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Master Degree in
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Master Degree Thesis

BIM and Management of Infrastructural Facilities/Asset: Possible Solutions for Plumbing Systems

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“To my parents who always supported me in every decision that I took in my life and though me to follow my dreams. Thank you for believing in me.”

Abstract

Nowadays, the construction industry is rapidly expanding, and the complexity of construction projects necessitates improved collaboration among the various professionals involved in this industry. In complex and huge projects such as that infrastructures, there are a huge amount of data usually with different formats. This makes the accessibility of required data time-consuming and costly. therefore, there is a need to adopt new systems and technologies to manage information more efficiently. Thanks to the application of BIM, the organization of data can be obtained and data sharing between different figures improves. BIM also helps in the optimization of MEP design by identifying interferences in the early stages of the design, reducing errors and thus speeding up the delivery time and saving costs.

The following thesis deals with generating an information model of the Fire Protection System for an underground railway station. The main objective of the thesis is to try to export the data from the Revit model into JSON Format to make it available for middleware or any kind of platform for facility management. The paper is divided into different parts that follow the consecutive order of development of the thesis. Starting from the introduction and the first part dedicated to knowledge of BIM methodology, general notions, and the role of BIM in the management and maintenance of the infrastructures. The central part will focus on developing the model and families. The next part is about verifying and validating the model in terms of the Clash Detection by Navisworks software and modifying the model based on the clashes found in the test to make sure that there are no conflicts between the model of fire protection system and the other model includes HVAC system which is done by the other colleague in her thesis. Finally, the last part will focus on exporting the model and data from the Revit to the JSON language by using Dynamo.

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Introduction

Building Information Modeling (BIM) is a growing trend in the Architecture, Engineering, Construction, and Operations (AECO) industry which guarantees to facilitate the integration, interoperability, and collaboration in the future of the building sector. It begins to make its way in the early 2000s in the United States [1]. Building Information Modelling (BIM), as defined by the U.S. National Building Information Model Standard Project Committee, “is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition” [2]. A BIM system is a centralized system for managing various types of information, such as Enterprise Resource Planning, resource analysis software packages, technical reports, and so on. The main feature of a BIM, however, is its 3D modeling system with data management, data sharing, and exchange throughout the building's life cycle. A building is, in fact, made up of geometric elements that serve as the foundation for its design. Furthermore, parametric modeling offers powerful mechanisms for automating the generation of building information. Knowing the object behavior, these mechanisms would ease the maintenance and validity of building designs. The model at the heart of the BIM approach is a common and calculable 3D model of the building, which aids in overcoming the shortcomings of a paper-based 2D approach. As a result, BIM is a methodology that facilitates multidisciplinary collaboration and information management among project stakeholders [3]. BIM was initially intended to be used for the building sector, but it is now being used in areas of construction that it was not intended for, such as civil infrastructure. It is thought that the use of BIM in infrastructure is nearly three years behind its use in buildings, but the use of BIM in infrastructure has recently increased. BIM can assist in various design phases such as the planning phase, detailed design, and design optimization. It improves design quality, provides a better visual representation of the infrastructure, and fosters collaboration. One of the most favored benefits of using BIM in infrastructure from the design stage is the reduction of omissions and errors, as well as the subsequent reduction of conflicts and coordination problems on the construction site [4]. The thesis is based on BIM and consist of the practical application of this methodology on a fire protection system of an underground railway station and focusing on exporting the data from the model in a format that can be used for the integration between Building Information Model (BIM) and Building Management Systems (BMS).

Chapter 1

The BIM Methodology

1.1. BIM Concept

BIM is an acronym for Building Information Modeling or Building Information Management. Building Information Modeling (BIM) is the foundation of digital transformation in the architecture, engineering, and construction (AEC) industry which is becoming increasingly popular around the world. Building Information Modeling is the holistic process of creating and managing information for a built asset. Based on an intelligent model and enabled by a cloud platform, BIM integrates structured, multi-disciplinary data to produce a digital representation of an asset across its lifecycle, from planning and design to construction and operation [5]. In recent years, the proliferation of BIM has offered designers and builders new opportunities to construct better quality buildings at lower cost and with a shorter project lifespan. Building sectors such as the architectural sector, the engineering sector, and the construction sector each have defined goals and unique advantages of BIM. For example, in the construction industry, BIM helps reduce building material waste and also virtually assesses project risk. Most importantly, BIM helps detect where clashes are occurring and also ensures a reduction in on-site errors, etc. Perhaps the main overall benefit of the BIM process is that it supports the construction process and the design process from scratch to the whole package and beyond for all parties involved. BIM has revolutionized the construction industry by allowing anyone authorized, from anywhere in the world, to access building information and to communicate and collaborate with people on-site. Having said that, it is therefore important that the builders, designers, and project sponsors fully understand the BIM models, the BIM software, and its components. [6].



Figure 1: Benefits of BIM process

Source: <https://outsourcestructuraldrafting.weebly.com/blog/how-bim-process-is-useful-in-construction>

The necessity to distinguish between modeling geometry in two and three dimensions led to the development of BIM dimensions. This has been part of the modeling evolution, moving from drawing boards to the first 2D CAD systems to 3D modeling packages [7]. BIM is not limited to the three-dimensional model of the building but also can be used for a pre-defined specific purpose which is called as-use cases. Depending on the complexity of the project and its requirements specific parameters can be added to the existing information known as BIM dimensions. these dimensions help better understand the construction project by enhancing the data associated with the model. Each of the BIM dimensions– 3D, 4D, 5D, 6D & 7D has its purpose and helps to understand the project cost, timeline, and sustainability. [8].

The UNI 11337 standards, the voluntary technical standards adopted in the Italian context on the digital management of construction process, report the following classification:



Figure 2: BIM Dimensions

Source: <https://biblus.acca.it/focus/le-7-dimensioni-del-bim/>

- 3D - Three-dimensional modeling: Provides a three-dimensional model of the project that can be used through the whole lifecycle of the building which helps to reduce the errors from design to construction and maintenance.
- 4D - Time management: This dimension is related to time management which reduces or cancels the possibilities of interferences in the entire life of the project. it results in optimization of the time management and coordination between different figures involved in the project.
- 5D - Economic management: the fifth “BIM-dimension” allows, through the 3D model and the 4D BIM, to have full control of costs over time. This option enables the creation of efficient and convenient constructions.

- 6D - Life cycle and maintenance: It allows optimization of the management and maintenance of the building object throughout its life cycle by providing information on the individual components from technical systems to finishes.
- 7D - sustainability: This dimension relates to analyzing the energy consumption of the building which helps in adopting better solutions for reducing energy consumption and ensuring the project's sustainability.

1.2. Interoperability

Interoperability can be defined as the ability of one system to work with other systems without any effort on the part of the end user of the system, especially when exchanging information between the systems. Fully interoperable systems would not contain errors, omissions, or data loss when the information is transferred from application to application [4]. BIM Interoperability is one of the pillars of Building Information Modeling. The design and construction of a building involve various figures whom each operate within their own area of interest. BIM makes possible the collaboration between the different figures involved in the different phases of the life cycle of a structure, in order to insert, extract, update or modify information in BIM.

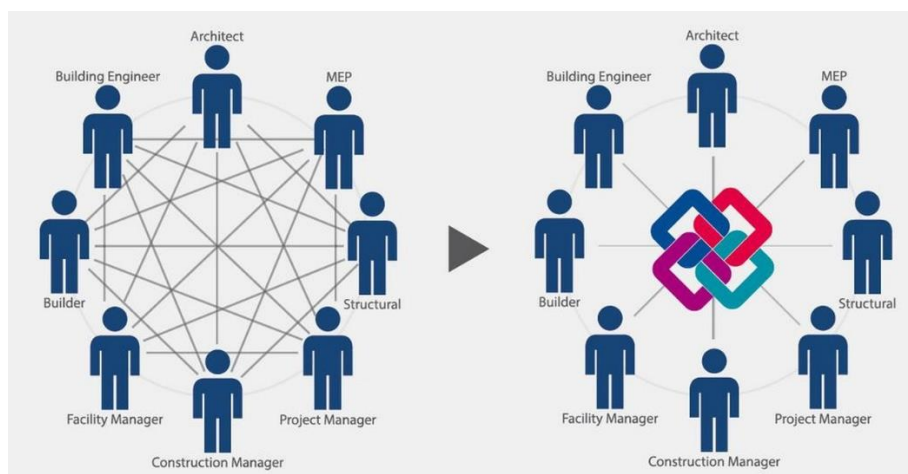


Figure 3: Interoperability of BIM

Source: <https://www.archweb.com/en/blog/post/meaning-interoperability-BIM/>

There are different levels of BIM interoperability:

- **Interoperability between software from the same vendor:**

A good example of interoperability between software from the same vendor in the construction industry is a service engineer, architect and structural engineer all working on separate 3D models in their versions of Autodesk Revit. These separate models are aligned to show a combined design model and are moved to the construction team in order to plan the work in Autodesk Navisworks. This helps in avoiding clashes between structure and services during construction.

- **Interoperability between software from the different vendors:**

A building cannot be fully designed and built using software from a single software vendor. When software from various vendors needs to communicate, then communication rules need to be agreed. As far as construction is concerned, for example, a user can design the building in ArchiCAD and complete the specification using NBS Create. This level of interoperability can greatly minimize costly errors and help with coordinating project information.

- **Interoperability through open data standards:**

The final method of BIM interoperability considered here is where the information is to be displayed or transferred between software applications through open data standards. Within the construction industry, there exist a well-established data standard for the transfer of data such as Green Building XML and Industry Classes. Open standards allow information and software from multiple sources to work together to improve the workflow in the construction industry. Standards also make data interchange in a secure way, without errors and/or loss of information [9], [10].

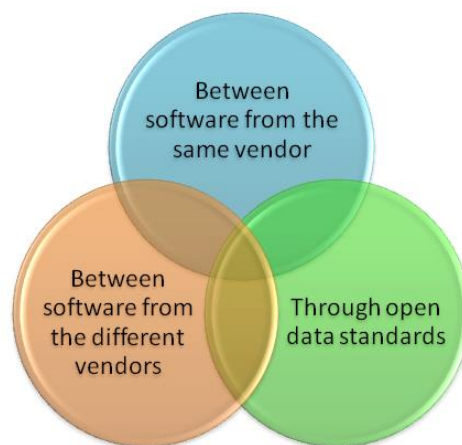


Figure 4: Different levels of BIM interoperability

Source: <https://www.revitmodelingindia.com/latest-blog/bim-interoperability/>

IFC Standard

The IFC format is an open and non-proprietary format that complies with the international standard ISO 16739. Designed by building SMART International, it serves to ensure interoperability between the various figures operating in the AEC sector. The IFC file is in fact used for the exchange of information and the sharing of data during all phases of design, construction, management and maintenance. The format allows you to produce files that include:

- IFC geometric information of the various entities of "simple" building components and all the data associated with them;
- IFC alphanumeric information that specifies the parameters, physical properties and construction information of the entire work.

All information belonging to the file is organized through classification systems that divide and distribute objects into categories and subcategories [11].

Open BIM

openBIM extends the benefits of BIM (Building Information Modeling) by improving the accessibility, usability, management, and sustainability of digital data in the built asset industry. At its core, openBIM is a collaborative process that is vendor-neutral. openBIM processes can be defined as sharable project information that supports seamless collaboration for all project participants. openBIM facilitates interoperability to benefit projects and assets throughout their lifecycle. openBIM empowers stakeholders to develop new ways of working by transforming traditional peer-to-peer work processes. By breaking down data silos, openBIM can greatly improve project delivery and asset performance. Firms that adopt an openBIM approach develop cross-party collaboration, enhanced communication, and industry-standard exchange methodologies. This delivers better project outcomes, greater predictability, improved performance, and increased safety with reduced risk. Throughout the whole lifecycle of an asset, openBIM helps connect people, processes, and data to achieve asset delivery, operation, and maintenance goals. openBIM plus seamless digital workflows make critical project information accessible to participants on a timely basis to support decision-making through various phases of the project from inception to hand-over to refurbishment and even demolition. openBIM removes the traditional problem of BIM data that is typically constrained by proprietary vendor data formats, by discipline, or by the phase of a project. By adhering to international standards and working procedures, openBIM extends the breadth and depth of the use of BIM by creating common alignment and language. Technical applications developed for openBIM improve the management of data and eliminate disconnected workflows. Independent quality benchmarks ensure reliable open data exchanges. openBIM permits digital workflows based on vendor-neutral formats such as IFC, BCF, COBie, CityGML, gbXML, etc. openBIM enables an accessible digital twin which provides the core foundation to a long-term data strategy for built assets. This provides better

sustainability for projects and more efficient management of the built environment [12].

