training plan for personnel in relation to their role, ii) a plan for the acquisition or maintenance of hardware and software tools for the digital management of decision-making and informational processes, and iii) an organizational act that specifies the process of control and management, the data managers, and conflict resolution.

Article 4 emphasizes the principle of interoperability by stating that contracting authorities are required to use interoperable platforms through open, non-proprietary formats.

Article 7, when discussing specifications for managing informational content, introduces a particularly important concept: from the entry into force of the method's mandatory use, the contractual prevalence of informational content is defined by the electronic model, and no longer by the paper support as is currently the case.

**UNI 11337** is an Italian set of standards that provides guidelines and specifications for the management of digital processes in the construction sector through BIM. Developed by the Italian Organization for Standardization (UNI), these standards cover various aspects of BIM implementation, including definitions, principles, and requirements for information management throughout the lifecycle of a building or infrastructure project. UNI 11337 addresses the needs for creating, managing, and exchanging digital information among all stakeholders involved in construction projects, aiming to improve efficiency, reduce costs, and enhance collaboration. The standards are structured in multiple parts, each focusing on different elements of BIM, such as terminology, digital management of documentation, and information exchange. UNI 11337 is instrumental in supporting Italy's BIM mandate, providing a comprehensive framework that aligns with international standards like ISO 19650, and facilitates the adoption of BIM across the Italian construction industry.



- **UNI 11337-1:2017** – Part 1: Models, drawings and information objects for products and processes
- **UNI 11337-3:2015** – Part 3: Models for collecting, organizing and archiving technical information for construction products
- **UNI 11337-4:2017** – Part 4: Evolution and information development of models, documents and objects
- **UNI 11337-5:2017** – Part 5: Information flows in digitized processes
- **UNI 11337-6:2017** – Part 6: Guidelines for drafting the information specifications
- **UNI 11337-7:2018** – Part 7: Knowledge, skill and competence requirements of the figures involved in information management and modelling

## 2.3 Digital Twin

The concept of **Digital Twin** was introduced by Michael Grieves at University of Michigan in 2002 [12]. His concept model shown in Figure 1 contained three main parts: a) physical products in Real Space, b) virtual products in Virtual Space, and c) the connections of data and information that ties the virtual and real products together.

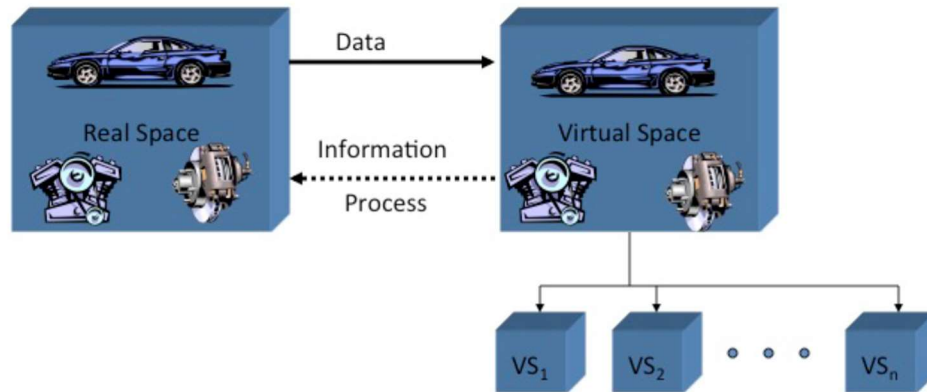


Figure 7. DT Concept by Michael Grieves [12]

Numerous definitions exist for the Digital Twin, with one of the most widely cited being that provided by NASA [13]:

*“A **Digital Twin** is a virtual representation that serves as the real-time digital counterpart of a physical object or process.”*

Figure below depicts the key milestones in the development of DT technology.

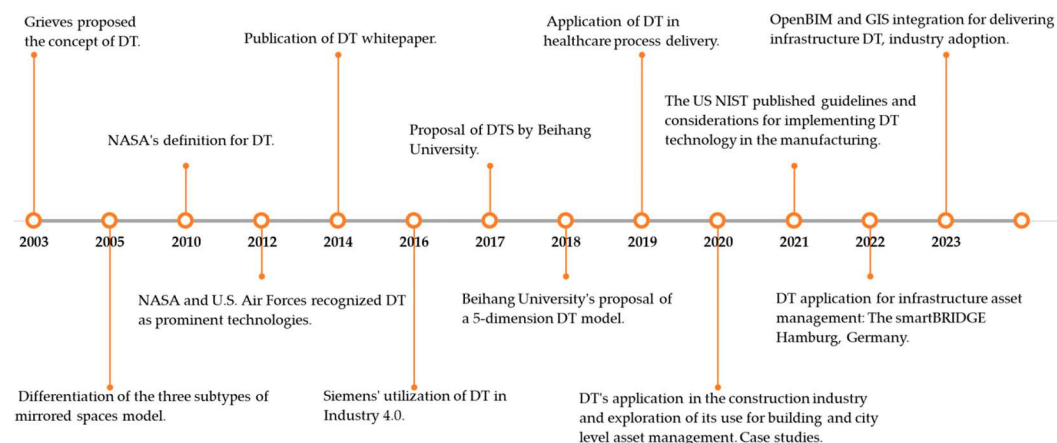


Figure 8. DT development and Adoption Milestones [14]

DT is not a BIM model. BIM and DTs have similar definitions; however, they differ in multiple ways [15] :

(i) digital environment: BIM focuses on the building, not the interactions of the building with external factors, while DTs relate to both the physical (data) and virtual (models) environments;

(ii) time: BIM offers static models, while DTs track changes to assets over time and update the models accordingly, enabling those responsible for asset management to roll the virtual representation of the infrastructure asset and related real-world conditions forward or backward in time.

BIM is seen as the starting point for the DT, acting as a semantically rich 3D reference model for the DT to use in various applications [16]. DTs integrate real-time data from sensors and other data sources to simulate the current state and behavior of physical assets throughout their lifecycle. This dynamic nature allows for predictive analytics, operational improvements, and lifecycle management in a way that BIM, by its very nature as a static model, cannot achieve.

Digital Twin technology has found applications across numerous sectors, including aerospace and manufacturing. Civil Engineering, and more generally the AEC industry, is still significantly behind other industries in the use of DTs [15]. However, recognizing the benefits of DT, interest in the subject is increasingly growing. As illustrated in the graph below, the number of relevant papers published each year for DT in this sector has increased steadily [17].

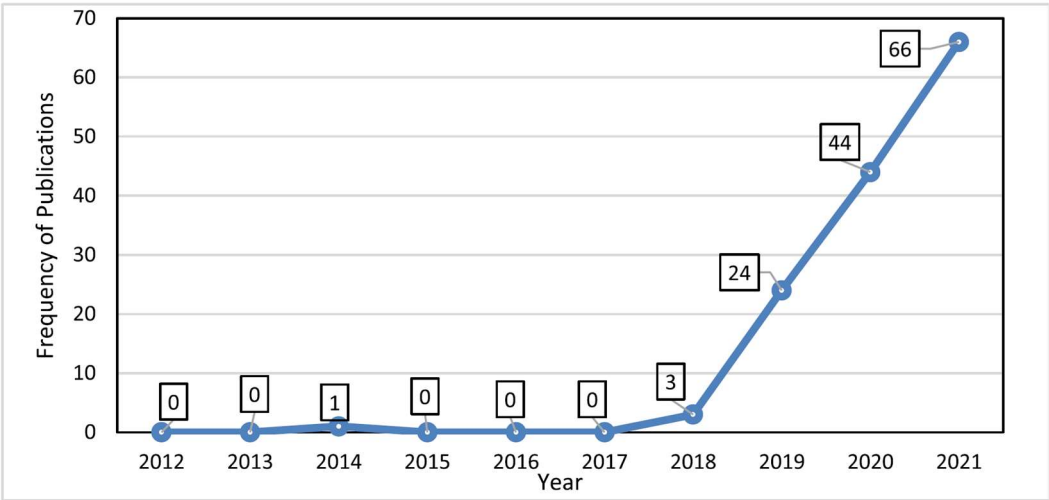


Figure 9. Frequency of DT-related publications per year in the AEC field [17]

One reason DTs have been gaining momentum in recent years is the increasing usage of various enabling technologies such as Internet of Things (IOT), Big Data Analytics, Artificial Intelligence (AI) and Cloud and Edge computing [18].

[19] conducted a systematic literature review to identify the set of factors driving the adoption of DT in the Construction Industry. The authors categorized these drivers into four main categories, symbolizing the four phases of the asset's lifecycle: concept-oriented drivers, product-driven drivers, operational success drivers, and preservation-driven drivers.

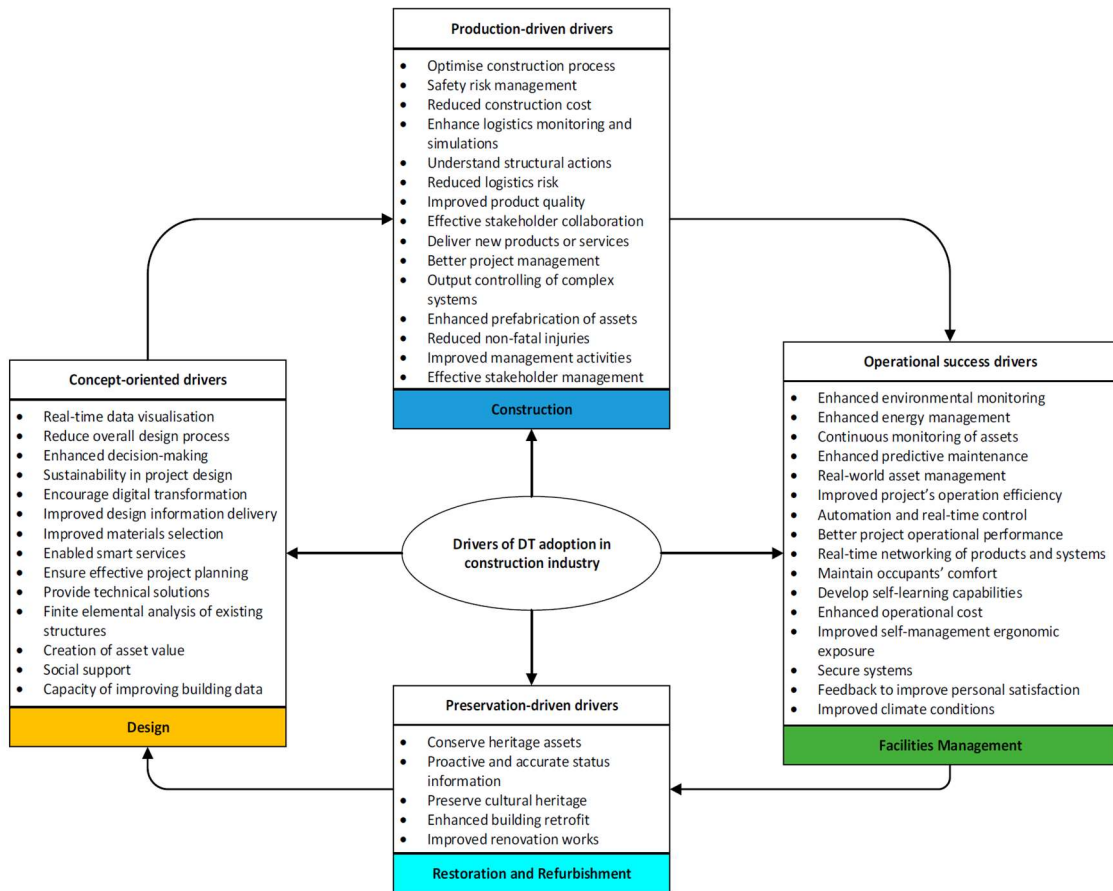


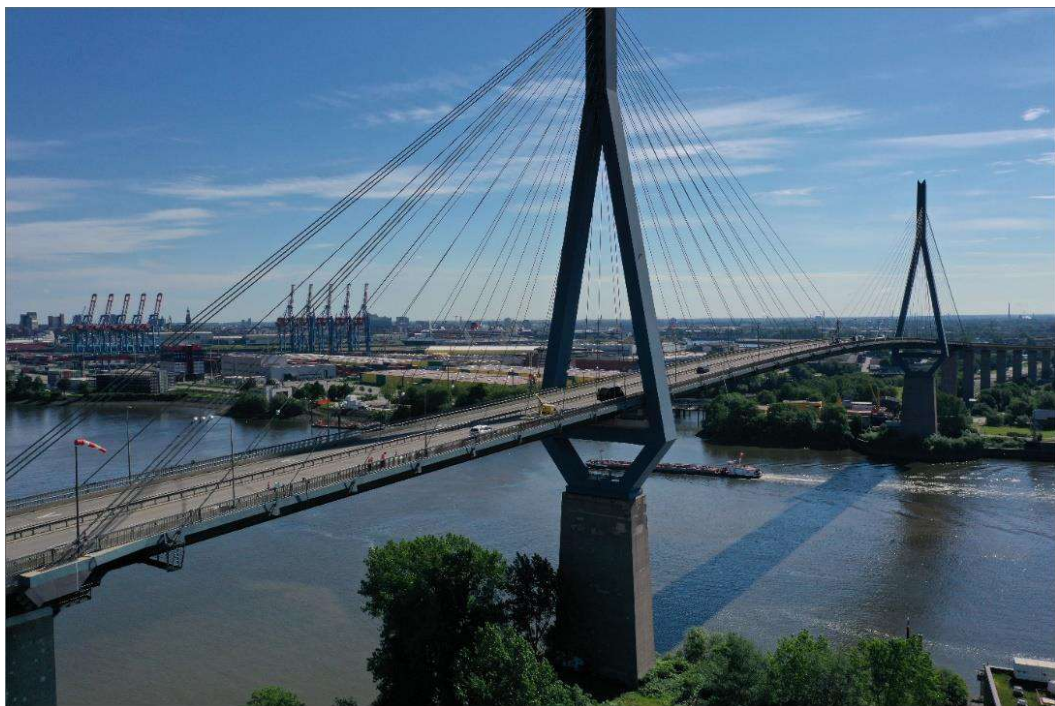
Figure 10. Main drivers for DT adoption in construction industry [19]

## 2.4 State-of-the-art in Infrastructure Asset Management

From the asset management point of view the aim of the DT is to combine conditional data coming from classical inspection, structural diagnostics and sensor-based monitoring with the structure information and geometry included in the BIM model [20]. The recorded condition data must be stored, transferred, managed, analysed and aggregated to be understood from Asset Managers [20]. It must be visualised in a clearly structured 3D environment in order to get an intuitive comprehension of the current structural health of the asset [20].

### 2.4.1 smartBRIDGE Hamburg

One of the most significant implementations of DT in infrastructure is the smartBRIDGE Hamburg. This project won the buildingSMART International Award for Asset Management in 2021. Faced with the challenge of improving the maintenance of the bridge, the Hamburg Port Authority found DT a suitable and attractive concept to address this issue. The concept is sufficiently flexible and powerful to combine information coming from classical inspection, from monitoring and from BIM and to process them with simulations or models in a continuous efficient digital process chain [1].



*Figure 11. Köhlbrand Bridge Hamburg*

The main objectives for building the DT were:

- To get current and objective condition information of the asset
- To combine classical inspection data with structural diagnostics and sensor-based monitoring
- To establish BIM as the central data hub in the operational phase of the asset
- To bridge the gap between increasing complexity and the need for consumable information
- To shift from REACTIVE maintenance to PREDICTIVE maintenance

To realise the DT they had to follow several steps. Given that the bridge was constructed in 1974, it lacked an As-Built BIM model, so the first step was to create one. To deploy the sensors, a careful planning process was done to identify the weak points of the bridge and determine the necessary types of measurements. More than 500 sensors (accelerometers, strain gauges, temperature, humidity etc.) were placed in critical points of the bridge transferring real-time digital data. This data is then analysed and translated into condition indicators, which are visualized in the digital twin of the bridge.

