Politecnico di Torino

Master's Degree in Civil Engineering

Master of Science in Civil Engineering Thesis

BIM and Management of Infrastructural Facilities/Assets: Possible Solutions for HVAC Systems

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December 2021

Abstract

The following thesis deals with BIM methodology implementation in Taormina underground railway station. The thesis is focused on the modeling of the Mechanical, Electrical, and Plumbing equipment (MEP). The main goal of the thesis is to elaborate a model that follows as accurately as possible and finally propose a framework of the Building Information Modelling (BIM) - Building Management Systems (BMS) data conversion method to open JSON database to improve the handling and storage of the building data. So, the objective is after modeling the components of elements, to try to understand how to make the model available for the interaction with BMS systems. In another word, the focus of the thesis is to export the model in JSON language to make it available in any kind of platform for facility/asset management.

The thesis is divided into different chapters that follow the chronological order of development of the thesis. First, it includes some BIM methodology background, especially focused on the Building Information Modelling (BIM), Facility Management (FM), and integration between these two main platforms and then develops into a real application of this methodology. After a brief introduction, we will focus on the parametric modeling of the case study, and then export the model into the Navisworks for clash detection and finally pass into the Dynamo and try to export it in the JSON format that is linked to the Building Monitoring Systems (BMS). In conclusion, this thesis represents a practical application of the BIM methodology to a real case study.

Keywords: Building Information Modelling (BIM), Building Management System (BMS), JSON Language, Facility Management (FM), Maintenance.

Acknowledgments

Foremost, I would like to thank Professor Anna Osello for supervising this master thesis and also grateful for my thesis advisor Doctor Arianna Fonsati who has shared with me lots of good research ideas and taught me many useful skills, technical knowledge, and motivation during the period of this research.

Lastly, but most importantly, my gratitude to my family for the unconditional support, motivation, and all the efforts towards helping me achieve my goals, even from a distance.

Many thanks to all of you, I could not finish this thesis research without your help and effort.

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The fool do not think he is wise, but the wise man knows himself to be a fool.

[WILLIAM SHAKESPEARE, As You Like It]

1 Introduction

This chapter introduces an overview of BIM and FM. The research objectives and work methodology that the thesis will follow are presented as well.

1.1 Overview

BIM (Building Information Modeling) is a potential advancement in the field of Architecture, Engineering, and Construction (AEC) that first emerged in the early 2000s in the United States [16]. BIM technology enables the creation of a digitally accurate virtual model of a building, and it is regarded as a methodological process for construction projects as well as an innovation that adds significant improvements in the field of construction, throughout the work's life cycle, facilitating the development of the various construction steps of the project, from conception to construction and use, and finally demolition. In addition, the use of BIM improves production and efficiency. BIM technology was first used in building construction design, and as a result, many standards and software programs were designed and developed to aid interoperability. The use of InfraBIM has grown in popularity around the world as infrastructure projects have become more complicated [30].

Facilities Management (FM) is a broad profession that emerged in the 1970s in conjunction with the outsourcing of services in the United States of America (USA). Its key goals are to create a quality environment and to respond to businesses' need for a competent and specialized single-point-of-contact who can optimize all internal service management activities that support the business [4].

BIM is ready to provide a new degree of functionality for building FM as well as physical assets in an era of increasingly complex and current technologies. However, before implementing integrated BIM in FM, the power manager must thoroughly examine numerous aspects, including personnel management, communication protocols, procurement, cost control, risk management, and an overarching BIM strategy [3].

FM can be characterized in a variety of ways, including financial and asset management, operations and maintenance facilities, and even 'fast track' management and planning methods [43]. Data connections from design, construction, and renovation can be used for the operation and lifecycle management of buildings, assets, and facilities when FM and BIM are integrated.

By reading related material, such as Teicholz's book (2013) [46] "BIM for Facility Manager," the author obtained a broad understanding of BIM/FM integration and its benefits and challenges.

1.2   Research Objectives

The major goal of this thesis is to better comprehend the development of a BIM model (management and maintenance) with the integration of a field monitoring system for an underground railway station's ventilation and smoke control systems.

Integration with Computer-aided Facility Management systems (CAFM) to organize and update maintenance activities in connection to the model's components may be required when developing a BIM model for the management and maintenance of ventilation systems. The database of the management BIM model's potential lies in its capacity to be interrogated and exported in various forms, allowing it to connect to other information systems. The data, which is organized and structured according to a particular hierarchy, may thus be implemented and updated throughout the work's life cycle and shared among the many stakeholders.
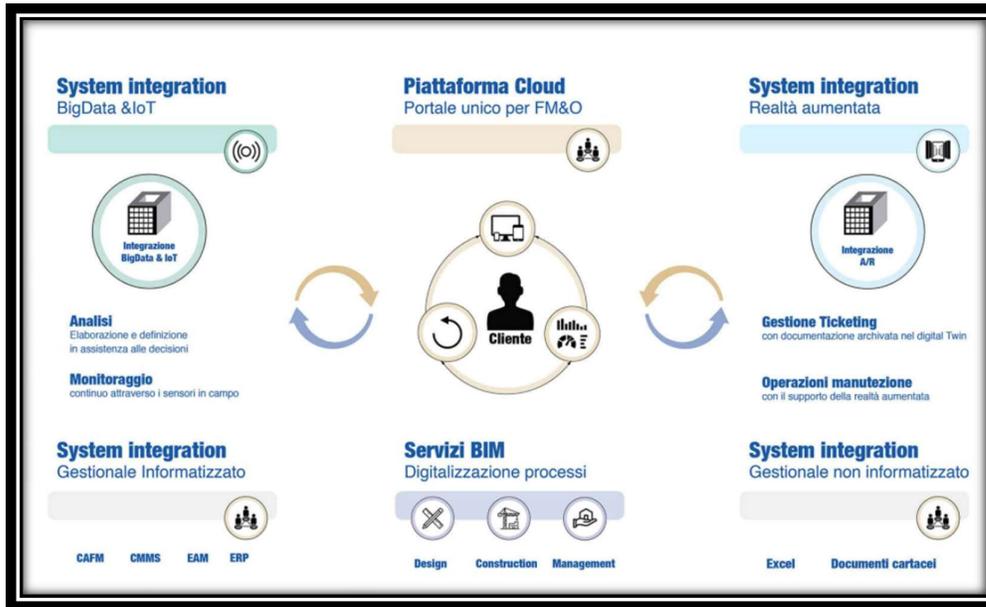
Figure 1 Cloud Platform for Facility Management Services

(Source: https://bimon.it/blog/piattaforma-cloud-facility-management/)

The management model created by combining BIM and CAFM platforms can be used as follows:

- integrated technical and documental knowledge database of the plants in question;
- the tool that simplifies the search for graphic and alphanumeric information;
- support to the design of new works;

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- mapping of spatial, functional, and hierarchical relations of the equipment;
- tool for traceability, analysis, design, and optimization of ordinary/extraordinary maintenance interventions;
- transfer of cognitive and maintenance know-how from the supplier to the ownership and coordination of the operators' activities;
- mapping and verification of safety aspects;
- a key tool for instruction at all levels, particularly through augmented and virtual reality applications.

1.2.1 Integration BIM - BMS - CMMS

Asset information must be easily accessible to improve the performance and efficiency of O&M activities. To facilitate those tasks and store asset data, FM currently uses two types of systems:

Both automated facility and real estate management are supported by the Computer-Aided Facilities Management (CAFM) technology. It is used to organize and monitor activities that occur across the facility by interacting with various platforms such as Computer-Aided Design (CAD), BIM models, and relational databases. It has a variety of facility management features, including space management, schedule repairs, preventive maintenance, and work orders monitoring.

The Computerized Maintenance Management Software (CMMS) system has as its objective the management of maintenance activities. It is regarded as a maintenance-only component of CAFM software. Engineers can have complete control over resource availability and work allocation with CMMS systems. A comprehensive maintenance process is provided by CMMS systems, which include resource records, parts/stock systems, and ordering systems.

Building Management Systems (BMS) are systems that monitor and regulate the equipment and electrical resources in a structure. Security systems, fire protection systems, electricity systems, temperature management, and other similar systems are examples of these. For further performance monitoring and maintenance management, BMS systems are frequently linked to other applications.
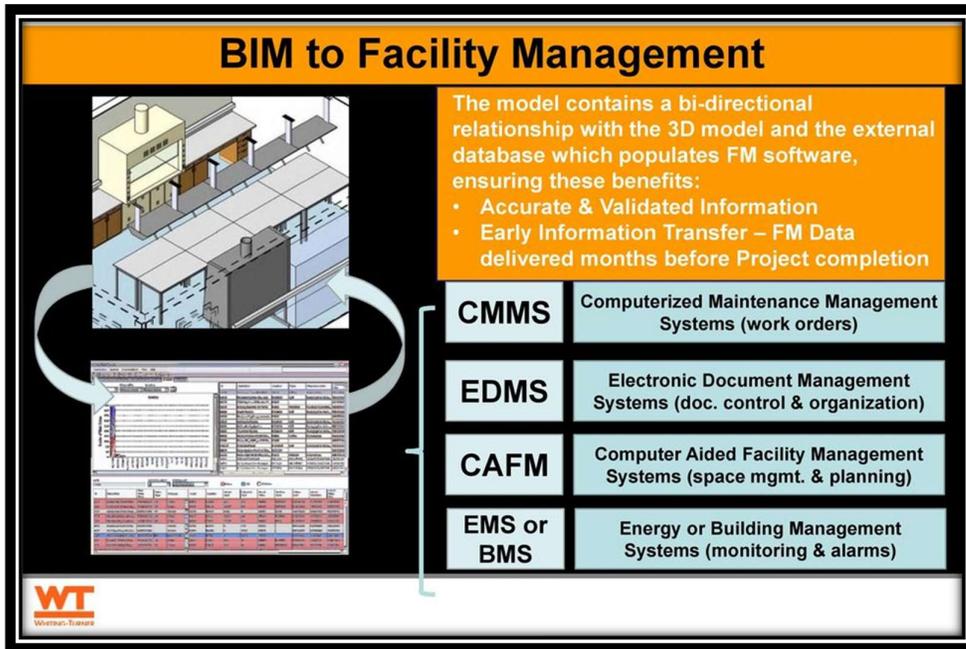
Figure 2 Integration BIM - BMS – CMMS

(Source: https://docplayer.net/22855063-Improve-efficiency-and-reduce-clutter-with-bim-for-fm.html)

1.2.2 Digital Twin

Starting with the concept of a management BIM model as an information repository that will be implemented over time, the development of a digital twin allows for the detection and monitoring of changes via physical components, as well as the specification of implementations via virtual components. The creation of a network of sensors for monitoring physical components is aimed at establishing a structure for dynamic knowledge control and its use inside the BIM environment for updating the management model.

The BIM model in Revit and the CMMS files both contain distinct information for the same power components and do not appear to be directly compatible. By combining the two resources, a more detailed and functional model of the building will be created, combining the visual advantages of the BIM model with the valuable maintenance information in the CMMS system. Extracting information from both files and creating a link between the data formats are required to make the two sets of data interoperable. The data from each source must be translated to a compatible format before Revit and CMMS may communicate information.

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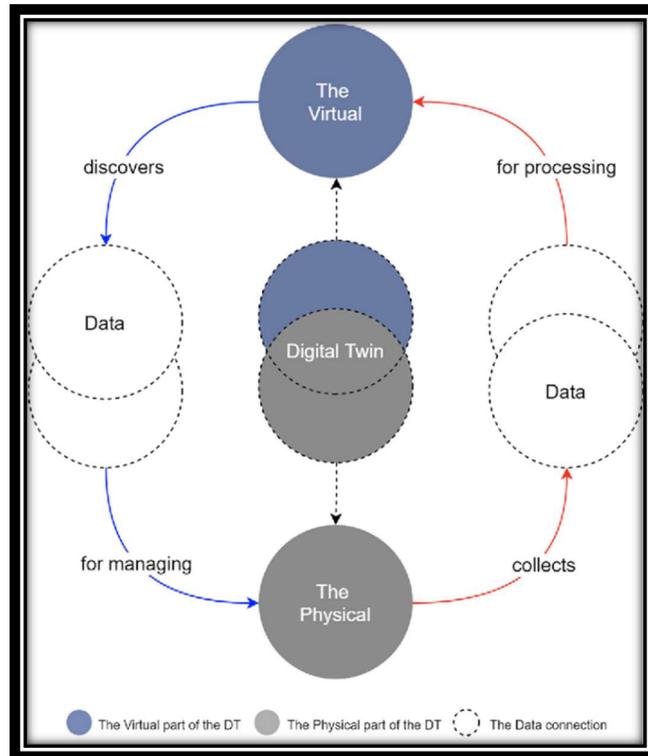
Figure 3 Digital Twin

The objective is to keep an eye on the ventilation systems and collect data from their many components. For example, if a system fails or is damaged, a type of alarm from building monitoring systems (BMS) should be sent to the building information model (BIM). To put it another way, if the systems fail, how can the failure or damage of the systems be reported by BMS and then filtered to show this alarm or problem mirrored in the BIM model, such as by highlighting the damaged BIM elements in red.

As a result, we must understand how information can be transferred from a physical asset to a digital model. It is important to implement a middleware system to integrate BIM authoring on one side and the CMMS system on the other. One option is to use the JSON language, which is a programming language that may be used to exchange data between these two main domains, BIM authoring, and the CMMS system. Because it is not possible or useful to create a direct connection between BIM authoring and CMMS system since data from BIM authoring is not properly set to be integrated with this platform and also requires different integration of two types of databases, a middleware system is

required to create the connection between BIM model and what is monitored from physical assets.

The time- and computational-intensive analytical process can be aided by proper data formatting and integration of BIM-BMS data. Data-exchange formats like JavaScript Object Notation (JSON) are not only simple to create and interpret, but also for humans and machines to read. The capacity to convert large, dynamic datasets into a language-independent text format can be applied to both difficult mathematical procedures and pattern visualization for FM specialists, occupants, and owners [45]. Simple data formats, such as JSON, are frequently used for transferring highly dynamic data [1], such as sensor data, since they are simple to read and interpret with little to no storage needs, and queries to massive operational databases are faster. When describing complicated things with basic data, JSON's simplicity is favored [25].
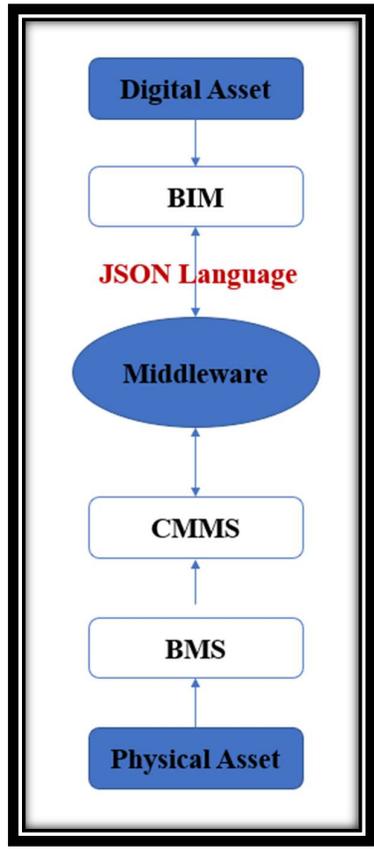
Figure 4 Integration Between BIM and CMMS

The core objective, as indicated in Figure 4, is to export data and parameters using JSON language to combine a BIM model with a BMS system. This gap was discovered through study and the researcher's reflections on day-to-day experiences. A case study of an underground railway station is also carried out to see if combining Revit with a CMMS system is feasible.

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1.3 Case Study

This thesis' case study is a type of typological underground railway station. It is not permitted to specify the project and related documents in public because the entire project has not yet been completed. The author will produce a part of the disciplinary model relating to the ventilation system and the other model including the fire protection system is created in the thesis of colleague Taraneh Memar. The following section will go over some basic ideas in BIM methodology and how they are used in an infrastructure case study.

1.3.1 MEP Systems

The mechanical system, often known as the Heating, Ventilation, and Air Conditioning (HVAC) systems, of an underground railway station, is the subject of this thesis.

MEP stands for mechanical, electrical, and plumbing engineering. As a result, the MEP model is the model that contains all of the information about a project's design, construction, interventions, and maintenance of a facility's systems and subsystems. The MEP systems in the facilities not only support our everyday demands but also play a critical part in the construction of a comfortable environment inside the structures. MEP refers to everything that has to do with the non-structural aspects of a structure's functioning. MEP engineering is a significant aspect of a facility and has a direct impact on efficiency, safety, and energy use [51].

MEP engineers are in charge of making the interiors of buildings comfortable. These engineers must deal with a variety of issues, including spatial coordination, the efficient operation of parts in a system or installation, as well as testing and maintenance procedures [19].

All systems linked to heating, ventilation, and air conditioning (HVAC) are considered mechanical systems. Other systems, such as lifts, escalators, or other forms of transportation, can, nevertheless, be included. Their goal is to keep the air quality high by managing temperature and humidity. Oversizing mechanical systems have undesirable implications, such as temperature fluctuations, rapid degradation, and poor humidity control [47].

MEP systems have become increasingly complex throughout time to meet advanced design and the needs of new facilities, necessitating additional space and coordination for installation. On the other hand, the amount of space available in buildings is constrained by cost and energy efficiency concerns. As a result, coordinating MEP systems in large buildings and infrastructures has become a particularly tough challenge [31].

Mechanical BIM MEP design was born and developed at the same time as architectural and structural BIM design models; in fact, only an overview of the building-plant system allows for evaluation of the dimensional and spatial coherence of the plants within buildings, as well as the avoidance of errors and interference [44].

The ability to combine a BIM MEP model with an architectural/structural BIM model is the starting point for a basic plant solution, which then allows for the creation and modification of MEP 3D plant structures (ducts, pipes, emission terminals) based on the architectural model, allowing for perfect coordination with the virtual model of the building and its modifications. From the preliminary through the final management and management phases of the work, the value of an integrated design is seen in terms of cost savings, time, and control over the project [29].

1.4 Work Methodology

The MEP model is created in the early step using Autodesk Revit 2020. After that, the model is exported as a Navisworks NWC file. Using the Clash Detective tool in Autodesk Navisworks Manage 2020, we can check for any clashes between the ventilation system model and other models, such as the fire protection system (created in the thesis of colleague Taraneh Memar). As a result, any geometric interferences between the models can be highlighted via clash detection. In the event of a clash or error, the findings are reported, and the model must then be modified. If there are no clashes, we can send the model into Dynamo and attempt to export it in the JavaScript Object Notation (JSON) format that is linked to the Building Monitoring Systems (BMS). The JSON format is a lightweight data-interchange format that is simple to read and write for people and easy to understand and create for machines.

The flowchart in Figure 5 depicts the technique used during the current thesis study, and it is summarized in the following main steps:

- Input: Collection of input data about the projects;
- Modeling: create the MEP model in Autodesk Revit 2020;
- Export: Start to export the model in Autodesk Navisworks Manage 2020;
- Validation: Check any interferences via Clash Detection;
- Output: Using Dynamo to export into the JSON format.

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INPUT
- Information for the Organization of Work
- Project Documents

MODELING
- Three-Dimensional Digital Information Model of the Ventilation System

EXPORT
- Three-Dimensional Model into Navisworks

VALIDATION
- Clash Detection for the Interferences between Disciplinary Models

OUTPUT
- JSON Format Using Dynamo Script
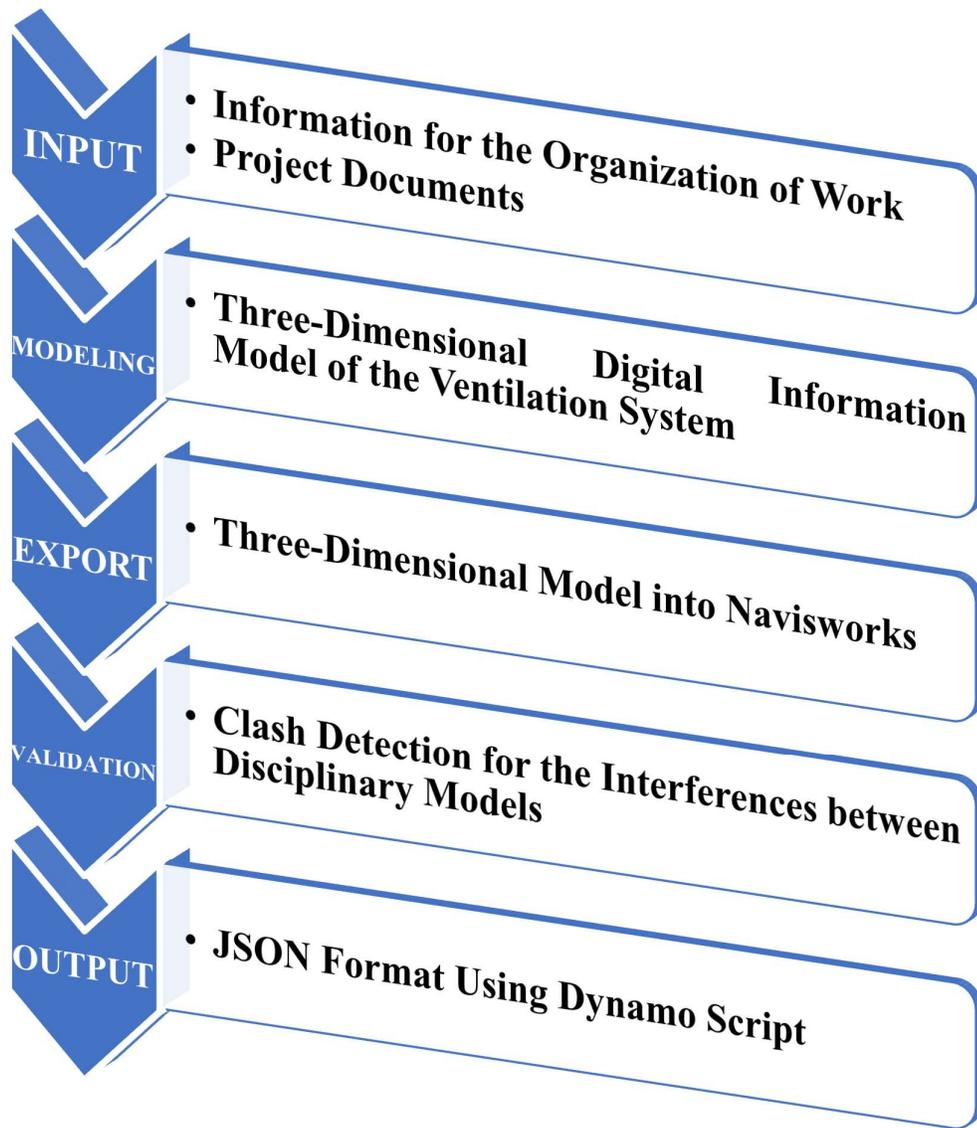
Figure 5 Methodology Workflow

2   Literature Review

This chapter summarizes the extant literature on the thesis's topic area. The definition and procedure of developing building information modeling are introduced in the first section of the chapter. The BIM dimensions, interoperability between software programs, level of development for information models, data sharing environment, and finally the usage of BIM for facility/asset management are covered in the following sections.

2.1   BIM Definition

BIM stands for Building Information Modeling. Dr. Charles Eastman of Georgia Institute provided an early definition of BIM. "Building information modeling combines geometric model data, functional needs and capabilities, and piece behavior data into a single, interconnected description of a building project throughout its lifecycle. It also contains process data for construction schedules and production processes" [21].

BIM, according to the National Building Information Modeling Standard (NBIMS), is "an improved planning, design, construction, operation, and maintenance process employing a standardized machine-readable information model for every facility, new or old, that comprises all relevant information created or gathered by this facility in a format that may be used by anyone at any time during its life cycle" [39].

"Building Information Modeling (BIM) could be a combination of interacting policies, processes, and technologies providing a plan to manage the fundamental building design and project data in digital format throughout the life-cycle of the building," according to another definition [14].