1.3. The Standardization System in the World

With the release of ISO 19650 (parts 1 and 2) at the end of 2018, the new regulatory scenarios at the international, EU and individual state level are slowly being outlined.

- The international standards, are developed and published by the ISO (International Organization for Standardization), can be adopted on a national level by each member state on a voluntary basis. In Italy they are recognizable by the UNI ISO acronyms;
- The European standards, which are elaborated by the CEN (European Committee for Standardization) in the three recognized languages, English, French and German. Each member state is obliged to transpose them and withdraw the norms in force, typically national, in contrast with them. For example, they recognize themselves as UNI EN;
- National standards are developed by the recognized national body. In Italy, UNI, and the related Federated Bodies, and the CEI are deputed to write standards. They are valid on the national territory and are written in the mother tongue of each country.

Thanks to recognition agreements between ISO and CEN, it is possible to activate the Vienna Agreement which allows joint publication of a standard both at European and international level. In this case the abbreviation for Italy would be UNI EN ISO. Furthermore, UNI has decided to make the standards more usable by translating the main ones into Italian. At the same time, the Italian national standards have been translated into English and are presented for European and international works [13].

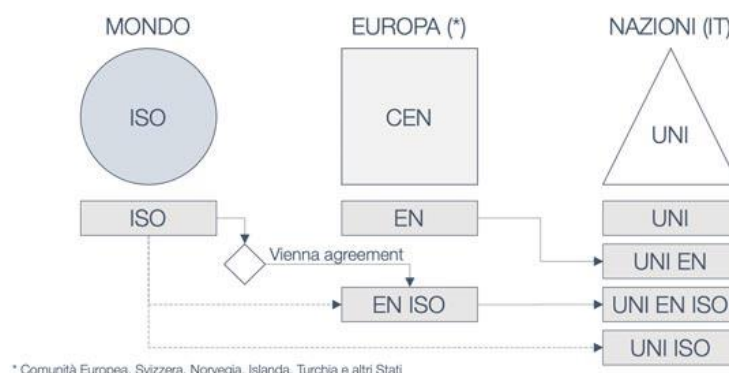


Figure 5: Application diagram of the Standards in the world

Source: <https://www.ingenio-web.it/26765-standard-bim-il-mondo-dopo-la-iso-19650>

1.4. LEGAL CONTEXT

1.4.1. UNI EN ISO 19650

UNI EN ISO 19650-1: 2019 and UNI EN ISO 19650-2: 2019 are the transposition Italian ISO, the international standards to be referred to in the context of BIM design. ISO 19650 part-1: Concepts and Principles. The standard provides recommendations relating to a conceptual framework for information management, which includes exchange, registration, updating and organization for all actors. The standard applies to the entire life cycle of an immovable asset, including strategic planning, initial design, engineering, development, preparation of documentation for assignments and construction, daily operational operation, maintenance, refurbishment, repair, and end of life. The standard can be adapted to real estate assets or to orders of any size and complexity. ISO 19650 part-2: Delivery phase of the assets. The standard specifies the requirements for information management, in the form of a management process, in the context of the real estate delivery and information exchange phase, when using Building Information Modeling (BIM). The standard can be applied to all types of real estate and from all types and sizes of organizations, regardless of the procurement strategy chosen. These international standards apply jointly to UNI 11337 series, which is a complementary standard.

1.4.2. Ministerial decree number 560/2016

Legislative Decree 50 of 2016, implementation of directives 2014/23/EU, 2014/24/EU and 2014/25/EU, establishes the beginning of the processes for the development of new rules, times to innovate and integrate previous provisions in the field of digitization. Article 23 paragraph 13 reads: "The contracting authorities may request for the new works as well as for interventions of recovery, redevelopment or variants, primarily for complex jobs, the use of electronic methods and tools. Such tools use interoperable platforms by means of non-proprietary open formats, in order not to limit competition between technology suppliers and the involvement of specific planning among the designers. By decree of the Ministry of Infrastructure and transport, the methods and times for gradual introduction are defined of the mandatory nature of the aforementioned methods at the contracting authorities, granting administrations and economic operators".

1.4.3. Ministerial decree number 560/2017

The Italian Decree 560/2017, implementing article 23 paragraph 13 of the Decree Legislative 50/2016, also known as the 'BIM Decree' is the reference standard within the national territory that defines the modalities and timing of progressive introduction, as reported in Article 6, of the gradual mandatory nature of the methods and electronic building and infrastructure modeling tools, second the following timing:

- For complex works relating to works with an equal or higher tender-based amount to 100 million euros, starting from 01.01.2019;
- For complex works relating to works with an equal or higher tender-based amount to 50 million euros, starting from 01.01.2020;
- For complex works relating to works with an equal or higher tender-based amount to 15 million euros, starting from 01.01.2021;
- For works with a tender-based amount equal to or greater than the threshold referred to in article 35 of the code of public contracts, with effect from 01.01.2022;
- For works with a tender amount equal to or greater than 1 million euro, starting from 01.01.2023;
- For works with a tender amount of less than 1 million euros, starting from 01.01.2025;

To the ministerial decree which represents a regulatory reference in the BIM field what defines the timing of introduction is flanked by the technical standard voluntary (non-mandatory), which defines the guidelines to be followed in the adoption of this methodology.

1.4.4. The UNI 11337 Standard

BIM is presently employed in Italy more than ever in a systematic fashion, thanks to the technical regulation (UNI11337), as opposed to before, when it was only used in projects built under international influences. The UNI 11337 standard is a ten-part document that deals with the management information processes of construction, specifically with models, documents, and information objects for products and processes, as well as the evolution and information development of models, documents, and objects, and information flows in digitized processes. The information is divided as follows:

- PART 1: models, drawings and objects
- PART 2: denomination and classification
- PART 3: (information sheets) LOI and LOG
- PART 4: LOD and objects
- PART 5: management of models and documents
- PART 6: example of informative specifications
- PART 7: qualification figures
- PART 8: PM / BIM-M
- PART 9: building file
- PART 10: administrative verification [14].

1.5. LOD

Within the framework of the methodological and conceptual approach that characterizes Building Information Modeling, particular importance is given to the theme of detail levels, the so-called LOD, the acronym for Level of Detail. The LODs have the task of precisely defining the level of depth of information of various kinds that are contained within the model. In this perspective, in particular, the Level of Detail represents a defined reference point that allows all the subjects involved in the project to specify and articulate the construction of a BIM model with a high degree of

clarity about its contents and maximum reliability. Information relating to it along with all the different phases in which the process of conception and realization of the work is articulated. The definition of the characteristics of every single Level of Detail concerning the type of element considered is a topic addressed by two important regulatory references, one of US origin one Italian [15].

American LOD System

In the American context, the American Institute of Architects (AIA) has published a Level of Detail framework for the AIA Protocol G202-2013 Building Information Modeling, where the term LOD refers to the level of development necessary in relation to the contents of the model elements; the choice to use the definition “level of development” instead of “level of detail” is motivated by the fact that an element, although it may appear visually detailed, could in reality be generic. According to this document, the degree of development obtainable through the drafting of a building model defined through a BIM-type approach is divided into five levels [16]:

- LOD 100: the element is represented in a generic way or with a symbol but does not meet the requirements for LOD 200; additional information about the model element can be derived from other elements;
- LOD 200: the element is represented with generic quantity, size, shape, position and orientation; non-graphic information can also be linked to the element;
- LOD 300/350: the element is represented with the correct size, position and orientation / the element is represented with the correct size, position and orientation and interfaces correctly with the other elements of the model;
- LOD 400: the element is shown with correct size, position and orientation, interfaces correctly with the other elements of the model, and reports details relating to manufacturing, assembly and installation;
- LOD 500: the element faithfully reflects reality, and is a representation verified on site in terms of size, shape, position, quantity and orientation.






LOD 100	LOD 200	LOD 300	LOD 400	LOD 500
				
<p>Modello contenente i requisiti di prestazione e le specifiche del sito.</p> <p>Modello concettuale di massa utile allo studio di tutto l'edificio inclusi area di base e volume, orientamento, stima costi iniziale.</p> <p>Progetto preliminare.</p>	<p>Modello contenente i sistemi generalizzati con quantità, dimensioni, forme, posizione ed orientamento approssimati.</p> <p>Progetto definitivo.</p>	<p>Modello di produzione o pre-costruzione, e per gli "intenti progettuali".</p> <p>Modello accurato e coordinato, utile per una stima più accurata dei costi.</p> <p>Progetto Esecutivo.</p>	<p>Modello accurato con i requisiti di costruzione e gli elementi costruttivi specifici.</p>	<p>Modello "as built" dell'edificio che mostra il progetto così come è stato realizzato.</p>

Figure 6: LOD, AIA

Source: <https://www.01building.it/bim/lod-progettazione-bim/>

Italian LOD System

The Italian legislation that refers to Level of Detail is UNI 11337-4: 2017, which has among its assumptions the possibility of using any of the existing Level of Detail scales, without exclusions or priorities, according to the specific needs of the contract and provided that the specific references, the logic, the objectives and the structure are defined in advance for the purposes of maximum transparency for the interested parties. The UNI 11337-4: 2017, in particular, makes its own the fundamental terminological distinction between LOD, LOG and LOI; in this perspective, the LOD, level of development of digital objects, is composed of LOG, level of development of objects - geometric attributes, and of Level of Detail, level of development of objects - information attributes.

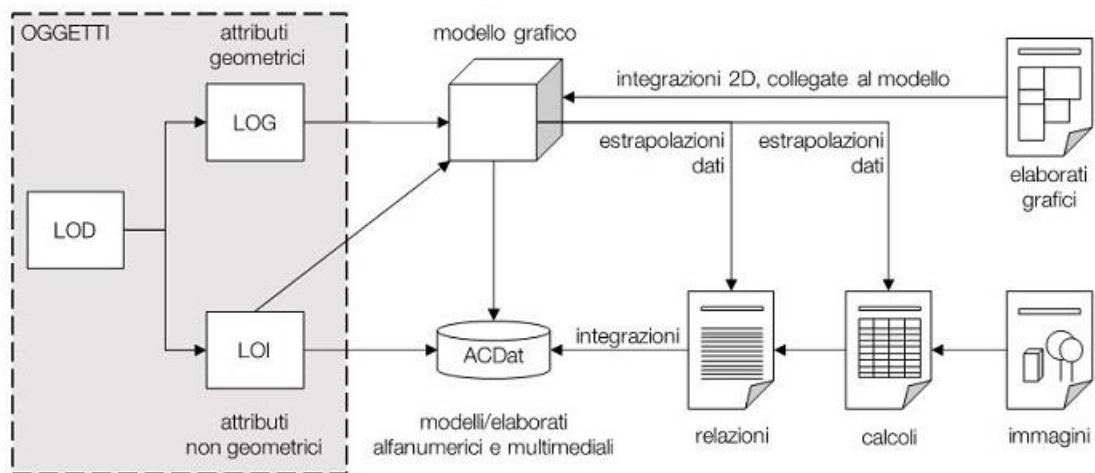


Figure 7: Data flow in the digital process through the LODs of the objects
Source: <https://www.ingenio-web.it/18667-sistema-dei-lod-italiano-uni-11337-4-2017>

Unlike the 5 levels proposed by the AIA, UNI 11337 identifies the LODs through an alphabetical scale:

- LOD A: the entities are represented graphically through a symbolic geometric system or a representation of genre taken as a reference without constraint of geometry. The quantitative and qualitative characteristics are indicative;
- LOD B: the entities are virtualized graphically as a generic geometric system or a bounding geometry. The qualitative and quantitative characteristics are approximate;
- LOD C: Entities are virtualized graphically as a defined geometric system. The qualitative and quantitative characteristics are defined generically in compliance with the limits of current legislation and the technical standards of reference and referable to a plurality of similar entities;
- LOD D: the entities are virtualized graphically as a detailed geometric system. The qualitative and quantitative characteristics are specific to a defined plurality of similar products. The interface with other specific construction systems is defined, including the approximate dimensions for operation and maintenance;

- LOD E: the entities are graphically virtualized as a specific geometric system. The quantitative and qualitative characteristics are specific to a single production system linked to the defined product. The level of detail relating to manufacturing, assembly and installation is defined, including the specific dimensions for operation and maintenance;
- LOD F: the objects express the virtualization verified on the site of the specific production system performed / built. The quantitative and qualitative characteristics are those specific to the single production system of the laid and installed product. The management, maintenance and / or repair and replacement interventions to be carried out throughout the life cycle of the work are defined for each individual product;
- LOD G: objects express the updated virtualization of the actual state of an entity in a defined time. The management, maintenance and / or repair and replacement interventions to be carried out throughout the life cycle of the work are defined for each individual product [15].