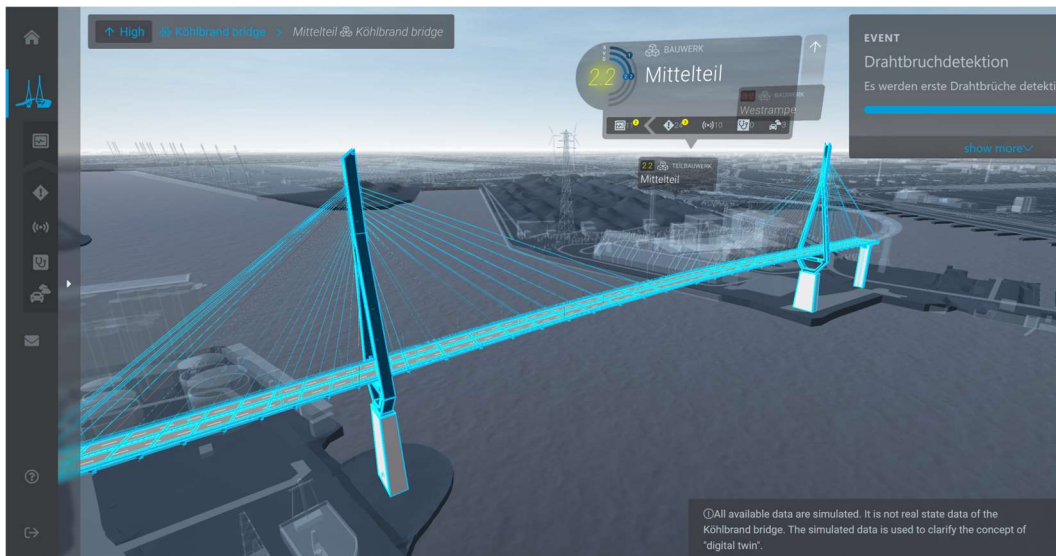


Figure 12. smartBRIDGE Hamburg (screenshot from demo website)

To make the information accessible and consumable they created two platforms:

*conditionCONTROL* which is the overall interface based on the 3D model of the monitored asset showing geolocated key figures and contextually added data allowing a quick capture and complete overview of the current asset state on a high aggregation level to enable rapid decision [1].

*expertCONTROL* which is the structured visualisation for the detailed data with access to the different aggregation levels from initial measured data to intermediate steps enabling to retrace the development of the computed data [1].

## 2.4.2 Anas Programma SHM (Structural Health Monitoring)

Italy, recognizing the need for improved infrastructure management, is also embracing the DT concept. The Programma SHM (Structural Health Monitoring) by ANAS is a comprehensive initiative aimed at enhancing the safety and management of infrastructure, particularly bridges and viaducts. Funded by 275 million euros from the "Fondo Complementare" connected to the PNRR (National Recovery and Resilience Plan), the program started in 2022 with tender processes for the sensor-based monitoring of a thousand bridges and viaducts across the ANAS network.



*Figure 13. A2 "Autostrada del Mediterraneo" - viadotto Sfalassà*

The Programma SHM allows for much broader control over the entire process of monitoring the health of infrastructure, enabling full integration with maintenance protocols through the use of a centralized database of artworks (bridges and viaducts) [21]. Moreover, the constant acquisition of information about the state of these structures will allow, through the application of Artificial Intelligence algorithms, the definition of predictive maintenance processes [21].



## 2.5 Enabling technologies for DT

In the DT concept, various technologies play pivotal roles in creating virtual replicas of physical entities, enhancing analytics, decision-making, and operational efficiency. The following is a concise overview of how each technology contributes within the DT framework:

- **IoT (Internet of Things)** : IoT devices are essential for data collection in the DT framework. They gather real-time data from the physical environment, such as temperature, humidity, vibration, and pressure, which is then used to update the DT, ensuring it reflects the current state of the physical object.
- **Big Data** : The vast amounts of data generated by IoT devices and other sources are categorized as Big Data. In DT, Big Data analytics are utilized to process and analyze this information, helping in understanding patterns, trends, and insights that inform decision-making and predictive analytics for the physical entity's maintenance, optimization, and innovation.
- **Artificial Intelligence (AI)** : AI, including machine learning and deep learning, is used in DT to make sense of the data collected. It enables the prediction of future states and behaviors of the physical counterpart by analyzing historical and real-time data. AI can optimize operations, predict failures, and suggest preventative measures, thus enhancing efficiency and reducing downtime.
- **Cloud and Edge Computing in DT** : In the Digital Twin framework, cloud computing provides the central infrastructure for extensive data storage and analysis, enabling global access and scalability. Complementing this, edge computing processes data locally, near the source, for quick responses and reduced latency. This combination ensures digital twins can operate in real-time while also benefiting from the powerful analytical capabilities of the cloud.

### 3. Methodology

This chapter will be structured into two distinct phases: the initial phase outlines the methodology for developing a BIM model in alignment with the contracting authority guidelines. The subsequent phase focuses on advancing the BIM model towards the development of a Digital Twin.

#### 3.1 Developing the As-Built BIM model

The contracting authority has published the Special BIM Specifications (Capitolato Speciale BIM), outlining the contractor's responsibilities related to the BIM methodology. Contractors must consider these responsibilities during the development of the As-Built model.

The specifications detail both the technical requirements for the BIM model's development and the procedures for the submission and evaluation of the work by the contracting authority.

This thesis will primarily concentrate on the technical requirements, with the goal of integrating (i) a standardized Work Breakdown Structure (WBS), (ii) a uniform classification system for elements, and (iii) the informational contents of the BIM model as stipulated by the specifications.

#### Characteristics of the WBS

The BIM model will need to be developed by anticipating the subdivision of the works into homogeneous elementary sections by type schematically reported in table below:

LOTTO	OPERA	PROGRESSIVO OPERA	PARTE D'OPERA	PROGRESSIVO PARTE D'OPERA	SUB CATEGORIA	PROGRESSIVO SUB CATEGORIA
01	RI	01	BF	01	SB	01

*Table 1. Subdivision for the WBS to be adopted in the BIM model*

For illustrative purposes, the abbreviations RI, BF, and SB represent "Rilevato," "Bonifiche," and "Scavo di Bonifica," respectively. The aim is to uniquely identify elements by associating them with information from the broadest category they belong to, down to the most specific. This approach facilitates grouping and ungrouping of elements based on the required level of detail. For example, if we need to identify and group all elements associated with BF (Bonifiche), we would filter the elements in the model that have the 'PARTE D' OPERA parameter equal to BF.

The structure with the levels of WBS along with the descriptions is provided by the contracting authority.

The BIM model must incorporate a mandatory set of parameters. Table 2 displays the names and types of these required parameters.

Nome campo, proprietà o parametro	Tipo parametro
<i>LOTTO</i>	Testo
<i>OPERA</i>	Testo
<i>PROGRESSIVO OPERA</i>	Testo
<i>PARTE D'OPERA</i>	Testo
<i>PROGRESSIVO PARTE D'OPERA</i>	Testo
<i>SUBCATEGORIA</i>	Testo
<i>PROGRESSIVO SUBCATEGORIA</i>	Testo

*Table 2. Name and type of parameters for the WBS*

## Definition of the system for classification of the elements

The implementation of a classification system is mandatory for the unique identification of elements, groups, or clusters of elements. The National Standard OmniClass has been chosen for this purpose.

Additionally, a new parameter has been created to store this information. Its name and type shown in Table 3.

Nome campo, proprietà o parametro	Tipo parametro
OMNICLASS	Testo

*Table 3. Name and type of the parameters for the system classification*

## The informational contents of the BIM model

For the management and control of the information present within the BIM model, reference will be made to the concept of Level of Development (LOD), which defines the nature, quality and stability of the data constituting each object of the model BIM.

It is required by the contracting authority reaching a LOD F that is indicated by the normative UNI 11337-4 .

**LOD F**: The objects represent the virtualization verified on-site of the specific production system executed/built (as-built). The quantitative and qualitative characteristics (size, shape, location, orientation, cost, etc.) are specific to the individual production system of the product laid or installed. For each product, the management, maintenance, and/or repair and replacement interventions to be carried out over the life cycle of the work are defined.

To accomplish this scope the following set of geometric and informative information will be provided:

- The characteristics of shape, dimensions, position, and geometric orientation of the elements included in the model.
- The elements and/or components of the BIM model will contain suitable parameters that allow for the spatial identification of the work, the definition of WBS coding and classification, and the input of data for the control and maintenance of the artifacts. To achieve this, the following parameters, containing the specified information, will be established for each element and/or component:
  - Indication of the WBS structure
  - Indication of the actual Executor
  - Indication of the progression and/or geographical coordinates
  - Indication of the delivery Milestone
  - Characteristics of the materials used
  - Indication of the cover depth for reinforced concrete structures
  - Indication of the manufacturer and model for all installed elements (e.g., systems)

Table below displays the names and types of these parameters.

Nome campo, proprietà o parametro	Tipo parametro
<i>LOTTO</i>	Text
<i>OPERA</i>	Text
<i>PROGRESSIVO OPERA</i>	Text
<i>PARTE D'OPERA</i>	Text
<i>PROGRESSIVO PARTE D'OPERA</i>	Text
<i>SUBCATEGORIA</i>	Text
<i>PROGRESSIVO SUBCATEGORIA</i>	Text
<i>OMNICLASS</i>	Text
<i>ESECUTORE EFFETTIVO</i>	Text
<i>PROGRESSIVA</i>	Number
<i>MILESTONE</i>	Text
<i>MATERIALE</i>	Text
<i>COPRIFERRO</i>	Length
<i>PRODUTTORE</i>	Text
<i>MODELLO</i>	Text

*Table 4. Name and type of parameters to be adopted for each BIM element*

- The elements and/or components of the BIM model will also contain suitable parameters that allow for the inclusion of external references (hyperlinks) to detailed technical documentation, test certifications, and maintenance plans.

## Software

To develop the As-Built BIM model, primarily two software tools are used: AutoCAD 2023 and Revit 2023.

### AutoCAD



AutoCAD is a computer-aided design (CAD) and drafting software application that enables the creation of precise 2D and 3D drawings. It is utilized to read and extract information from original drawings provided in the .dwg format. As both AutoCAD and Revit are developed by Autodesk, they exhibit high interoperability. This compatibility allows for the seamless importation of plans and sections into Revit without losing any information along the way.

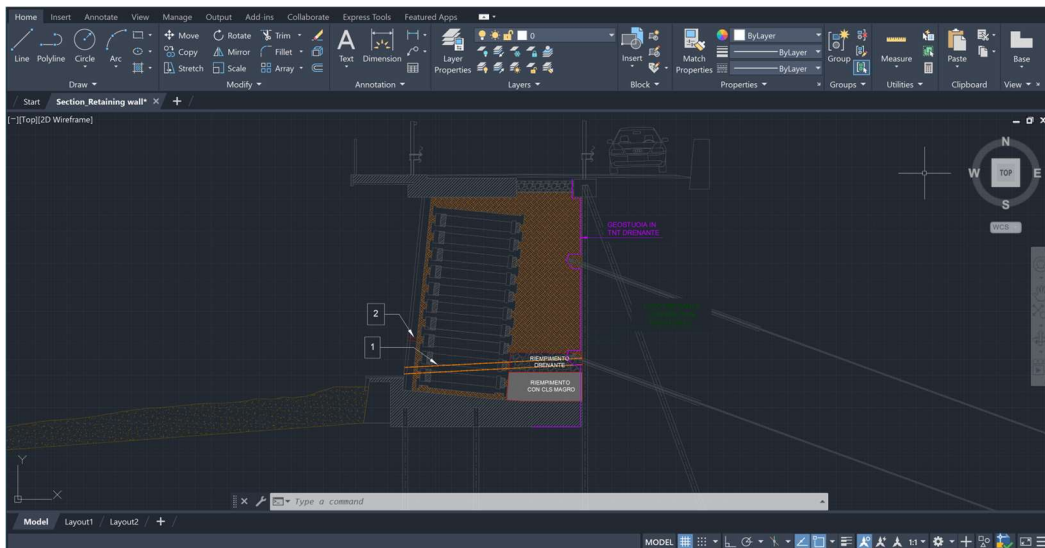


Figure 14. Section view in AutoCAD

### Revit



Revit is a building information modeling (BIM) software developed by Autodesk. It is widely used by architects, engineers, designers, and contractors across the construction industry. Revit allows users to design a building and its components in 3D, annotate the model with 2D drafting elements, and access building information from the building model's database.

In Revit, the creation of a 3D model typically involves utilizing predefined families and types, which represent individual elements of the asset being modelled. These families and types can be customized or obtained from libraries.

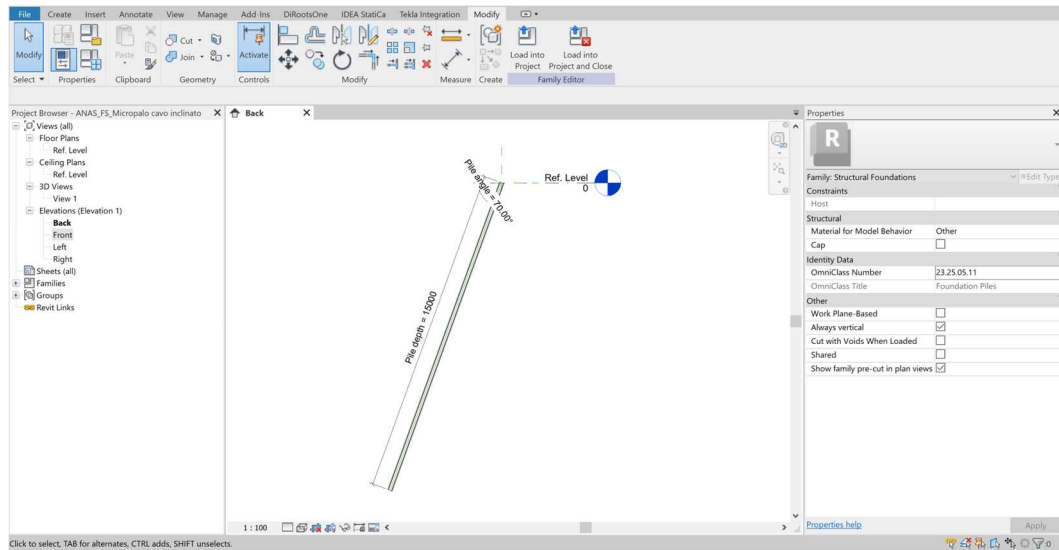


Figure 15. Family in Revit

After being created as families, these elements are positioned in the appropriate Level within the 3D space of the model according to their real-world locations.

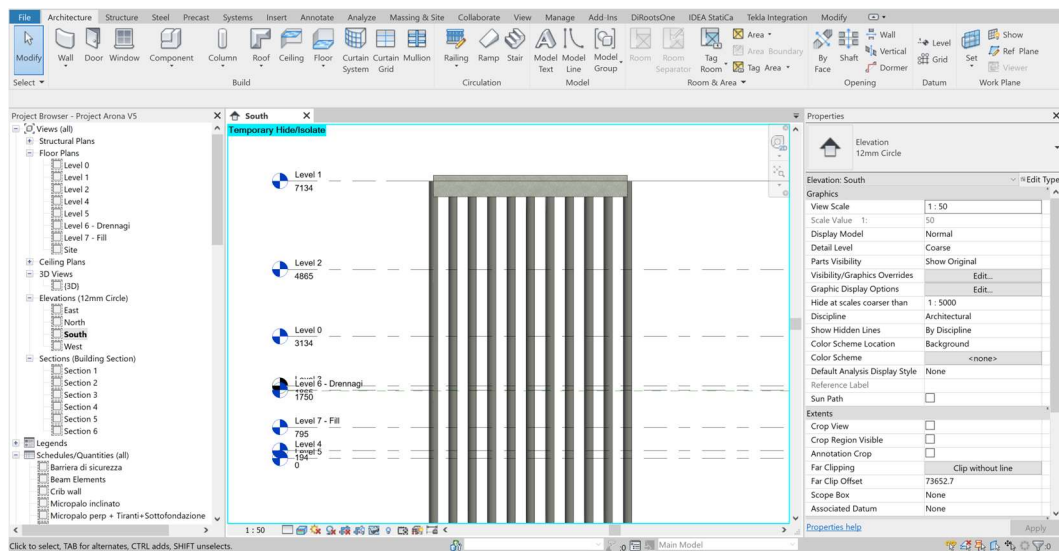


Figure 16. Levels in Revit

Revit lets you create and assign different types of parameters such as shared parameters, project parameters and global parameters. They are important to assign to the elements the non-geometric information that is required by the Special BIM Specifications.