Figure 6 illustrates a different meaning of BIM.
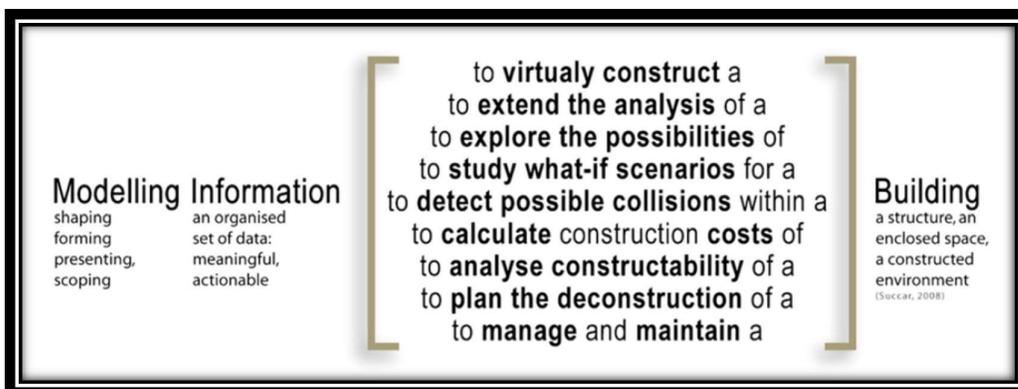
Figure 6 Some Common Connotations of Multiple BIM Terms [14]

Increased efforts are being made to take advantage of BIM's benefits to improve the operation and maintenance phases of a building's lifetime [18]. With the advent of smart building technologies, several structures are being supplied with intelligent building automation systems that use a variety of sensors to gather vast amounts of data [33]. It is possible to combine real-time data collected and aggregated by sensors with geographical information retrieved from a BIM model. This integration may be beneficial in assessing the performance of building systems and in making decisions concerning facility management and operations [33].

2.2 BIM Dimensions

BIM is also known as n-D modeling, and Oraee et al. characterized it as a "technological and management methodology" [7]. BIM was first employed because of its digital parametric modeling capabilities, which demonstrated its superiority over CAD. However, BIM eventually stopped addressing the dimension associated with geometric modeling, instead of adopting an n-D approach: time was added as a fourth dimension, and costs were added as a fifth. The sixth component of BIM is sustainability, project life cycle, energy, safety, facility, and construction management. Sustainability and facility management are options for the seventh dimension, while some publications refer to the eighth dimension of BIM as accident prevention, for example [4].

The following classification is based on the UNI 11337 standards, which are voluntary technical standards adopted in the Italian context for the digital management of construction information processes:

- 3D - Three-dimensional modeling: the building object is displayed during its entire life cycle using the "traditional" 3D visual model. It is feasible to successfully manage modeling in this way, eliminating errors in both the design and execution and maintenance phases;
- 4D - Time management: this dimension allows for the planning of time management, or a sort of associated work schedule, to the model to decrease the risk of process disruption during the project's life cycles. Furthermore, during the life of the building, the times and coordination of the personnel are engaged;
- 5D - Economic management: using a 3D model and 4D BIM, the fifth dimension enables for complete cost control throughout time. This option enables for the creation of efficient structures;
- 6D - Life cycle and maintenance: the sixth dimension enables the management and maintenance of a construction object over its entire life cycle to be optimized;

- 7D - Sustainability: this dimension includes an analysis of the building's energy consumption. Analyzing the energy performance from the beginning enables the implementation of solutions that ensure lower energy consumption and, as a result, project sustainability.

Figure 7 shows the dimensions of BIM.
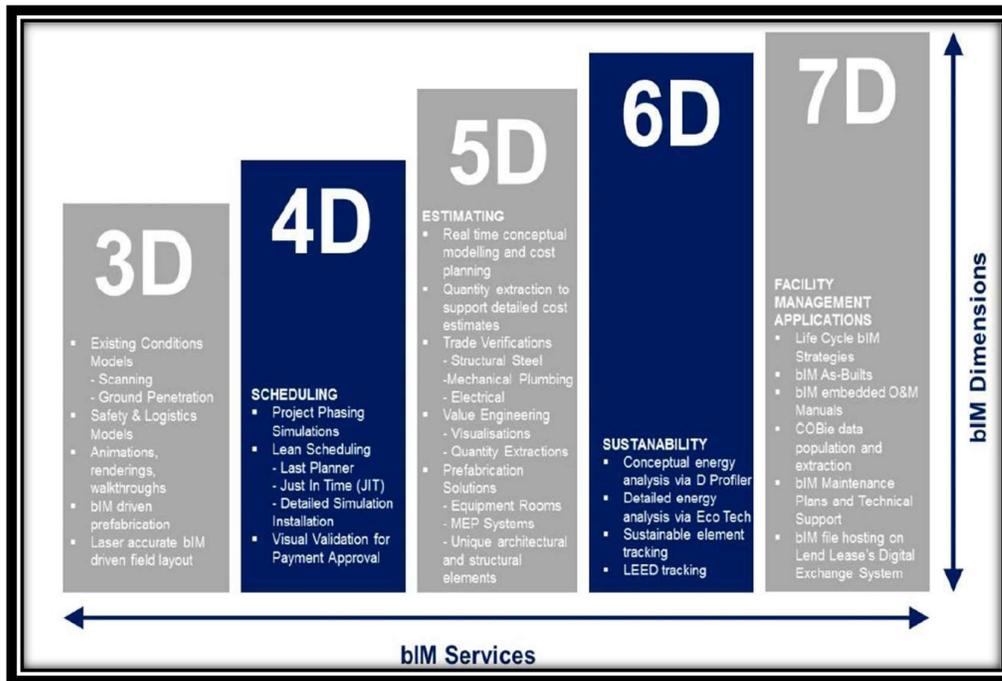
Figure 7 The Dimensions of BIM

(Source: http://www.pinterest.com/pin/849491548436309669//?d=t&mt=login)

2.3 Interoperability

The information models created or modeled throughout the BIM process must be shared among software programs. From the construction phase to the end of the structure's useful life and demolition phase, interoperability allows all specialists involved in the design to have access to all relevant information and share it [17].

The National Building Information Modeling Standard (NBIMS) states that adopting an open data model of facilities and a corresponding interface to that data model for each participating application is required for successful software interoperability in the capital facilities sector. The software applications of each industry can be made interoperable if the adopted data model has industry-wide properties (i.e., represents the complete facilities life cycle) [39].
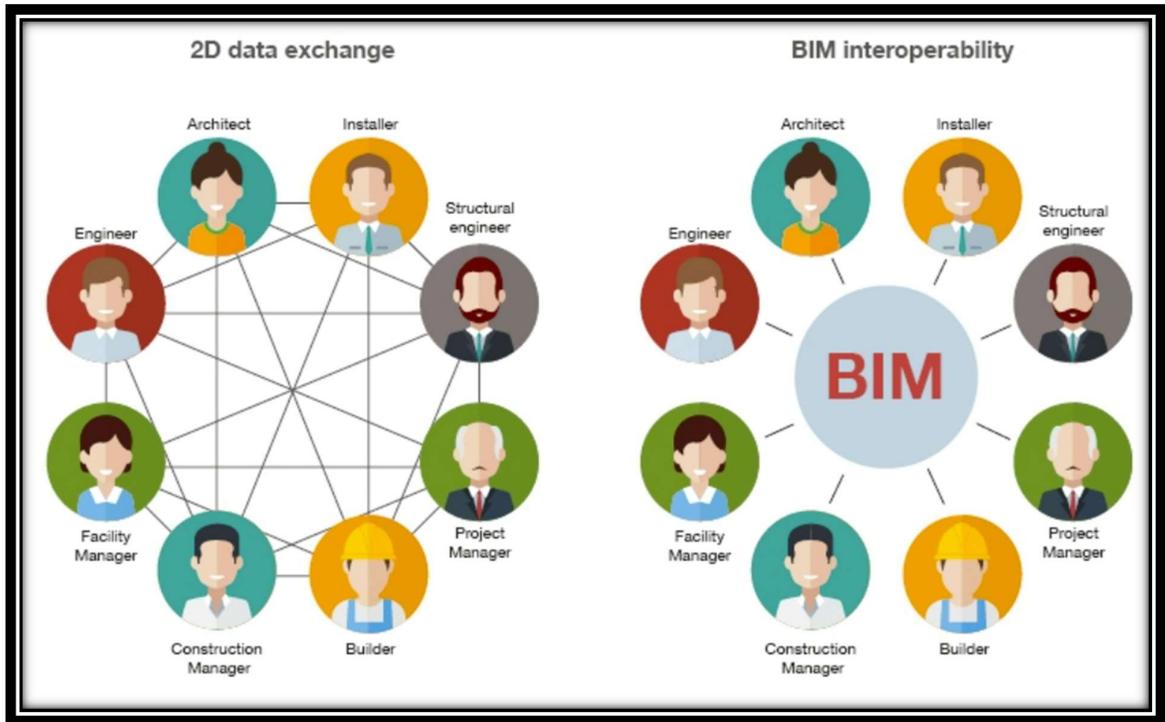
Figure 8 The Interoperability Concept

IFC Standard

BuildingSMART, a worldwide organization, maintains and develops the Industry Foundation Classes (IFC) file format. The IFC is open-source international standards, allowing them to be readily adopted by software [30]. IFC is a software interoperability solution that allows different software programs to communicate with one another. Throughout the life cycle of a building, IFC increases communication, productivity, delivery time, and quality. With established standards for common objects in the construction sector, it prevents data loss while transmission from one application to another.

UNI EN ISO 19650

The Italian versions of ISO, UNI EN ISO 19650-1: 2019, and UNI EN ISO 19650-2: 2019, are the international standards to be referred to in the context of BIM design. Part one includes background information and defines the ISO 19650 principles for information management. It also consists of a series of recommendations for the actors participating in the design process that is always related to information management, such as sharing, registration, updating, and organizing. The standard covers the whole work life cycle, including strategic

planning, preliminary design, engineering, development, assignment and construction documentation preparation, daily operation, maintenance, restoration, and repair. The standard can also be adjusted to fit any size or complexity of the structure. Part two lays out the requirements for information management and exchange during the work's delivery phase. Regardless of the procurement approach, this section can apply to all types of construction and all types and sizes of organizations. These international standards apply in conjunction with UNI 11337, which is a complimentary standard.

UNI 11337

The UNI 11337 standard is a ten-part document that addresses the management of construction information processes, specifically models, documents, and information objects for products and processes, model evolution and information development, and flow information in digital processes.

2.4 LOD/LOIN

The Level of Development (LOD) specification allows industry professionals to describe how an element's geometry and accompanying information have changed over time. It reflects how much various members of the team can rely on information related to a specific element. In reality, LODs indicate the quantity of valuable information required to meet the BIM operator's expectations during each design phase [35].

In recent years, the construction industry has paid more attention to information management, thanks in part to the continued development of BIM systems. A project's management is divided into numerous phases, ranging from design to maintenance, each of which necessitates a particular amount of data [35]. The data's Level Of Development (LOD) is determined by the project team and is provided in the Model Production and Delivery Table (MPDT). The LODS enables the precise definition of the depth of information contained in the model.

The American Institute of Architects (AIA) initially introduced LOD in 2008, when it defined multiple levels of development to specify detailed levels in a BIM model [9].

- LOD 100 – Conceptual: A symbol or other general representation of the Model Element may be graphically depicted in the Model. Other Model Elements can be used to get information about the Model Element. Any data derived from LOD 100 elements must be considered approximate;
- LOD 200 - Approximate Geometry: The Model Element is graphically represented as a generic system, object, or assembly within the Model, with

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approximate quantities, size, shape, location, and orientation. Any data derived from LOD 200 elements must be considered approximate;

- LOD 300 - Precise Geometry: The Model Element is graphically represented as a specific system, object, or assembly within the Model in terms of quantity, size, shape, location, and orientation Model. The Model Element can also have non-graphic data associated with it. The project origin has been determined, and the element has been precisely positioned to the project origin;

- LOD 350 - Precise Geometry with Connections: The Model Element is graphically represented as a specific system, object, or assembly within the Model in terms of quantity, size, shape, location, orientation, and interfaces with other building systems. The Model Element can also have non-graphic data associated with it;

- LOD 400- Fabrication-ready Geometry: The Model Element is graphically represented within the Model as a specific system, object, or assembly with detailing, fabrication, assembly, and installation information in terms of size, shape, location, quantity, and orientation. The Model Element can also have non-graphic data associated with it;

- LOD 500 - Operational/As-built Models: The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Model Elements can also have non-graphic data connected to them.
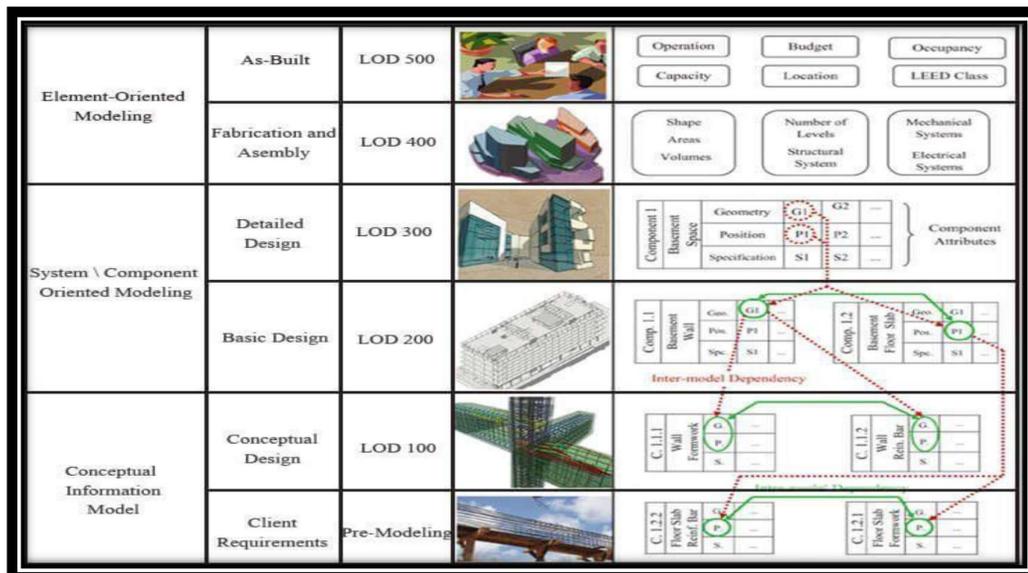

Figure 9 Fundamental Chart of Level of Detail

(Source: https://www.srinsofttech.com/bim-level-of-development-lod-300-400-500.html)

In Italy, the LOD is defined by the UNI 11337-4 of 2017, which states that a digital object's level of development is determined by the nature, quantity, quality, and stability of the data and information that make up the object. The LOG (Level of development of Geometric object attributes) and LOI (Level of development of Informative objects attributes) classifications are used. UNI 11337, unlike the AIA's five levels, uses an alphabetical scale to identify the LODs:

- LOD A: the entities are graphically represented using a symbolic geometric system or a representation of genre used as a reference with no geometric constraints. The quantitative and qualitative features are indicative;
- LOD B: the entities are graphically simulated as a general geometric system or a line geometry. The quantitative and qualitative attributes are approximations;
- LOD C: the entities are graphically simulated into a specific geometric system. The qualitative and quantitative features are defined generically within the limits of current legislation and reference technical standards, and they can be applied to a variety of related entities;
- LOD D: the entities are graphically simulated as a complex geometric system. The qualitative and quantitative qualities are unique to a group of similar products. The interface with various specialized construction systems is established, as well as the approximate operational and maintenance dimensions;
- LOD E: entities are graphically simulated as a geometric system. The quantitative and qualitative features are unique to a single manufacturing system that is connected to a certain product. The level of detail for production, assembly, and installation, as well as exact measurements for maneuverability and maintenance, is specified;
- LOD F: the objects represent the virtualization of the unique production system that was performed/built on-site. The quantitative and qualitative features of the product laid and installed are those peculiar to the single production system. For each unique product, the management, maintenance and/or repair, and replacement actions to be carried out during the work's life cycle are defined;
- LOD G: objects represent the updated virtualization of an entity's actual state at a given point in time. For each product, the management, maintenance and/or repair, and replacement actions to be carried out during the work's life cycle are defined. [34]

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	LOD A	LOD B	LOD C	LOD D	LOD E	LOD F	LOD G
Geometria	Elemento architettonico verticale o pseudoverticale rappresentato mediante un simbolo 2D.	Solido generico per rappresentazione elemento architettonico verticale o pseudoverticale con forma, spessore e posizione approssimata.	Elemento architettonico (sistema e sottosistema) verticale o pseudoverticale rappresentato con ingombri calcolati secondo la normativa tecnica.	Elemento architettonico verticale o pseudoverticale rappresentato mediante un solido avente dimensioni pari alle dimensioni reali. Sono modellate tutte le stratigrafie.	Elemento architettonico verticale o pseudoverticale rappresentato mediante un solido avente dimensioni pari alle dimensioni reali. Sono incluse tutte le stratigrafie, i dati specifici del fornitore dei materiali e le finiture.	Oggetto parete.	Oggetto parete.
Oggetto	Grafica 2D (linee e campiture 2D)	Solido 3D	Solido 3D strutturato	Solido 3D complesso	Solido 3D complesso	Solidi parete completa	Solidi parete
Caratteristiche	• Posizionamento di massima	• Semplici geometrie di ingombro	• Spessore • Lunghezza • Larghezza • Volume • Definizione dei materiali	• Definizione stratigrafie dettagliata • Spessori componenti • Struttura • Isolamento • Camera d'aria	• Tipo finitura interna • Superficie finitura interna • Tipo finitura esterna • Superficie finitura esterna	• Manuale di manutenzione • Classificazione (UNI 8290, CSI, etc.) • Certificazioni di prodotto	• Data di manutenzione

Figure 10 LOD, UNI 11337

(Source: allplan.com)

Information models are made up of a set of qualities as well as geometric data (type of elements, materials, characteristics, performance, etc.). As a result, the model can be classified according to its graphic detail and information. In addition, the inhomogeneity of the definition and content of the LODs, which differ by country and standard, is taken into account. These considerations led to the introduction of a new definition in ISO 19650 called "Level of Information Need," or LOIN, which uses terminology that emphasizes and reiterates, on the one hand, the importance of information content regardless of its nature, and on the other hand, the need, number, and type of information contained in the model are limited to those.

2.5 Common Data Environment

BIM is naturally efficient since it brings project partners together to access and exchange information through a single database structured with numerous interfaces [36]. This environment is referred to as CDE (Common Data Environment) in several nations, according to British PAS 1192 regulations. The CDE is a virtual environment that allows users to access complete and up-to-date project information and is used to improve BIM interoperability [12].

According to British Standard BS 1192-2007, a CDE technique should be used to allow information to be shared across all project team members. A CDE is essentially an online platform where a project team may gather, manage, and share information. As a result, the CDE is necessary for more successfully carrying out

restructuring, maintenance, and new construction operations, with results that meet the quality, time, and cost expectations outlined in the initial plan.

The data-sharing environment in Italy is known as ACDat (Ambiente di Condivisione Dati), and it is defined as follows by art. 2 of DM 560/2017: "A digital environment for the organized collection and sharing of data relating to a work and structured in information relating to digital models and documents primarily attributable to them, based on an IT infrastructure whose sharing is governed by precise security systems for access, traceability, and historical succession of the changes made to the information contents, of conservation over time and relative accessibility of the information assets contained, of the definition of responsibilities in the elaboration and protection of intellectual property." [13]

Because this project is a mega project that covers Architecture, MEP, and Structural design, it involves various students who have been working on it. The CDE platform in this case is Autodesk Docs.

2.6   BIM and Facility/Asset Management

Facilities management is a multidisciplinary field that assures the built environment's functionality by integrating people, processes, and technology. The use of BIM in facilities management is gaining popularity, especially for the aim of providing accurate, consistent, and up-to-date building facility information. Operation, lease occupancy, maintenance, cleaning, and other FM activities are common (BIM DICTIONARY). Facility managers utilize computer maintenance management systems (CMMS) to keep their building's information up to date [41].

Figure 11 Facility Management

(Source: https://www.pinterest.com/explore/facility-management)

Buildings are becoming increasingly complex, necessitating the use of facility information to maintain and run them [18]. Such data can be used to properly track components, detect inefficiencies in building operations, and respond to client requirements [23].

Existing facility management and maintenance planning and implementation approaches are mostly reliant on the personal experience, expertise, and intuition of facility management staff or tradespeople. Typically, facility managers do not have access to records that aid them in recognizing or diagnosing problems, enhancing their understanding of previous problem histories, or maintenance history information for the component they are managing [2].

In a review of BIM for sustainability, Chong, Lee, and Wang concluded that BIM can help to decrease inefficiencies in existing buildings with real-time FM-enabled BIM systems to save energy [28].

Gao & Pishdad-Bozorgi (2018) observed BIM application trends in building operation, maintenance, and repair, as well as limitations in understanding FM process workflows and how they relate to BIM [24].

Other FM-enabled BIM application areas identified by Bercerik-Gerber et al. in their survey include finding building components, simplifying real-time data access, checking maintainability, updating digital assets, space management, and energy usage control [11].

Although interoperability between software systems has been examined, Edirisinghe et al. (2017) analyzed and categorized several research articles, found research trends, and concluded that data gathering strategies are still lacking [22].

Kassem et al. (2015) investigated the obstacles and benefits of BIM in FM applications, concluding that there is a lack of interoperability and standards issues that could prevent data from being transferred from BIM to FM systems [32].

Aziz et al. (2016) examined BIM in FM applications that affect workplace Quality Of Life (QOL), concluding that retrieved data might be used and directed to complete facility management activities, resulting in long-term advantages [10].

Yalcinkaya and Singh (2016a) discussed the research on BIM and FM integration, including the background, benefits, and drawbacks of COBie, and, in particular, VisualCOBie, a project to improve COBie data display. COBie is a digital facility data delivery standard. It was created to address industry issues such as data transformation inefficiencies among different disciplines in AEC projects, and inadequate user experience when examining and querying facility data, and others [50].

Hu et al. (2018) emphasized the importance of retrieving MEP system information for an accurate assessment throughout the Operation and Maintenance (O&M) phase. The authors created an O&M management system that enables the digitalization of MEP data for revision and use during the O&M phase [27].

Motawa and Almarshad (2013) designed a system architecture to contrast information retrieved from a BIM model with a system that captures building maintenance information. By supervising the maintenance activities taken on existing objects, traceability is available [37].

On a database level, Liu and Issa focused on automatic bidirectional interactions between Computerized Maintenance Management Systems (CMMS) and BIM models. Data can be transmitted bi-directionally between BIM models and the CMMS system using operations on the BIM database. A template for bi-directional data transfer between design and facilities management software was created [42].

Ignatov and Gade looked into how uniform data formatting can help with BIM and sensor data management by making it faster, easier, and more realistic. They presented a data handling framework that would format and link the various datasets into simple and easy-to-read data objects using data conversion and mapping methods. They then created a prototype, exhibited BIM and sensor database management and linkage, and analyzed and visualized the BIM-

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enhanced and highly dynamic sensor record data in a simulated BMS environment.

Teicholz, P. (Ed.) (2013) defines BIM/FM Integration benefits in his book "BIM for facility managers." BIM is widely used in the AEC industry, particularly throughout the design and construction phases of a project. The implementation of BIM in FM, on the other hand, is not that simple. When FM joins BIM, the integration process begins to make the FM process easier. BIM, as a rich database container, could provide facility managers with a better approach to process data, resulting in a significant increase in work performance [46].
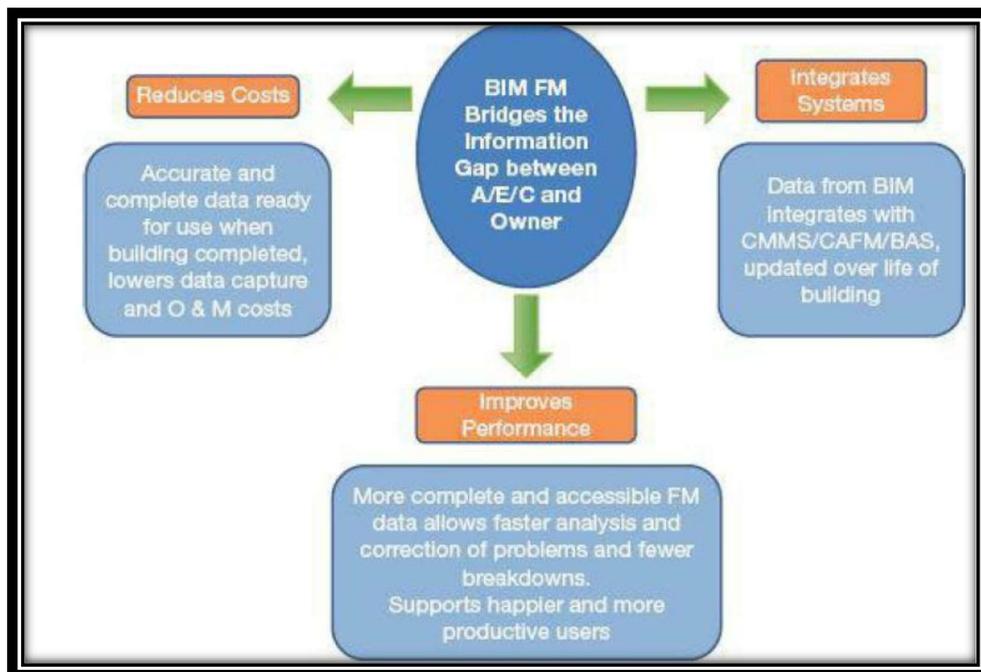
Figure 12 Summary of the Main Benefits Achieved by BIM/FM Integration [46]

Four options for BIM/FM integration are presented in the book [46]:

The first involves entering facility information into a spreadsheet and then importing it into a specific FM system. This solution is simple to implement and might be used for small projects right away. However, the disadvantages are clear: because the data is entered manually without any validation, this strategy has a high risk of inaccuracy.