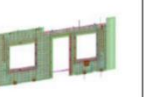

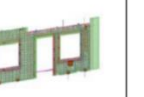
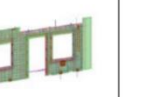
LOD A	LOD B	LOD C	LOD D	LOD E	LOD F	LOD G
						
Geometria Elemento strutturale bidimensionale verticale o pseudoverticale rappresentato mediante un simbolo 2D.	Geometria Elemento strutturale bidimensionale verticale o pseudoverticale rappresentato mediante un solido di estrusione abbozzato con aperture.	Geometria Elemento strutturale bidimensionale verticale o pseudoverticale rappresentato mediante un solido avente dimensioni calcolate secondo la normativa tecnica.	Geometria Elemento strutturale bidimensionale verticale o pseudoverticale rappresentato mediante un solido avente dimensioni pari alle dimensioni reali. Sono modellate tutte le armature in posizione corretta e sono posizionati degli inserti 3D tipici.	Geometria Elemento strutturale bidimensionale verticale o pseudoverticale rappresentato mediante un solido avente dimensioni pari alle dimensioni reali. Sono incluse tutte le armature in posizione corretta, gli inserti specifici del produttore, i dati specifici del fornitore dei materiali e delle armature.	Geometria Come LOD E (rilievo di quanto eseguito).	Geometria Nuovi interventi: Come LOD F (con aggiornamenti) Manutenzione e gestione su elementi esistenti: Come LOD C o D (a partire da).
Oggetto Simboli grafici 2D	Oggetto Solido 3D	Oggetto Solido 3D complesso	Oggetto Solidi 3D complessi	Oggetto Solidi 3D complessi	Oggetto Solidi 3D complessi	Oggetto Solidi 3D complessi
Caratteristiche <ul style="list-style-type: none"> • Posizionamento di massima 	Caratteristiche <ul style="list-style-type: none"> • Materiali ipotizzabili • Incidenza di armatura standard 	Caratteristiche <ul style="list-style-type: none"> • Materiali da calcolo • Incidenza di armatura calcolata 	Caratteristiche <ul style="list-style-type: none"> • Armature 3D • Inserti 3D tipici 	Caratteristiche <ul style="list-style-type: none"> • Inserti 3D reali • Gestione dei getti 	Caratteristiche <ul style="list-style-type: none"> • Certificati di collaudo • Piano di manutenzione 	Caratteristiche <ul style="list-style-type: none"> • Data di manutenzione/sostituzione • Soggetto manutentore • Tipologia di intervento

Figure 8: UNI 1137-4, Example of LOD prefabricated walls
 Source: <https://www.shelidon.it/?p=7828>

Information models not only contain geometric data, but they are also a series of attributes (type of elements, materials, characteristics, performance, etc.), consequently, the model can be characterized by levels of graphic detail and information. Furthermore, add the inhomogeneity of the definition of the contents of the LODs, which varies by country and by the standard used. These considerations led to the introduction of a new definition "Level of Information Need" or LOIN in the ISO 19650 standard, using terminology that underlines and reiterates, on the one hand, the importance of information content whatever both their nature, the need, and the number and type of information on the other contained in the model are limited to those actually necessary.

1.6. Common Data Environment (CDE)

The term Building Information Modeling (BIM) describes the process of creating and managing a digital model containing information of different types (structural, energy, geometric, plant engineering, etc.) of a building, whether it is in the design and construction phase or already existing. This process requires a specific tool for managing all information, which can be used by all the actors involved. It is precisely for this reason that the need arises to have a data-sharing environment. In many countries, this environment is defined as CDE (Common Data Environment) as defined by the British PAS 1192 standards and is adapted to allow the best use of the interoperability of BIM [17]. The Common Data Environment (CDE) is the single source of information for the project, used to collect, manage and disseminate documentation, the graphical model, and non-graphical data for the whole project team (i.e. all project information whether created in a BIM environment or a conventional data format). Creating this single source of information facilitates collaboration between project team members and helps avoid duplication and mistakes [18].

In Italy, the CDE takes the name of ACDat (Ambiente di Condivisione Dati) and is defined by Article 2 of Ministerial Decree 560/2017 and governed by UNI 11337. The art. 2 of the draft BIM decree states: "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 mainly attributable to them, based on an IT infrastructure whose sharing is governed by precise systems of security for access, traceability and historical succession of the changes made to the information content, conservation over time and relative accessibility of the information contained, the definition of responsibilities in the processing and protection of intellectual property" [19].

In the British technical standards, the CDE is defined in an organic manner, while the Italian standard, UNI 11337, does not specify how the ACD will have to work and how it will have to be organized, but it only lists the aspects that must be met:

- accessibility, according to pre-established rules, by all the actors involved in the process;
- traceability and historical succession of the revisions made to the data contained;
- support of a wide range of types and formats and their processing;
- high query flows and ease of access, recovery and extrapolation of data (open data exchange protocols);
- conservation and updating over time;
- guarantee of confidentiality and security [17].

In this thesis it is used the Autodesk Docs platform for data sharing since this project has divided into different parts (Architecture, Structure, and MEP) and different students involved in which each of them had to develop his area. Autodesk Docs is a unified platform which is connecting the project teams and data in real-time, from design through construction, supporting informed decision-making and leading to more predictable and profitable outcomes.

Project Information Model (PIM)

It is an information model that provides all the data required to carry out the delivery phase of an asset. That is when an asset (building) is designed, constructed and commissioned. PIM resides in the project's Common Data Environment and the collection of its information responds to the requirements set out by the Appointed Party in Exchange Information Requirements. It consists of all sorts of information containers: models, databases, spreadsheets and documentation. The amount of different data (information containers) in PIM augments gradually together with the development of the delivery process. In the brief phase, it may comprise only the scheme architectural model and some spreadsheets with requirements. Then further in the design or construction phase, it may contain a vast amount of information. In practice, Project Information Model is all relevant data that sits in the Project's Common Data Environment platform. PIM lasts as long as the project continues to develop.

Asset Information Model (AIM)

It is an information model that provides all the data required to carry out the operation phase of an asset (in contrast to PIM which provides data for the delivery phase). At the end of the project, some elements of the Project Information Model are transferred into the Asset Information Model and unnecessary data (residual project information) is archived. AIM comprises graphical models, non-graphical data, and all necessary maintenance, operation, and management documentation for objects in the model. Appointing parties, end-users, and facility managers create and use Asset Information Model, during the operational phase of the asset. The creation and structure of data in AIM should enable transfer to computer-aided facility management systems (CAFM), COBie, or another format for later management of the building. Requirements to the format of the deliverables should be agreed upon beforehand in Exchange Information Requirements. In practice, AIM comprises all files and data that the Delivery Team gives to the Appointing Party during the handover after completion of the project. Building Owner uses that information to set up a Facility Management system and operate the building [20].

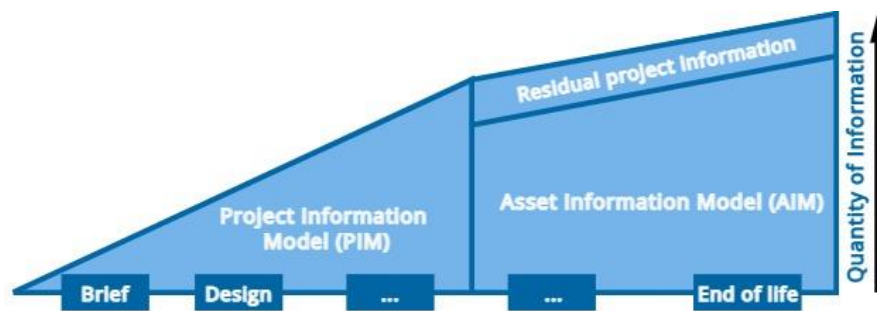


Figure 9: Graphics bases on ISO 19650-1 presenting Information progress during different delivery phases.

Source: <https://bimcorner.com/iso-19650-terms-explained-in-this-simple-way/>

1.7. Roles and Responsibilities

BIM technology applied to the entire life cycle of a building generates a significant production of data and information. In order to correctly and efficiently manage all the information involved, it is necessary to provide for an organizational structure where the roles and responsibilities of each actor in the process are well defined. It is therefore natural to expect that BIM in construction generates new professional figures with specific tasks and skills. The processes underlying BIM are positioned between the construction sector and the IT sector (it becomes necessary to manage information in an automated manner). The new figures responsible for the implementation, management and coordination of these processes are complex figures, who must possess distinctly multidisciplinary requirements. The whole of Europe is developing training courses and plans for these professionals. The same part 7 of UNI 11337 will define the professional figures related to BIM.

- **BIM SPECIALIST:** The figure of the BIM Specialist is able to use the software for the realization of a BIM project, according to his disciplinary competence (architectural, structural, plant engineering, etc.). The BIM Specialist is able to understand and use the company's technical and operational documentation for the production of drawings and models. He carries out the activities of extracting data from models, artifacts and objects, processing graphic models and parametric objects, modifying the models and objects following the outcome of the multidisciplinary coordination procedures, modifying models and objects following design reviews. He can work under the supervision and coordination of the BIM Coordinator or the BIM Manager [21].
- **BIM COORDINATOR:** The BIM coordinator plays the role of coordinator of the BIM design team (including BIM Manager and BIM Specialist) involving them within the entire design process. The standard applies to the entire life cycle of an immovable asset, including strategic planning, initial design, engineering, development, preparation of documentation for assignments and construction, daily operational operation, maintenance, refurbishment, repair, and end of life. The BIM Coordinator is the one who guarantees the efficiency and compliance with standards and procedures defined at a managerial level by the BIM Manager. The BIM Coordinator will be able to deal with the information specifications and the information management plan will participate in the definition of the staff and the necessary equipment. It will take care of the quality, manage interference and conflicts, and the correctness of digital information flows. In addition, he will coordinate the work team by optimizing resources, coordinating the process of creation, management, verification, and management of digital models [22].

- **BIM MANAGER:** The BIM Manager is the manager of digitized processes. He deals with the organization of digital processes, the supervision and general coordination of ongoing orders and the specialized human resources involved in the BIM process. The BIM Manager manages all the orders and interfaces mainly with two other management figures: the BIM Specialist and the BIM Coordinator; but he must have the right preparation to make the final decisions on his own. Although he is not always technically proficient in the software used by the group, he must nevertheless have a practical knowledge that allows him to be fully involved in the process of management and creation of standards and documentation. Some tasks of BIM Manager are: coordinate and supervise orders, prepare reports and collaborate in the audit activity, designate the BIM Coordinator, define the contractual aspects, draw up the information management offer and information specifications, drafting and updating organizational guidelines on information management, support the drafting of the information management plan [23].