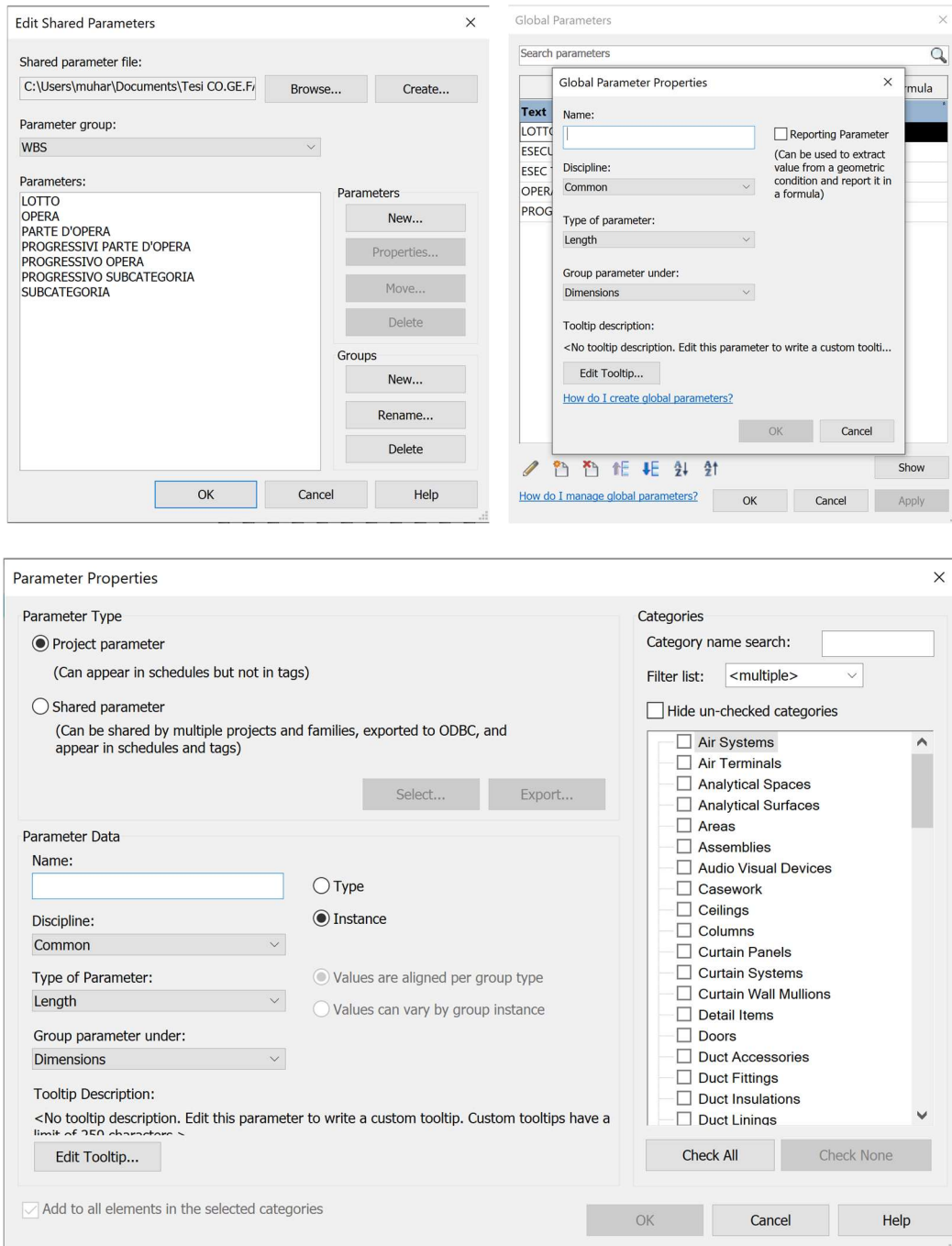


Figure 17. Types of parameters in Revit

## 3.2 Advancing toward the Digital Twin

The primary focus of this thesis is on the architecture underlying the Digital Twin. In the absence of real sensors, data will be simulated using Postman software, and the procedure will be explained in detail in the subsequent chapter. The digital model will be the As-Built BIM model that is required by the contracting authority.

The workflow will be based on the five layers of the DT system architecture for building level proposed by [22].

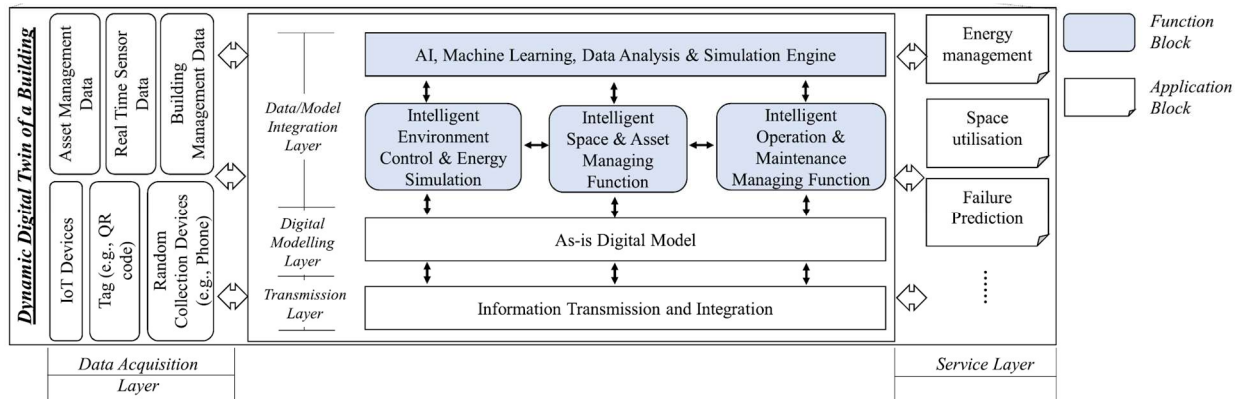


Figure 18. DT system architecture [22]

The five layers composing the architecture are: *data acquisition layer*, *transmission layer*, *digital modeling layer*, *data/model integration layer*, and *service layer*.

### *Data Acquisition Layer*

The data acquisition layer is crucial for Digital Twins. Designing the data acquisition mechanism and approach is a primary and challenging task, given the diversity in data types, formats, sources, and contents. Examples of data collection techniques include contactless methods such as radio-frequency identification (RFID) and image-based techniques, along with distributed sensor systems, wireless communication, and mobile access, like WiFi environments.

### *Transmission Layer*

The transmission layer is responsible for transferring data to higher layers for modelling and analysis. It utilizes various communication technologies, including short-range options (WiFi, Zigbee, NFC, M2M, Zwave) and those with wider coverage (3G, 4G, LTE, 5G, LP-WAN).



## *Digital Modelling Layer*

The digital modelling layer contains the digital representation of the physical asset. Some examples include Building Information Modelling (BIM), City Information Modelling (CIM) etc. Here we would have the As-is model, the model which constantly updates with external information. When a DT is designed, a predefined schema and well-organized modeling processes are required to conform firstly and aligned to the target specific applications from a single infrastructure to entire cities and buildings.

## *Data/Model Integration Layer*

The data/model integration layer is the core of this architecture. This layer aims at integrating all the data resources based on the designed data structure. This layer also contains the functions required for data and model manipulating, storing, analysing, integrating, processing. Additionally, this layer offers the option to incorporate Artificial Intelligence (AI), which, through training on the collected data, can identify patterns and trends to enhance decision-making processes. Cloud storage and computing technologies play a crucial role, ensuring global access and scalability.

## *Service Layer*

The service layer is the top and implementation layer of the DT architecture that enables the interaction between people/society and the data/model integration layer. This layer should allow for a complete overview, helping the users get an intuitive comprehension of the current state the asset.

## Software

To develop the Digital Twin, primarily two software tools are used: Postman and Autodesk Tandem.

### **Postman**



Postman is a popular software development tool used by developers and companies around the world for API (Application Programming Interface) development. Postman allows users to send different types of HTTP requests (GET, POST, PUT, DELETE, etc.) to a specified API endpoint.

Given an API endpoint (URL of the Tandem Stream), Postman will be used to send a HTTP POST request via the internet.

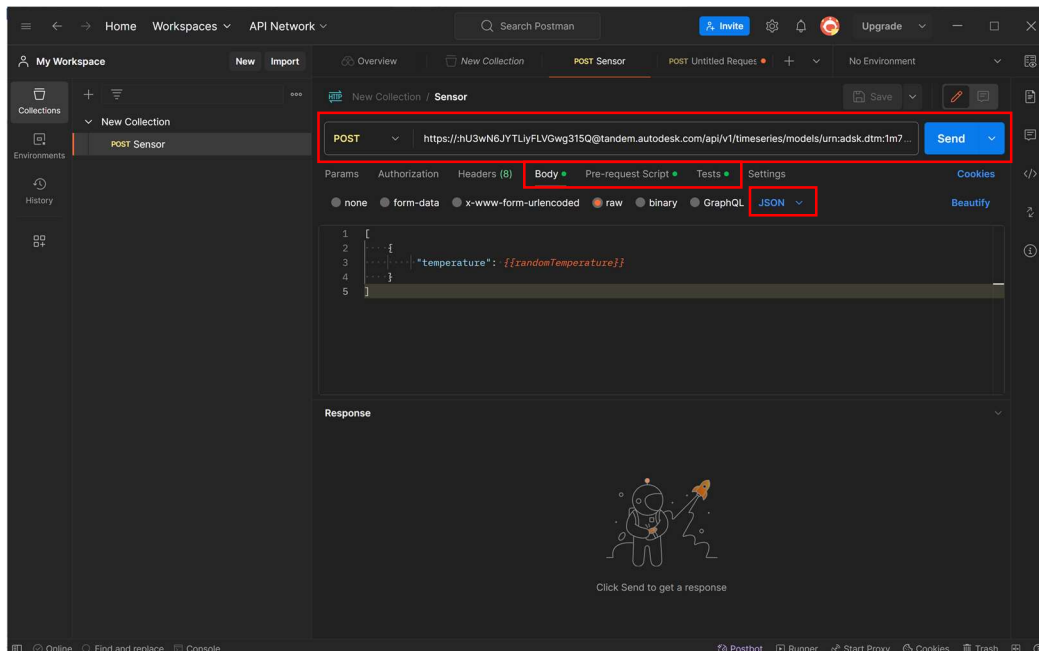


Figure 19. Postman

There are 3 sections that are important for simulating the sensor data for the Digital Twin. There is the (i) Pre-request Script, (ii) Body and (iii) Tests.

- (i) The Pre-request Script section allows you to write JavaScript code that runs before the actual API request is sent. This will serve as the **Data Acquisition Layer** where a variable will be created with the supposed value of the real sensor.
- (ii) The Body section of a Postman request is where you define the data you want to send to the API. This section will serve as the **Transmission Layer** where the script in JSON (JavaScript Object Notation) format will be transferred via the internet as an HTTP request.
- (iii) The Test section in Postman lets you execute JavaScript code after a request is sent. It's useful for setting timers to automatically repeat requests at set intervals, such as every few minutes, during collection runs.

So basically, a value will be supposed in the Pre-request script, recalled in the Body section and send as a HTTP request through the internet to the Tandem Stream, and then there is a time-out before the cycle runs again.

To simulate the real sensor, the script will be left running 24 hours in a Virtual Private Server (VPS) in Amazon Web Services (AWS).

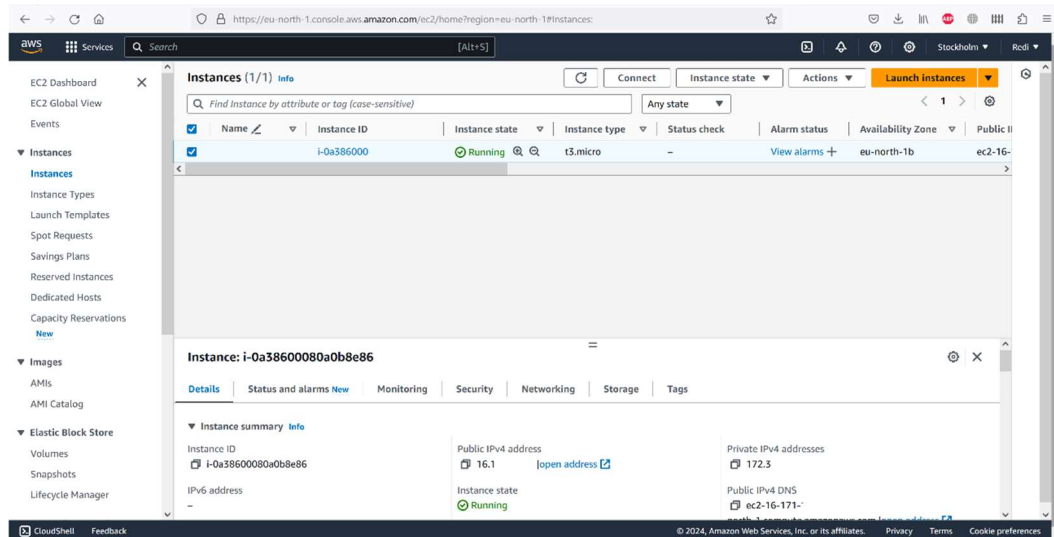


Figure 20. Virtual Private Server on AWS

## Autodesk Tandem



Autodesk Tandem is a digital twin platform developed by Autodesk, designed to create a comprehensive digital representation of a physical asset, process, or system. It enables users to bring building information modelling (BIM) data together from various stages of the project lifecycle to create a Digital Twin that mirrors the real-world construction or infrastructure project.

Tandem will be used as the main platform for hosting the DT.

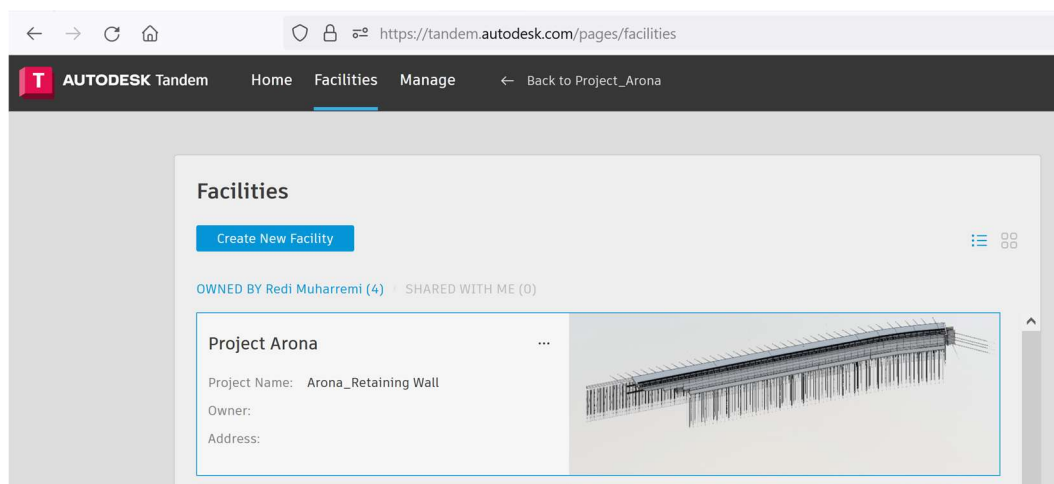
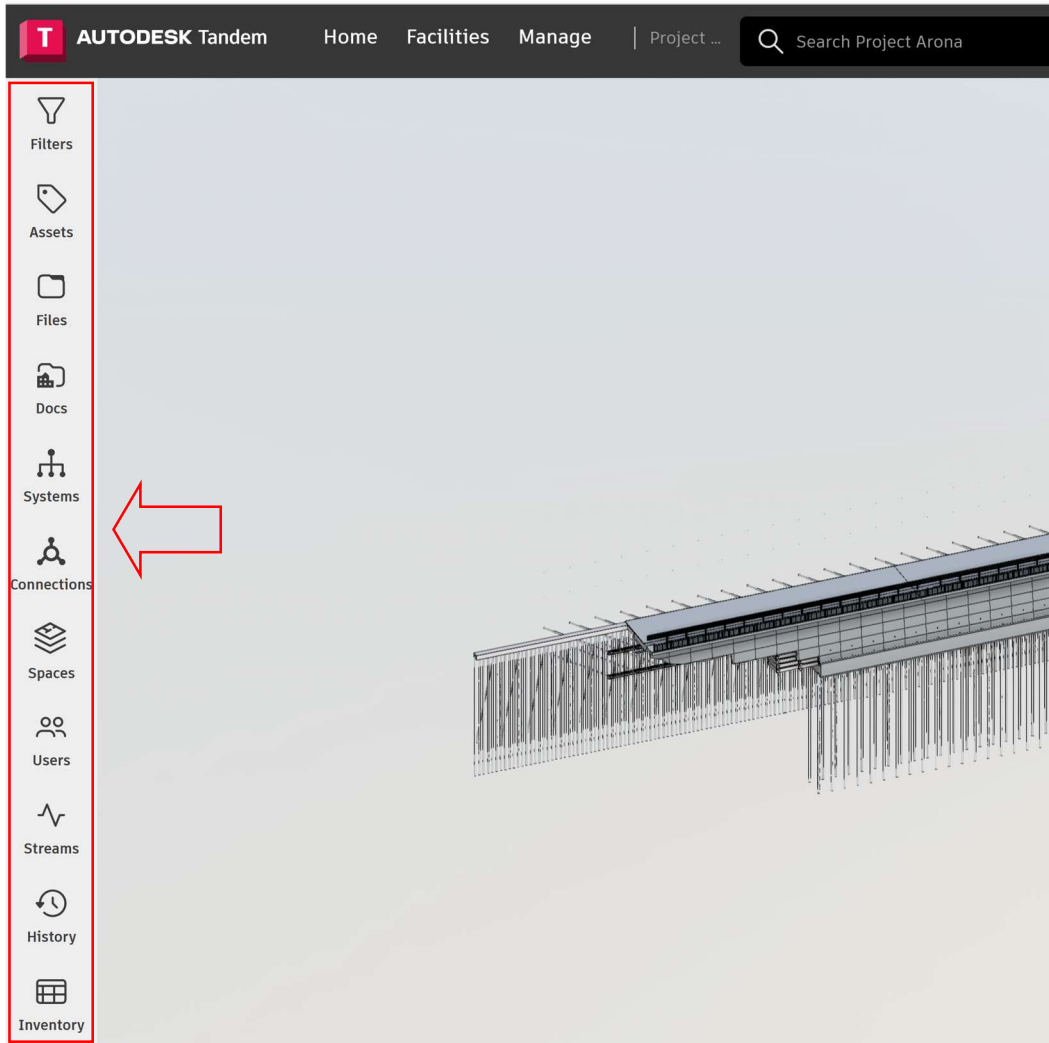