The second option is to use COBie. COBie defines facility data in each organized form, with distinct workbooks representing different facility categories.

The third method involves using an external link between the BIM and FM systems.

A fourth alternative is to use the BIM Application Programming Interface (API) to directly connect an FM system to a BIM modeling system. This offers a dynamic and immediate connection between BIM and FM, allowing BIM data to be translated and mapped to the FM system.

There are also third-party programs available for data transfer. Dynamo is a Revit open-source visual programming plugin [20]. In a recent project, Dynamo was utilized to extract BIM information for automatic work order scheduling utilizing a facilities management system [49].

Previous studies and industry implementation have shown that integrating BIM with facilities management has numerous advantages. These advantages demonstrate the need for successful BIM application in facility management and how this can benefit facility owners. The following are some of the benefits and interests of utilizing BIM for FM in general [3] [40]:

- Improved FM efficiency, effectiveness, and speed: This is accomplished by giving information that can be exchanged rapidly and efficiently by AECO contractors;
- The results of a more straightforward simulation: For upgrade and refurbishment projects, BIM assists in the careful analysis of design and, as a result, the easier and more orderly implementation of simulation;
- Streamlined maintenance: Entering the product and asset information required for preventative maintenance is the most difficult part of designing a maintenance program. BIM models can save months of work by accurately populating maintenance systems with information about building equipment;
- Efficient energy use: Facility managers can utilize BIM technology to study and compare various alternative energy sources to reduce the environmental effect and operational costs;
- More cost-effective and simple modifications: The BIM model gives one or a few simple procedures for representing a building's three-dimensional properties. Information regarding the current state of the building helps reduce the cost and complexity of renovations;
- Building equipment management: Maintain a suitable inventory of building equipment using information from the BIM model to avoid the time-consuming and costly task of creating a coordinated maintenance program;
- Better space management: With the help of a BIM model, facility managers may create inventory space and make optimum use of existing building property. This will save money by eliminating excessive expenses;

- Building lifecycle management: A model developed by the designer and updated over time by the construction phase can be supplied to the owner as a 'Built' or 'As Built' model. All specifications, operating and maintenance (O & M) manuals, and information assurance will be stored in the model, which will be beneficial for future maintenance. This eliminates issues that may arise presently if the O & M documentation is misplaced or stored in a distant location.

3   Information Modeling

The procedure of developing a digital information model based on parametric objects of the underground railway station's HVAC system will be illustrated in this chapter.

3.1   Input Data

After a preliminary study of the input data, the modeling phase began. The Autodesk Docs platform is employed as the data sharing environment, as previously stated. Autodesk Docs is a single collaborative platform that provides the complete project lifecycle, from design to construction. Members of the project team can simply transfer information from one phase to the next, maintaining all of the project's information and data in one place [5].
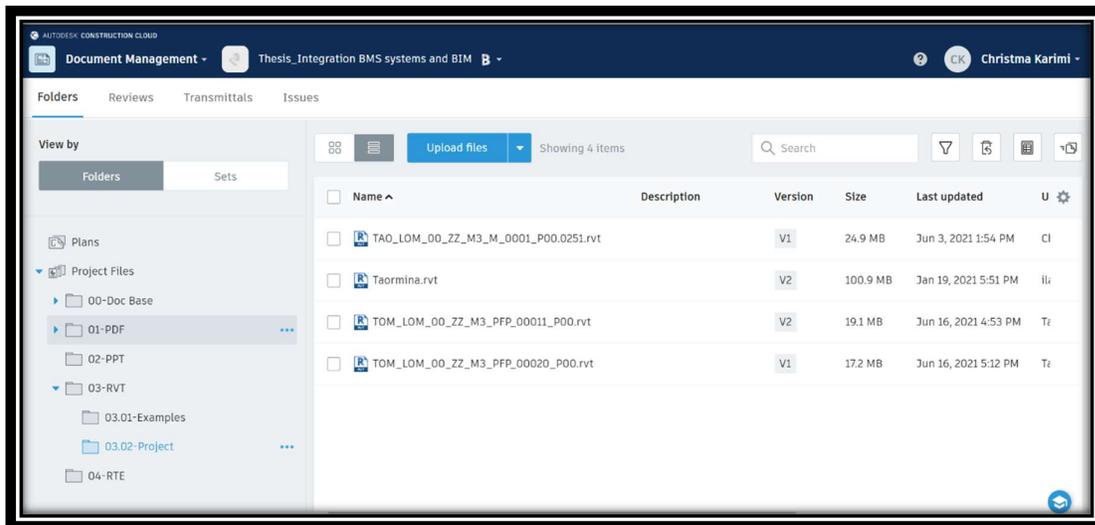
Figure 13 Data Sharing Environment, Autodesk Docs

3.1.1   Name Coding

The name coding of documents and project parameters is a critical part of the BIM Execution Plan (BEP) that must be explicitly stated from the beginning. Furthermore, all shared material must follow pre-established coding principles to promote interoperability. The coding instructions are contained in a text file that is accessible to all members of the project team. Table 1 shows the coding process and therefore the project file related to this thesis work has been renamed to the following:

TAO_LOM_00_ZZ_M3_M_0001_P00

Table 1 Project File Encoding

TAO	Project acronym: TAORMINA
LOM	Responsible organization acronym: Lombardi Ingegneria srl
00	This indicates that the project is not divided into zones or volumes
ZZ	Multilevel project
M3	3D model file
M	Discipline: Mechanical
0001	Indicates the first file in the series
P00	This indicates that the file has not been validated

3.2   Tools

BIM software is now broadly applied by a variety of construction organizations, both large and small, particularly in the engineering sector. As previously stated, the Autodesk Revit 2020 authoring platform was employed for this thesis. Architects, landscape architects, structural engineers, mechanical, electrical, and plumbing (MEP) engineers, designers, and contractors can utilize Autodesk Revit to produce a single model that all disciplines and professions can use to accomplish their work.

To improve data sharing between the project's users, the parametric digital model is created on Revit 2020, although Revit 2021 is already available on the market. The architectural and structural models had previously been developed in the 2020 version; it would have been feasible to update them to the 2021 version, but they would no longer be convertible to the 2020 version; as a result, it has been decided to preserve the 2020 version for the MEP model as well.

3.3   Template

The Template is a Revit workspace that includes a set of design settings, families, annotations, and labels that define the project in detail [26]. The Revit modeler requests that a project template file be opened before beginning a new project. The RTE project templates are the starting point for new models since they include view templates, loaded families, and further defined settings (such units, fill patterns, line styles, line weights, view scales, and more) [7].

Default templates can be used or customized templates can be created. To be consistent with the rest of the design, the same customized templates that were produced for modeling the other facilities in the same railway project were used in this thesis. The company's architects and engineers have already prepared **STD_LOM_00_ZZ_TE_FMEP_0001_P00.rte**, a basic customized template for ventilation and air conditioning systems.

In the next sections, the template setup allows for the defining of rules and specific details.

3.3.1 Revit links

The templates for all disciplines are available in the CDE, inside the folder containing the Revit files. It was decided to link Revit models with shared coordinates to be consistent with the architectural structural model and to make MEP modeling activities easier. The first step is to link the architectural structural design by selecting the architectural structural template from the Insert menu > Link Revit. In the dialog, it is required to select the name and type of the desired file to link and the desired option among the available ones related to the positioning. By clicking on Insert > Manage Links or on Manage > Manage Links, a tab opens, Figure 16, which allows to view all the files link and modify some properties.
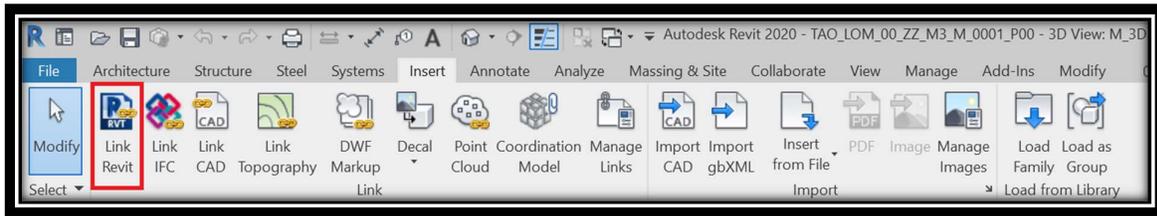
Figure 14 Link Revit, Revit

Figure 15 Import/Link RVT, Revit
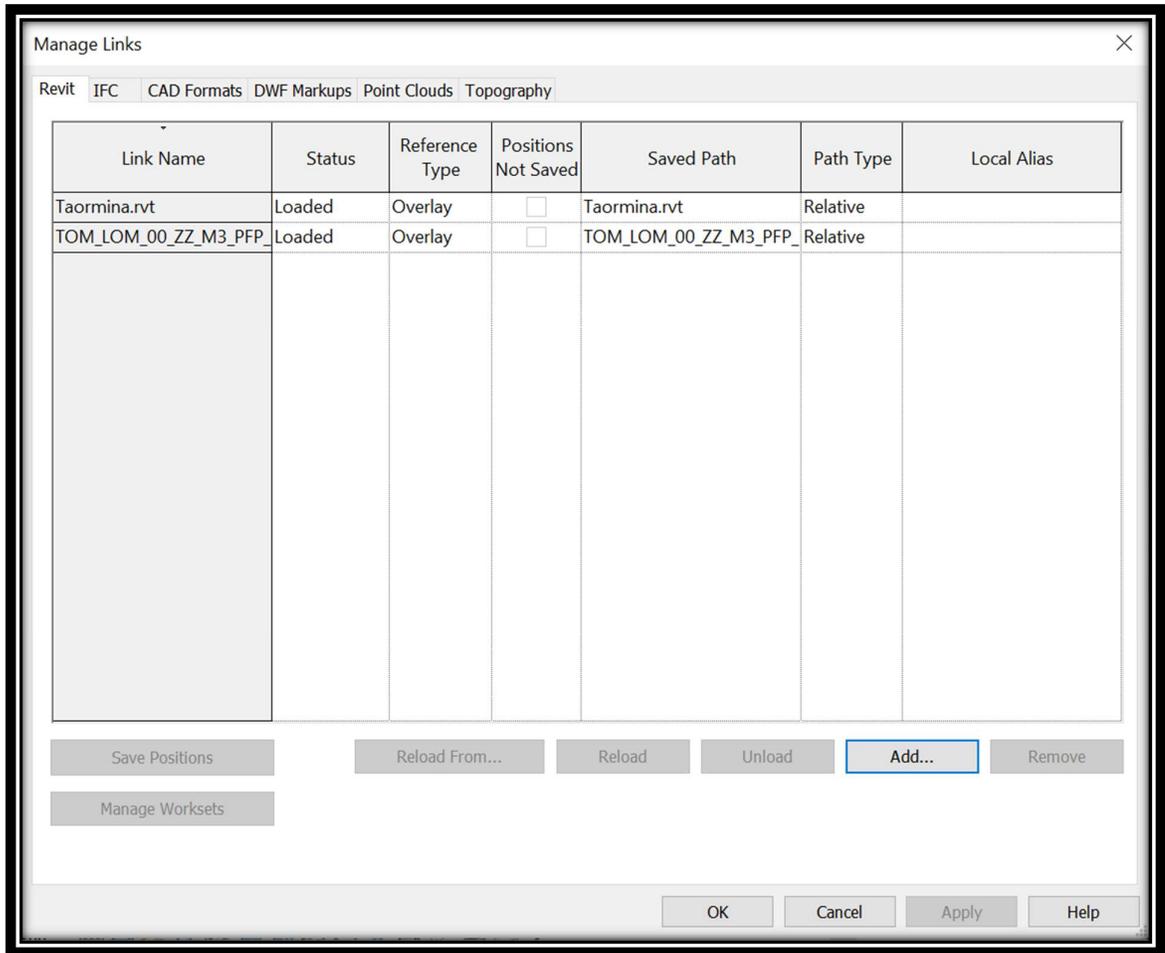
Figure 16 Manage Links, Revit

3.3.2 Shared Coordinates

Once the architectural structural model is connected, the coordinates are acquired by going to Menu > Manage > Coordinates > Acquire Coordinates. The acquisition of coordinates allows to determine the coordinates used in a linked project, and use them for the current project, this means that the origin of the linked project's shared coordinates becomes the origin of the host project's shared coordinates.
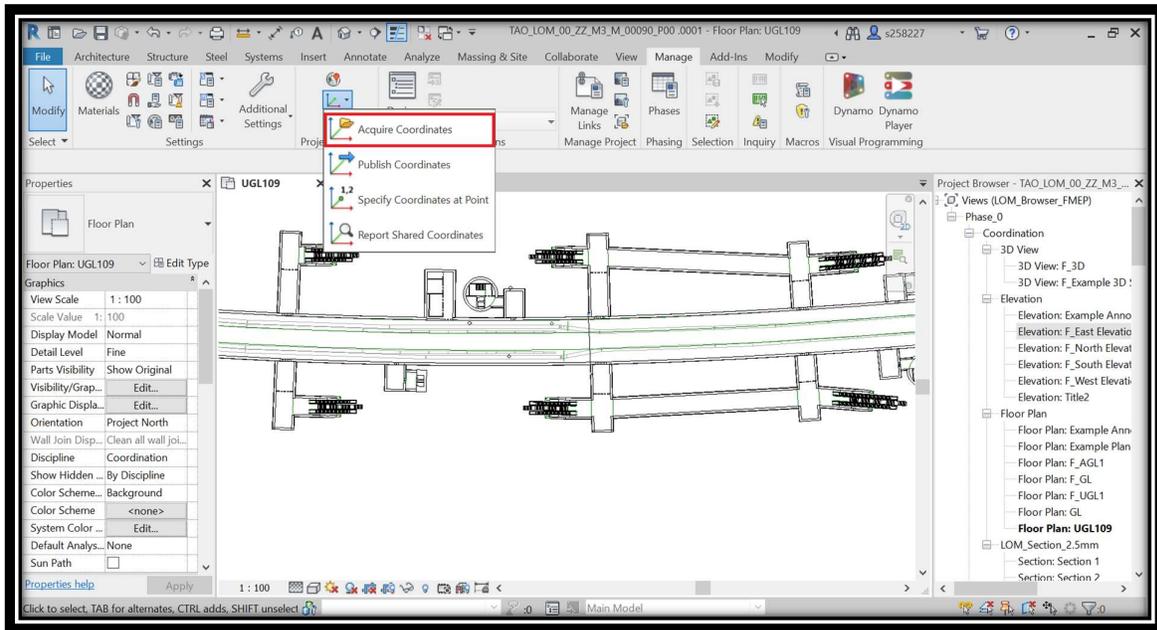
Figure 17 Acquire Coordinates, Revit

3.3.3 Workset

A workset is a collection of elements in a project that is widely shared. Revit facilitates collaboration between experts working on the same project by allowing them to work on the same project at the same time. Each workset can only be edited by one person at a time. Worksets can be viewed by all team members, including those owned by others, although they cannot always be modified. This eliminates the possibility of internal dispute inside the project.

To make a workset in Revit, go to Collaborate > Workset and select New. From there, we can make as many worksets as we want. We can also view the current one and make changes if necessary in the collaborate section.

Figure 18 Workset, Revit

3.4 Parametric Family

All of the elements that can be added to a 2D or 3D project are called Revit families. Families are divided into three categories in Revit:

- System Families
- Loadable Families
- In-place Families

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The system families include foundations, pillars, beams, floors, roofs, and staircases, among other structural elements. They are not loaded from external files because they are predefined in Revit and saved in templates and projects. Through the Architecture, Structure, Steel, and Systems tabs, system families can be added to the project.

All non-structural elements, such as doors, windows, and plants, are considered as loadable families. Loadable families can be obtained in the Revit libraries, on the Internet, or created from scratch in the Family Editor.

The in-place families are those who are specifically assigned to a project. The loadable families can be used in numerous projects, however, the in-place families can only be utilized in the original project. In-place elements can increase file size and degrade software performance.

A default loadable family library can be inserted and possibly updated in Revit. Simply select Insert> load Family to insert a default family (Figure 19). Once the family of interest has been selected, the Open button allows loading the family into the project. Hence, the family type is available to place in the project and displays in the appropriate category under Families in the Project Browser.
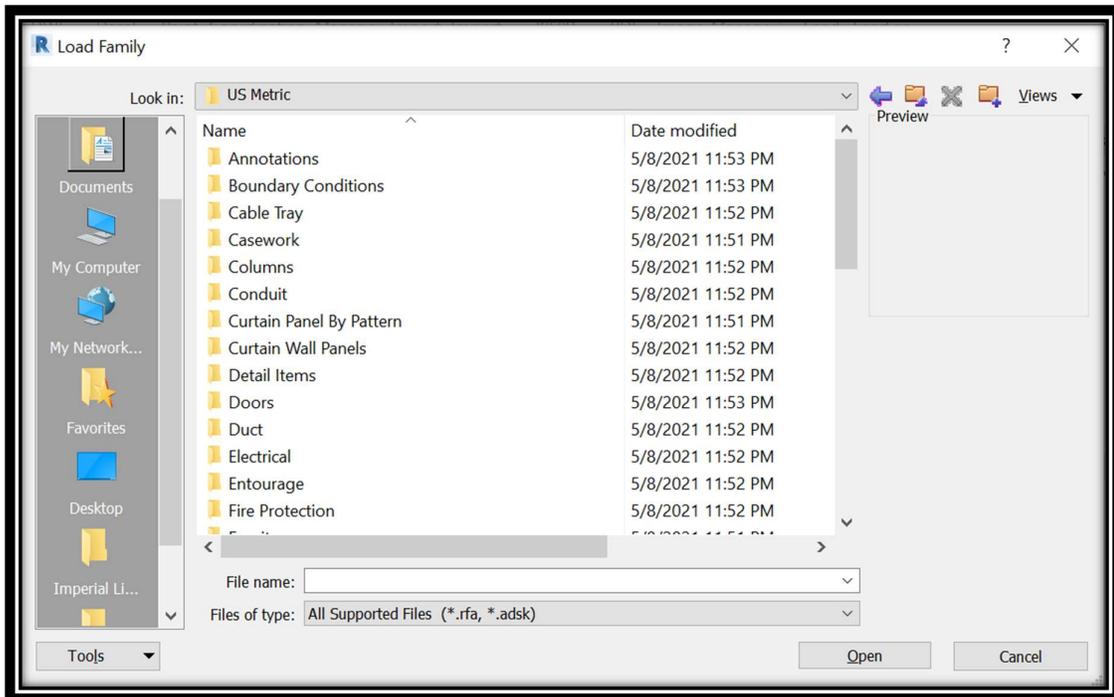
Figure 19 Load Family, Revit

If the default families do not meet the requirements, there is the possibility to create the families that can be loaded by clicking on File > New > Family (Figure 20).
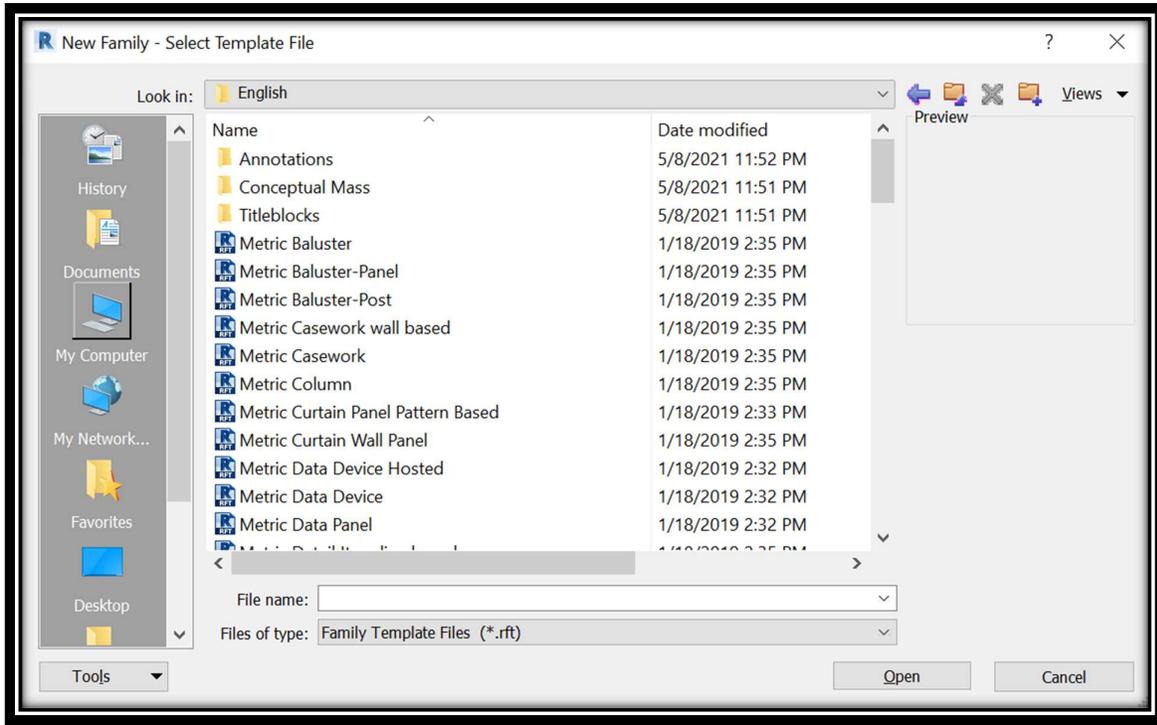
Figure 20 New Family, Revit

Revit allows choosing between different types of families, for example, to model the damper or silencer we start with a family based on mechanical equipment, while some families are modeled as a generic metric and then are assigned to the correct category to which they belong. All families are created as parametric elements, this means that the geometric dimensions are variable type parameters. Once a family is created, many types of the same can be generated as the dimensions vary. Within the project, there are different types of mechanical equipment. We will analyze in detail some of these types to highlight their criticalities.