Figure 10: Different figure involves in a BIM Process

Source: <https://bim.acca.it/bim-manager-bim-specialist-e-bim-coordinator-chi-sono-cosa-fanno-e-come-si-diventa/>

1.8. BIM for Management and Maintenance of Infrastructure

Transportation infrastructure is a critical component to a nation's economy, security, and wellbeing. Therefore, there is a great need for more efficient and cost-effective technologies and techniques to build, maintain, monitor, and repair these kinds of structures. Transportation infrastructure includes roads, railways, bridges, tunnels, and mass transit hubs (such as airports, ports, and harbors). BIM can be a suitable solution for extremely complex projects such as infrastructures where there is a need to manage a huge amount of data with different formats. Managing data involves creating data (i.e., supplying data using data models); preserving data (i.e., storing, archiving, securing, and retrieving data); and, provisioning, exchanging, or sharing data for use during a variety of business operations. BIM helps to provide a visual data base that could be used through the whole lifecycle of infrastructure from design to construction to operation and maintenance (Figure 11). During the operation phase the benefits of using BIM include control of maintenance management process, integrated life cycle data, rapid and accurate information about update and change activities, and more effective Facility Management (FM) with easier information exchange. As a result, it reduces the time, risk, and cost of O&M management, which is the most expensive consumption of the entire infrastructure lifecycle, while contributing to more reliable, sustainable, and secure network performance and to better decision making [4], [24], [25], [26].

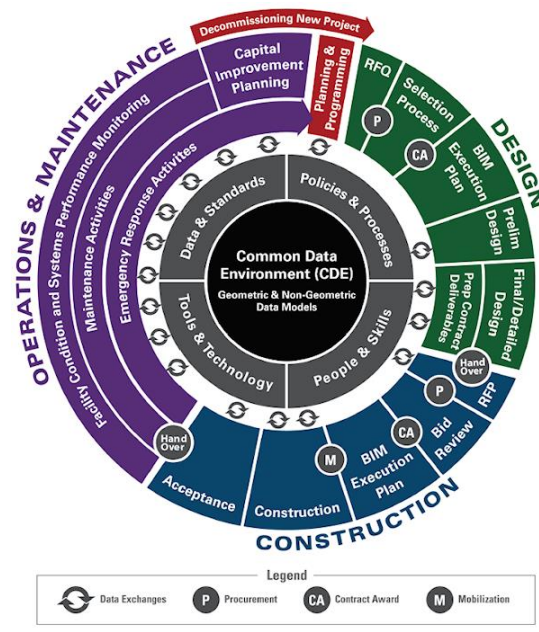


Figure 11: Lifecycle Phases

Source: <https://highways.dot.gov/research/research-programs/infrastructure/building-information-modeling-bim-infrastructure-overview>

Chapter 2

Case Study

2.1. Metro Station

The case study of this thesis is a typological metro station. as mentioned above, these types of infrastructure are of significant importance to the city in several ways. As with other similar case studies in this context, carried out by implementing the BIM methodology, this project includes several students each assigned to do part of a multidisciplinary model for this metro station. the task of the author is to develop the fire protecting system classified in the plumbing sub systems. As the whole project is still in progress, it is not possible to publish the project specifications. The three-dimensional model below (Figure 12) shows the work done by the author for the fire protecting system of the metro station which will be explained in detail in the following chapters.

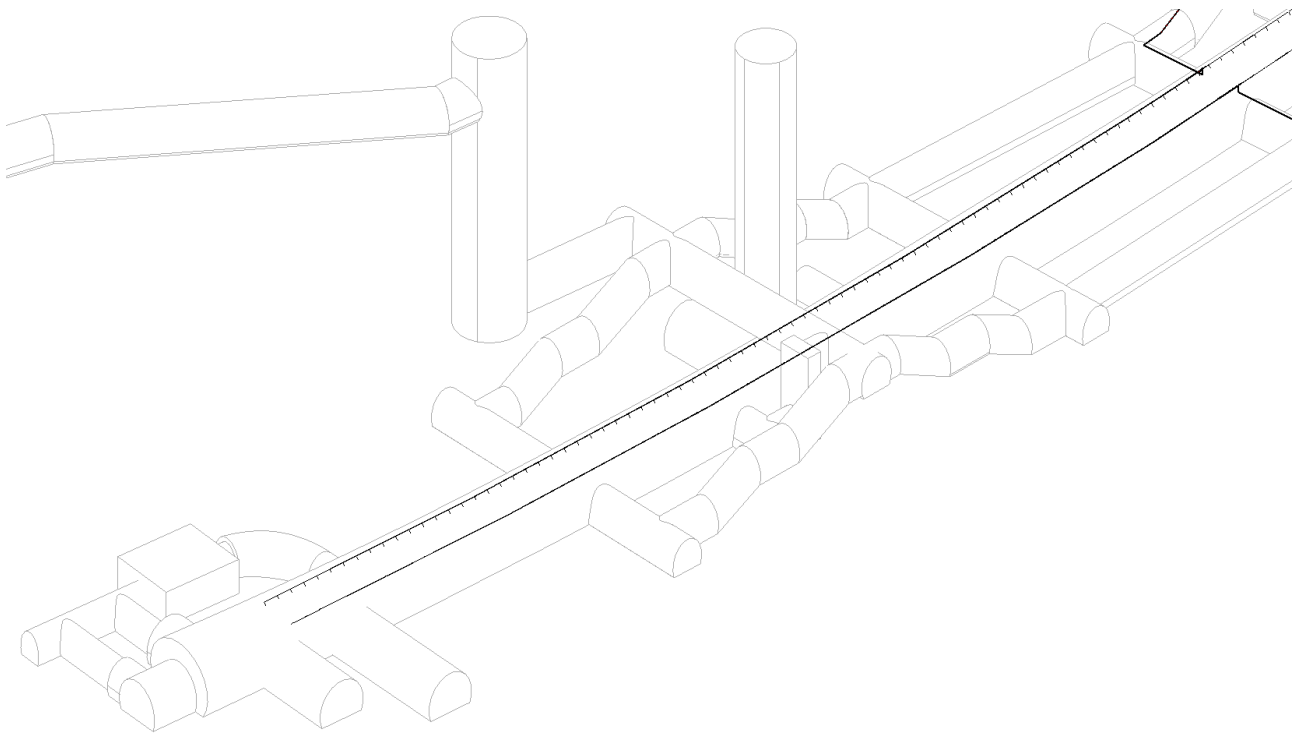


Figure 12: Three-dimensional model of the Fire Protecting system

2.2. MEP Engineering

The acronym MEP (Mechanical, Electrical, Plumbing) refers to the BIM design of mechanical, electrical, and plumbing systems. MEP engineering is a term that relates to the management of a building's non-structural functions. It can consist of managing more than ten subsystems, including heating, ventilation, and air conditioning (HVAC), energy distribution, telecommunications, automation, fire protection, water supply, and drainage. Each system is a complex combination of different components, such as equipment, pipes, and cables. MEP engineering is concerned with the life cycle of any MEP subsystem, including the design, construction, operation, and maintenance (O&M) of the MEP system and its subsystems [27], [28].

MEP systems have become increasingly complicated over the time to fulfill advanced design and new facility needs, requiring greater space and coordination for installation. However, due to economical and energy efficiency reasons, the amount of space available in the structures is limited. As a result, MEP system coordination has become a particular challenge in large projects such as infrastructure [29]. BIM is an intelligent 3D model-based process that enables MEP professionals to design, detail, and document building systems more efficiently. By using a BIM process, project teams can achieve more complete project data and feasibility while reducing risk and improving results [30]. The possibility of having an MEP model with an architectural model already in the design phase allows creating and modifying the Mechanical Components (pipes, ducts) based on the architectural or structural model [31]. Another advantage of using Revit MEP is to prevent location conflict which is a common error in mechanical design by helping to understand the space occupied by mechanical equipment. Furthermore, by using Autodesk Navisworks it is possible to highlight all clashes for instance within MEP systems against other MEP systems or MEP against the structure to make sure there is harmony between the Architectural, Structural, and MEP design. Conflicts eliminated at an early stage will surely have a positive outcome on the project [32].

2.3. Methodological Approach

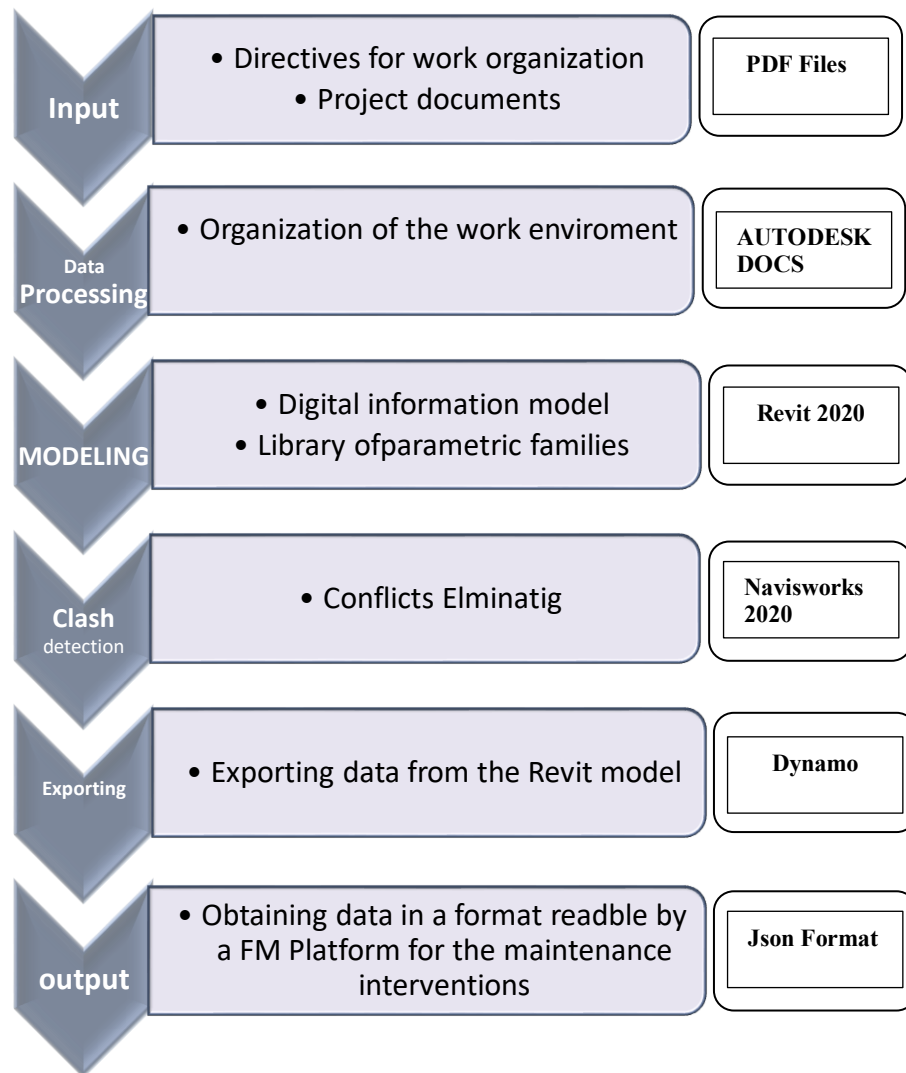


Figure 13: Project Workflow

Chapter 3

Information Modeling

3.1. Data collection

The first step is analyzing the input data shared in Autodesk Docs. The project team may transfer and share information and data within a single solution using Autodesk Docs, which supports the whole project workflow. Disciplines are separated into different folders.