Figure 21. Autodesk Tandem

It is a web-based application, allowing for easy access for different stakeholders without the need for downloading and installing a heavy software.

The Tandem toolbar allows for quick access to different functions such as filters for highlighting specific elements, file depository, systems, connections, streams, inventory etc.



*Figure 22. Tandem toolbar*

A particular important feature is the creation of connections/streams that allow for linking and storing data from IOT devices. This feature is crucial as it enables bi-directional connection of data and information between the physical model and its virtual counterpart.

## 4. Case study

The case study consists of a rehabilitation project on a roadway in Arona, where significant damage to the retaining wall led to the road's collapse. The major problems were created by the erosive effect of the waters of Lake Maggiore and leakage of underground pipelines, which undermined the retaining wall over an extension of 300 m. This also caused a partial emptying of the road body and, consequently, a subsidence of the road surface.



*Figure 23. View of the retaining wall*



*Figure 24. Road subsidence*



*Figure 25. Damage on the retaining wall*



*Figure 26. Road Subsidence*

Given the critical conditions, the decision was made to entirely dismantle the old retaining wall and construct both a micropile wall and a new retaining wall. The project was executed in two stages: initially, the micropile wall was erected, followed by the construction of the new crib wall.

## 4.1 Building the As-Built BIM Model

The first step will be to create a Work Breakdown Structure (WBS). For each identified element within the WBS, we will assign a unique OmniClass code to ensure standardized classification. Following this, we will model the retaining wall in Autodesk Revit, following the requirements specified by the contracting authority.

### WBS

From the original drawing, we will compile a list of all elements comprising the retaining wall. Subsequently, these elements will be categorized as the example shown in section 3.1, in accordance with the attachment provided by the contracting authority.

Elementi	WBS						
	LOTTO	OPERA	PROGRESSIVO D'OPERA	PARTE D'OPERA	PROGRESSIVO PARTE D'OPERA	SUB CATEGORIA	PROGRESSIVO SUB CATEGORIA
Micropali	01	TR	01	OS	01	PPM	01
Micropali inclinati	01	TR	01	OS	01	PPM	02
Tiranti	01	TR	01	OS	01	PPM	03
Cordoli CA	01	TR	01	OS	01	PPM	05
Travi di Contrasto	01	TR	01	OS	01	PPM	04
Banchettone	01	TR	01	SS	06	FS	01
Crib wall	01	TR	01	OS	04	MS	01
Pannello prefab.	01	TR	01	OS	04	MC	05
Tubo microforato	01	TR	01	IF	05	IMA	01
Fondazione	01	TR	01	FD	01	PZ	01
Pali fondazione	01	TR	01	FP	03	PMD	01
Calcestruzzo magro	01	TR	01	OS	04	FS	02
Ciottoli	01	TR	01	OS	04	MAV	03
Rinterro	01	TR	01	OS	04	MAV	04
Sottofondazione	01	TR	01	SF	02	STF	01
Pacchetto pav.	01	TR	01	SS	06	PV	02
Barriera di siccur.	01	TR	01	SCS	07	BS	01
Barriera Parapetto	01	TR	01	SCS	07	BS	02
Pavimento carrab.	01	TR	01	SS	06	PV	03

Table 5. WBS of elements

## OmniClass

Now for all the elements identified we are going to assign the OmniClass number.

Elementi	OmniClass number	OmniClass Title
Micropali	23.25.05.11	Foundation Piles
Micropali inclinati	23.25.05.11	Foundation Piles
Tiranti	23.10.05.10	Grouted Anchors
Cordoli CA	23.25.05.11.11.27	Pile Caps
Travi di Contrasto	23.25.30.11.14.14	Beams
Banchettone	23.25.05.17	Shallow Foundations
Crib wall	23.10.20.14.30	Crib Walls
Pannello prefabricato	23.35.10.17.14.11	Precast Concrete Wall Cladding Panels
Tubo microforato	23.10.10.12.10	Piped Drainage
Fondazione	23.25.05.17	Shallow Foundations
Pali fondazione	23.25.05.11	Foundation Piles
Calcestruzzo magro	23.20.15.11.21	Low Density Concrete
Ciottoli	23.25.05.00	Foundations
Rinterro	23.25.05.00	Foundations

Sottofondazione	23.20.15.11.21	Low Density Concrete
Pachetto pavement.	23.15.10.11	Roadways and Runways
Barriera di sicurezza	23.15.10.11.21.11.17	Guardrails
Barriera Parapetto	23.15.10.11.21.11.17	Guardrails
Pavimento carrabile	23.15.10.11	Roadways and Runways

Table 6. OmniClass classification of elements

## As-Built Model

The initial step involves creating families and types for all components of the retaining wall in Revit. We have the option to import these families if they have been previously modelled, or we can create them anew. This process is crucial for ensuring that each element of the retaining wall is accurately represented in our model.

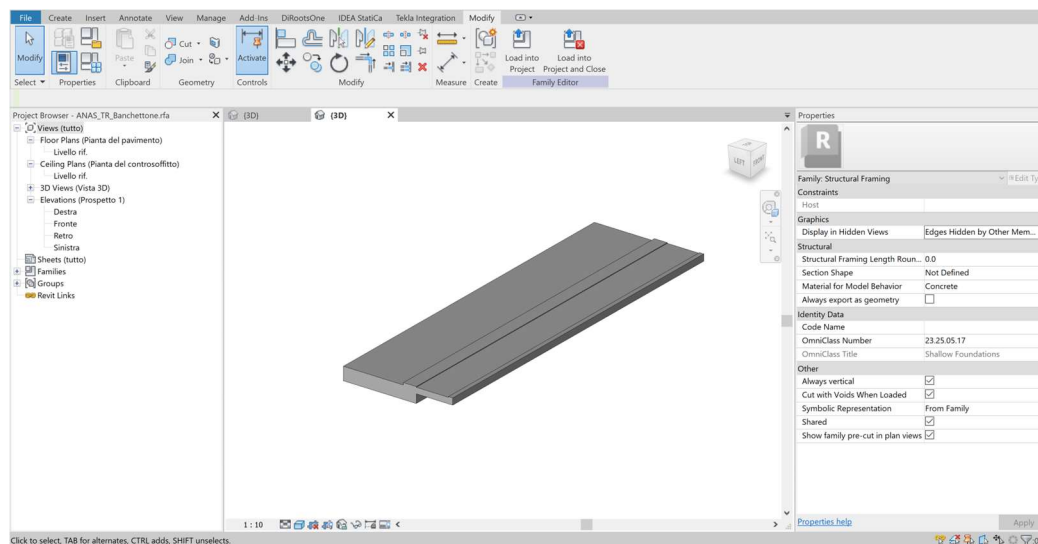


Figure 27. Example of banchettone family

The geometries and dimensions of the Families have been derived from the CAD drawings, ensuring they accurately reflect the real-world dimensions of the objects.



The next step is to place the elements into the 3D space. To do this different levels have been created.

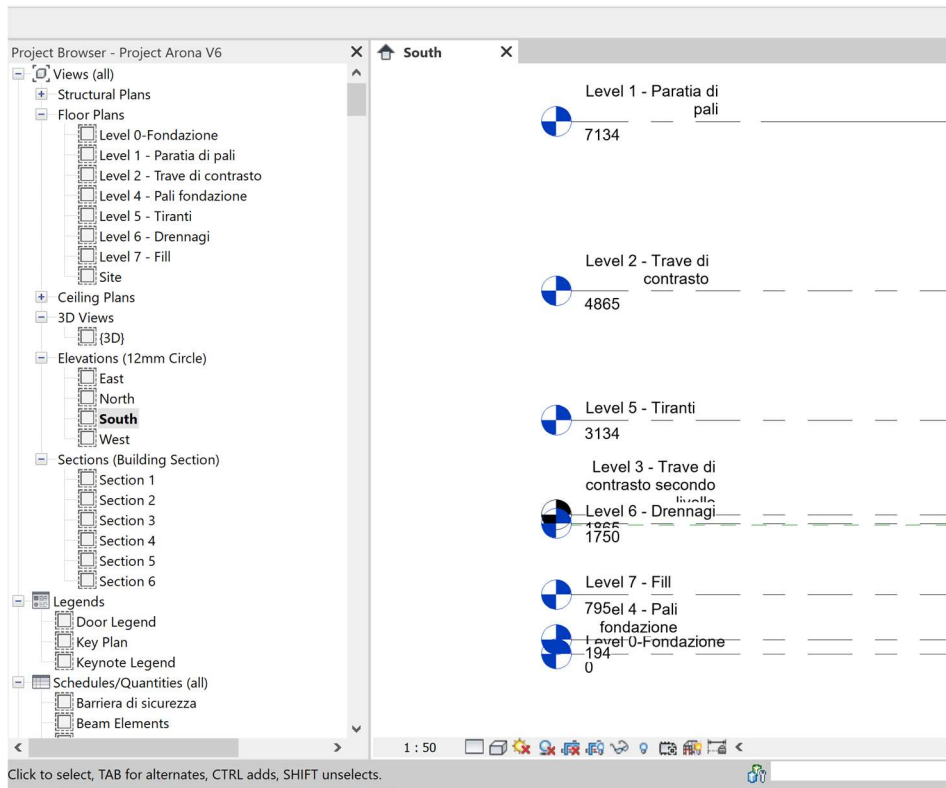


Figure 28. Levels in Revit

Subsequently, various plan views are imported into these Levels, assisting in the precise positioning of objects within the plan.

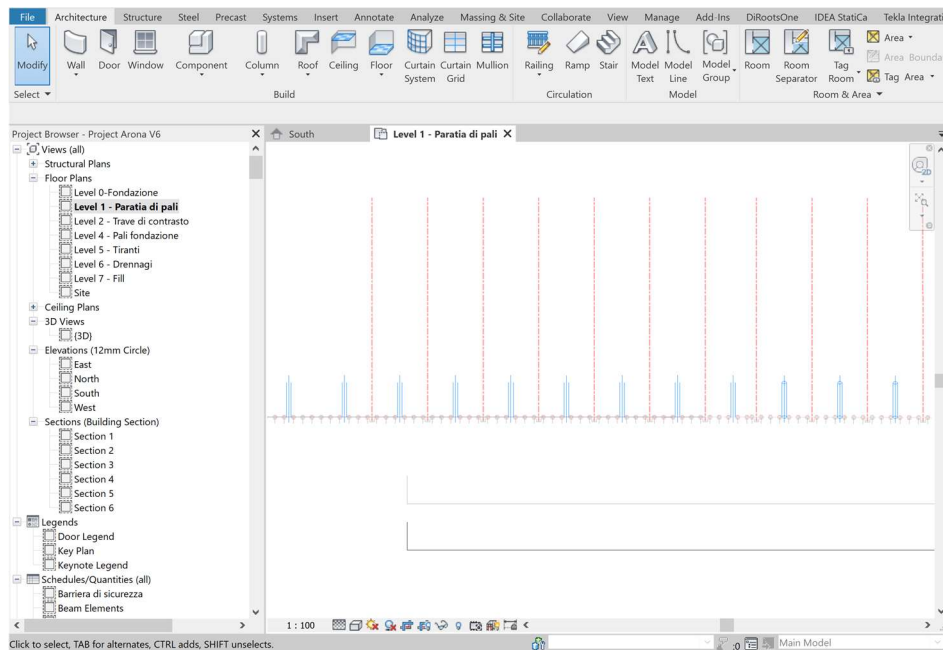


Figure 29. Imported plan view

For positioning in elevation, section views are imported, allowing the elements to be appropriately positioned.

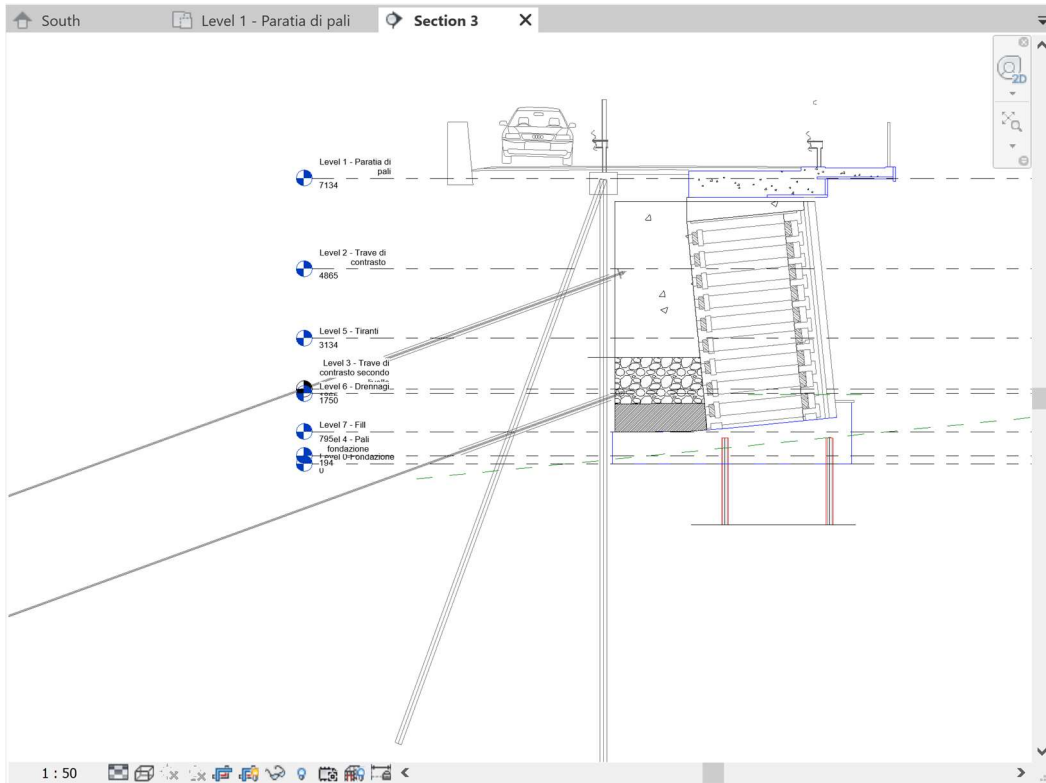


Figure 30. Imported section view

By placing each element in the appropriate position we are able to construct the geometric 3D model.