3.4.1 Ventilator

The ventilation system has centrifugal fans as its source. There are three ventilation systems positioned in the room. These systems belong to the family:

TAO_LOM_M_Mechanical Equipment_Ventilator

Table 2 Ventilation Encoding

TAO	Project acronym: TAORMINA
LOM	Responsible organization acronym: Lombardi Ingegneria srl
M	Discipline: Mechanical
Mechanical Equipment	Revit category: Mechanical Equipment
Ventilator	Type of object: Ventilator
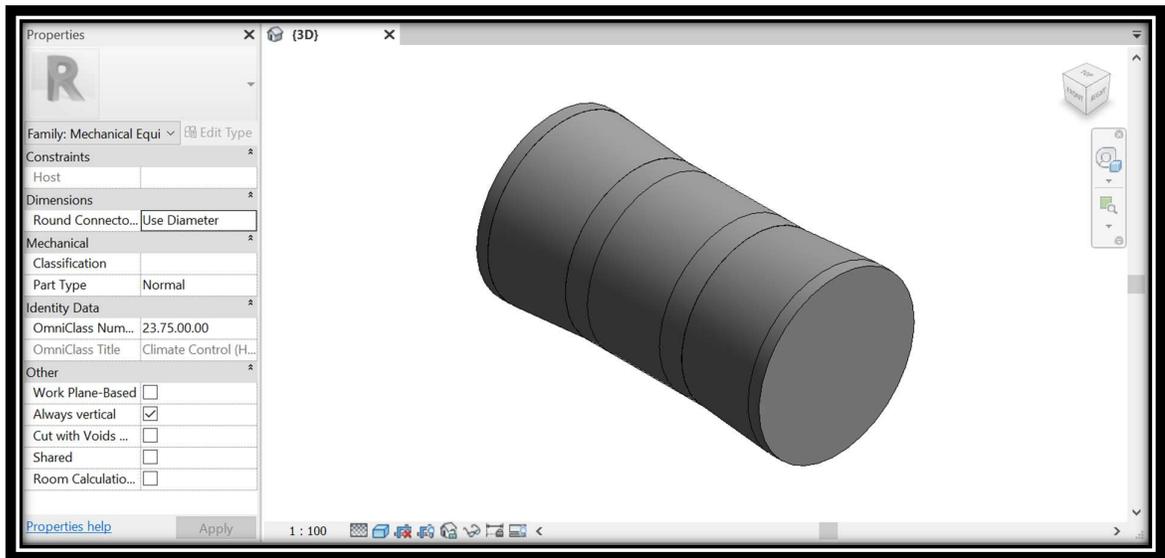
Figure 21 Isometric View of Ventilator, Revit
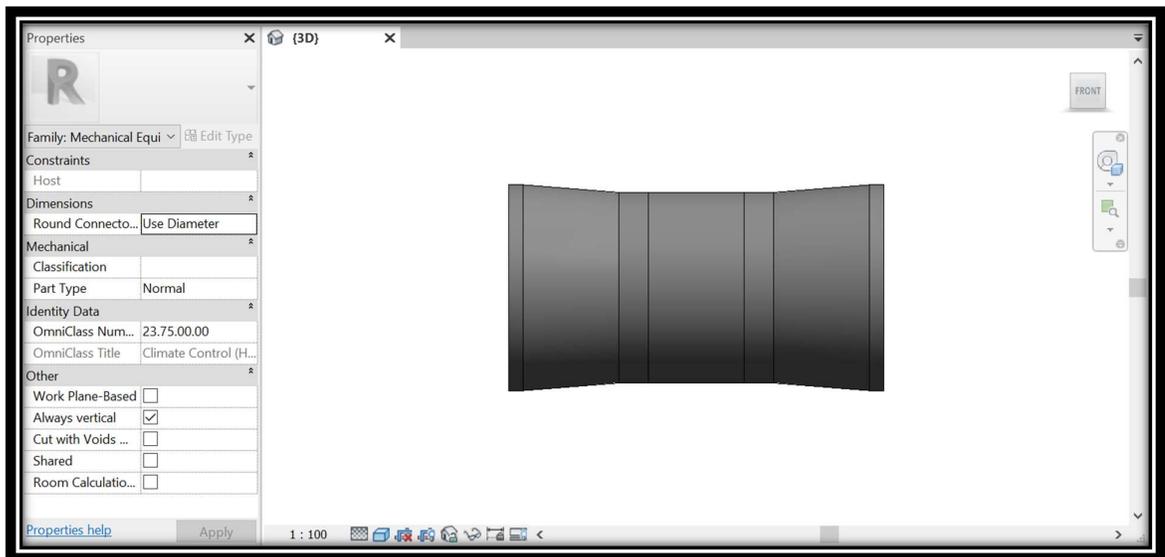
Figure 22 Front View of Ventilator, Revit
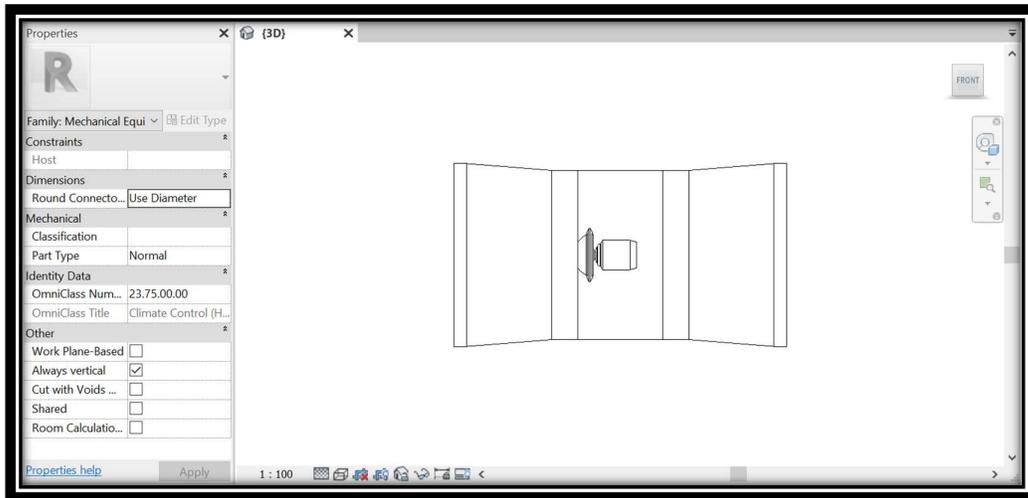
Figure 23 Front View of Ventilator, Revit

When finished, this family is inserted in the category of mechanical equipment. Once saved and loaded in the project, it is possible to place the ventilation systems in the model.

3.4.2 Silencer

In the project, there are two silencers located in front and behind the ventilators. These systems belong to the family:

TAO_LOM_M_Mechanical Equipment_Silencer

Table 3 Silencer Encoding

| TAO	Project acronym: TAORMINA
LOM	Responsible organization acronym: Lombardi Ingegneria srl
M	Discipline: Mechanical
Mechanical Equipment	Revit category: Mechanical Equipment
Silencer	Type of object: Silencer
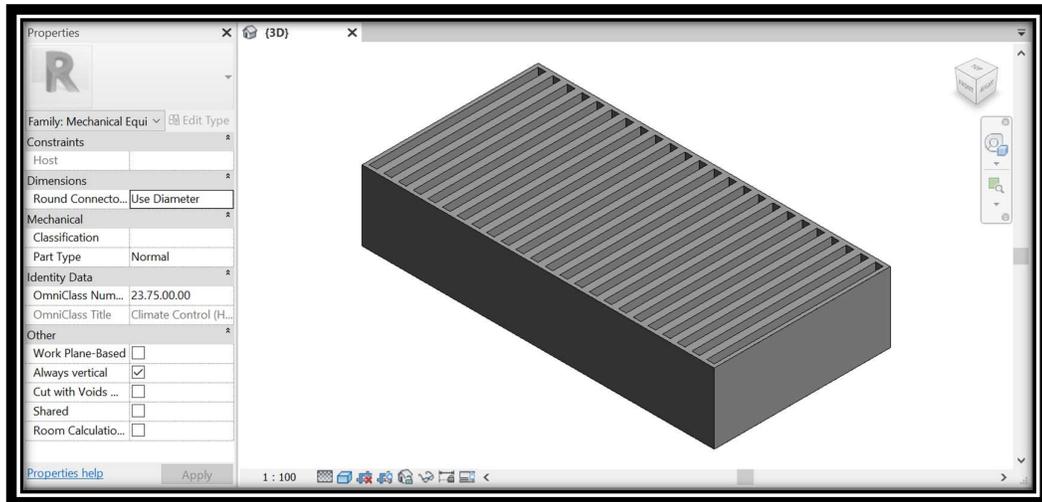
Figure 24 Isometric View of Silencer, Revit
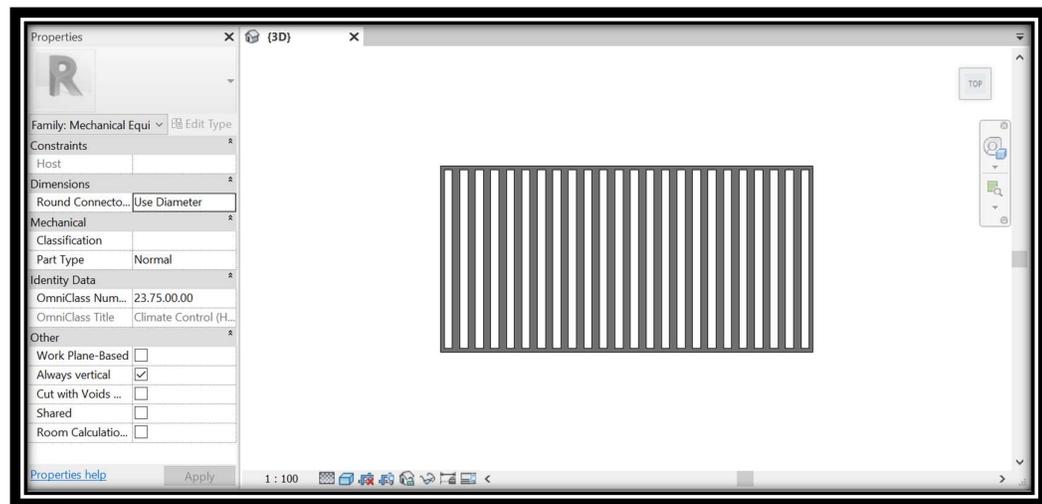
Figure 25 Top View of Silencer, Revit

When finished, this family is inserted in the category of mechanical equipment. Once saved and loaded in the project, it is possible to place the silencers in the model.

3.4.3 Damper

There are some dampers with different dimensions in the project. These systems belong to the family:

TAO_LOM_M_Mechanical Equipment_Damper_1700_1900

TAO_LOM_M_Mechanical Equipment_Damper_2250_3500

TAO_LOM_M_Mechanical Equipment_Damper_2250_4000

TAO_LOM_M_Mechanical Equipment_Damper_2600_3300

Table 4 Damper_1700_1900 Encoding

TAO	Project acronym: TAORMINA
LOM	Responsible organization acronym: Lombardi Ingegneria srl
M	Discipline: Mechanical
Mechanical Equipment	Revit category: Mechanical Equipment
Damper	Type of object: Damper
1700	Length of damper
1900	Width of damper
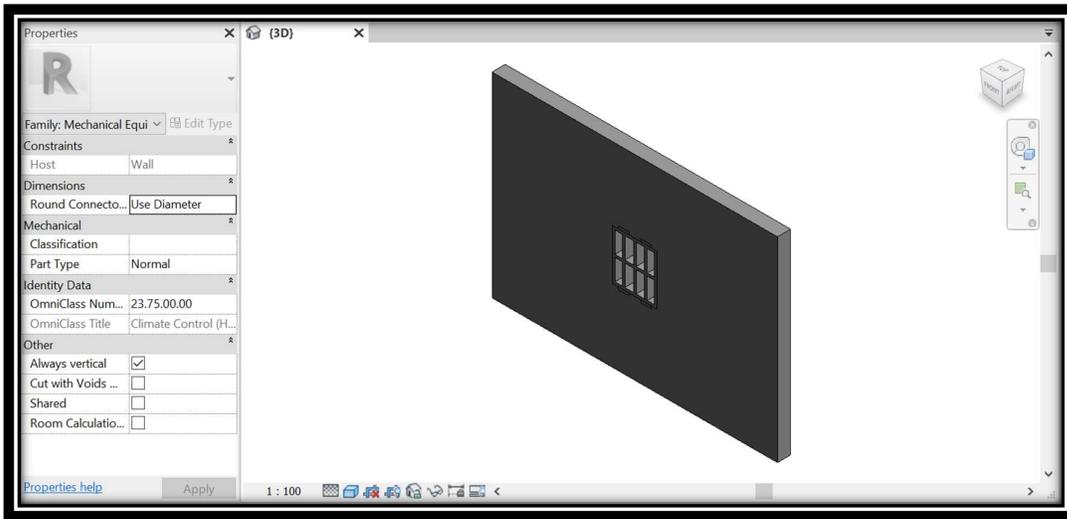
Figure 26 Isometric View of Damper_1700_1900, Revit
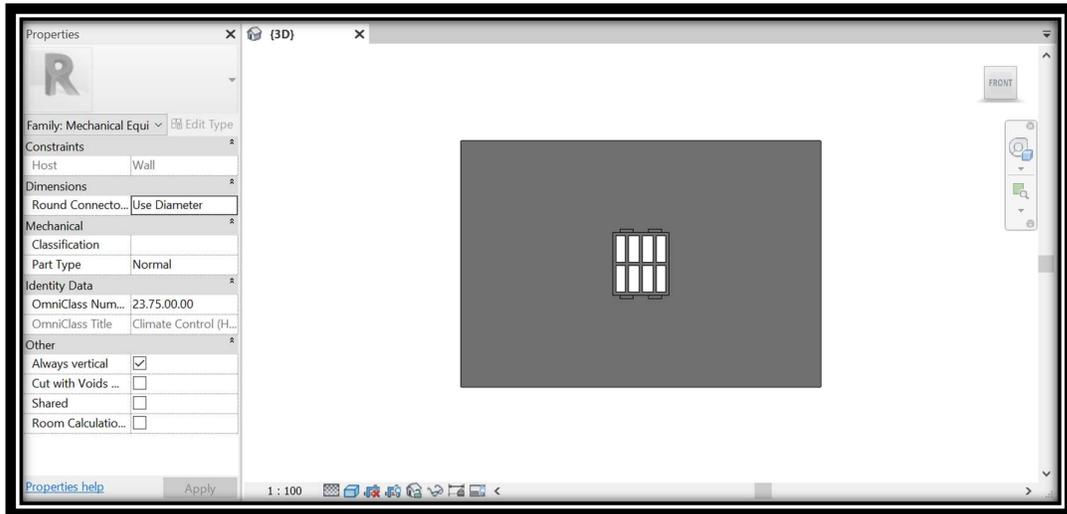
Figure 27 Front View of Damper_1700_1900, Revit
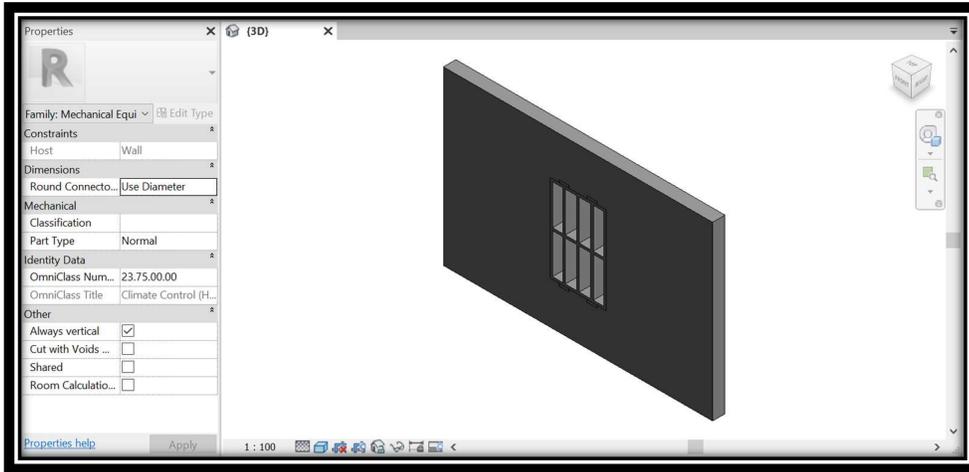
Figure 28 Isometric View of Damper_2250_3500, Revit
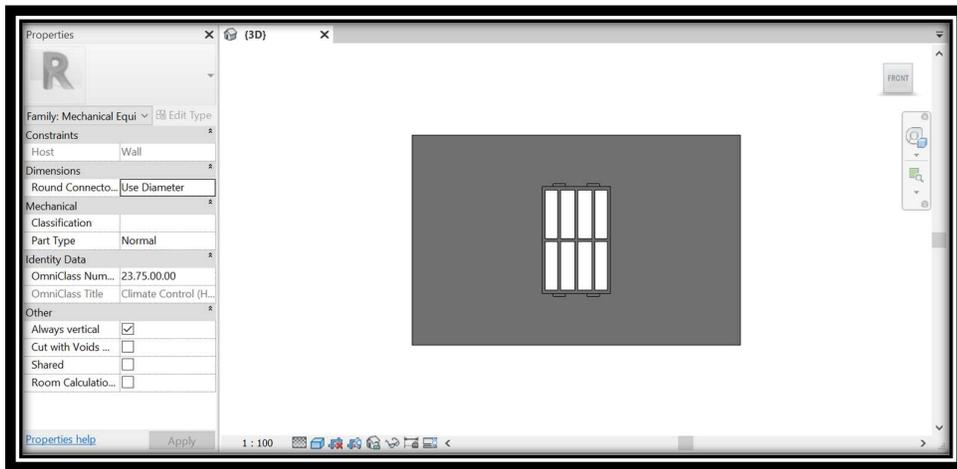
Figure 29 Front View of Damper_2250_3500, Revit
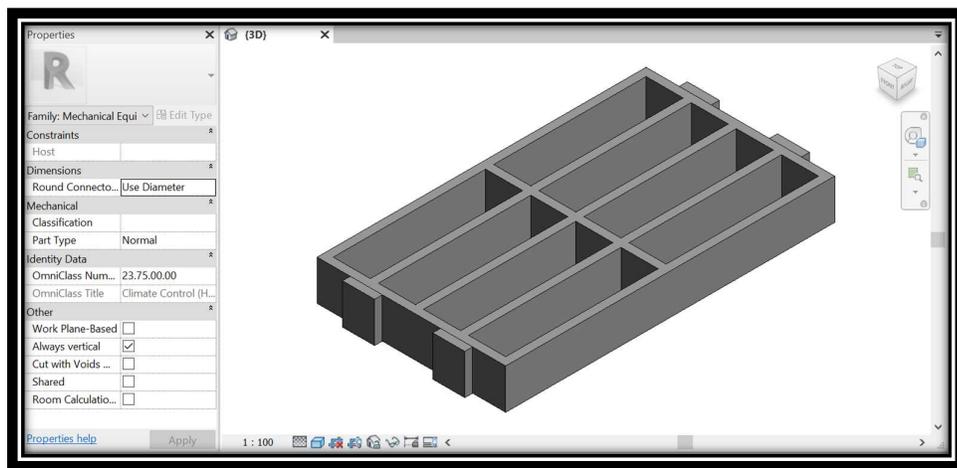
Figure 30 Isometric View of Damper_2250_4000, Revit
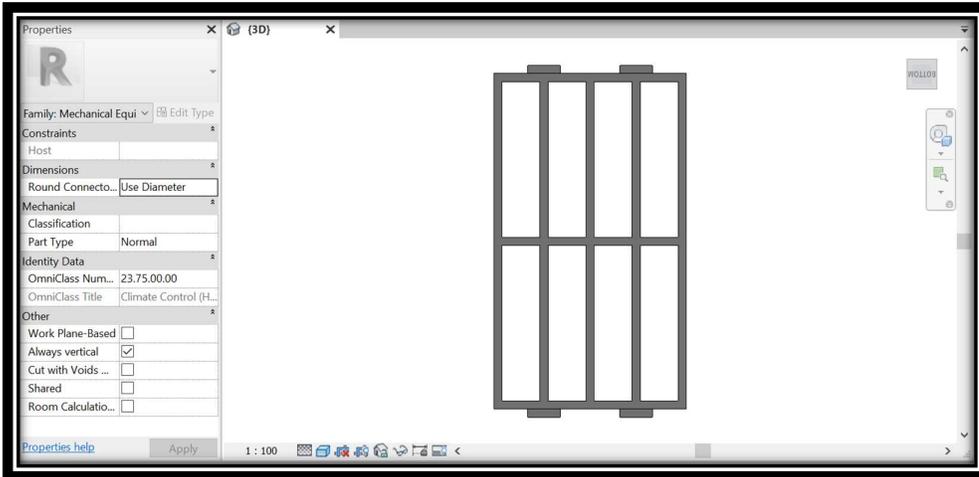
Figure 31 Bottom View of Damper_2250_4000, Revit
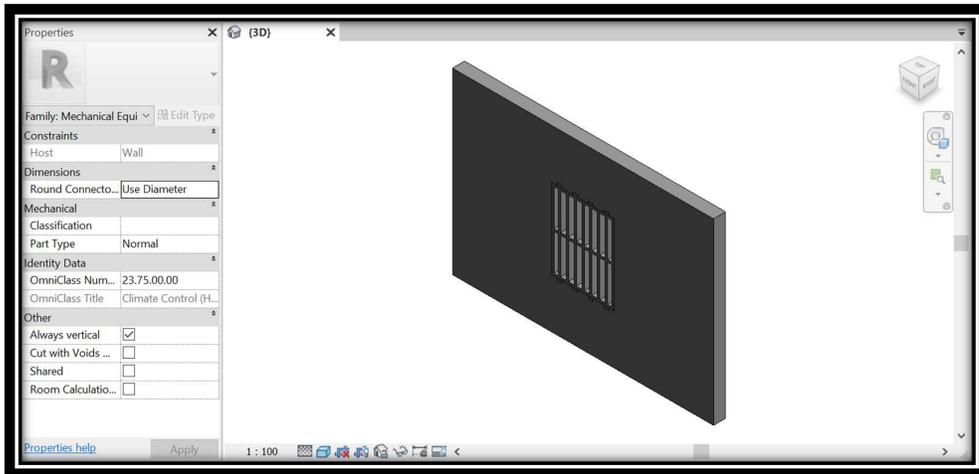
Figure 32 Isometric View of Damper_2600_3300, Revit
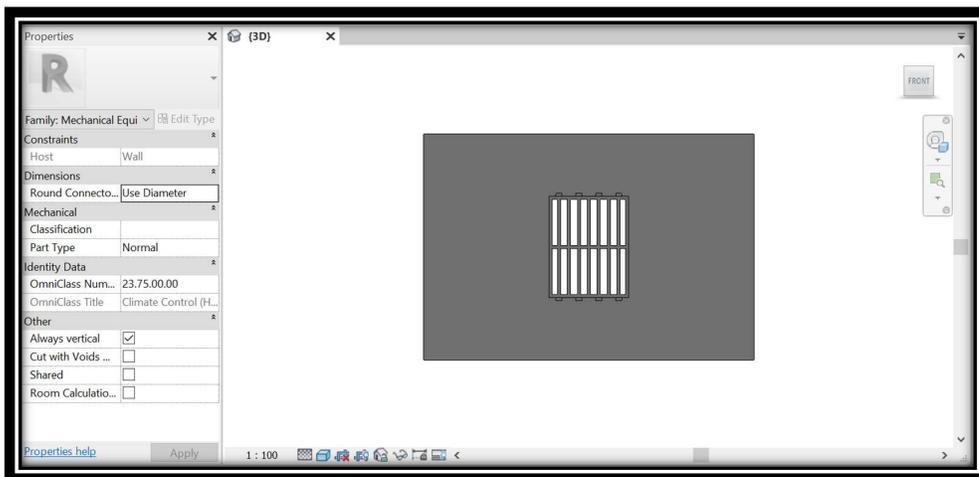
Figure 33 Front View of Damper_2600_3300, Revit

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When finished, this family is inserted in the category of mechanical equipment. Once saved and loaded in the project, it is possible to place the dampers in the model.