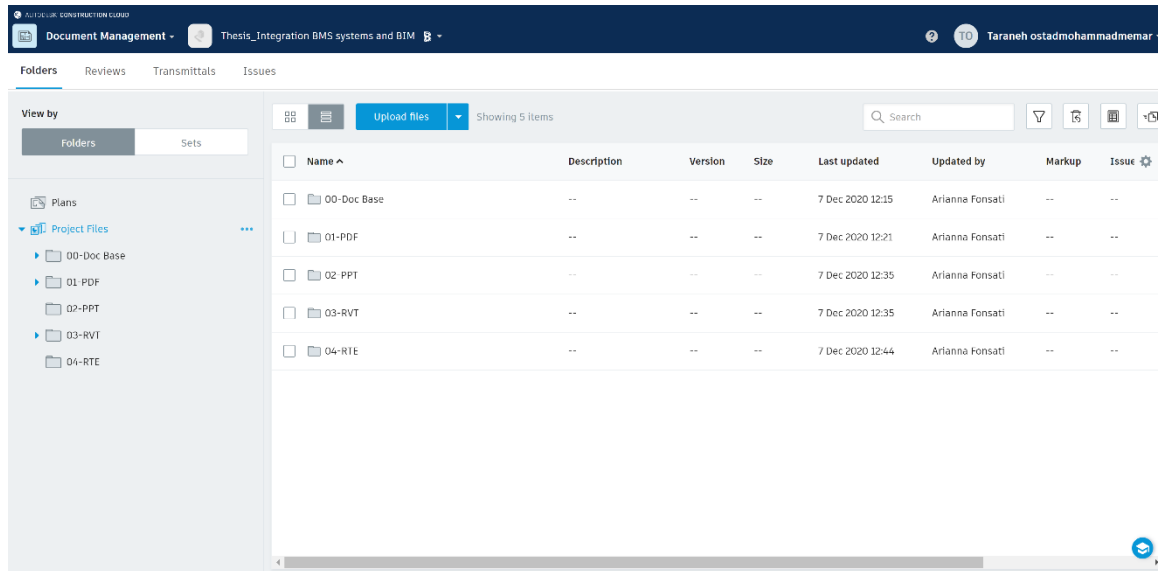


Figure 14: Autodesk Docs platform

All data was saved with particular codifications according to a text file that established indications for the template and file naming and was accessible to all members of the team, enabling better interoperability. Table 1 shows how the coding related to this thesis has been renamed:

TOM_LOM_00_ZZ_M3_PFP_0001_P00

Code	File type	
TOM	Project acronym	
LOM	Responsible organization acronym	
00	Indication of the zones and volume to which it refers the file	All zones
ZZ	Indicates levels and positions to which the file refers	Multiple levels
P FP M A S F	Indicates the discipline and any sub-discipline the file belongs to	Plumbing Fire Protection Mechanical Architecture Structure Coordination
0001	Indicates the first file in the series	
P00	Indications that the file has not yet undergone validation	

Table 1: File codification

Since Fire Protection was not presented in the table relating to the "discipline" it is considered necessary to create a sub-discipline of “Plumbing (P)”, named “Fire protection (FP)” (See Table 1).

3.2. Software

The popularity of BIM has increased in recent years and so many companies have adopted BIM for their projects around the world. The graphic interface is divided into tabs and enables for multiple views to be viewed at the same time, with a dynamic relationship between them. so if you modify or change something in a view, it will be update automatically in other views. In this case study, Autodesk Revit 2020 is used. Autodesk Revit is a software created for BIM with the capabilities for architectural, MEP (mechanical, electrical, plumbing) and structural disciplines of the AEC sector. Revit gives the user the possibility of interacting with different file formats like DWG, DXF, IFC, DWS, gbXML.

- Revit Architecture: allows you to create a model starting with the initial design and ending with construction documents, as well as optimizing building performance with centralized access to performance data. It allows you to add architectural features to your model, make accurate renderings.
- Revit structure: It helps to simplify projects, from design idea to manufacturing, by linking the structural design to the detailed model, it is possible to improve the precision and constructability of the installation. It is possible to make a comparison with the other components of the building and analyze their structural and safety compliance with the current rules.
- Revit MEP: It allows mechanical, electrical, and plumbing (MEP) engineers, designers, and contractors in modeling to a high level of detail and coordinating with construction project stakeholders. As a result, it is able to design complex duct and piping systems, model and document electrical systems, design sanitary systems, and test for interference.

The parametric digital model is made in Revit 2020, although the 2021 version was already available on the market since the Architectural and structural parts already have been done in the 2020 version and it could be possible to update them to 2021, but in this way, they were no more convertible to 2020, so for the better interoperability between data and project teams, it was decided to continue in 2020 version also for the MEP part.

3.3. Setting Phases - Template

The Template is the Revit work environment, which is designed to serve as a binder containing a set of design settings, families, annotations, and labels to fully explain the project [32]. A project template provides a starting point for a new project, including view templates, loaded families, defined settings (such as units, fill patterns, line styles, line weights, view scales, and more), and geometry, if desired [33]. It is possible to choose a default template or define a custom template. The project template uses the file extension RTE while the template family use the file extension RFT.

3.3.1. User Interface and Display

Setting the rules for the Project Browser in Autodesk Revit allows you to organize the user interface. This method enables the establishment of an effective object visualization hierarchy. 2D, 3D Views, Schedules, and other elements make up a Revit model. By clicking on a view name, one can navigate and switch between multiple views. Each view has its own set of characteristics, such as scale, discipline, and so on. These views can be duplicated, with each duplicated view having its own set of characteristics. As a result, rules for viewing and querying views must be defined. This structure enables a more efficient viewing of data (Figure 15).

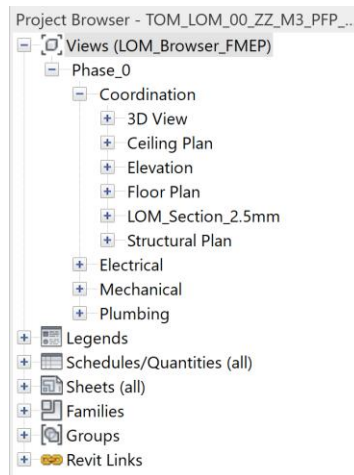


Figure 15: Project Browser, Revit

3.3.2. Revit links

The structural model of the project which was uploaded into a folder containing the Revit files in the common data environment (CDE) which in our case was Autodesk Docs has been linked to the Revit project. From the menu insert > Link Revit, select the structural template (Figure16). By selecting the Revit link a window appears in which we can search the file name. Then we have to position the file into our project choosing Auto – by shared coordinates (Figure17). If we click insert > manage links or manage > manage links, it will open a tab that shows all the files linked to the project and change their properties (Figure 18). For instance, we can define the reference type as overlay or attachment. If the model that is linked to the project contains other linked models the links become nested. By choosing overlay the nested models can be not loaded into the host model and therefore they are not displayed but if we choose attachment instead the nested models will be loaded in the host model and we can see them in the project.

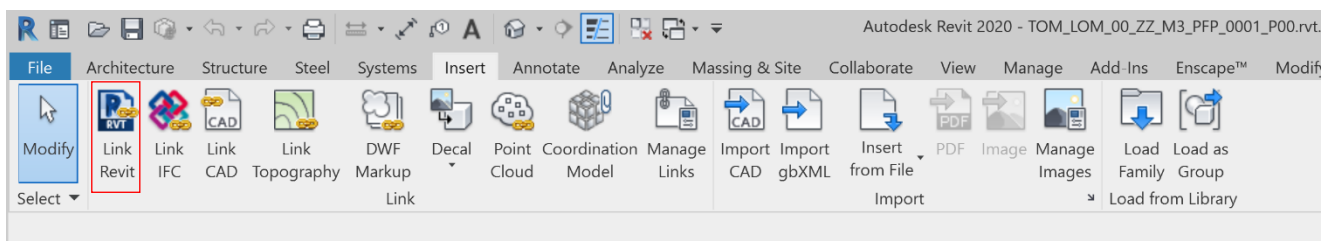
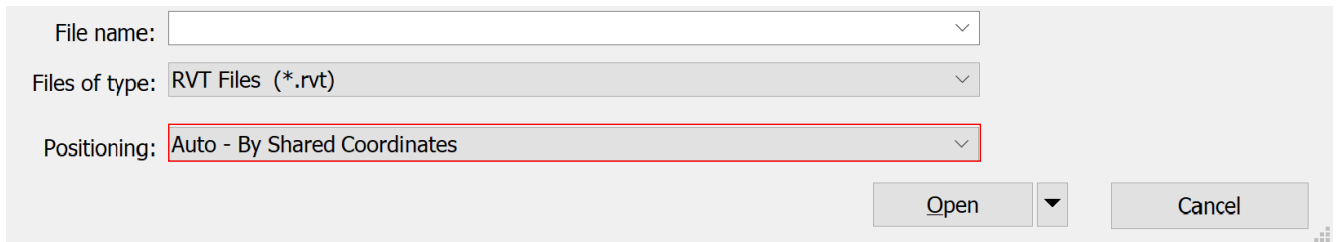


Figure 16: Link Revit, Revit



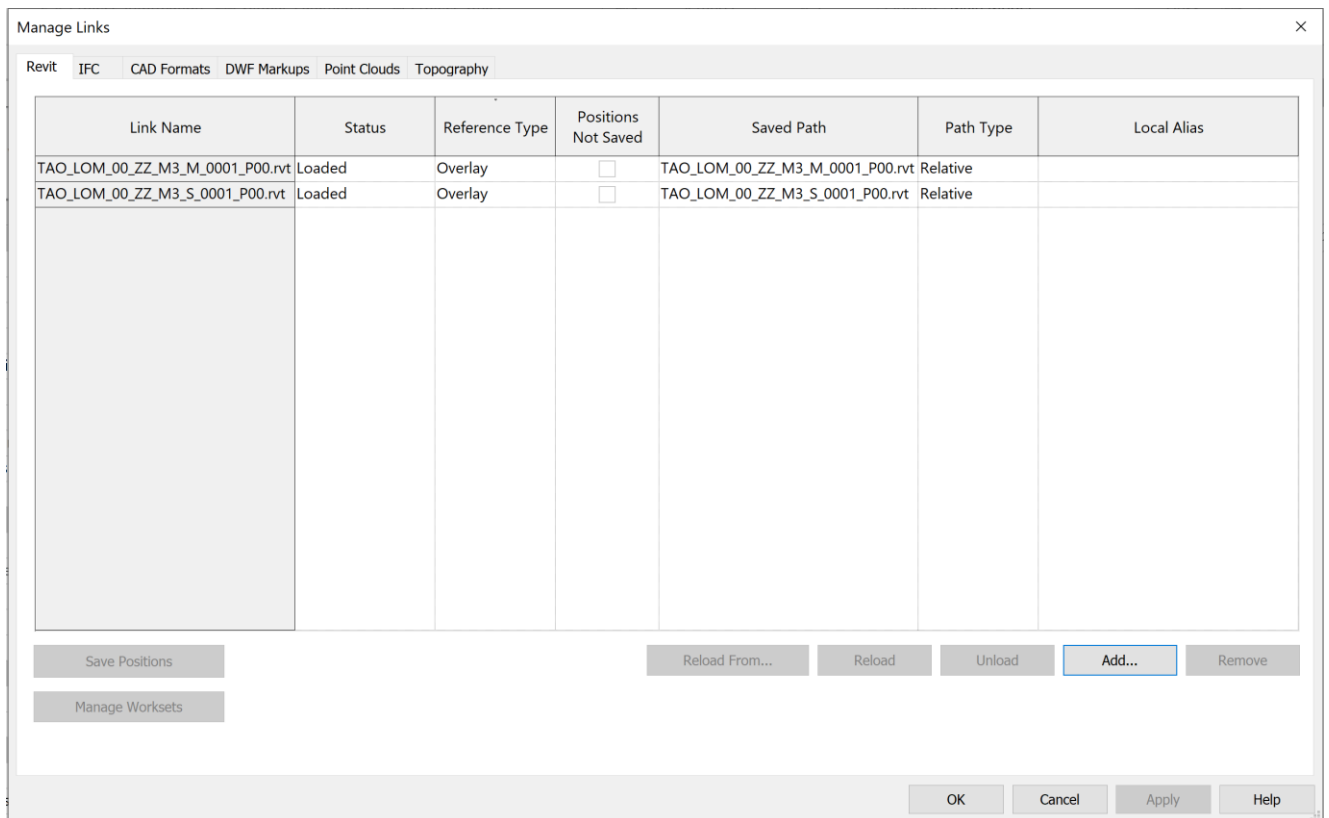
File name:

Files of type: RVT Files (*.rvt)

Positioning: Auto - By Shared Coordinates

Open Cancel

Figure 17: Import/Link RVT, Revit dialog



Manage Links

Revit IFC CAD Formats DWF Markups Point Clouds Topography

Link Name	Status	Reference Type	Positions Not Saved	Saved Path	Path Type	Local Alias
TAO_LOM_00_ZZ_M3_M_0001_P00.rvt	Loaded	Overlay	<input type="checkbox"/>	TAO_LOM_00_ZZ_M3_M_0001_P00.rvt	Relative	
TAO_LOM_00_ZZ_M3_S_0001_P00.rvt	Loaded	Overlay	<input type="checkbox"/>	TAO_LOM_00_ZZ_M3_S_0001_P00.rvt	Relative	

Save Positions Reload From... Reload Unload Add... Remove

Manage Worksets

OK Cancel Apply Help

Figure 18: Manage Links, Revit

3.3.3. Shared Coordinates

When you get coordinates from a linked model or file, the linked model's coordinates become the host model's shared coordinate system. True North is also acquired by the host model from the linked model. The shared coordinates origin of the linked model becomes the shared coordinates origin of the host model. The internal coordinates of the host model remain unchanged. To acquire coordinates going to menu > manage > coordinate > acquired coordinates (See figure 19).