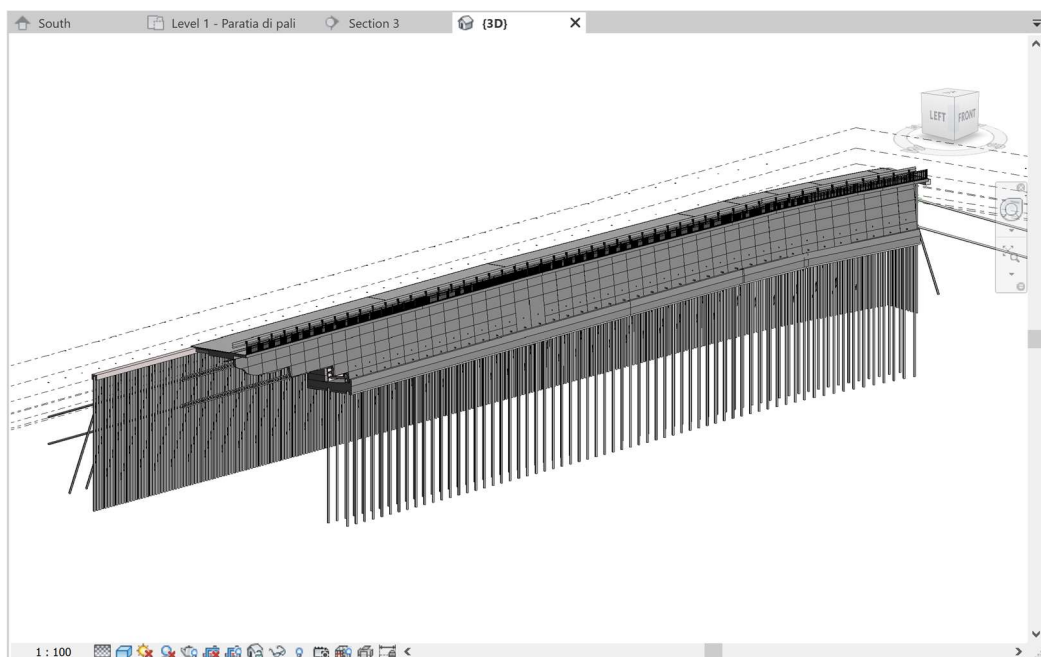


Figure 31. 3D geometric model

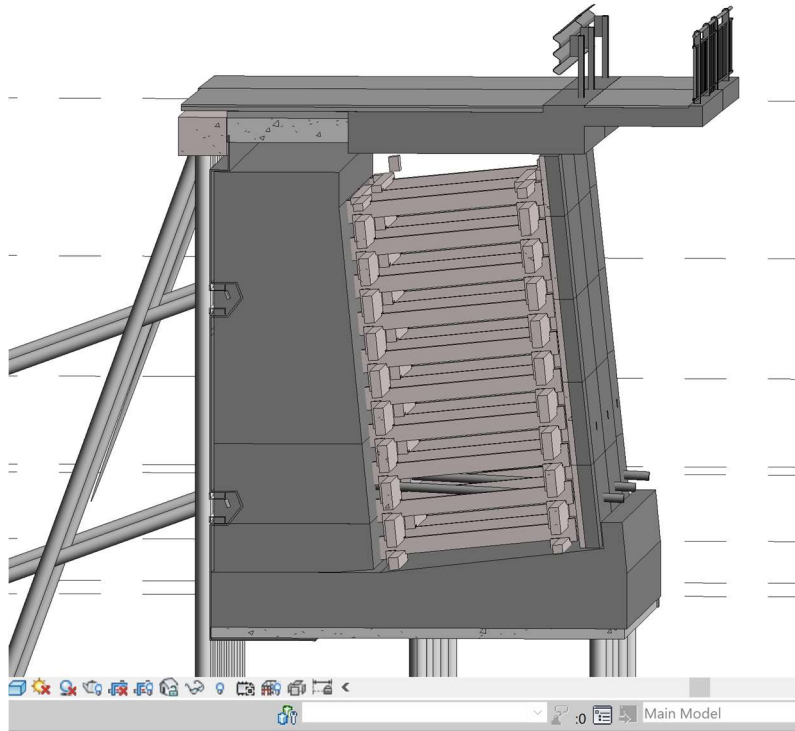


Figure 32. 3D view of a section (LOD F)

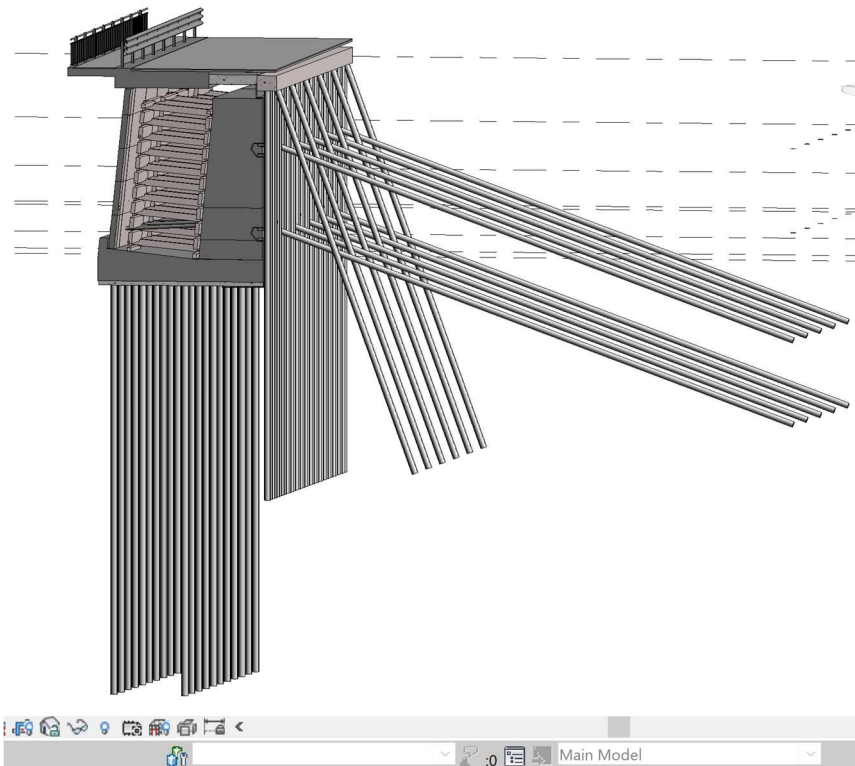
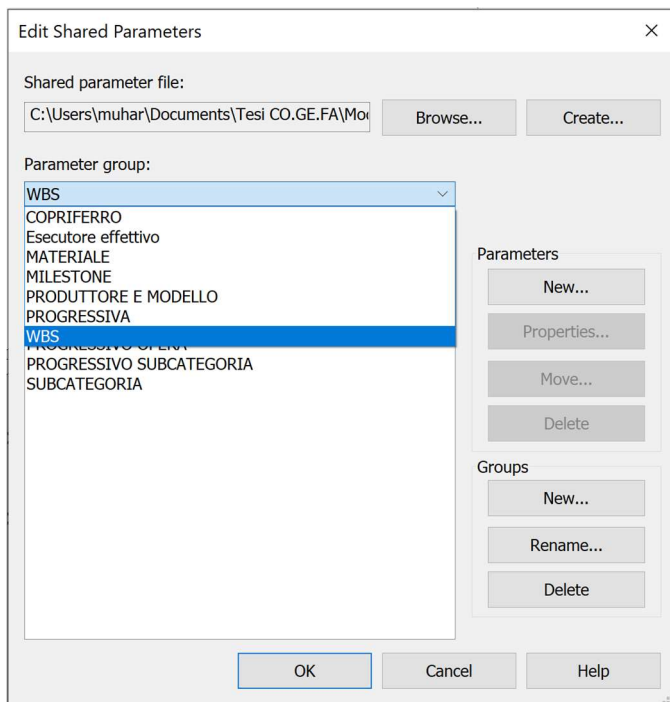


Figure 33. 3D view of the deep foundations (LOD F)

Now, it is needed to add the non-geometric information, such as WBS (Work Breakdown Structure), Milestones, material characteristics etc., mentioned in section 3.1. To accomplish this, we will create a set of parameters and assign them to the elements.

First, a set of shared parameters will be created, which will be useful to then be assigned as project parameters for the different categories of elements that compose the retaining wall.



Different parameter groups are created within the shared parameter file, and each group has its own parameters.

Figure 34. Shared parameters

Then, each of these parameters will be assigned as a project parameter for the categories of elements to which it belongs.

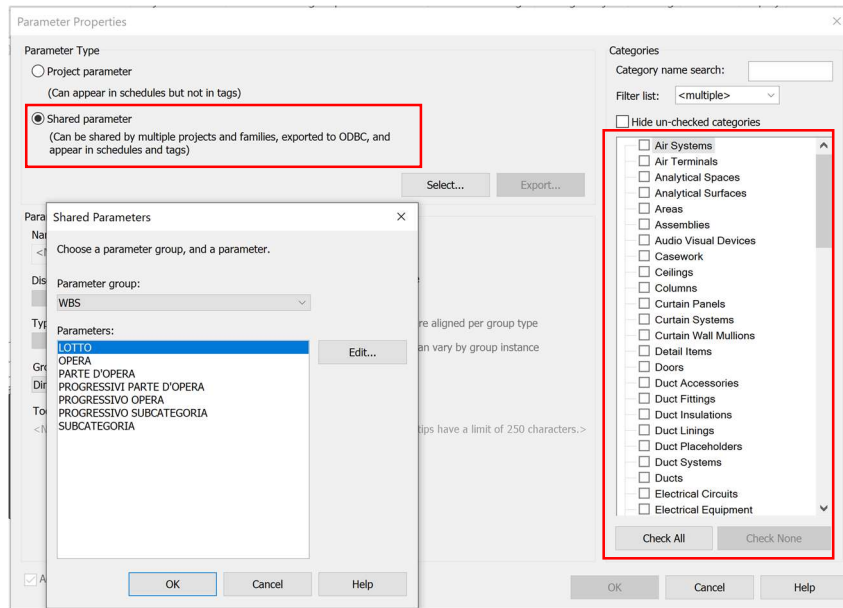


Figure 35. Project parameters

For simplicity, the parameters that have the same value for all the elements are set as global parameters.

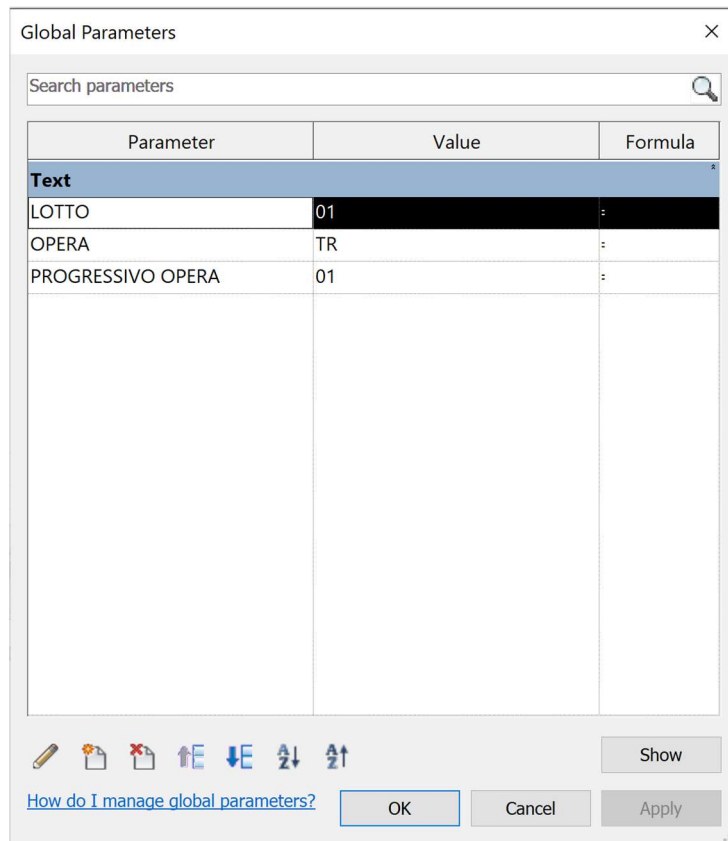


Figure 36. Global parameters

So for each element on the model we have information for:

- WBS
- OmniClass number
- Shape, dimension, position and orientation.
- The actual Executor
- The progressive
- Delivery Milestone
- Material
- Concrete cover for reinforce concrete structures
- Manufacturer and model (for manufactured elements)

It is also possible for each element to have a hyperlink (linking to external sources).

The image shows two overlapping software property panels. The left panel is titled 'Properties' and contains the following sections:

- Generic Models (1)**: ANAS\_FS\_Micropalo cavo inclinato, ANAS\_FS\_Micropalo Cavo, inclinato\_MT\_Ø163.8-sp12.5mm
- Constraints**:
 

Level	Level 1 - Paratia di pali
Elevation from Level	583.7
Host	Level : Level 1 - Paratia d...
Offset from Host	583.7
Moves With Nearby Ele...	<input type="checkbox"/>
- Text**:
 

LOTTO	01
PROGRESSIVI PARTE D'...	01
SUBCATEGORIA	PPM
PROGRESSIVO OPERA	01
OPERA	TR
PARTE D'OPERA	OS
PROGRESSIVO SUBCAT...	02
ESECUTORE EFFETTIVO	TERRA.CON S.R.L.
- Dimensions**:
 

Volume	0.662 m <sup>3</sup>
--------	----------------------
- Identity Data**: Image, Comments, Mark
- Phasing**:
 

Phase Created	New Construction
Phase Demolished	None

The right panel shows additional properties:

- Phasing**:
 

Phase Created	New Construction
Phase Demolished	None
- IFC Parameters**:
 

IFC Predefined Type	
Export to IFC As	
Export to IFC	By Type
IfcGUID	1jjPUWvaLBCuLFNFsG\$rfk
- Other**:
 

MODELLO	TUBO NERO TONDO SA...
PRODUTTORE	MARCEGAGLIA CARBON...
MILESTONE	M1
PROGRESSIVA	350.000000
- Materials and Finishes**:
 

MAT_Iniezione	ANAS_CZ_C20/25
MAT_Palo	ANAS_AC_S355J2H
- Dimensions**:
 

Pile angle	70.00°
------------	--------
- Identity Data**:
 

Type Image	
Keynote	
Model	
Manufacturer	
Type Comments	
URL	
Description	
Assembly Code	
Cost	

Figure 37. Properties of element

## 4.2 Advancing toward the Digital Twin

The workflow will be based on the DT system architecture presented in Section 3.2. Given that the primary damage was caused by water erosion, a piezometer sensor will be installed in the area most affected. Additionally, an inclinometer will be positioned on the surface of the retaining wall to track its inclination over time. Together, these sensors will enable both real-time monitoring and access to historical data, assessing the water level within the area and monitoring any changes in wall's inclination.