3.4.4 Duct Modeling

Some ducts with diameters ranging from 500, 600, 700,...1500 millimeters are also included in the project. The best work is to check the "Show Disconnects" option while drawing the ducts, as this helps to identify whether there is a problem in the duct system that prevents the system from being closed. When attempting to link two elements, these problems can happen due to a disconnection or inconsistency among systems. This tool can be found on the Check Systems panel of the Analyze tab.
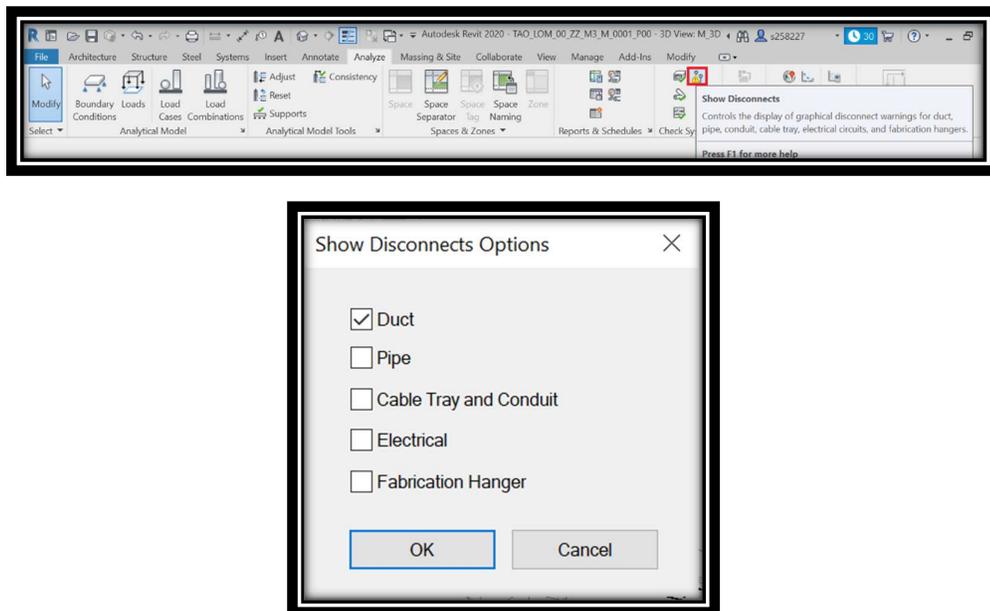
Figure 34 Show Disconnects, Revit

As a result, duct elements are created. Duct elements belong to the "Duct" category, where all families correspond to the System Families type. Only types can be created, modifying some settings such as the routing preferences. Routing preferences allow the selection of the default duct fittings that will be placed during the use of this type of duct. It is possible to load the required duct fitting families from the libraries since they are loadable families. Some other settings can be also customized: Elbow, Preferred Junction Type, Cross, Transition, Union, and Cap. These settings are saved into the Revit model.
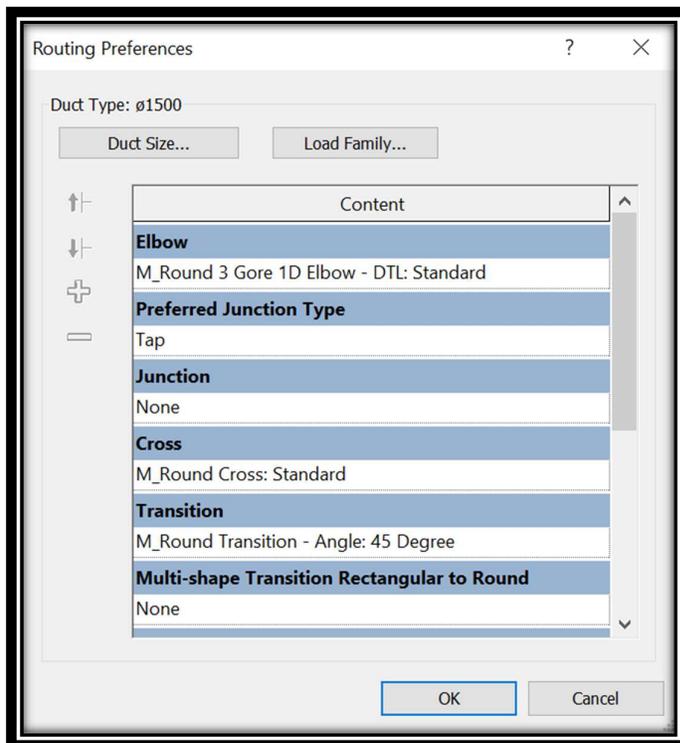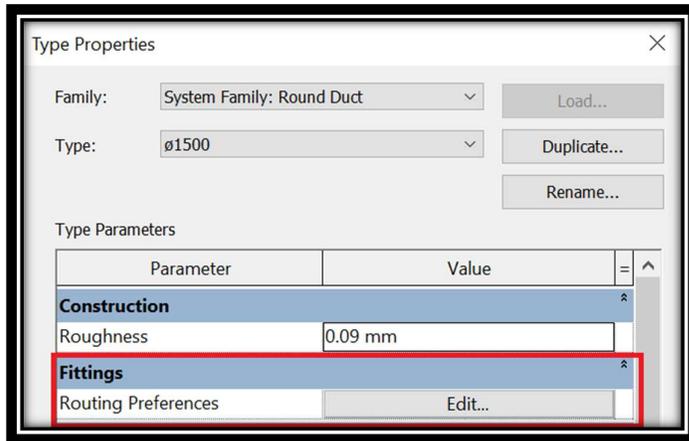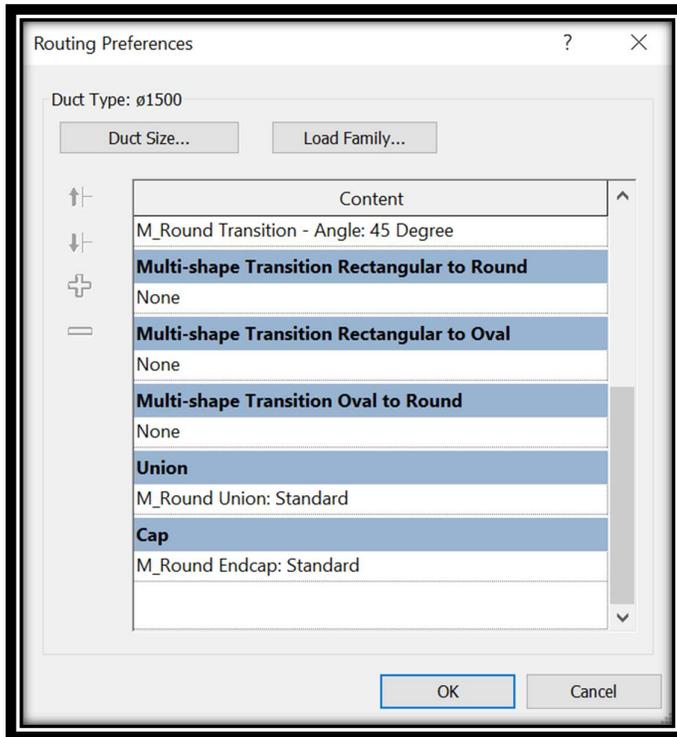
Figure 35 Routing Preferences, Revit
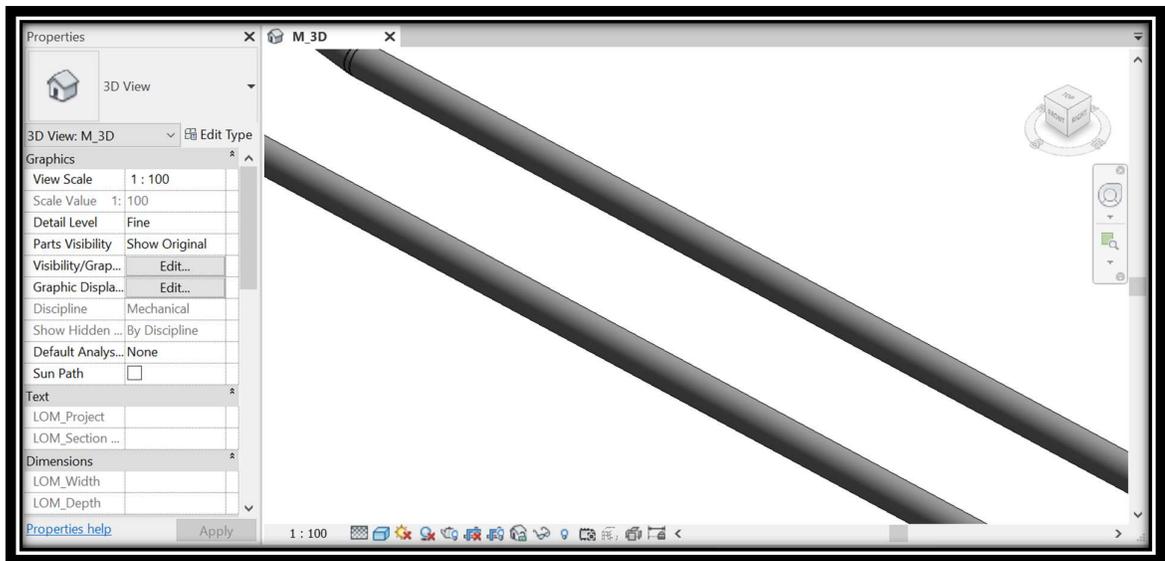

Figure 36 Ducts, Revit
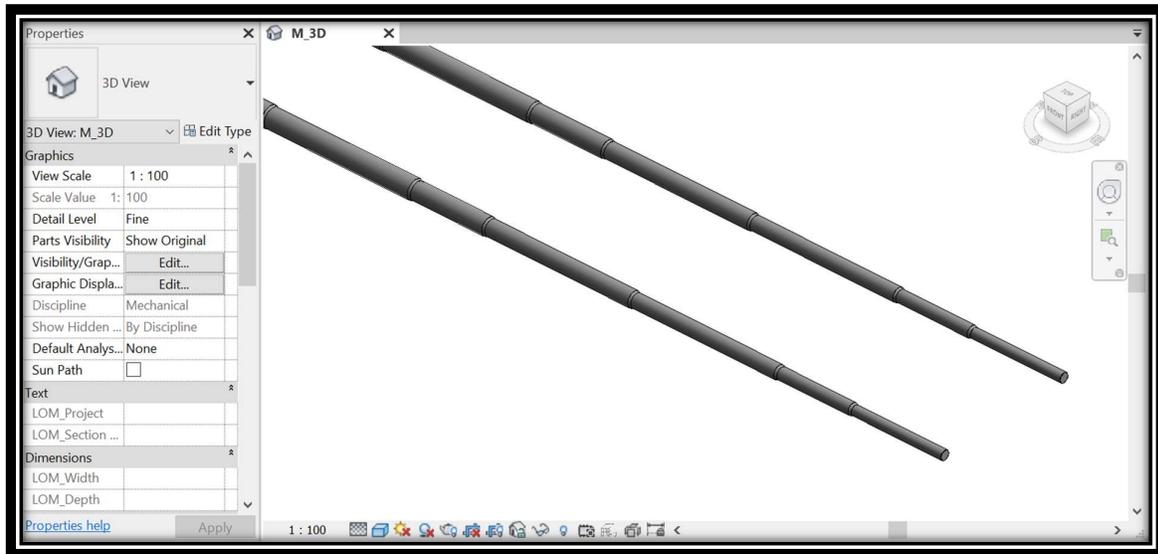
Figure 37 Ducts with Different Diameters, Revit

3.5 Parameters

The importance of information in a BIM project cannot be overstated. The non-geometric information content of a family is indicated by the Level Of Information, which is commonly abbreviated as LOI. Data sheets, manufacturing specifications, and maintenance instructions, for example, may be included in a family with a high level of information. Custom parameters for a project and any category of elements or components can be created in Revit. The parameters created are visible in the properties dialog of the type or the property palette, depending on whether they are of type or instance, in the selected group. There are different types of parameters:

- Global parameters;
- Shared parameters;
- Project parameters;
- Family parameters.

Global parameters are project-specific parameters that are not related to any category. They can be simple values, values derived from formulae, or even model parameters derived from other global parameters.

Parameter definitions that can be used among numerous families and projects are known as shared parameters. It is possible to use a new shared parameter as a family or project parameter after entering it. The parameters that are provided can be tagged and scheduled. A schedule is a table that displays information taken from the properties of project elements. Schedules in Revit are highly valuable tools, and they may also be exported to other programs, such as a spreadsheet.

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The project parameters are also unique to a single project, just like the global parameters. The information included inside these types of parameters cannot be shared with other projects, but they can be used to create schedules, order them, and create filters.

Family parameters are particular family settings that can also be used to manage nested family parameters by linking the host family parameter to the nested family parameter.

To create a family parameter, open the family wanted to associate with the parameter, click on the Family Types icon and create the new parameter (Figure 38).
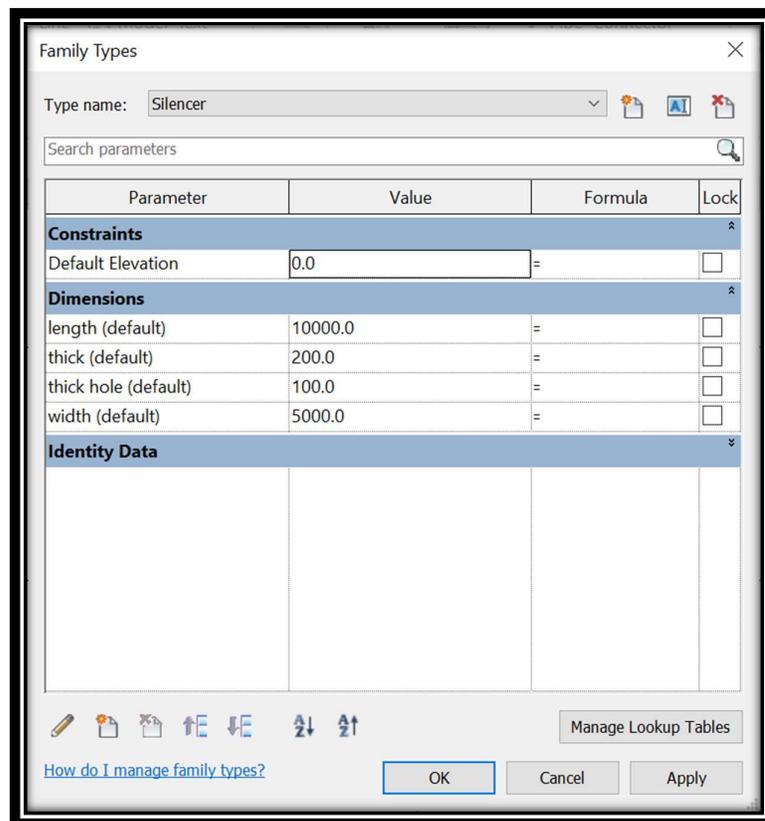
Figure 38 Family Types, Revit

3.6 Materials

The choice of materials is made for visual and not qualitative purposes, it must be specified which materials have been created that identify the system. Inside the HVAC model, there is a supply air system of different sizes. To assign a material to a system, (Figure 39), just click on Manage > Materials.
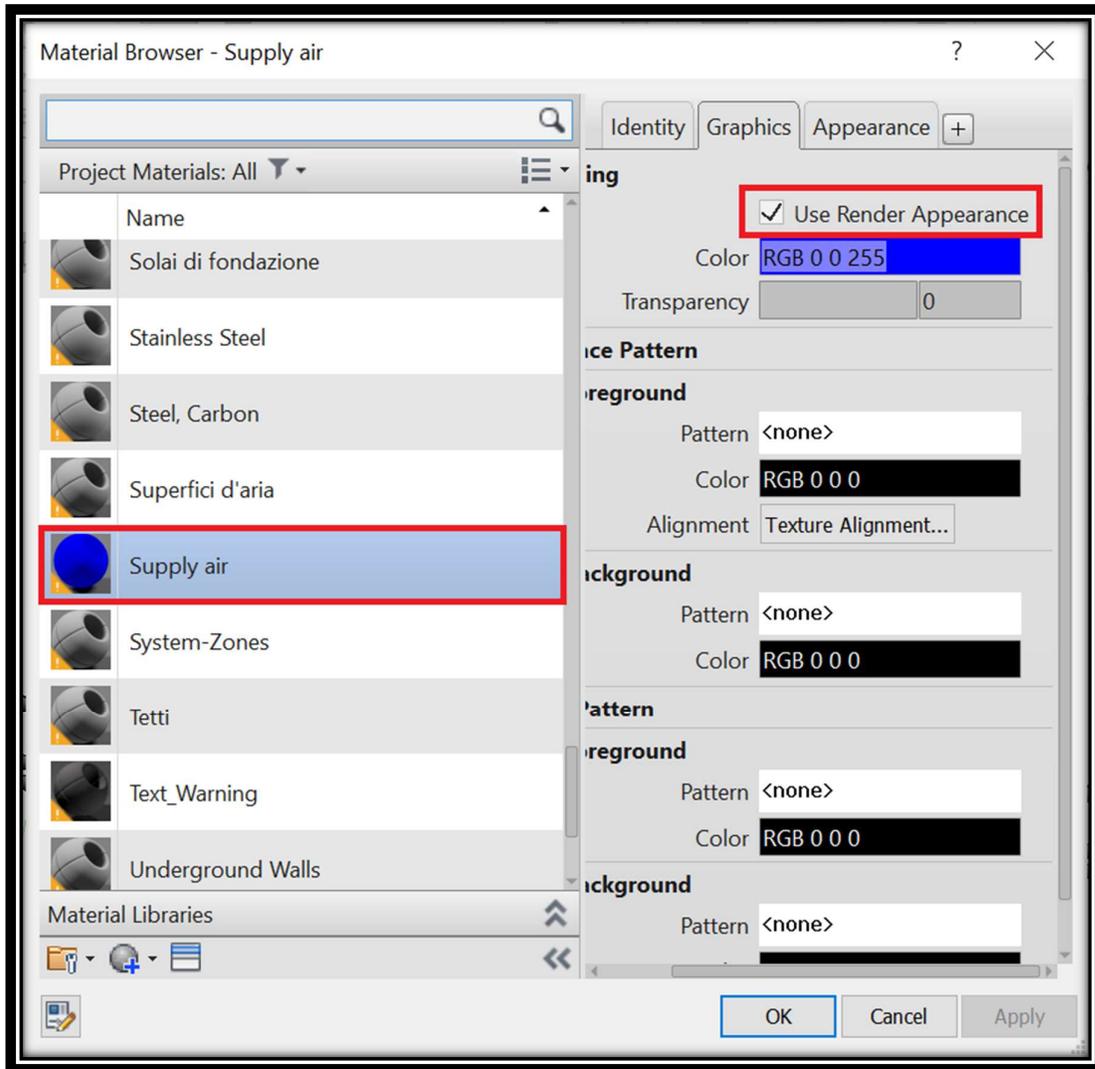
Figure 39 Material Browser, Revit