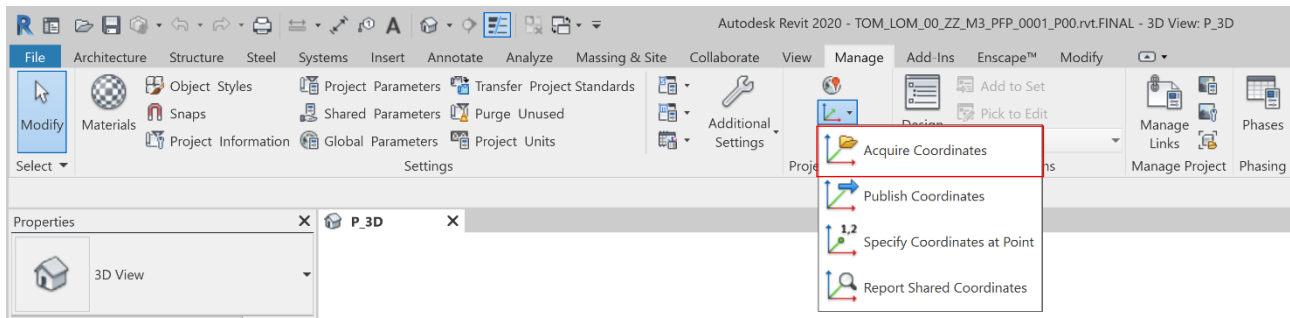


Figure19: Shared Coordinates, Revit

3.3.4. Levels

Levels, as well as project files, also have a standard encoding defined in the file present on Autodesk Docs. The levels are coded with respect to the GL (Ground Level - ground floor), AGL (Above Ground Level - above ground), and UGL (Under Ground Level - underground).

3.3.5. Work-set

When working on a team project, you must choose an active work-set. The active work-set contains each new model element you add to the project. The work-set for the current view contains view-specific components such as annotations and dimensions. It is possible to create work-sets based on functional areas, such as for architecture and structural engineering: interior, exterior, and the site or for systems: HVAC, electrical, or plumbing. When working with ownership of items in a work-set, the difference between making a work-set editable and borrowing from a work-set is critical. You take complete ownership of all objects in a work-set when you make it editable in Revit. At any given moment, only one user can edit each work-set. All team members have access to other team members' work-sets, although they are not always able to make modifications to them. This stipulation eliminates the possibility of internal controversy in the project. You can borrow an element from a work-set that you do not own [34]. To create a work-set in Revit click on collaborate > work-set, by selecting new you can create all the desired work-sets. In the collaborate section, you can also view the current one and modify it if it is necessary (Figure 20).

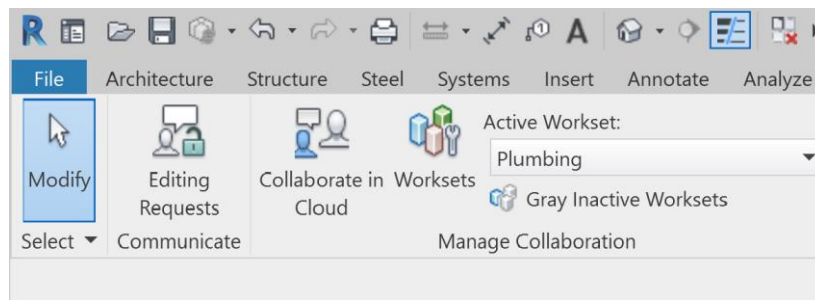


Figure 20: Work-set, Revit

3.3.6. Revit Families

Revit Families are a group of elements with the same set of properties, known as parameters, and their associated geographic representation. In simpler terms, Family is a remarkable feature of Revit BIM that provides libraries of pre-built objects that can be modified to fit the needs of any project. It is an important aspect of the software because it generates all of the parts that are used in the project or created to meet the project's requirements. Walls, doors, windows, beams, columns, and annotations and tags are examples of both structural and non-structural features. You may also obtain control over a group of elements with the same behavior and features by using families, making it easier to manage the overall project. There are three types of Revit Families:

- **SYSTEM FAMILIES:** System families are pre-defined families that contain elements used to create basic components needed for assembly on a construction site. Their parametric and graphical representations already exist; they cannot be loaded into the system, created, deleted, or saved. For example, walls, floors, roofs, and so on. These families are used to create 3D models where only show the placements of basic components needed.
- **LOADABLE FAMILIES:** Loadable families, also known as component families are user-defined and are built in a family template using an editing mode called, Family Editor. They can be created and then imported into Revit projects. Their parameters and graphical representation can be defined from scratch. These are created in external RFA files and then imported and loaded into the project, unlike system families. They are the most commonly used Revit families because of their highly configurable nature, which allows you to create, change, delete, and save from the project. Using varied materials and sizes, a variety of types can be created within this one family. A lot of types can be created within this one family using various materials and sizes. There are different types of loadable families:

- a) **Parametric Families** This form of family is mostly used to control the fundamental properties of any component, such as its height, breadth, and length. Frameworks, materials, and category assignments are all basic parametric aspects.
- b) **Nested families:** Nested families are families that exist within other families, as the name implies. The fundamental benefit of these families is that they may be mirrored, flipped, and rotated into the desired configuration while maintaining the same relationship with one another. When there are repeating elements, such as the louvered window, these families are typically used.
- c) **Hosted families:** These are the kinds of families that need a host to be included in the model; they can't stand on their own. If a family is designed to be wall-hosted, for example, it can only be installed if a wall is present in the host model.

Revit has default families that can be inserted and, if necessary, modified. To insert them click on Insert > Load Family (Figure 21).

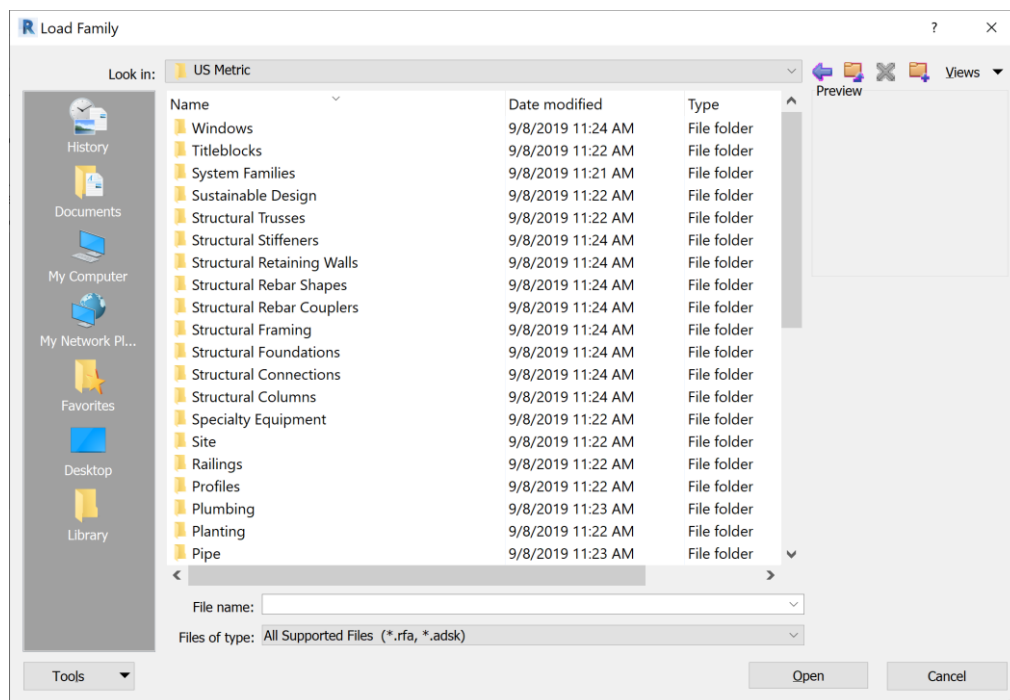


Figure 21: Load Family, Revit

If the default families do not meet the requirements, there is the possibility to create of the families that can be loaded by clicking on File> New> Family (Figure 22).

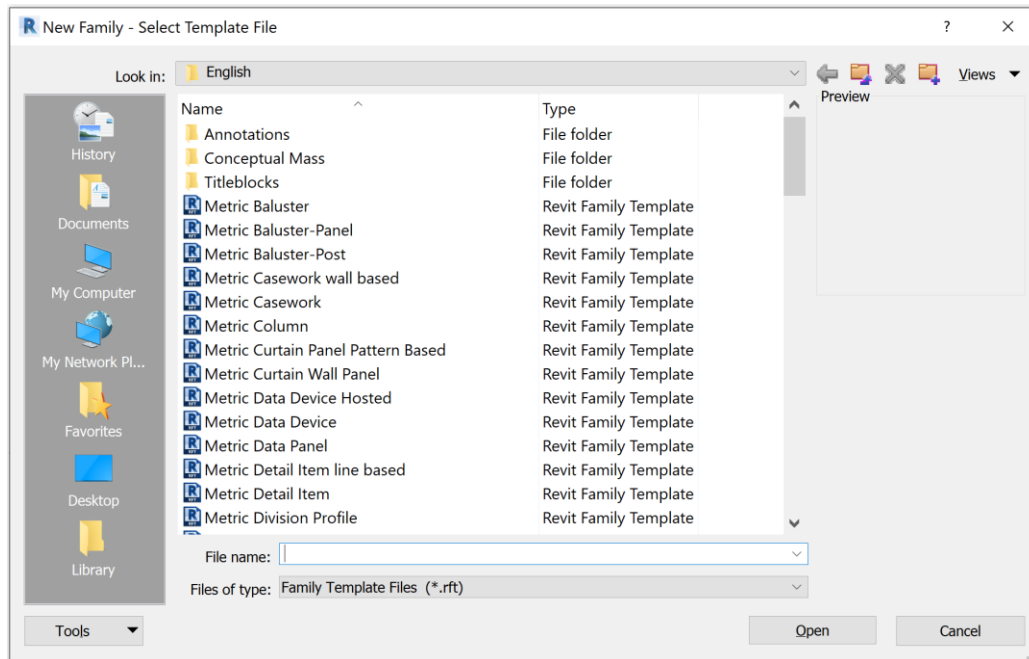


Figure 22: New Family – Select Template file, Revit

- In place families: Custom elements that are specific to a project can be created using in-place families. These are project-specific; thus they don't allow you to create different types like loadable families do. These families are similar to system families, but they cannot be generated or used as standalone families; instead, they can be developed, edited, or inserted within a model. There are no distinct RFA files for them to be created in. These families are particularly valuable in complex construction plans that require components that are specially designed. Custom gutters, special trim, and built-in furniture are examples of such features. Thus, in-place families in Revit Family Creation are particularly used when there is a need to represent a unique element to the project.