In this case study, the system architecture is illustrated as follows:

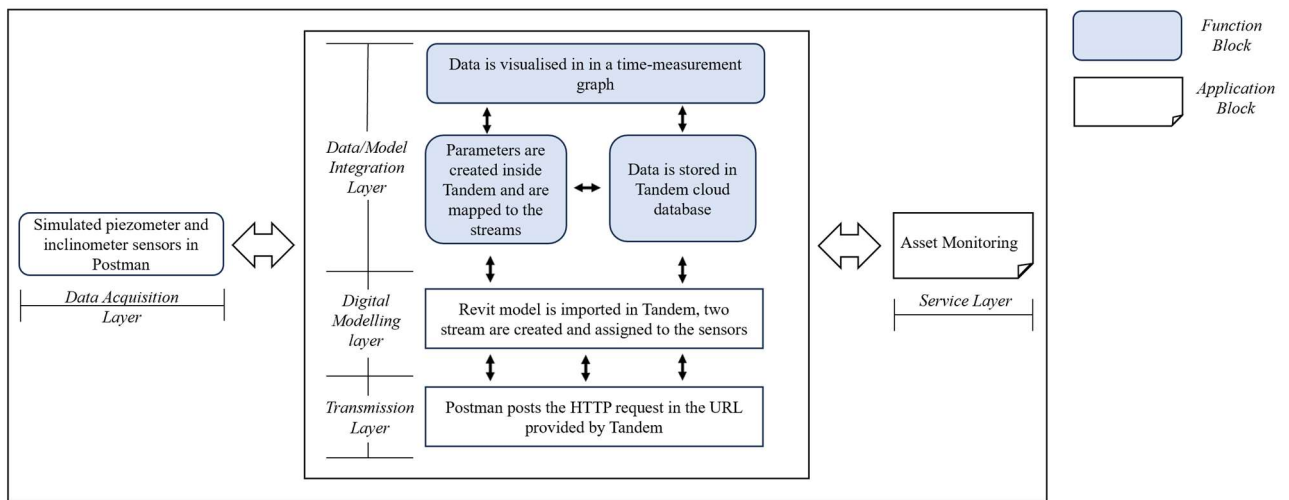


Figure 38. System architecture of the DT

### Data Acquisition Layer

The simulated piezometer and inclinometer will be positioned as follows:

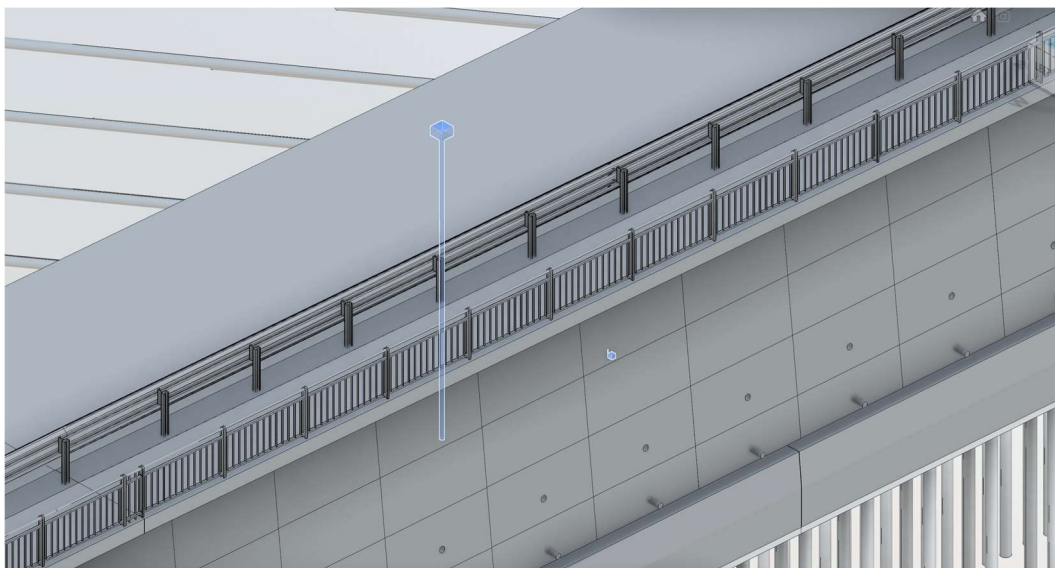
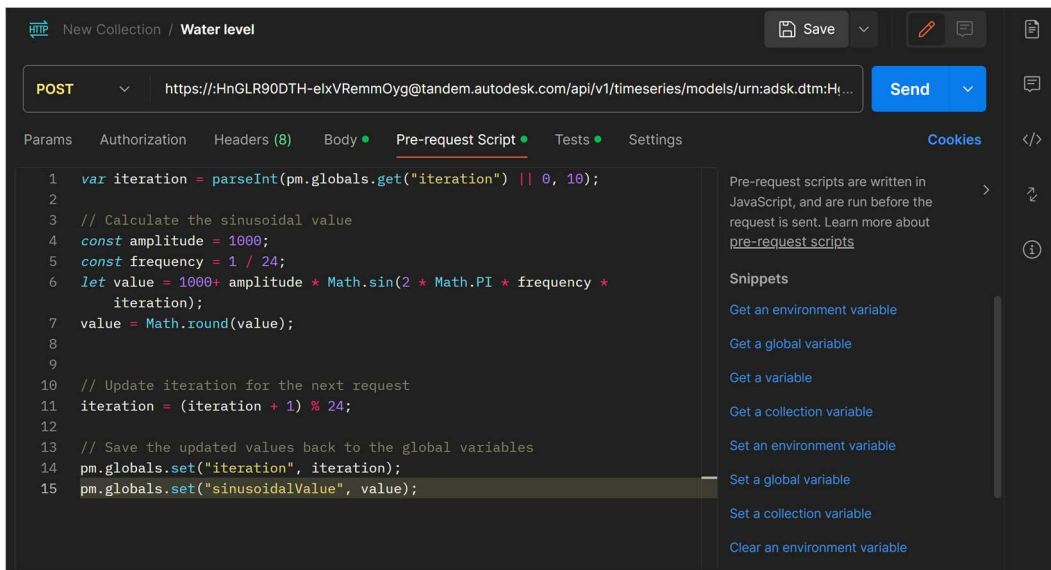


Figure 39. Position of the sensors

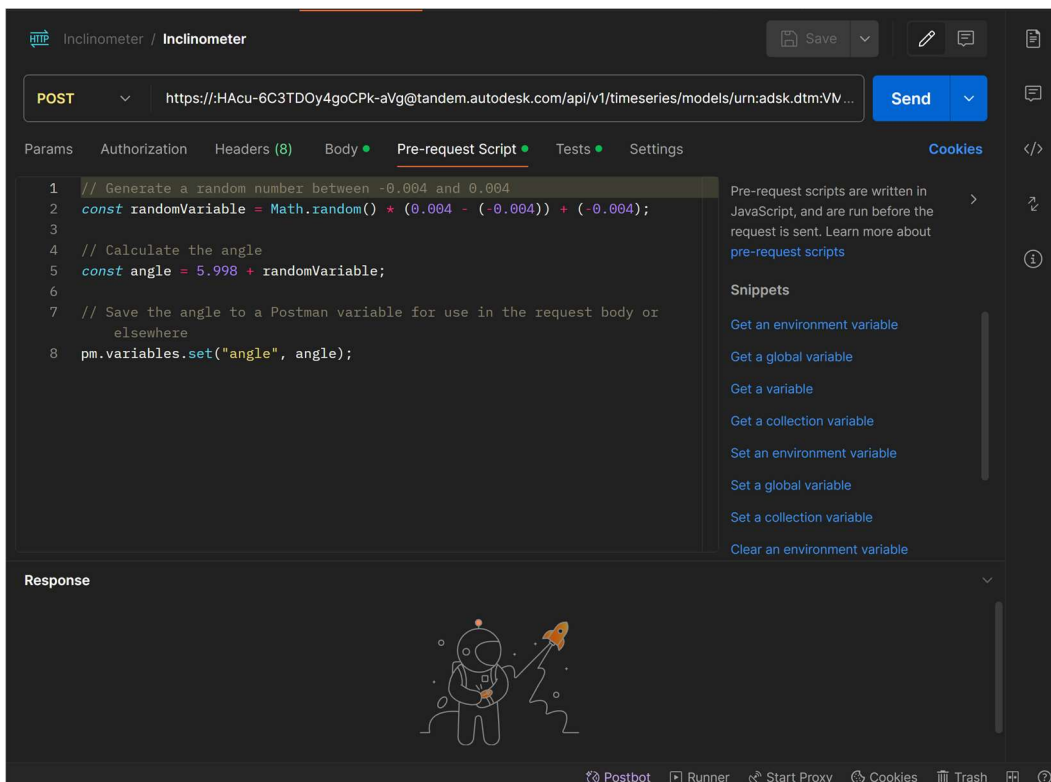
For the piezometer, the values transmitted will mimic a sinusoidal function, and the corresponding code will be implemented in the Pre-request Script section of Postman. The code is as follows:



```
1 var iteration = parseInt(pm.globals.get("iteration") || 0, 10);
2
3 // Calculate the sinusoidal value
4 const amplitude = 1000;
5 const frequency = 1 / 24;
6 let value = 1000 + amplitude * Math.sin(2 * Math.PI * frequency *
  iteration);
7 value = Math.round(value);
8
9
10 // Update iteration for the next request
11 iteration = (iteration + 1) % 24;
12
13 // Save the updated values back to the global variables
14 pm.globals.set("iteration", iteration);
15 pm.globals.set("sinusoidalValue", value);
```

Figure 40. Pre-request script for the piezometer

For the inclinometer, the transmitted values will resemble a constant function with added random noise, aiming to closely replicate the behaviour of an actual sensor.



```
1 // Generate a random number between -0.004 and 0.004
2 const randomVariable = Math.random() * (0.004 - (-0.004)) + (-0.004);
3
4 // Calculate the angle
5 const angle = 5.998 + randomVariable;
6
7 // Save the angle to a Postman variable for use in the request body or
  elsewhere
8 pm.variables.set("angle", angle);
```

Figure 41. Pre-request script for the inclinometer



## Transmission Layer

The first step is to create the connections inside Tandem.

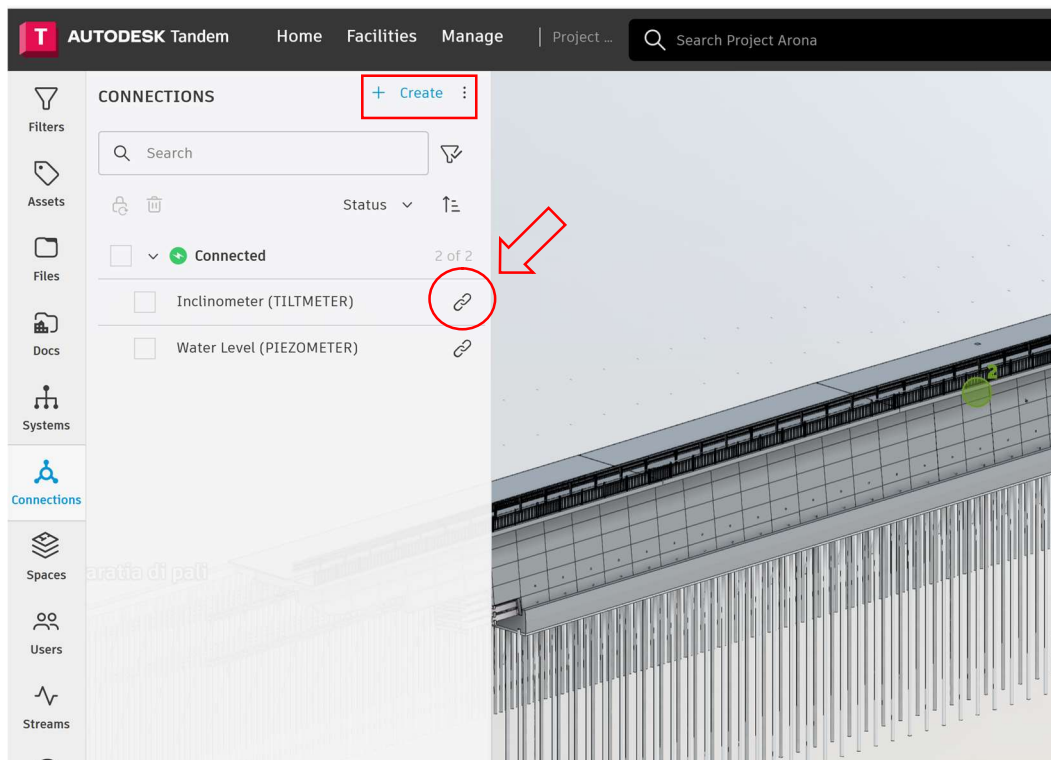


Figure 42. Creating Tandem connection

Then after creating the stream, the link to these connections is copied and pasted in Postman. In the Body section we recall the variable created before and send it in the following format:

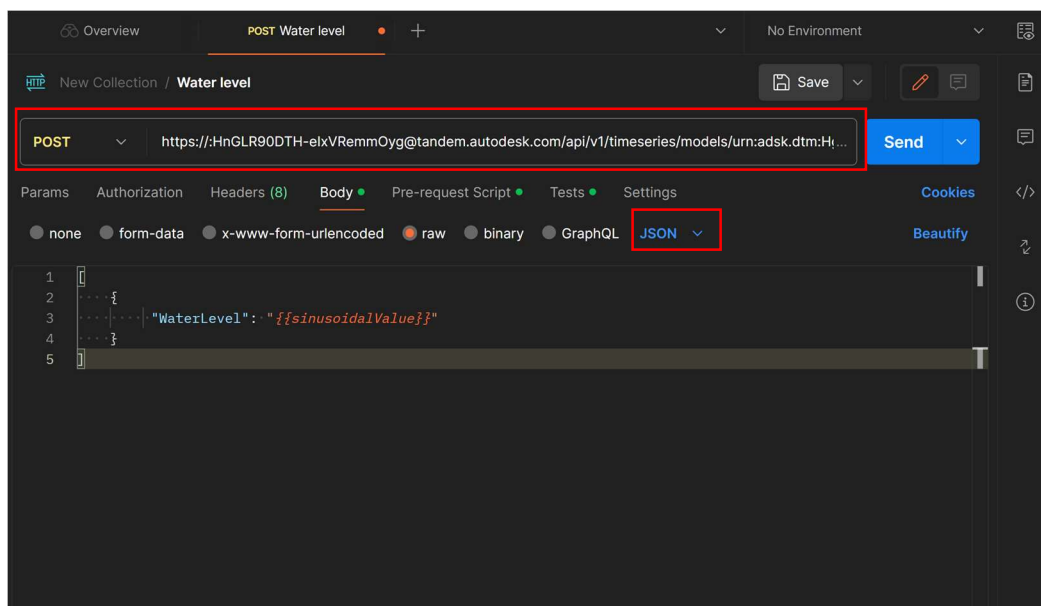


Figure 43. Post the request in the URL provided

## Digital Modelling Layer

The model will utilize the As-Built BIM model detailed in Section 4.1. We will import the .rvt file into Tandem and then assign the connection to the sensors.

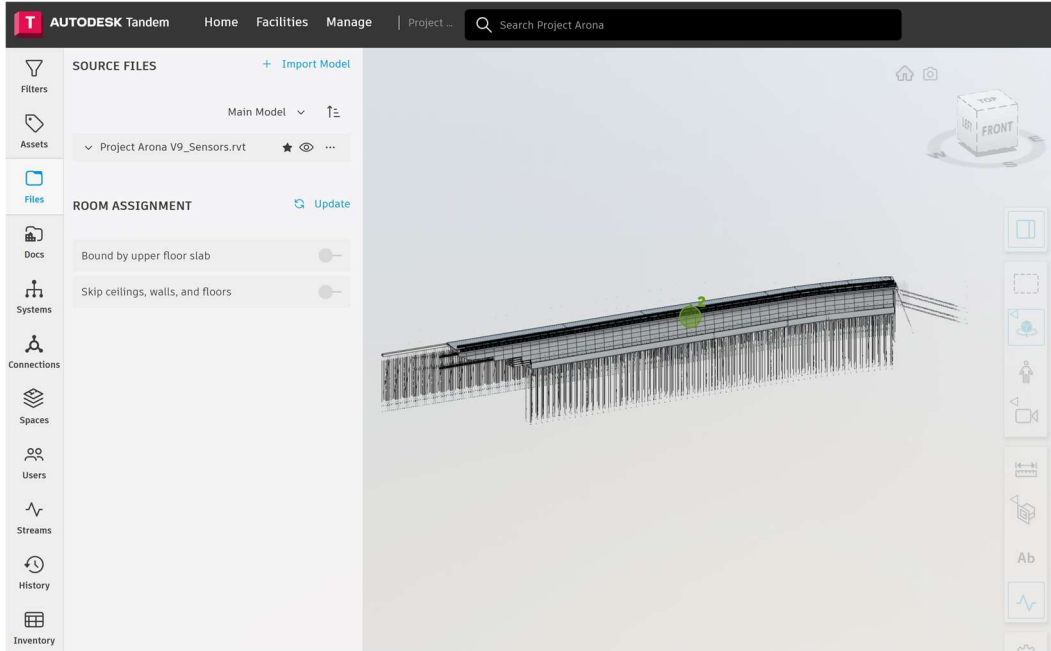


Figure 44. Imported model in Tandem

To have a constantly updated model, the As-is Model, the streams from the simulated sensors should be assigned to the specific elements they correspond to. In this case, the Water Level stream to the Piezometer element and the Inclination to the Inclinometer element.