3.7 Results

In conclusion, at the end of the modeling phase, a three-dimensional HVAC system is obtained.
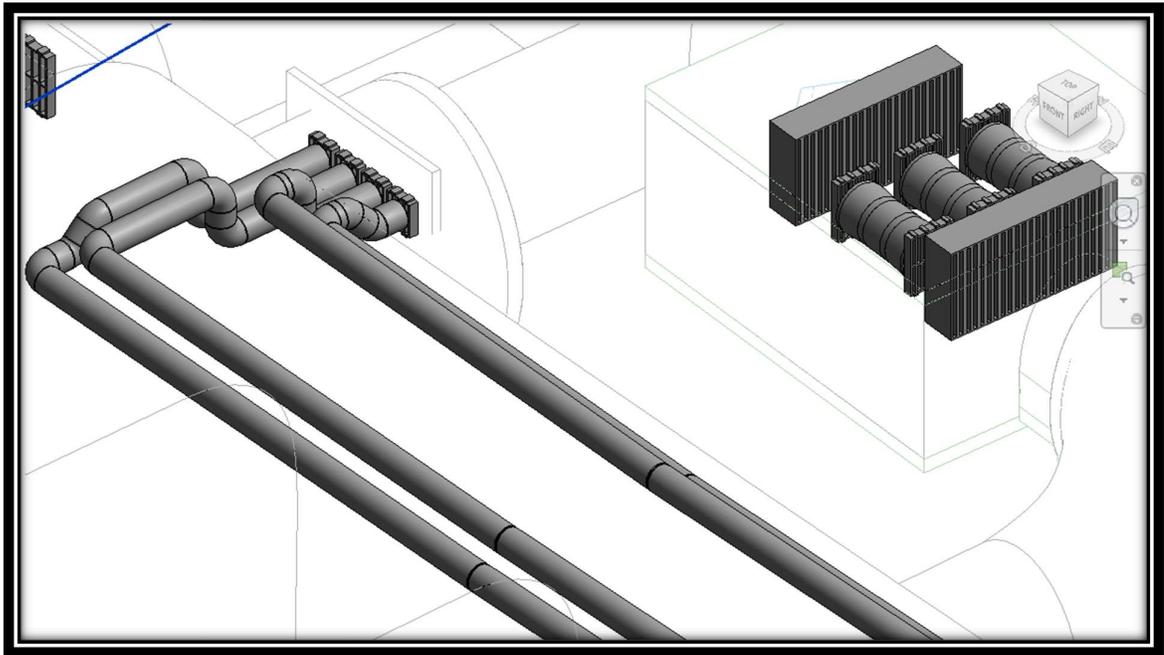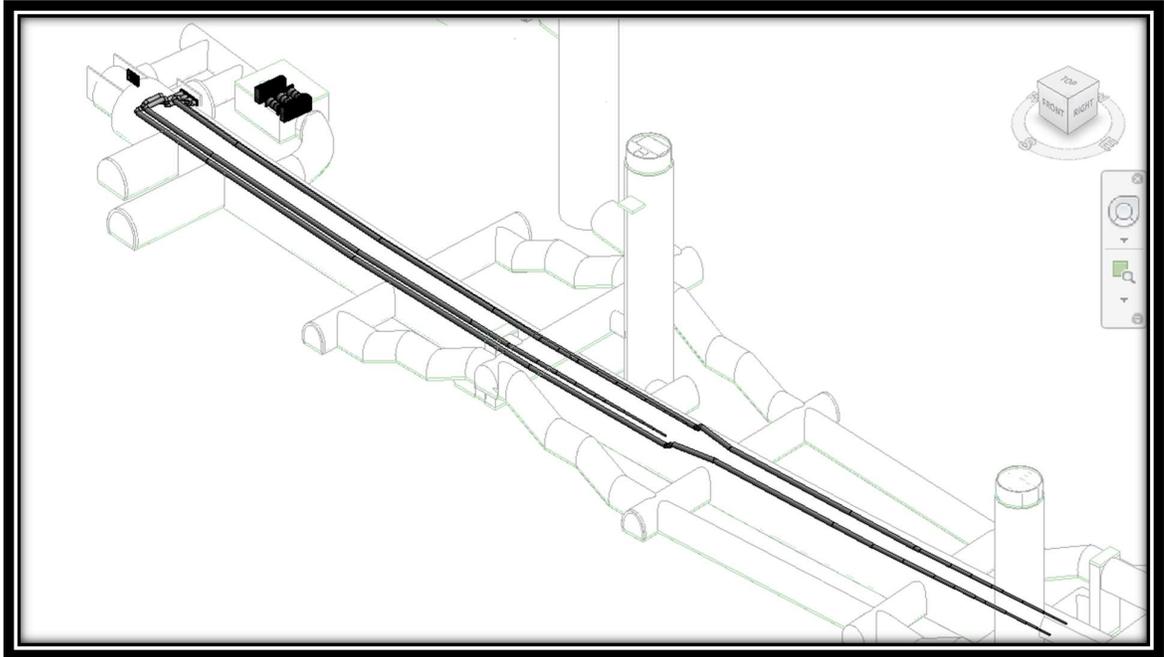
Figure 40 Isometric View Model, Revit
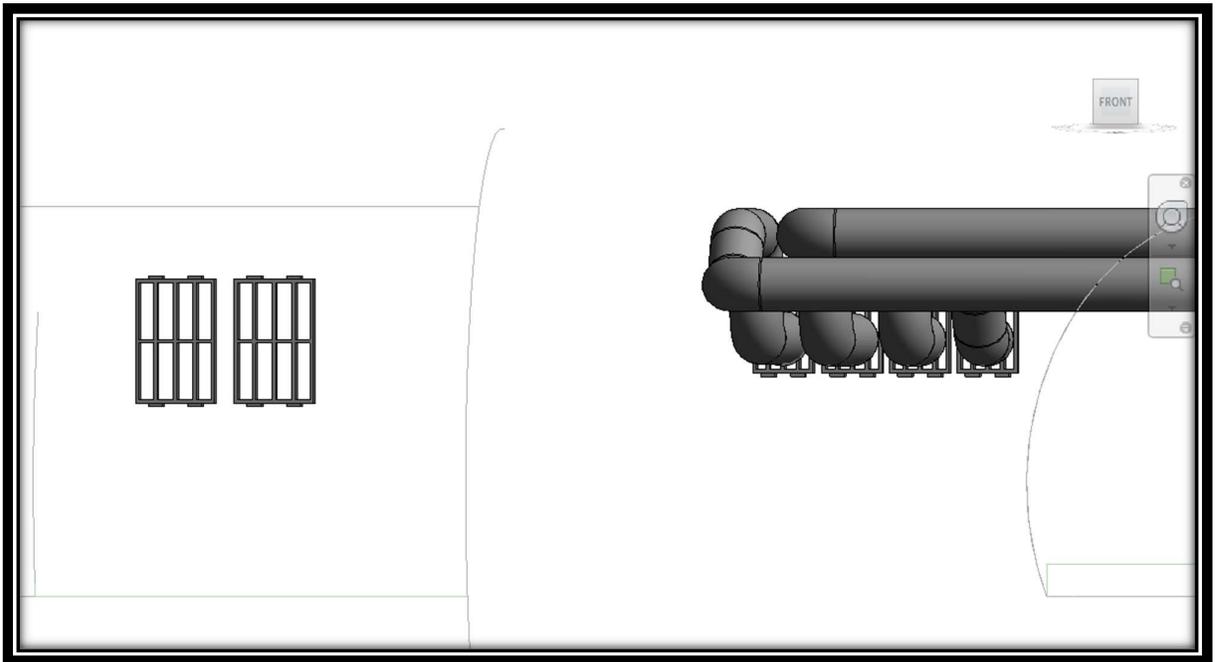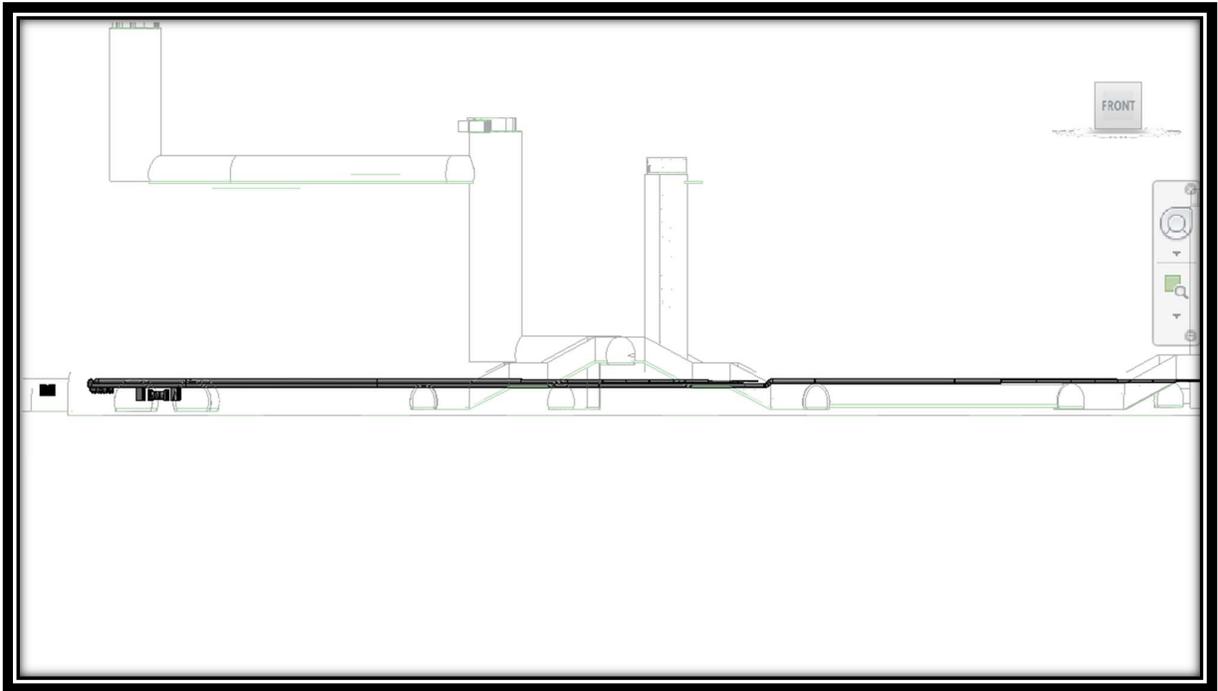
Figure 41 Front View Model, Revit
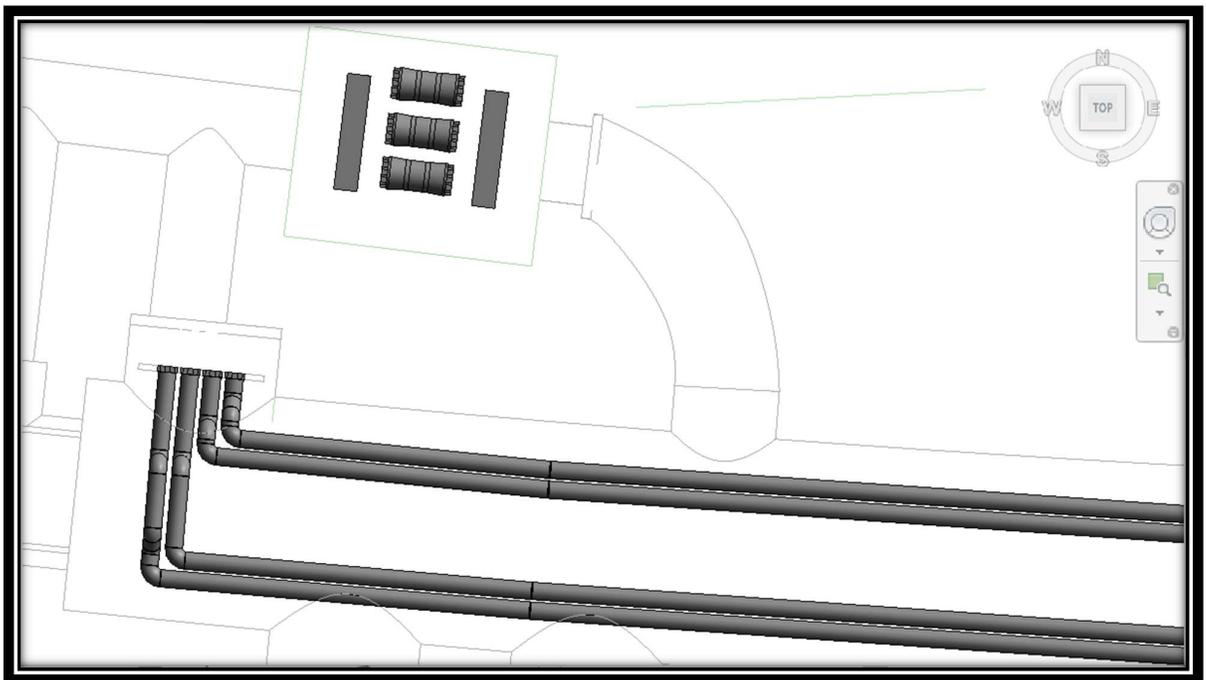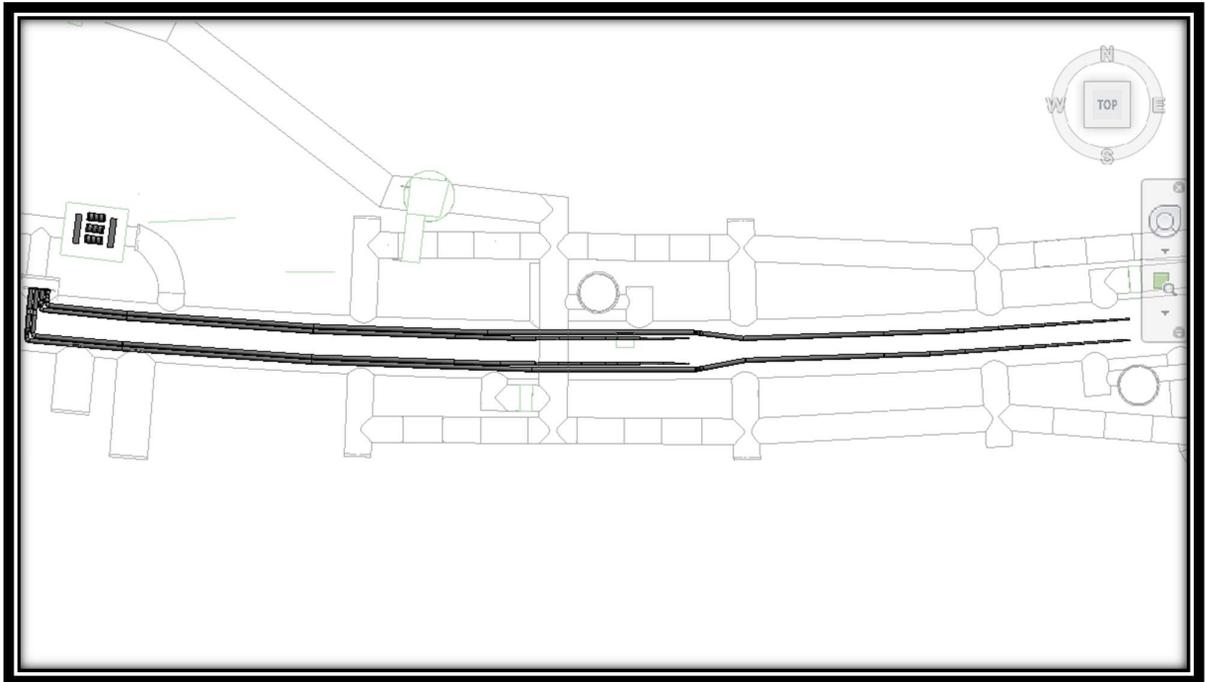
Figure 42 Top View Model, Revit
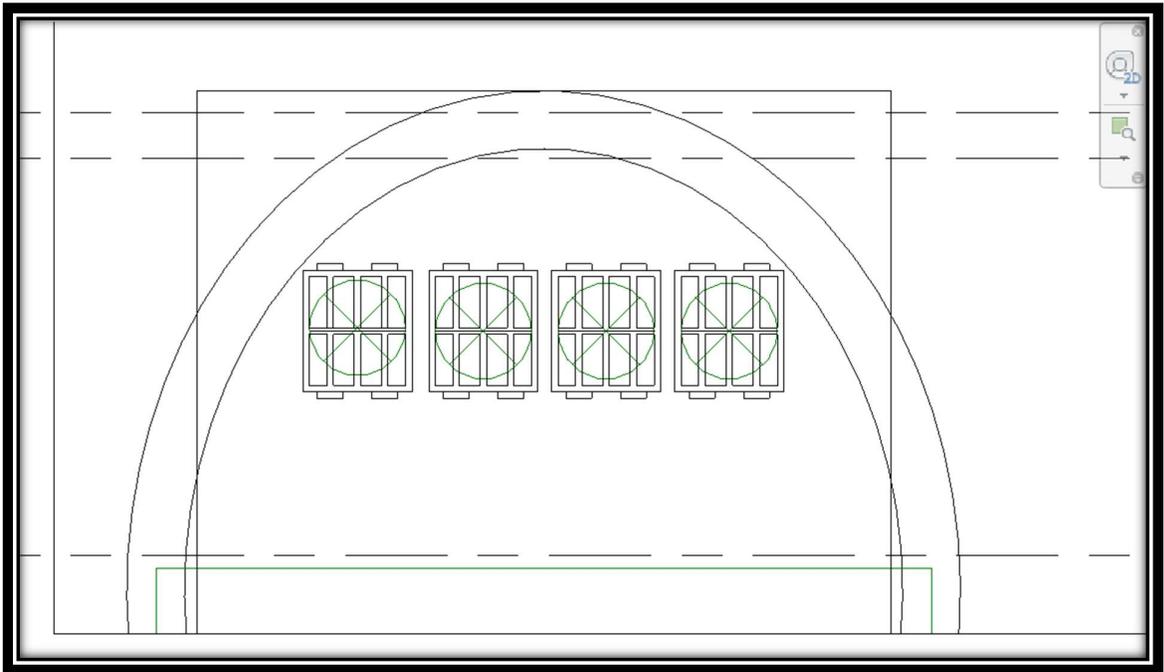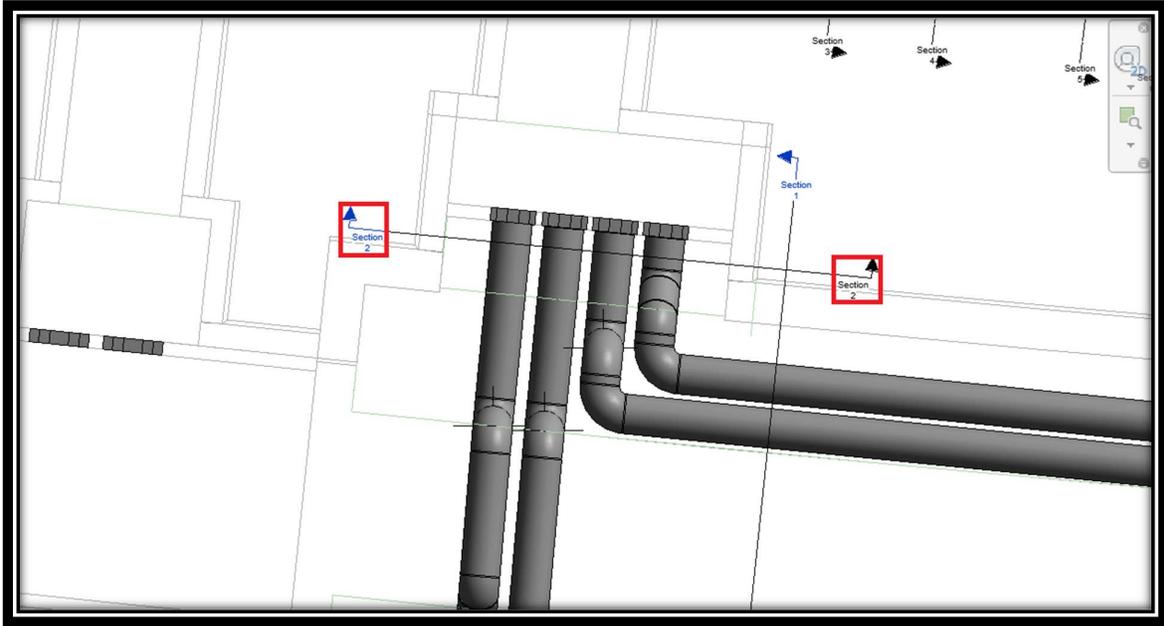
Figure 43 Section 2, Revit
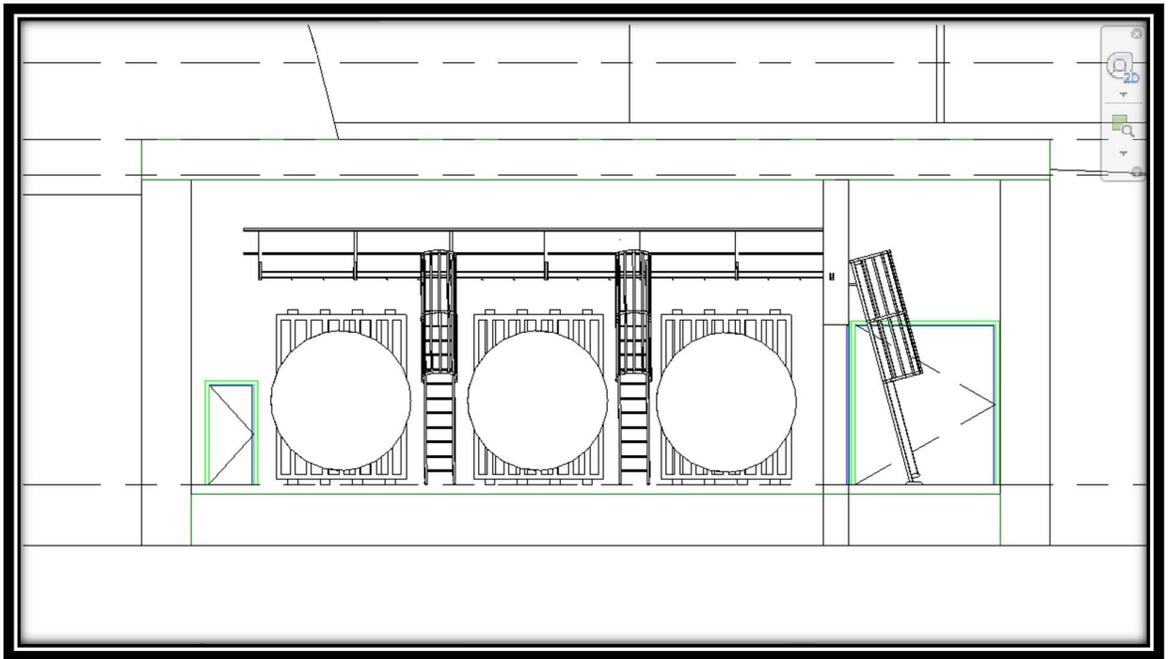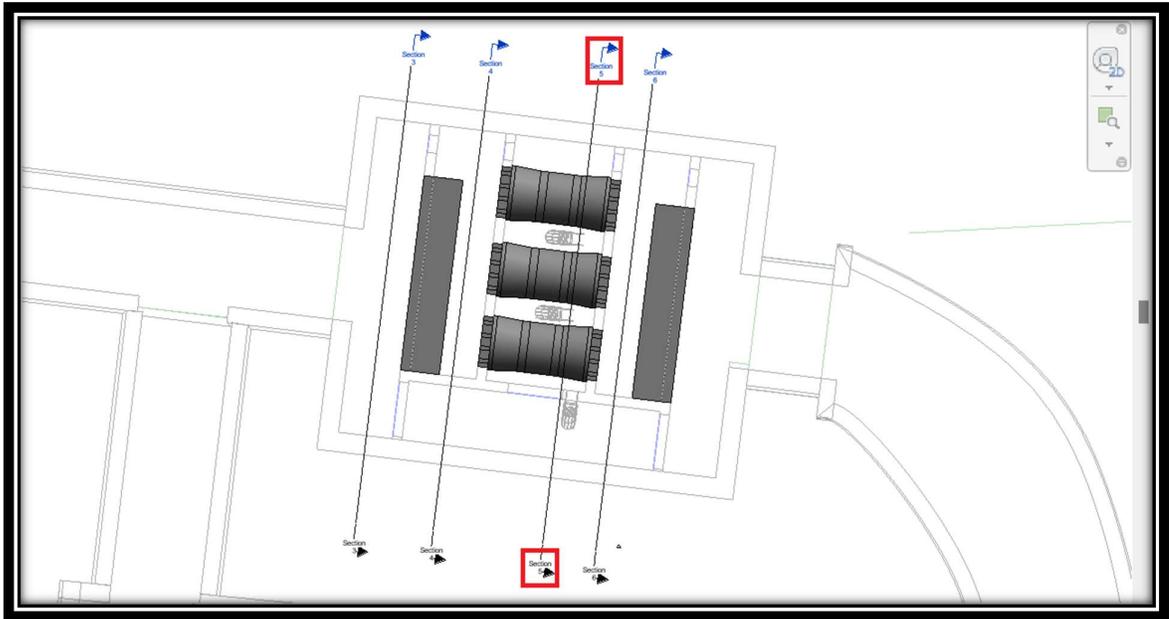
Figure 44 Section 5, Revit
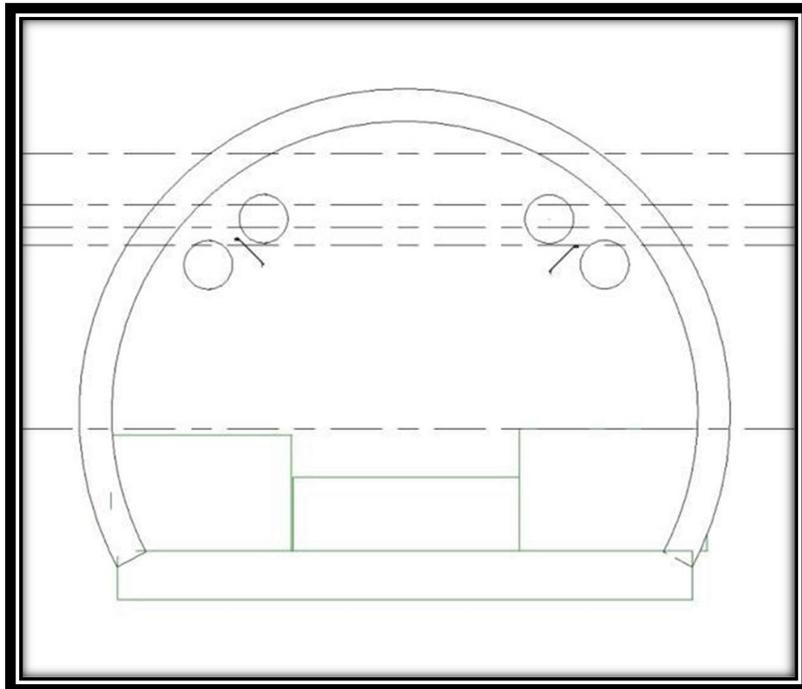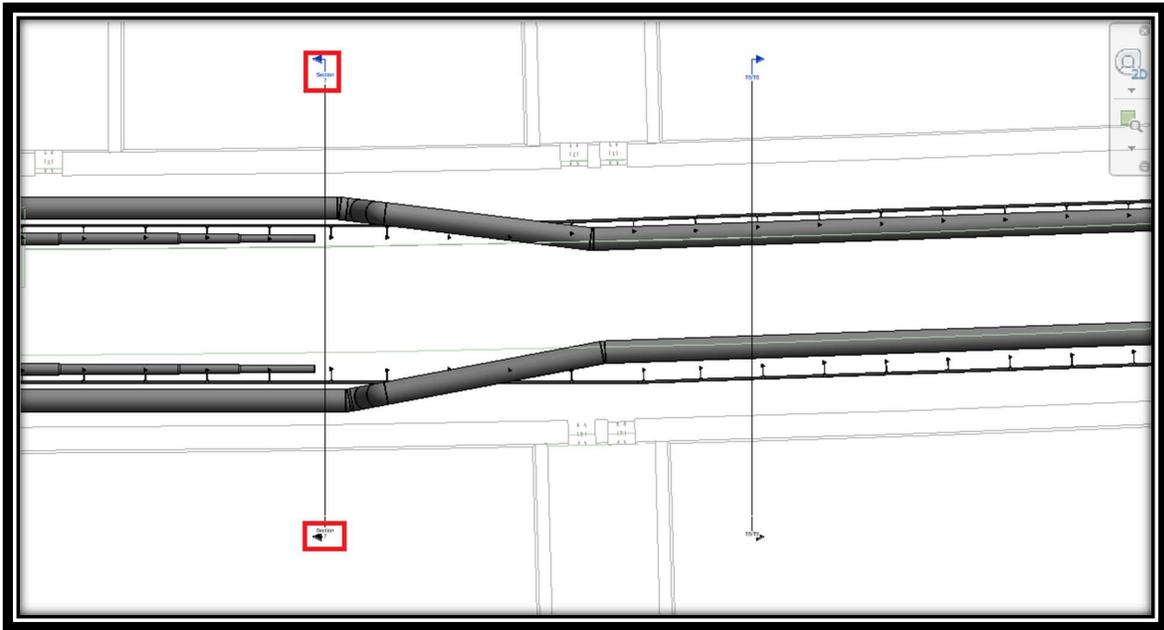
Figure 45 Section 7 , Revit

4 Development of BIM Model for Facility/Asset Management

In this chapter, it will be illustrated the development of the BIM model (management and maintenance) of the underground railway station.

4.1 Interference Check

3D analysis and interference control are activities that exploit graphic information of the objects in the model and the relationships between them. The BIM model must contain the representation of the work in its entirety (from architectural works up to the systems) and therefore it is necessary to coordinate all the parts between them to avoid interference. In general, coordination and clash detection activities are carried out in the design context to avoid the propagation of these errors in the construction phase of the work. So, the clash detection allows controlling and especially solve the problems of overlapping and interference that are created inside of the federated model, generated by the coordination of the various disciplinary models, like architectural, structural, and plant engineering.