There are other types of families but these are the most known. Revit families have different purposes to meet different needs which makes Revit user-friendly [35].

For the template file naming, there is codification rules also for the families, the indications for family encoding present below (see Table 2):

TOM_LOM_PFP_Pipe Fittings_ (Elbow Fitting)

Code	type	
TOM	Project acronym	
LOM	Responsible organization acronym	
P FP	Indicates the discipline and any sub-discipline the file belongs to	Plumbing Fire Protection
Elbow	Revit category	Pipe Fittings
(...)	Object type	Elbow Fitting

Table 2: Family Codification

3.3.7. Parameters

The information has great importance in the Revit as explained before in the part dedicated to LODs. Level Of Information is known as LOI and it is used to indicate non-geometric information of a family. Every family created for the project has LOD card. A family with a high level of information may include information like datasheets, manufacture specifications, and maintenance instructions. The information can be added to the project using parameters. In Revit, it is possible to create parameters for any elements category or components or even for a project. The created parameters are visible in the properties dialog of the type of property palette depending on whether they are a type or instance parameters., different types of parameters are listed below:

- **Global Parameters:** Global parameters are unique to a single project file and are not associated with any categories. Global parameters can be simple values, values derived from equations, or values extracted from the model by combining them with other global parameters. To drive and report values, use global parameters.
- **Shared Parameters:** Shared parameters are parameter definitions that can be used in multiple families or projects. You can use a shared parameter definition as a family or project parameter after adding it to the family or project. The definition of a shared parameter is protected from change because it is stored in a separate file (not in the project or family). As a result, shared parameters can be tagged and scheduled.

- **Family Parameters:** Family parameters control the family's variable values, such as dimensions or materials. They are unique to the family. A family parameter can also be used to control a nested family parameter by associating the host family parameter with the nested family parameter. For creating the Family parameter, you need to first you have to open the family to which you want to associate the parameter, click on the Family Type icon and create the new parameter (Figure 23 and 24).
- **Project Parameters:** Project parameters are specific to a single project file. They are added to elements by assigning them to multiple categories of elements, sheets, or views. Project parameters contain information that cannot be shared with other projects. In a project, project parameters are used for scheduling, sorting, and filtering [36]. For creating the project parameter Clicking on Manage > Project Parameters > Add and it will open the window (Figure 25). To select the newly created shared parameter, just click on Shared parameter > Select, and then select the parameter. Depending on the parameter, it is possible to choose whether to assign it to "Type" or "Instance" and define the parameter data, such as name, discipline, parameter type, grouping. Also, you need to select the categories of items in which it will come inserted this parameter.

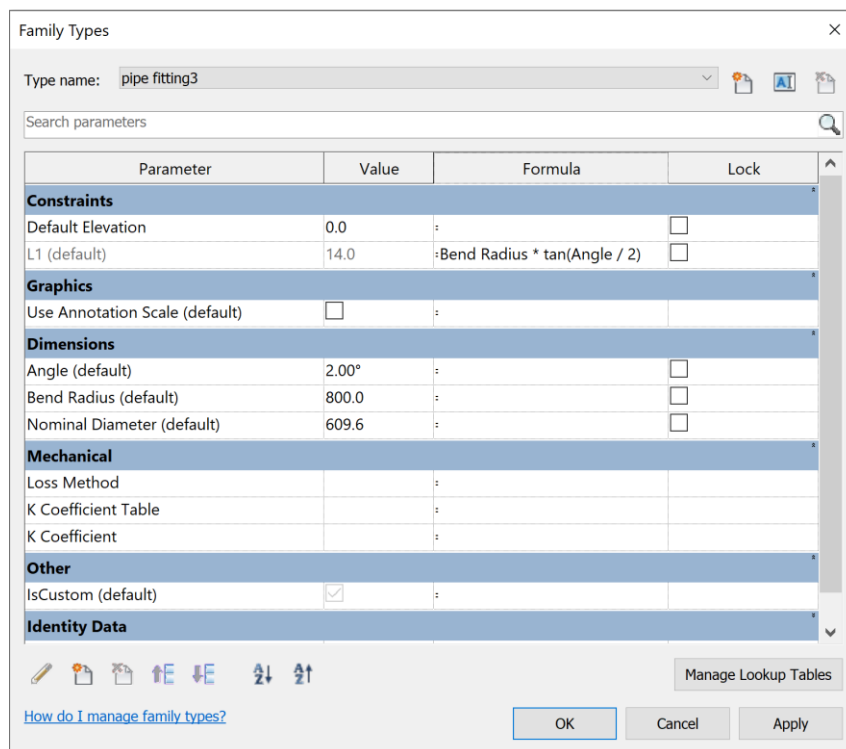


Figure 23: Family Types, Revit

By clicking on New Parameter it will open a window where you can define a new Parameter Property.

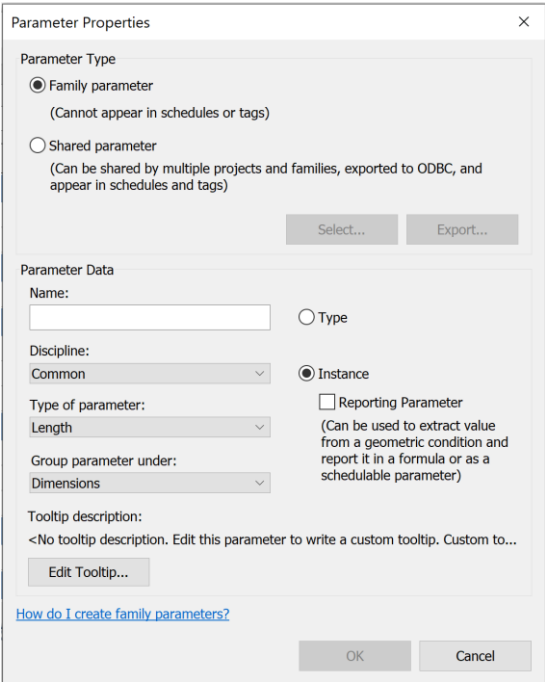


Figure 24: Parameter Properties, Revit

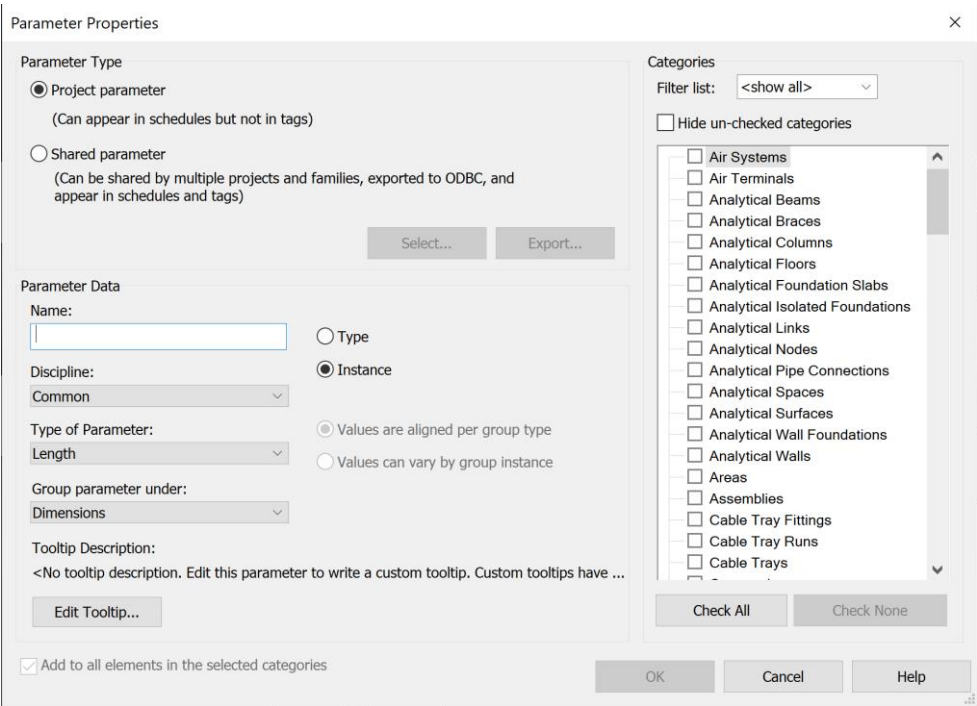


Figure 25: Project Parameters, Parameter Properties, Revit

3.4. Modeling

The first step is to create the views plan of the project in Revit by clicking on view > plan views > floor plan, it appears a window that allows creating a view of the plan for the desired level. Then we insert the associated DWG or PDF file of the associated plan. In our case since we did not have accessibility to DWG files of the project, we used PDF documents. For inserting the PDF File clicking on Insert > PDF and select the desired file (Figure 26).

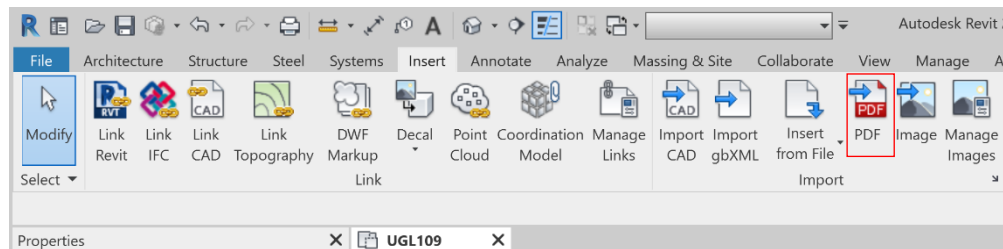


Figure 26: Import PDF, Revit

3.4.1. Fire Protection System

The Fire Protection System is classified in the plumbing subsystems and this thesis is a wet Fire-Extinguishing system which consists of a distribution network of pipes to allow the water reach to sprinklers. These pipes are made from steel because they should make out of fire-resistant material. They are always full of pressurized water. In Revit, Pipes are part of the System Families type. The model was created by using the default pipes family found on the Revit. The diameter of pipes is changed and they are varied from DN20 to DN200. To draw a pipe clicking on Systems > Pipe > Pipe types (Figure 27 and 28).