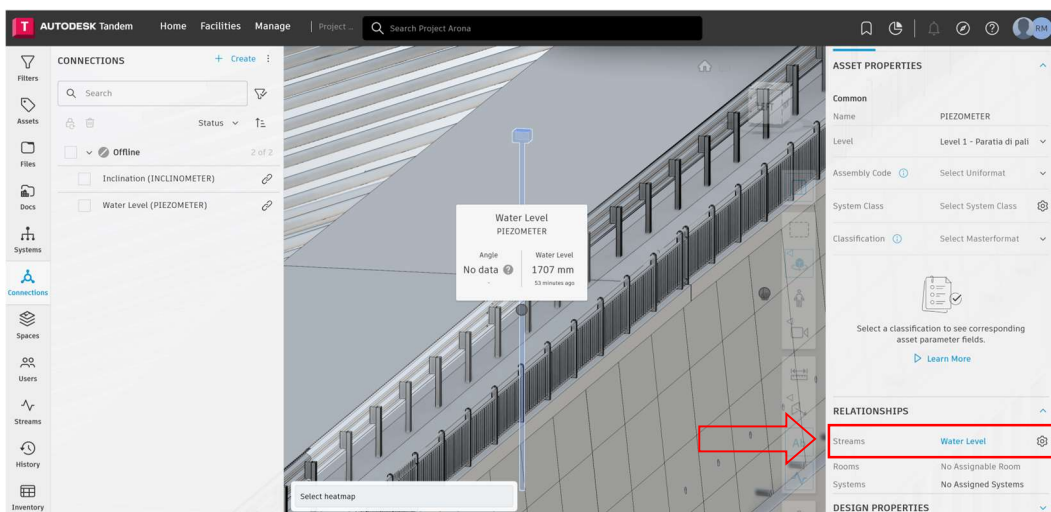


Figure 45. Assignment of the stream to the Piezometer

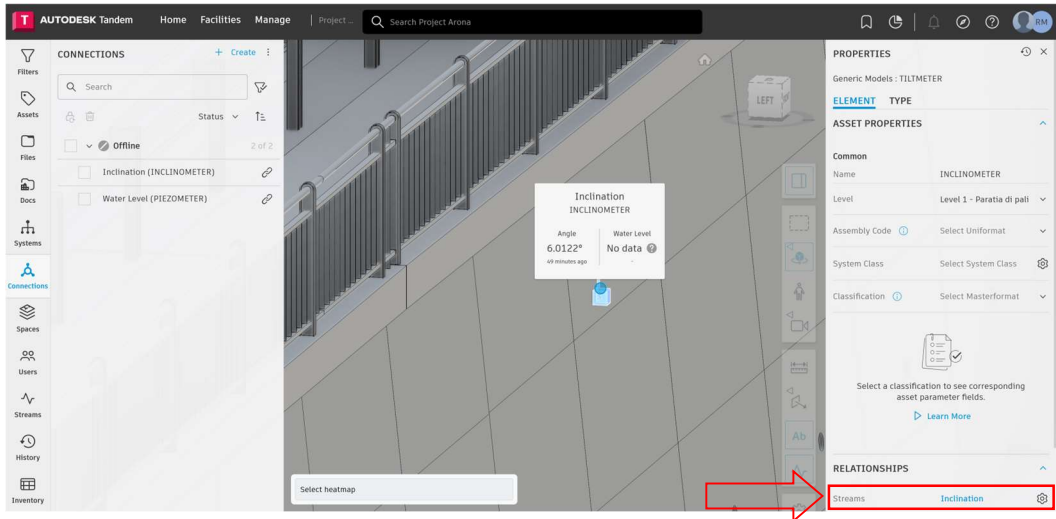


Figure 46. Assignment of the stream to the Inclinometer

An important aspect is that in Tandem, the parameters that update are not those of BIM elements, but rather pre-defined parameters within the Tandem web-based application, which are properties of the created Connections/Streams.

## Data/Model Integration Layer

In this layer, a data structure is designed to integrate the information coming from the simulated sensors. Basically, appropriate parameters within the DT are necessary to hold the incoming data. The workflow for creating these parameters is shown in the scheme below:

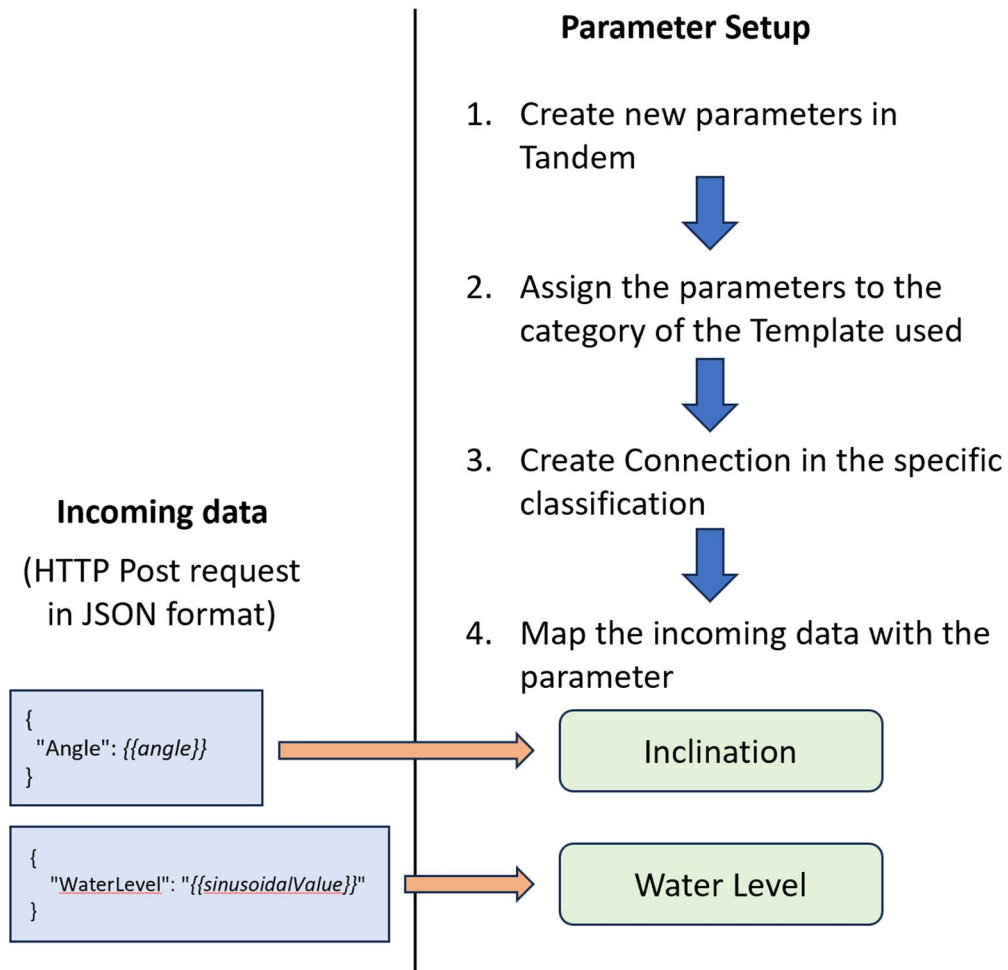


Figure 47. Parameter Setup and mapping

Tandem automatically stores the data in a Cloud Database and makes it possible to be visualised in a time-measurement graph:

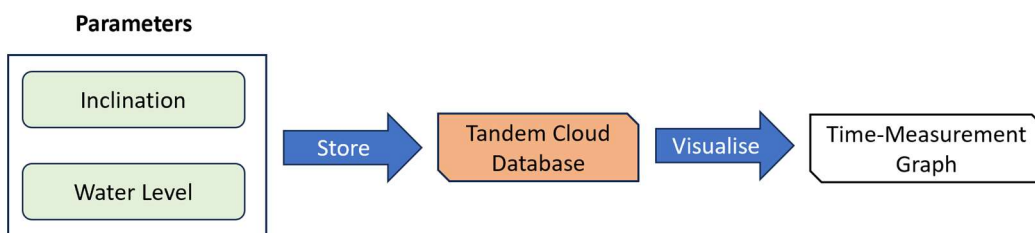


Figure 48. Storage and visualisation functions

1. The first step is to create the parameters inside Tandem:  
**Manage→Parameters→Add Parameter**

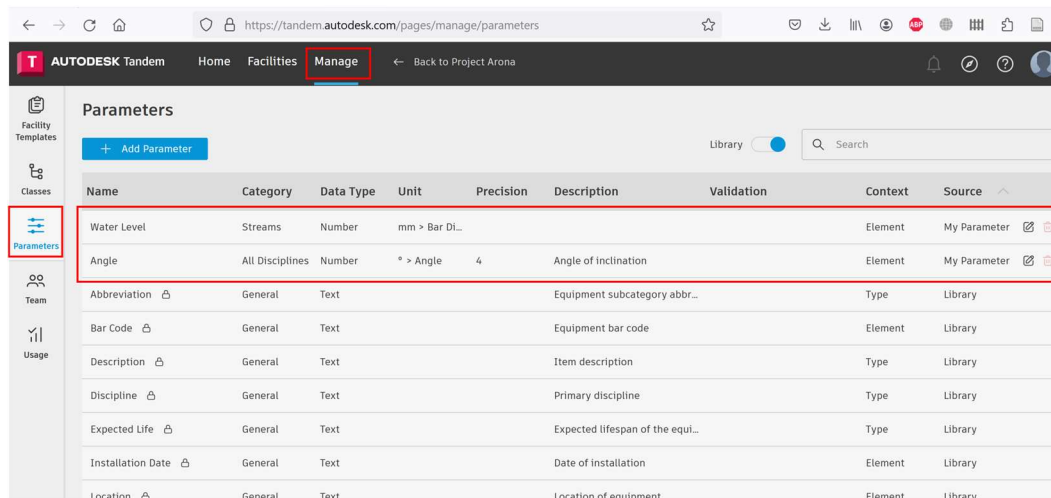


Figure 49. Creating parameters inside Tandem

2. The second step is to assign the parameters to the category of the Template used:  
**Manage→Facility Templates→Edit Template→Update the classification with the parameters**

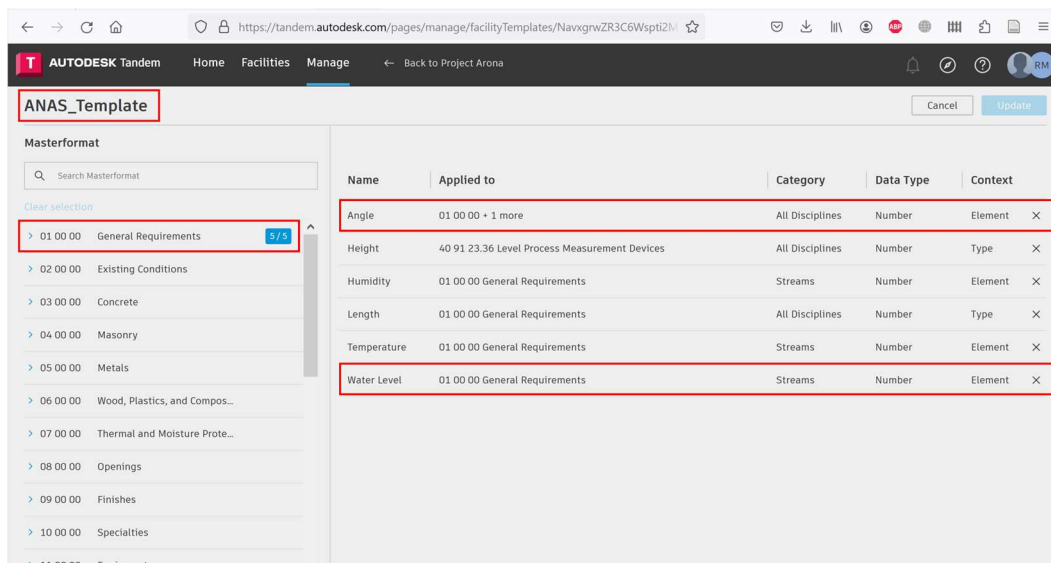


Figure 50. Updating Template with the parameters

3. Next step is to create the Connection inside Tandem in the specific classification:  
**Facilities → Connections → Create → Name and Classification → Create Connection**

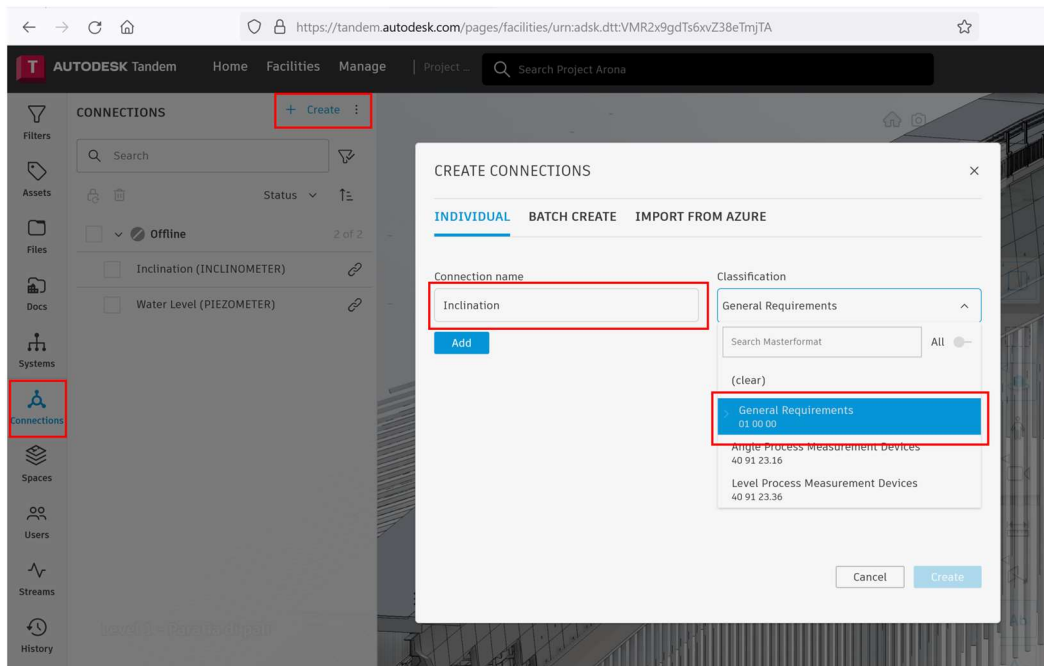


Figure 51. Creating Connection inside Tandem

4. The fourth step is to map the incoming data with the parameter they belong to:  
**Facilities → Connections → Configure Connections → Select Connection → Map the parameter with the JSON Path**

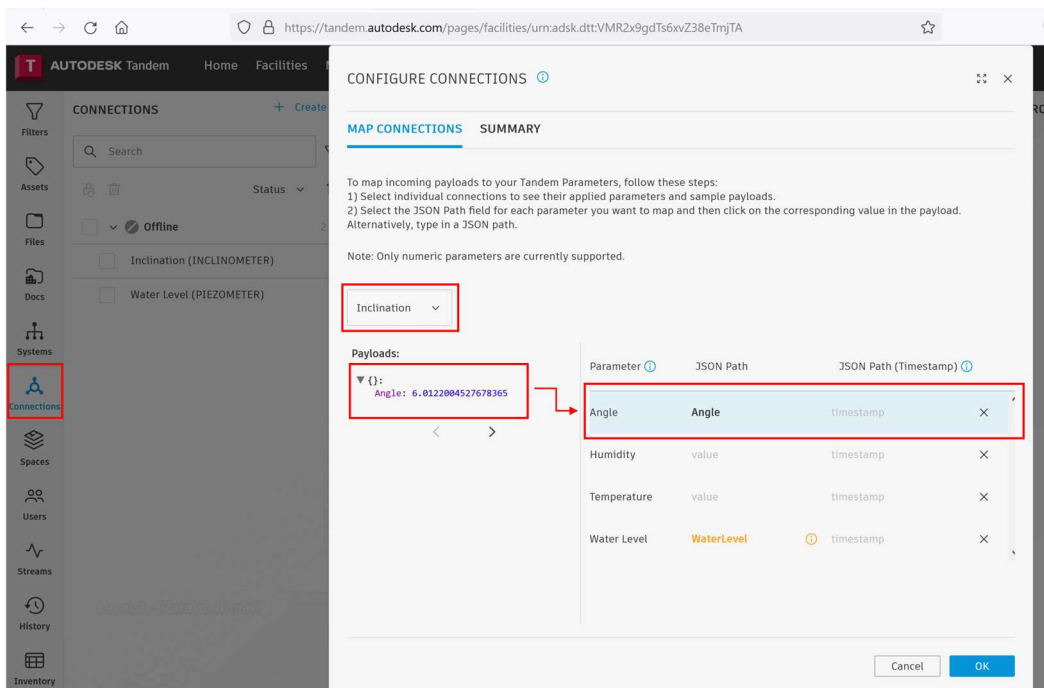


Figure 52. Mapping the Parameter with the JSON Path

## Service Layer

The service that the DT provides is **Asset Monitoring**, allowing for both real-time monitoring and access to historical data. This allows Asset Managers to assess the water level and the wall's inclination in real time, as well as to track historical changes.