4.1.1 Data Collection

Once the 3D information model is obtained, it is possible to export each model from Revit in an appropriate format to be opened by another software. To check any interferences or errors between the elements of the model, it is necessary to export the model generated on Revit to the Navisworks NWC file. In this case, each of the two files is exported to the NWC. To export the project from Revit, go to File > Export > NWC to obtain the model in NWC (Figure 46).
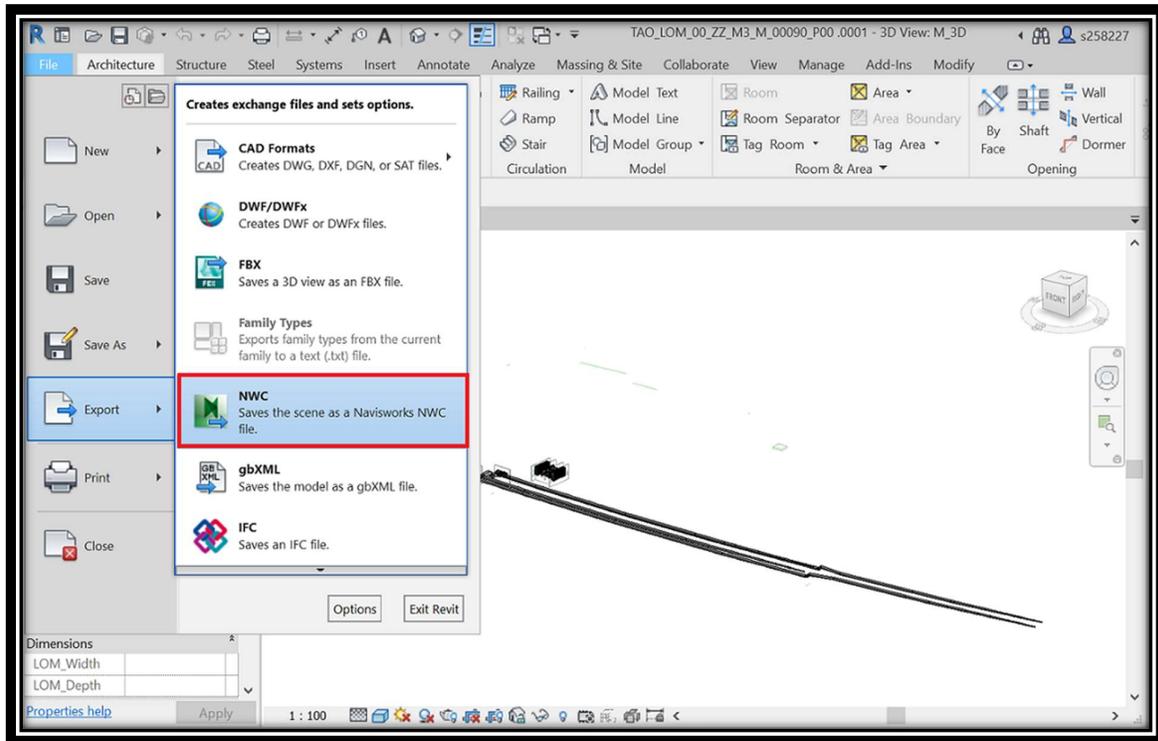
Figure 46 Export to NWC from BIM Authoring Platform

4.1.2 Software

For static and dynamic interference checking, it is used the Autodesk Navisworks Manage software, the 2020 version. This program allows the identification and management of problems caused by conflicts and interference before the construction of the work. With Navisworks, it is possible to create renderings of the photorealistic model, create simulations and animations of the model, etc. Also, the software can produce a list of all interferences detected in the project, verifying the presence of temporal and spatial coordination [6].

4.1.3 Import disciplinary models

As described before, the use of model checking is essential especially in the coordination, control, and verification phase. It allows to identify any interferences in the model and correct them in a good time to reduce the risk of changes in progress that would be more costly and time-consuming.

To be able to do a Clash Detection on Navisworks, first, it is necessary to add all the disciplinary models (architectural, structural, ventilation, and fire prevention systems) previously converted from Revit in the NWC format. In our case, the ventilation and fire prevention systems are added. Just click on Append and select the desired files to import (Figure 47).

50
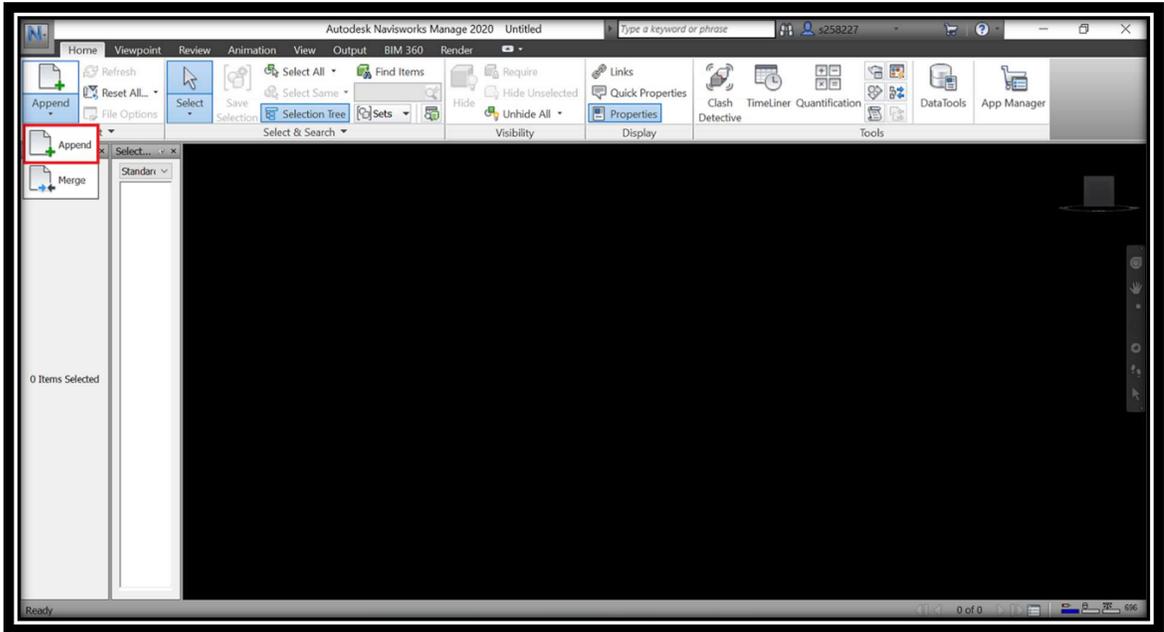
Figure 47 Add NWC, Navisworks
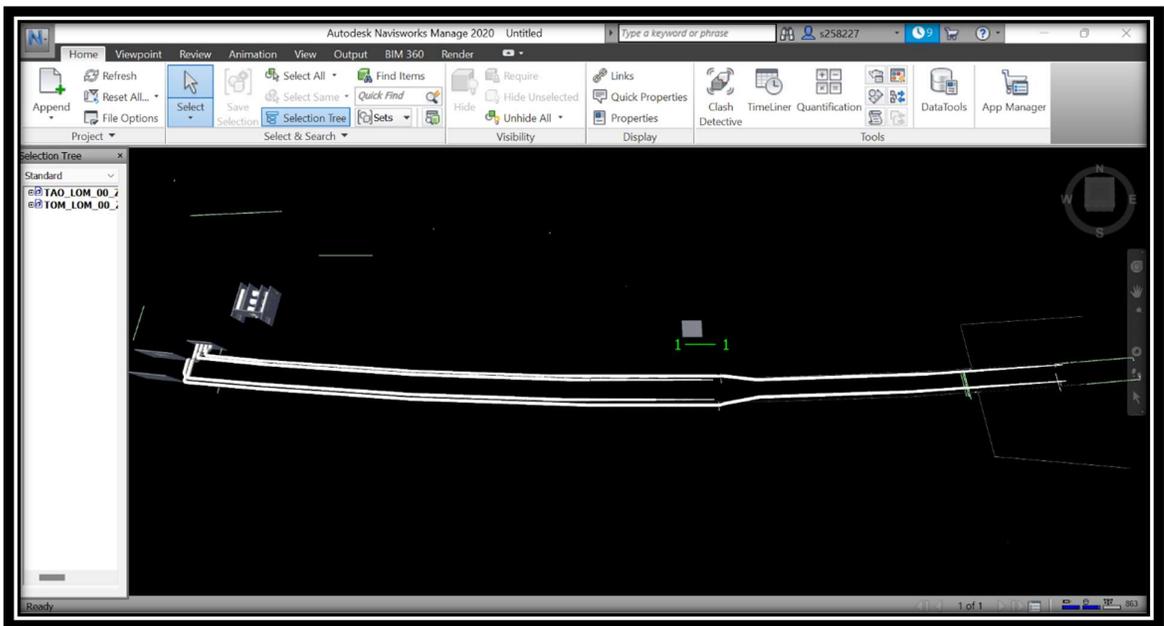
Figure 48 3D Model, Navisworks

4.1.4 Clash Detection

This section enables to perform a clash detection considering several parameters and different kinds of clashes. For clash detection, select Clash Detective from the top menu. The tests of interference are created by clicking on Add Test (Figure 50). So it is possible to check static interference between systems. The following procedures must be followed:

- Rename the test (for example "M vs PFP" corresponds to the control of the interference between the ventilation system model and the firefighting one);
- Choose the two files to compare. Remember that it is also possible to check for interference between two elements/objects; in this case, it is necessary to select the two or more interested parties;
- Change the settings (Figure 50). We have chosen to use the type "Clearance", Tolerance equal to 0.001 m and "None Link";
- At this point, it is possible to click on Run test and it will automatically appear clash detection results.

The results are shown in Figure 50. Some interferences arise when two objects are physically in conflict with each other. These types of clashes need to be solved early on phases, moving or replacing the elements causing the conflict.

Once the test has been completed and the results have been viewed, we can download the report of the clash detection in "HTML" format by clicking on "Write Report" (Figure 52).
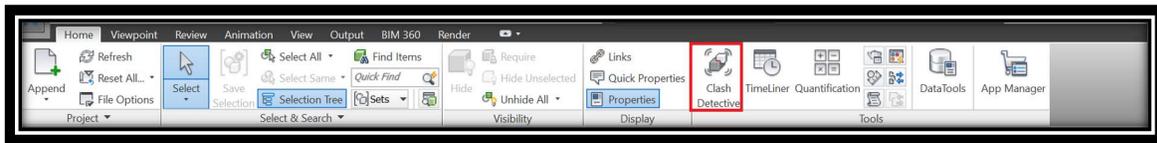
Figure 49 Clash Detective, Navisworks
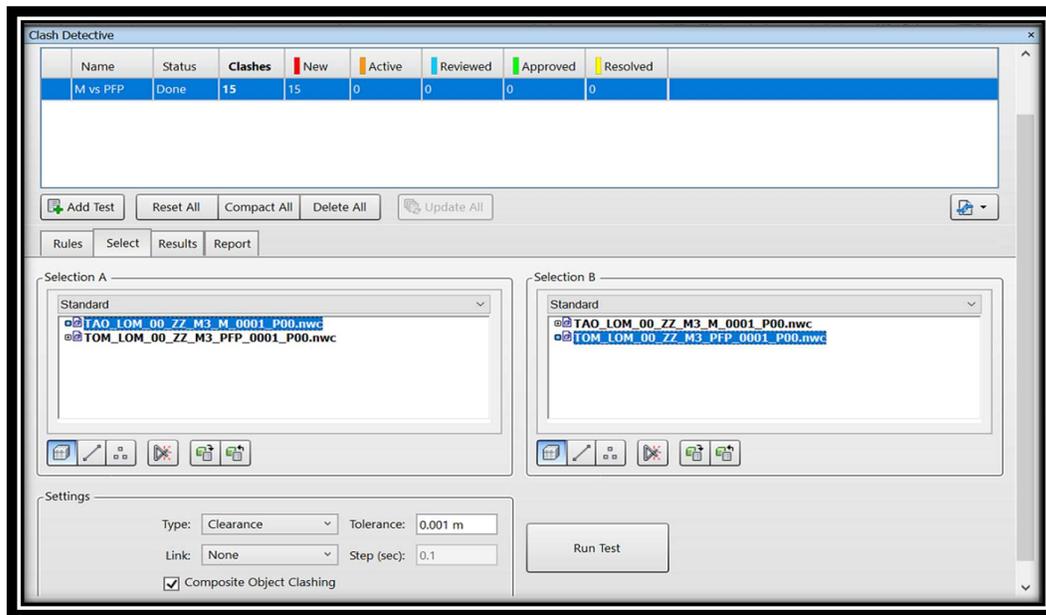
Figure 50 Clash Detection, Navisworks
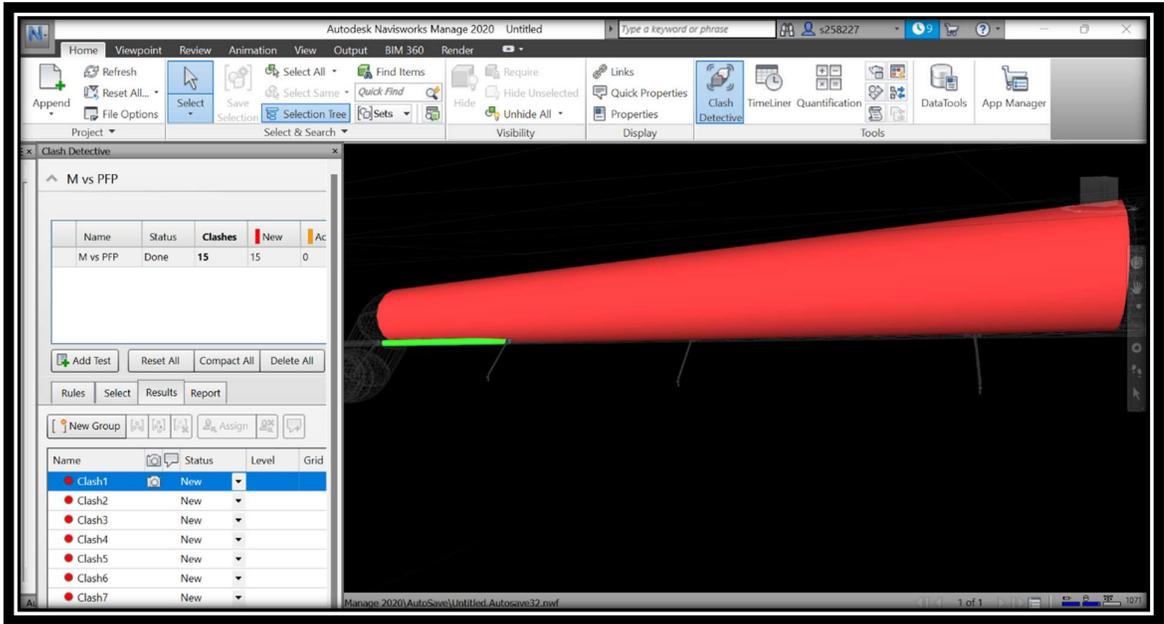
Figure 51 Clash Detection Result Example, Navisworks
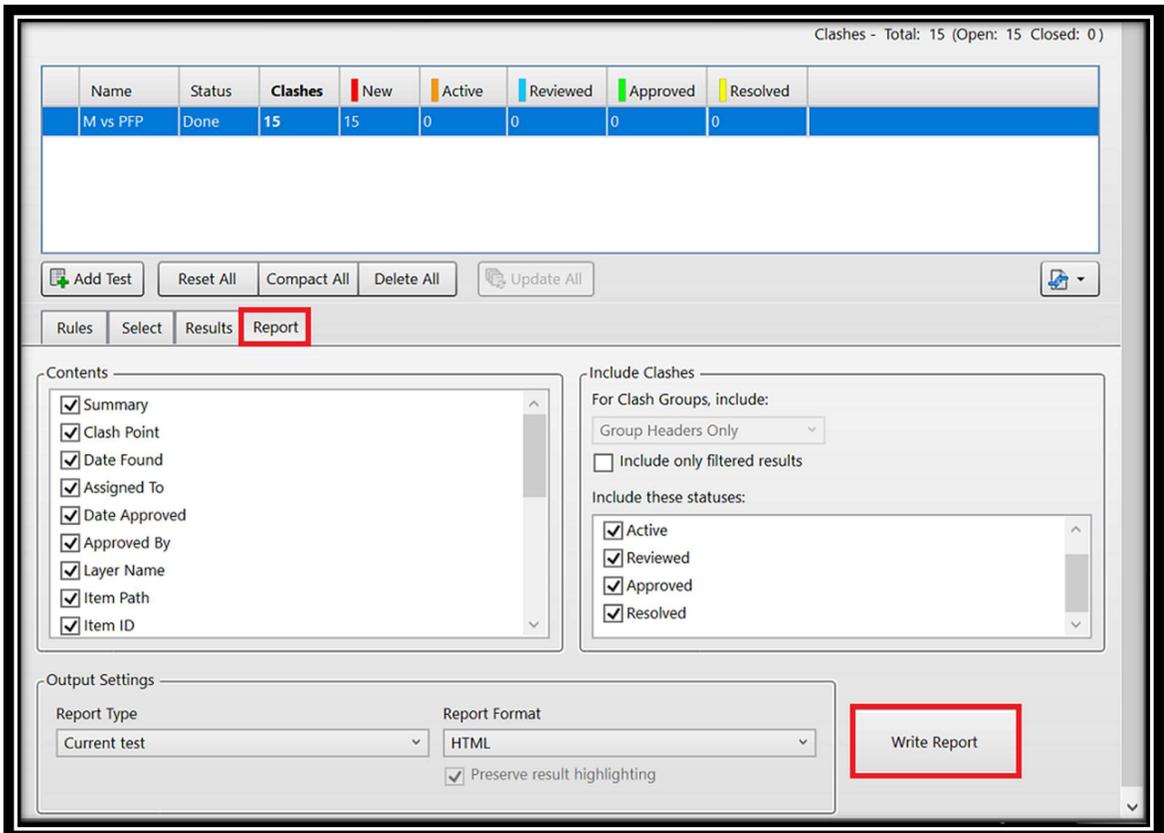
Figure 52 Interference Report, Navisworks

To insert a comment regarding any interference found, just click with the right mouse button on the desired interference and choose to Add a Comment. In Figure 53 an example of a comment referring to the interference found in Figure 51 is shown.
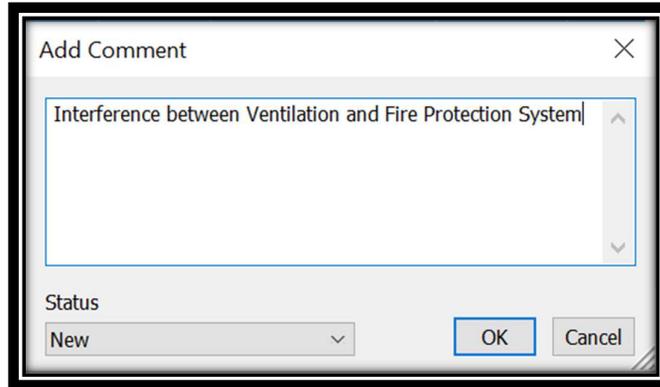
Figure 53 Comment Example, Navisworks

As we will see in Figure 52, there are a total of 15 clashes between the elements. These types of clashes need to be solved, moving, or replacing the elements causing the conflict. After modifying the model and running another clash detection, there are not any interferences at all (Figure 54) .
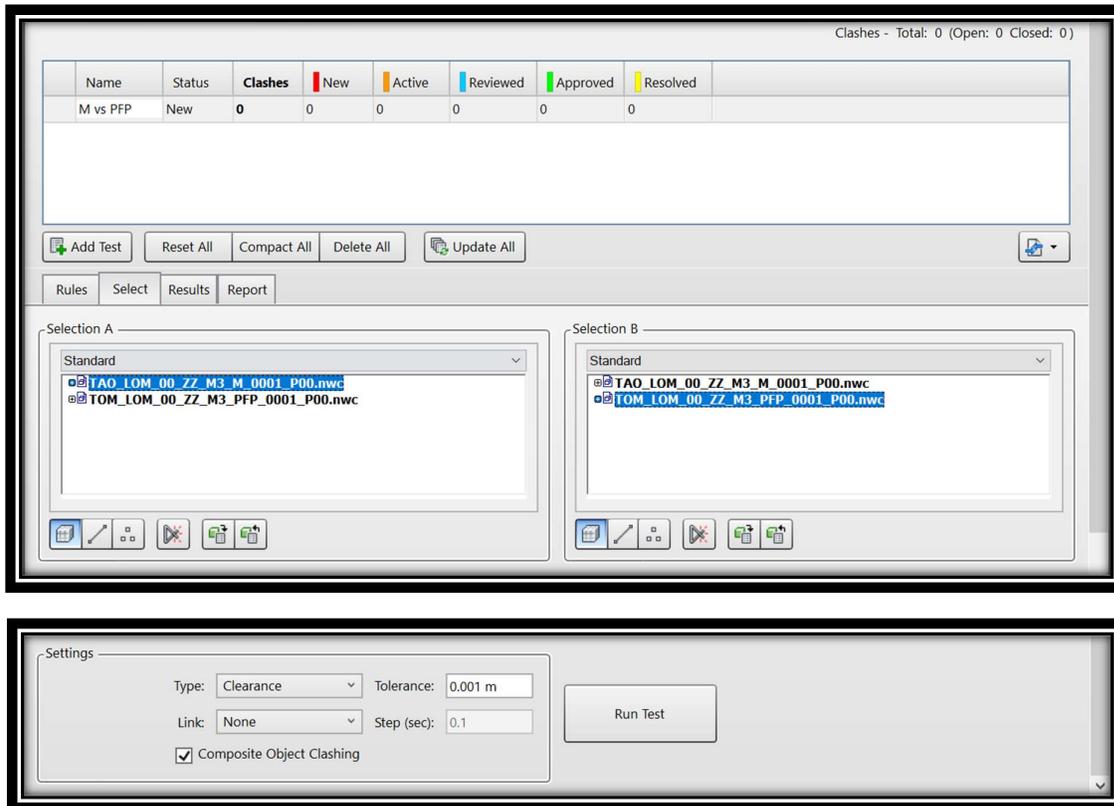
Figure 54 Clash Detection after Modifying the Model, Navisworks

4.2 Integration BIM-BMS Using Dynamo

Dynamo is an open-source visual programing language for Revit, written by designers and construction professionals, and aims to be accessible to both non-programmers and programmers alike. Dynamo can be added as a plug-in into Revit. In Dynamo, nodes are the objects we connect to form a Visual Program. The nodes in Dynamo are Python scripts that have assigned a particular task that may range from a simple operation to the creation of geometry [38].

Most nodes in Dynamo are composed of 5 parts. The anatomy of every node may be described as follows (Figure 55):

- Name - This is the name of the node that has a category;
- Main - The Node's main body - Right-clicking here brings up choices at the Node's overall level;
- Ports (In and Out) - The Wire receptors that give the Node with input data as well as the consequences of the Node's actions;
- Lacing Icon - The Lacing option for matching list inputs is indicated by this icon;
- 5. Default Value - Right-click an input Port; certain Nodes have default values that may or may not be used.
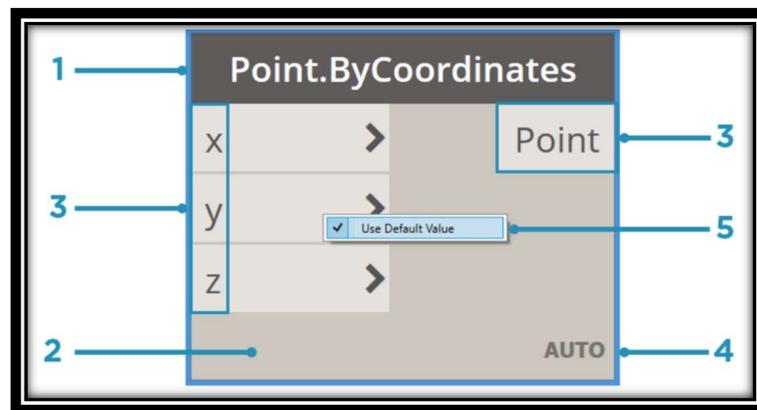
Figure 55 Anatomy of a Node, Dynamo

(Source: https://primer.dynamobim.org/03_Anatomy-of-a-Dynamo-Definition/3-1_dynamo_nodes.html)

4.2.1 Dynamo for Exporting Data

In the first step, Dynamo is employed to access the BIM database and extract any data required by the BMS. This data is then processed and converted to JSON strings. JSON data proves easy to convert to, organize, combine, and parse. In this case, a Dynamo script is developed to extract Revit parameters from different

Revit Categories. The main idea is to pass these parameters into the JSON format to integrate with BMS.