The figures below show the time-measurement graph for both the Water Level and the Inclination. In a real case scenario, it would be possible to identify any anomalies on the behaviour and intervene early to reduce cost of intervention and increase safety of the infrastructure users.

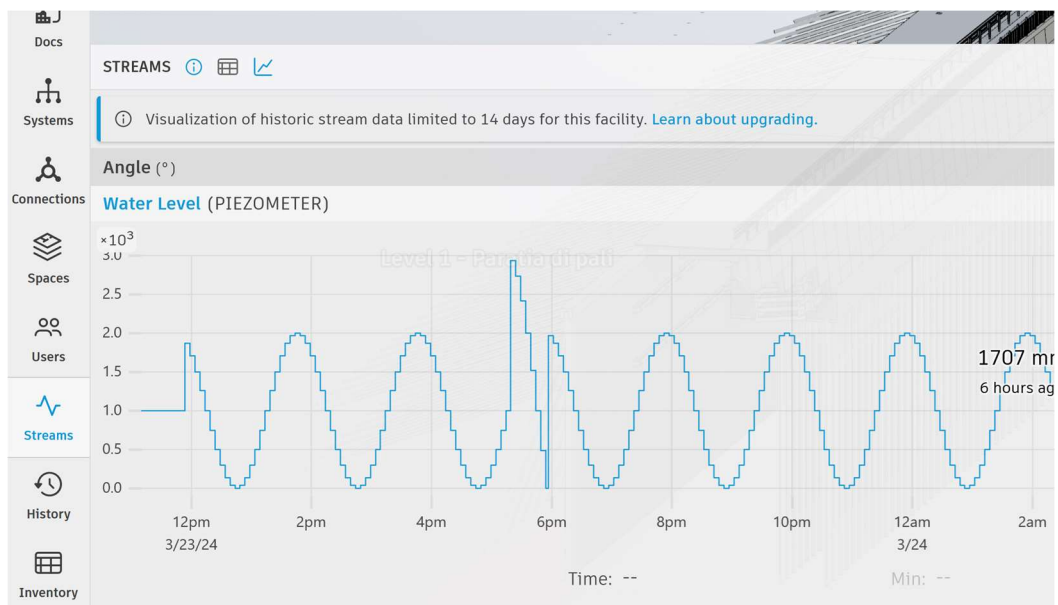


Figure 53. Water Level-Time graph

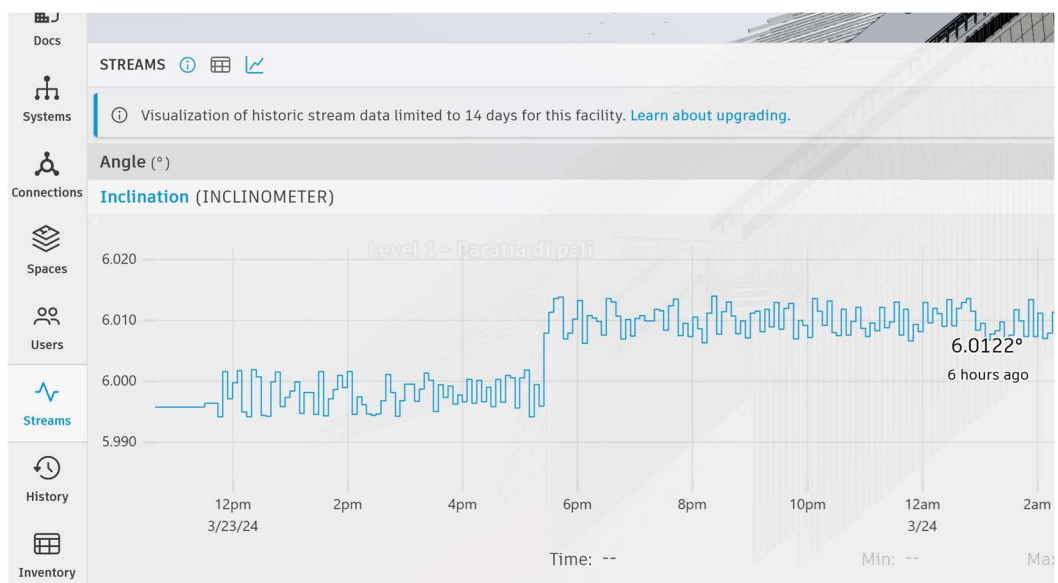


Figure 54. Inclination-Time graph

Apart from real-time and historical data monitoring, in Tandem there are other useful features such:

- Ability to add and visualise all the properties assigned to the BIM elements
- Ability to filter elements by properties, levels, classification etc. This function is particularly useful in the case where the WBS is set up for each BIM element, which allows for grouping elements with common properties. In the example below only the elements that have Parte d'Opera equal to SCS and SS are shown:

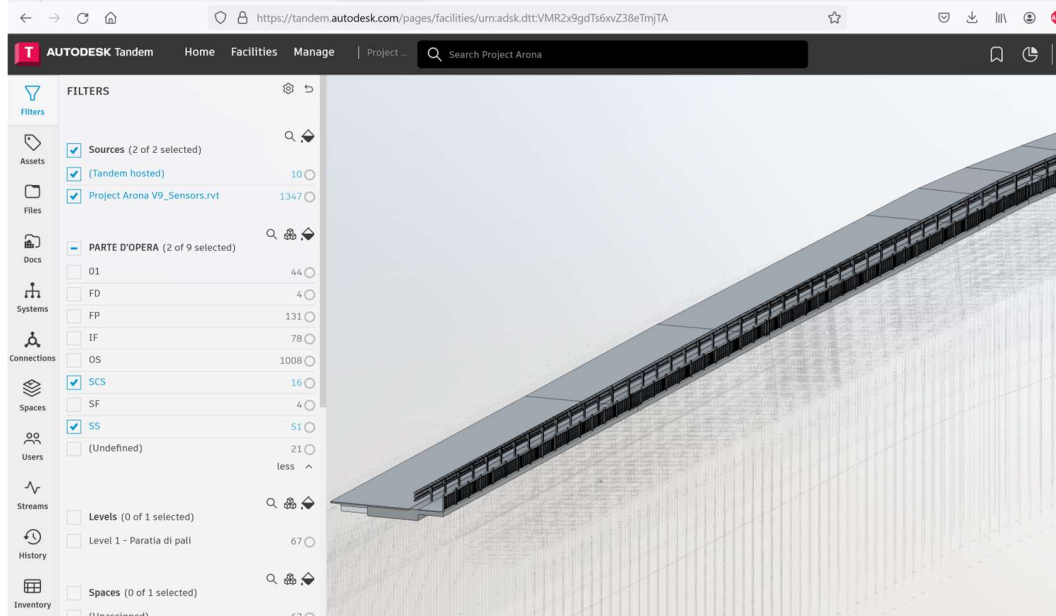


Figure 55. Parte d'Opera SCS and SS

- Ability to add more than one BIM model in the workspace.
- Ability to add documents and serve as a Common Data Environment
- Ability to assign spaces
- Ability to define thresholds in streams and get notified when these thresholds are exceeded
- Ability to view modification history
- Ability to view the inventory, import and export the data etc.



## 5. Results

The objective of this thesis was to create an infrastructure Digital Twin following the 5-layer system architecture. The 5-layer system architecture effectively guides in the identification and creation of the DT components. All the layers play important roles and are essential in creating a functioning DT:

- Data acquisition layer
- Transmission layer
- Digital modelling layer
- Data/Model integration layer
- Service layer

Building a Digital Twin is a complex process that demands expertise from various fields, including civil and electronic engineering, as well as computer science. Structuring the process into layers enhances understanding and assists in designing the DT specifically tailored to its intended purposes.

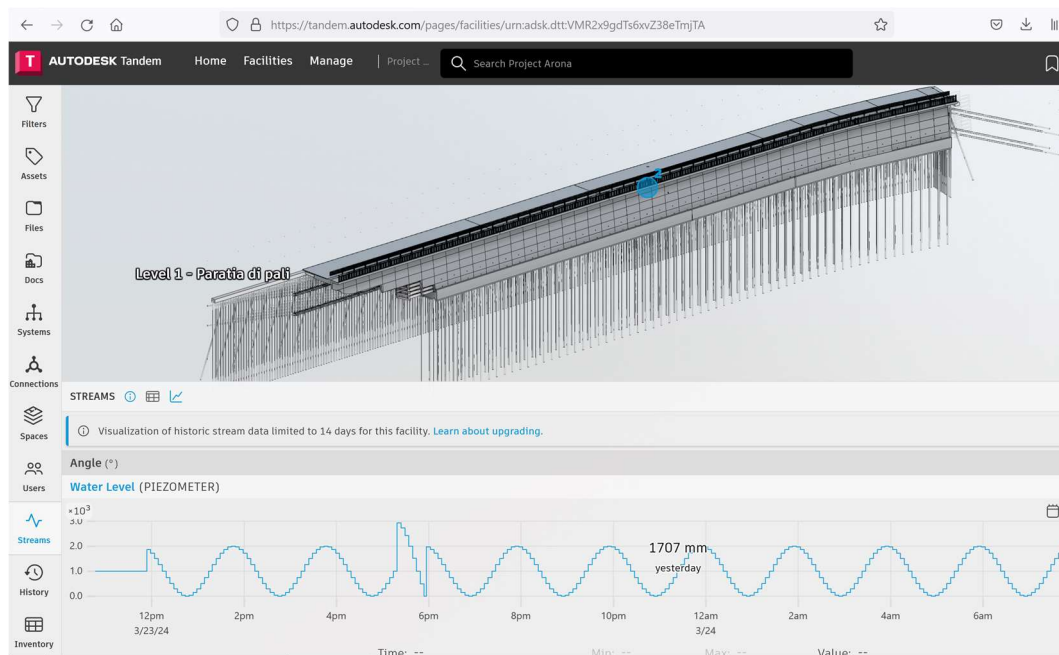


Figure 56. Digital Twin

The image below is an actual photograph of the constructed retaining wall. The real retaining wall serves as the Physical Twin in the DT concept.



*Figure 57. Physical Twin*

The DT is particularly useful in the context of infrastructure, where there is a need for better asset management. Making BIM mandatory represents a significant push towards the implementation of the DT, as it serves as a foundational element in the Digital Modelling Layer.

The BIM model, developed in accordance with Italian regulations, contains the necessary information to achieve the goal of creating a DT. The required Level of Development, identified as LOD F according to UNI 11337, ensures high fidelity with precise geometric and non-geometric information.

The BIM model serves the following purposes within the scope of this project:

- 3D geometry representation for clear visualisation
- Sensor localisation
- Structural classification that follows the WBS structure
- Material properties and other non-geometric information

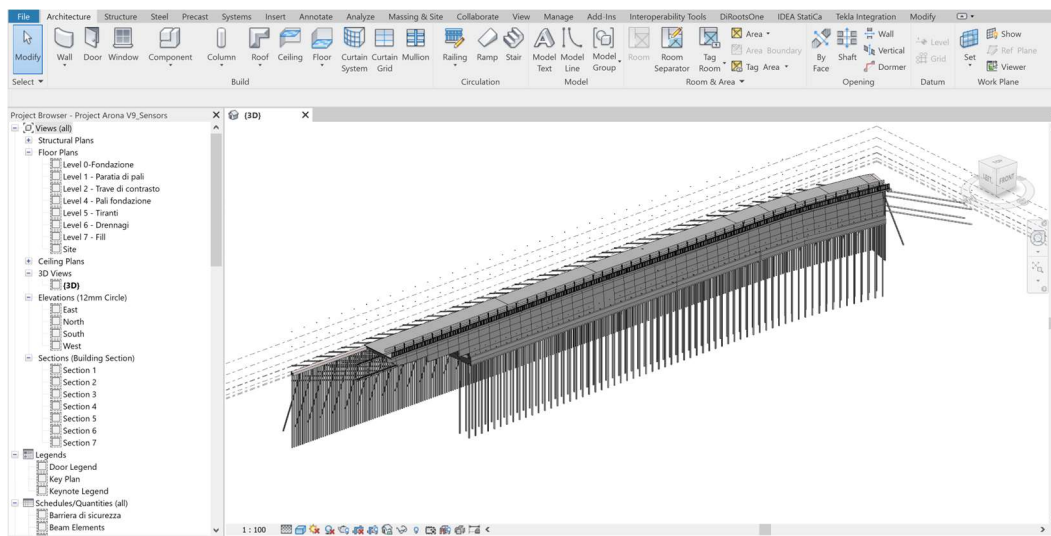


Figure 58. BIM

# 6. Conclusions

Digital Twin concept has high potential in aiding Infrastructure Asset Management. Its primary contribution lies in the shift from current REACTIVE maintenance practices to PREDICTIVE maintenance. This shift becomes possible with advancements in new technologies, particularly AI, which can be trained on large datasets gathered from sensors and classical inspections.

Because infrastructure is primarily publicly owned, it is appropriate to build a centralised platform for hosting the DT (similar to Tandem's role in this thesis) that is specifically designed for the public body concerned with Infrastructure Management. This platform should enable clear visualization of the asset's condition and integrate data from both traditional inspections and sensors. Moreover, this platform should be developed in accordance with principles of interoperability and open standards to ensure compatibility and facilitate seamless data integration across various systems.

DT aligns with the vision declared by EU BIM Task Group for Government BIM Programs. Specifically, it supports the objectives of delivering greater value for public money, stimulate innovation and growth in the construction and digital sectors and growing digital construction market.

DT enhances the benefits of BIM, identified by EU BIM Task Group, particularly in the Use Phase of the built asset and in both Construction and Digital sector:

	BUILT ASSETS		SECTORS	
	Delivery Phase	Use Phase	Construction	Digital
ECONOMIC	10% savings on time delivery	Lower maintenance costs  Lower operations costs	Improve sector competitiveness  Grow export capability	Grow digital services industry  Digital single market
ENVIRONMENTAL	Less site waste	Optimise operational energy use  Assess whole life-cycle analysis	Resource efficiency  Circular economy	Data infrastructure resource efficiency
SOCIAL	Higher standard of health and safety  Improved public consultation and engagement	Improve social outcomes (e.g. patient care, pupil learning)	Cleaner and safer jobs in construction  Attract next generation to the sector	Data Security  Attract digital talent to construction

Figure 59. BIM benefits identified by EU BIM Task Group [10]

Digital technologies such as BIM and DT will open new job opportunities in construction industry and make it more attractive for digital talent. This shift will help accelerate the construction industry toward the goal of Industry 4.0, especially when considering its current pace compared to more advanced sectors like manufacturing and aerospace.

Although the sensors were simulated in this thesis, the work is significant as it outlines the process of building a Digital Twin and clarifies its concept helping readers identify potential use cases. The process is scalable, meaning that it can be replicated to other built assets such as bridges, buildings etc. Future steps could include implementing real sensors, creating a data structure for storing information from classical inspections, and applying machine learning algorithms and other functions in Data/Model integration layer.

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