To easier understand the process realization, the whole script has been divided into different groups with a different task for each group (Figure 56).
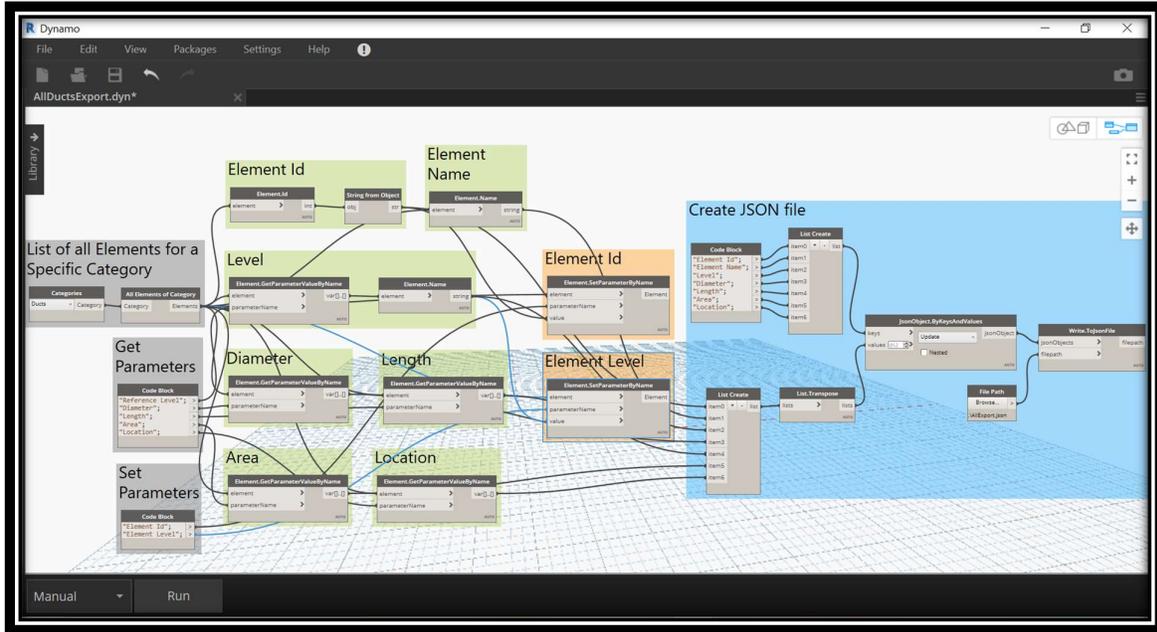
Figure 56 Dynamo Script for Ducts, Dynamo

Gray Groups: this group is related to the input information. This is a list of how we can get categories from the project. The way we can extract the information from the model is by using categories and selecting a category. We can use the node "Categories" and select a category like "Ducts". Then, we can extract all the elements of a specific category using the second node "All Elements of Category".
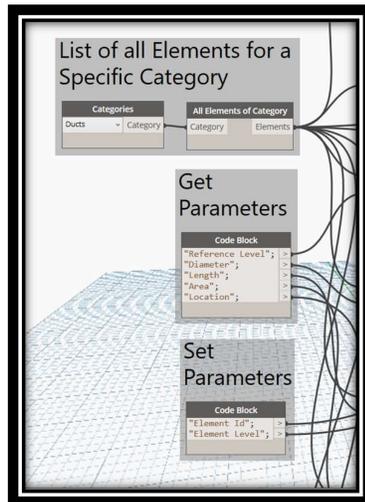
Figure 57 Gray Groups, Dynamo

Green Groups: by providing a list of elements, we want to extract specific parameters from the elements and then create a report of elements that we want to export into a JSON file. The first thing we need is the node "Element.GetParameterValueByName". for example, if we want to extract the "Level" information, we can go and find how the parameter is called for ducts, so we must find the right information. In this case, we use a node "Code Block" and write "Reference Level" as a parameter name, the same name in Revit. After Run, we have a list of levels, exactly what we need. Then to extract the level name, we need to use another node which is "Element.Name", so after this one, we have a string with a level name.

Also, we need to understand the "Diameter" of elements, so we use another node which is "Element.GetParameterValueByName". Here, we write "Diameter" in the node "Code Block". After Run, we have a list of diameters. We do the same way to extract "Length", and "Area" of elements.

To extract Element Name, we can use a node "Element.Name", after Run we have a list of the element name.

To extract Element Id, there is a node "Element.Id". In this case, we have an Id of elements as an integer, but we need this one as a string, so we can convert an integer number into a string. Here we use a node "String from Object" that is doing exactly this operation. The Element Id is a kind of information that we would like to have back into the project because we can use this information to keep track of the elements later, so the Element Id is important.

Finally, we also need to know the location of elements. To do that, we create a project parameter or shared parameter "Location" in Revit which says that in the plan we have several sections with a range from a to c, so in this way, we can understand from that parameter which is the location of that specific element. In this case, we use a node "Element.GetParameterValueByName" and after Run, we have a list of locations.
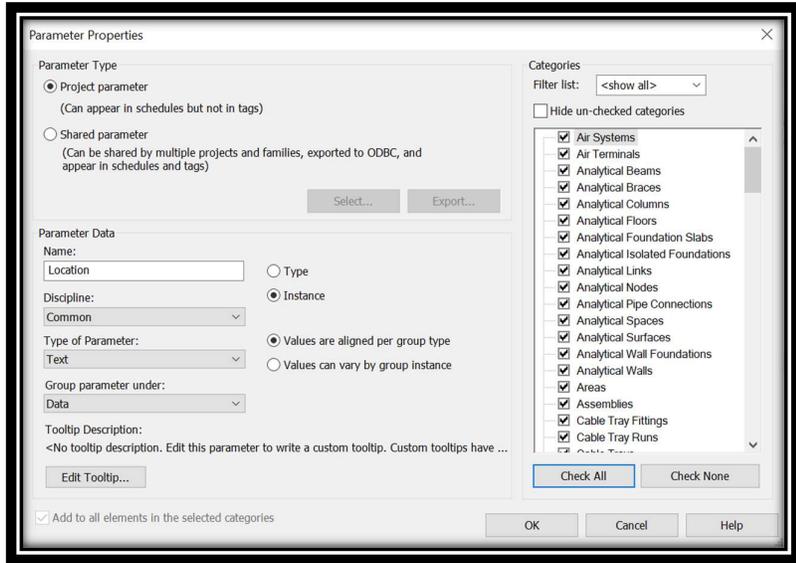
Figure 58 Location, Project Parameters, Revit
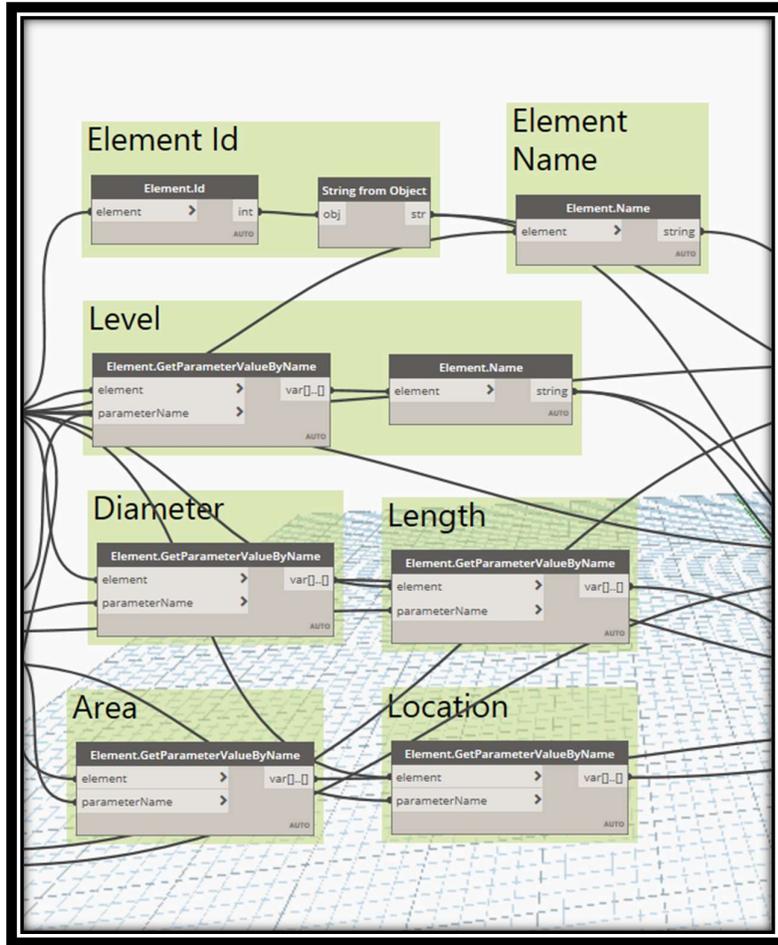
Figure 59 Green Groups, Dynamo

Orange Groups: We can create two new project parameters or shared parameters called "Element Id" and "Element Level" which are instance parameters. To do that, in Revit click on Manage > Project Parameters > Add. So, we have two new parameters, but they are empty. We can write this information back to the elements, to do that, there is another node "Element.SetParameterByName" where we can say that the element where we want to write information is the same element from where we are reading information.

In summary, the workflow is to first select all elements, and connect elements to get the Element Id of each element, then convert this integer value into a string value and use the same value to write this into a new parameter which is a project parameter. To do that, we need a list of elements and to be sure that we are using the same elements to extract and to write back information, then we must connect this information to the same elements. It is important to know that this information cannot be a Type Parameter because it is changing every time, so it should be always an Instance Parameter. If click Run, we will have all Ids back into each element inside Element Id information. We do also the same thing for "Element Level", and after Run, the value of Element Level is available now.
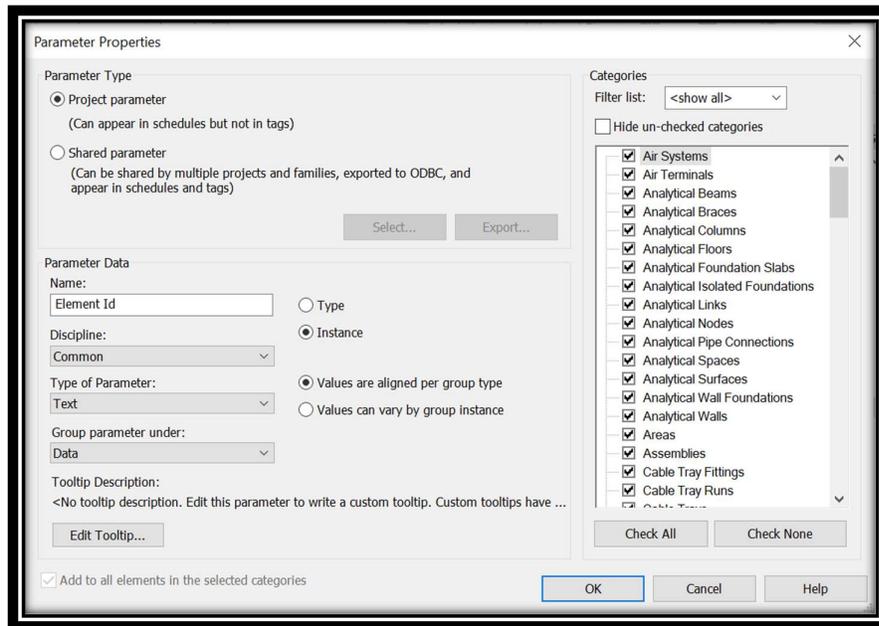
Figure 60 Element Id, Project Parameters, Revit
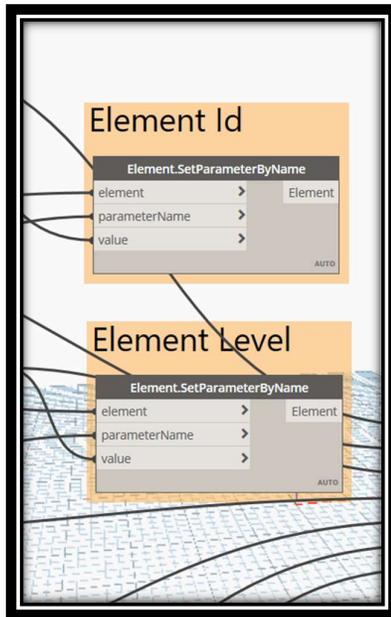
Figure 61 Orange Groups, Dynamo

**Blue Groups:** We can use tools in Dynamo to export this information directly to JSON format. To do that, first, we download a package called JsonData from the Packages menu. It has several nodes to perform different functions, but the main one is to create the base structures of the JSON format: JsonObject. A JsonObject is the representation of the key/value pair structure of the JSON format. They will be created by using the node "JsonObject.ByKeysAndValues", which returns a brand-new instance of a JsonObject. In this node, for the keys, we create a list with a node called "List Create" and put all the parameters that we want to export like "Element Id", "Element Name", "Level", "Diameter", "Length", "Area", and "Location" in a node "Code Block". For the values, we also create a list with a node called "List Create" and put all the parameters coming from the green groups which are the real information. Here, we do not need to connect the orange groups because they are information that is being used to write back into Revit. There is a node called "List.Transpose" to make a list of columns that we actually need.

Finally, to export this information directly to JSON format, we use a node called "Write.ToJsonFile". in this node, we need jsonObjects that are already created and a file path. The file path is the name of the JSON file. To do that, we need to use a "File Path" node, then we can click on Browse and choose the file name. It is important to remember that we must write the entire file name with the name of the file and extension of the file and then connect it to the filepath.

60
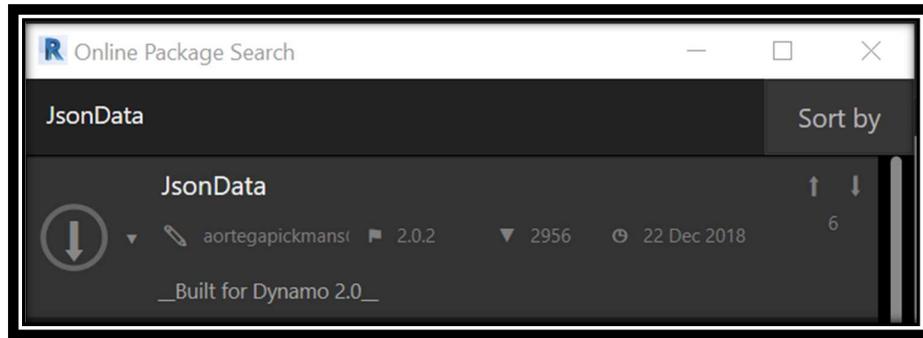
Figure 62 JsonData Package, Dynamo
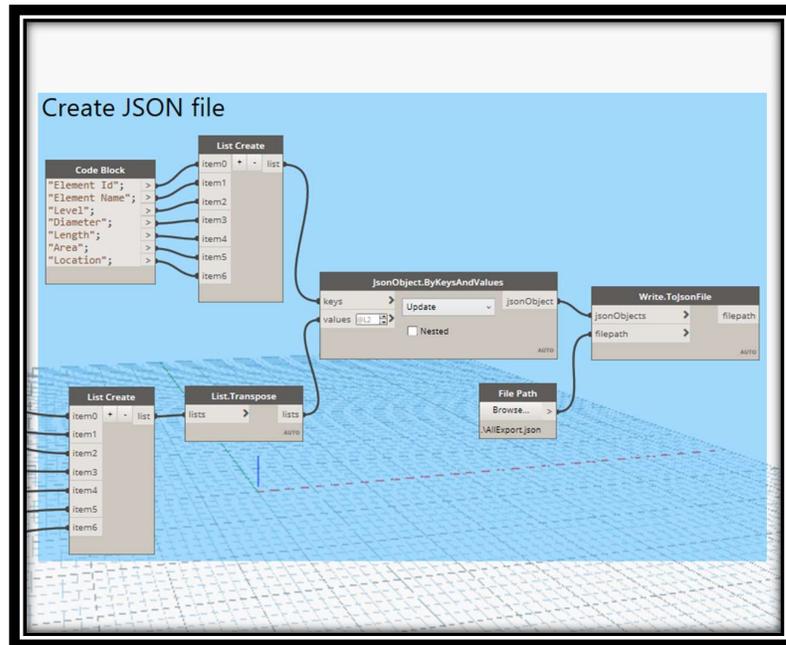
Figure 63 Blue Groups, Dynamo

If we need to export something else, such as duct fittings or mechanical equipment, we may follow the same steps, starting with selecting "Duct Fittings" or "Mechanical Equipment" from the element Categories. The related workflow is shown in Figures 64, 65.
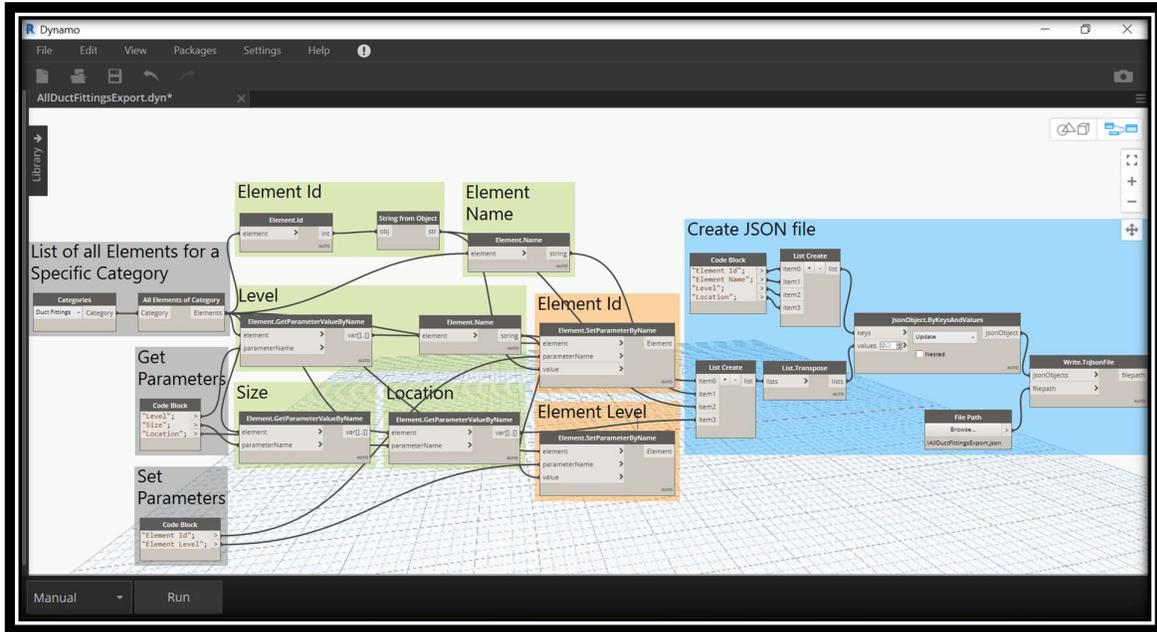
Figure 64 Dynamo Script for Duct Fittings, Dynamo
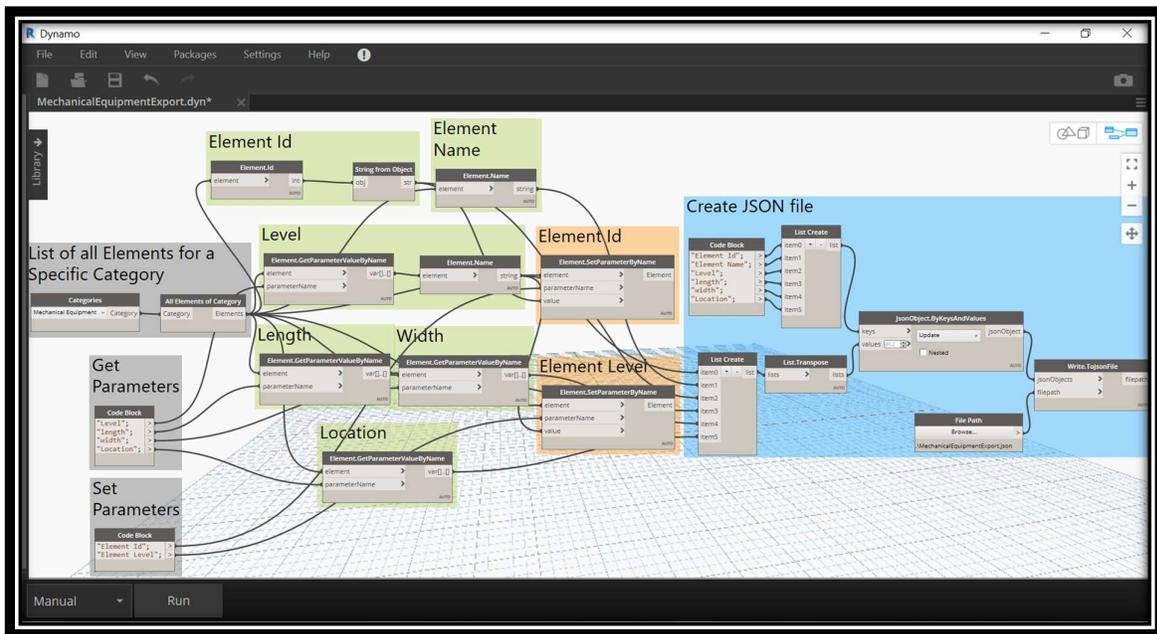
Figure 65 Dynamo Script for Mechanical Equipment, Dynamo

4.3 Results

After Run, we have all the information in JSON string.

```
[
  {
    "Element Id": "129040",
    "Element Name": "ø1500",
    "Level": "UGL109",
    "Diameter": 1500.0,
    "Length": 63.894207099851982,
    "Area": 301.09435744775942,
    "Location": "a"
  },
  {
    "Element Id": "129082",
    "Element Name": "ø1500",
    "Level": "UGL109",
    "Diameter": 1500.0,
    "Length": 63.800128576029195,
    "Area": 300.651022848806,
    "Location": "a"
  },
  {
    "Element Id": "129528",
    "Element Name": "ø1500",
    "Level": "UGL109",
    "Diameter": 1500.0,
    "Length": 59.248682069349378,
    "Area": 279.20283648591766,
    "Location": "b"
  },
  {
    "Element Id": "131859",
    "Element Name": "ø1500",
    "Level": "UGL109",
    "Diameter": 1500.0,
    "Length": 29.799130422580387,
    "Area": 140.42509382841385,
```

Figure 66 JSON String for Ducts

```
[
  {
    "Element Id": "128549",
    "Element Name": "Standard",
    "Level": "UGL109",
    "Location": "a"
  },
  {
    "Element Id": "128623",
    "Element Name": "Standard",
    "Level": "UGL109",
    "Location": "a"
  },
  {
    "Element Id": "129144",
    "Element Name": "Standard",
    "Level": "UGL109",
    "Location": "a"
  },
  {
    "Element Id": "131977",
    "Element Name": "Standard",
    "Level": "UGL109",
    "Location": "a"
  },
  {
    "Element Id": "132037",
    "Element Name": "Standard",
    "Level": "UGL109",
    "Location": "a"
  },
  {
    "Element Id": "132450",
    "Element Name": "Standard",
    "Level": "UGL109",
```

Figure 67 JSON String for Duct Fittings

```
{
  "Element Id": "208955",
  "Element Name": "Ventilatore",
  "Level": "UGL109",
  "length": 5.0998354010965716,
  "width": 2.6,
  "Location": "a"
},
{
  "Element Id": "208958",
  "Element Name": "Ventilatore",
  "Level": "UGL109",
  "length": 5.0998354010964784,
  "width": 2.6,
  "Location": "a"
},
{
  "Element Id": "225586",
  "Element Name": "Ventilatore",
  "Level": "UGL109",
  "length": 5.0998354010965352,
  "width": 2.6,
  "Location": "a"
},
{
  "Element Id": "227024",
  "Element Name": "2600*3300",
  "Level": "UGL109",
  "length": 2.6,
  "width": 3.3000000000000007,
  "Location": "a"
},
{
  "Element Id": "227104",
  "Element Name": "2600*3300",
```

Figure 68 JSON String for Mechanical Equipment

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5 Conclusion and Future Developments

In conclusion, this thesis work has dealt with several issues whose main theme turns out to be the BIM methodology. It can be said that the present thesis was aimed at obtaining a digital information model with all the data necessary for the management and maintenance of the ventilation system belonging to the railway line infrastructure. There have been some problems related to the interpretation of the .pdf files because in certain situations there were discordant data regarding the dimensions of the elements, but in any case, they were then resolved during the modeling.

In this study, the author tried to explore how to put a relation like a JSON file in the link between BIM and BMS environment. In another word, the main focus is to exchange information from BIM model to use this information and put them in communication with building monitoring system, so if there is something that is happening to the physical asset for example a failure or damage, this information is then sent back into BIM model, and the user that has to control and check if everything is working properly, can use the model to identify problems and then, for instance, open a ticket for maintenance activities. The author tried to define how the BIM model could be in communication with BMS system by using JSON language.

Simple data interchange formats, such as JSON, provided an advantage in the speed of the data extraction and analysis in the contemporary BMS, especially when handling large amounts of dynamic datasets. This thesis will contribute to the idea by demonstrating a successful link and exchange of useful BIM data between platforms, using JSON, while still retaining the ontology of the building information models. This will help for a more useful database through semantic queries. Hence, the methodological approach for the information model was aimed at being connected with building management systems.

So, in this case, we need a middleware, a kind of platform that is integrating information coming from both building information models and building management systems. The author tried to export information in JSON format, but we need to go further. Therefore, further developments include creating a platform and putting in relation with data. In this case, we put those frameworks where we can have BIM, BMS, and CMMS platforms. So, we can use these frameworks to give some possible solutions or approaches. Also, different methods regarding web- or cloud-based BIM data transfer and storage can be used for future developments in this area.

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