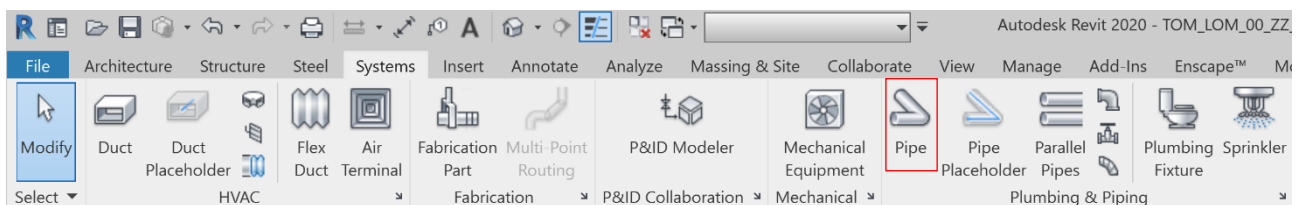


Figure 27: System Families – Pipe, Revit

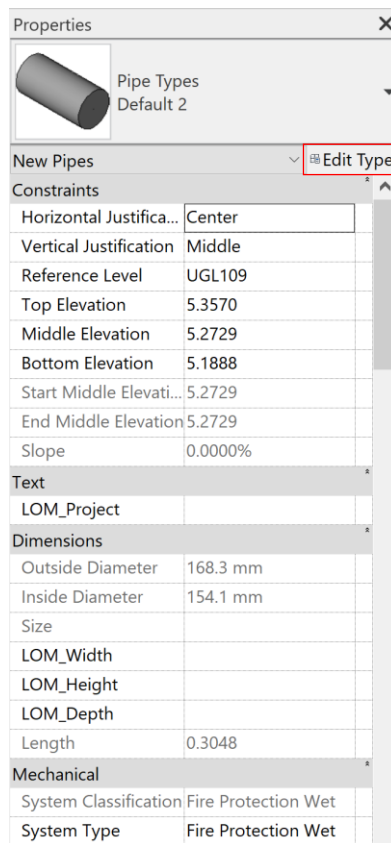


Figure 28: Pipe Properties Window, Revit

3.4.2. Routing Preferences

After selecting the pipe, we need to set the routing preferences. In Routing Preferences, it is possible to select the fittings that will be placed during the use of this type of pipe. Multiple fittings can be added for each part type section (Elbow, Junction, Cross, Transition, Union, Cap) thus for the pipe segments, Multiple pipe segments may be added to a routing preference. In order to do that just click on the plus sign. If more than one part for a fitting satisfies the criteria during layout, the first part listed is used. You can move a row up or down to change the priority for a part. When specifying the size range for a part, none means the part will never be used and All means the part will always be used. Setting the size range to None is useful when modifying fittings after layout. A fitting whose size is set to None will display in the Type Selector when the Constrain to routing preferences option is enabled. It is possible to use default families of fittings or create a new fitting family. If none of the default fittings doesn't meet our needs, we can create a customized fitting. For setting the routing preferences clicking on properties > Edit Type > Routing Preferences (Figure 29).

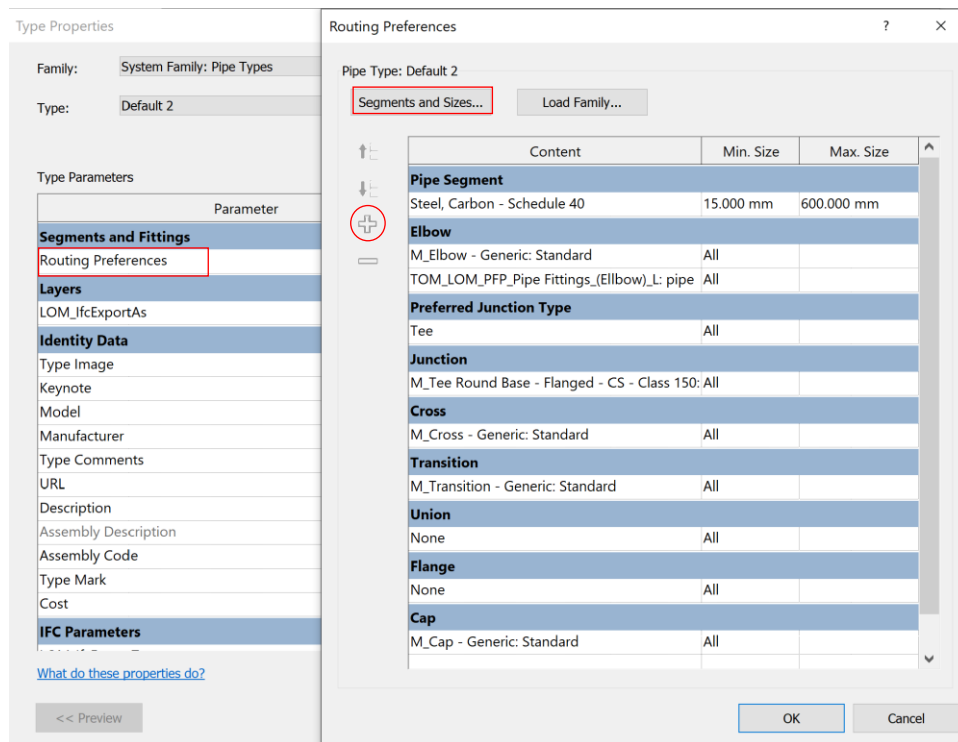


Figure 29: Routing Preferences, Revit

The fitting that is used during this project for the pipe is partly default families and partly instead created according to since there were no default fittings that corresponded to required features. Below there is the list of pipe fittings used (Figure 30):

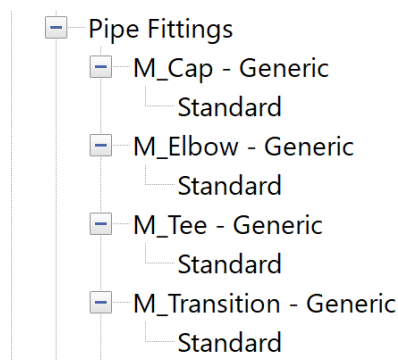
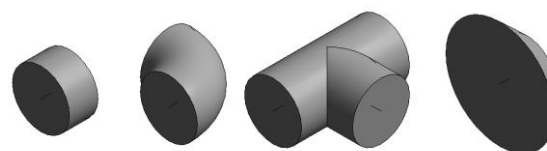


Figure 30: Pipe Fitting Families, Revit

Since the pipes in the plan didn't follow a straight route there are inclinations in some parts, it was necessary to create an Elbow fitting with a specific angle based on the pipe inclination degree to obtain the joints between the pipes. In order to do this a Revit "Generic model" family template is used. It is possible to create different types for the family by changing the parameters like angle or size since it is created as a parametric element (Figure 31).

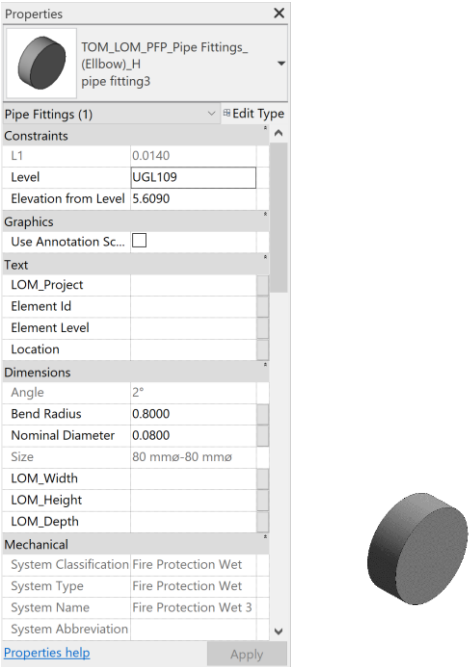


Figure 31: Elbow Fitting Family, Revit

Additional settings can be added to the pipe in the routing preferences dialog by clicking on segment and size. In the window of mechanical settings, it is possible to set other settings for the pipe, for instance, angles, conversion, segments and sizes, fluids, etc. The size range and material of the pipe and other properties like roughness also can be set here (Figure 32).

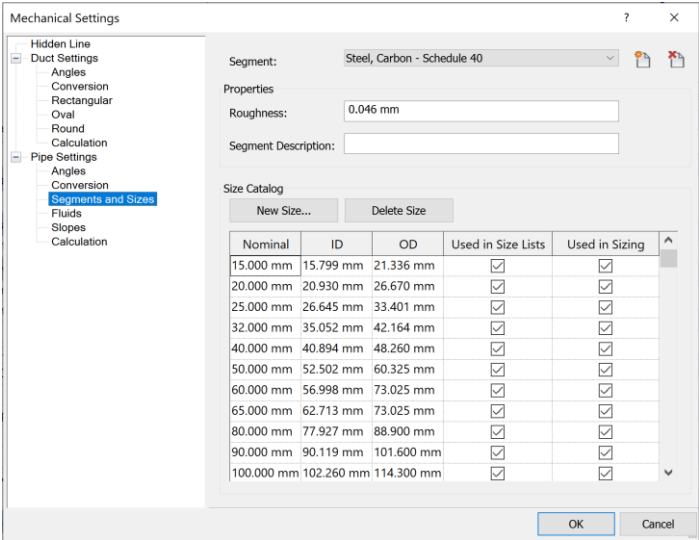


Figure 32: Mechanical Settings, Revit

While drawing the pipe system the best practice is to have checked the “Show Disconnects” option, since it helps to realize if there is any problem in the piping system. These problems can occur due to a disconnection or inconsistency between systems when trying to connect to elements from two different classification systems. For doing that click on Analyze > Show Disconnects and choose Pipes (Figure 33 and 34).

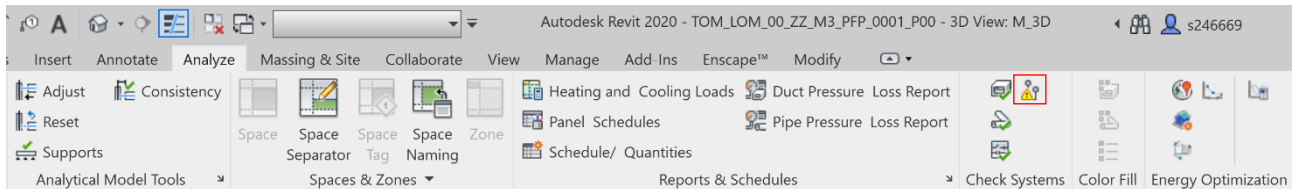


Figure 33: Analyze – Show disconnect, Revit

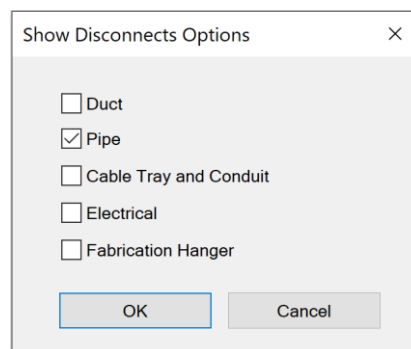


Figure 34: Show Disconnects Option – Pipe, Revit

3.4.3. Materials and colors

The choice of material and color was made for the visual representation of the pipes. It is possible to assign a color to material by clicking on Manage > Materials (Figure 35).

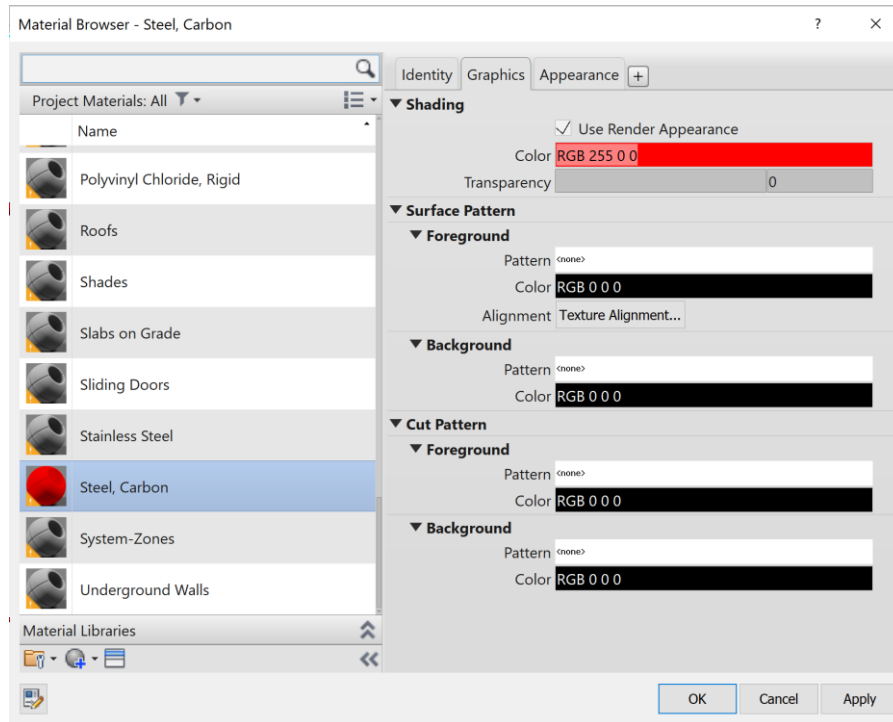


Figure 35: Material Browser, Revit

3.4.4. Pipe Accessories

Pipe accessories includes families of calibration, regulation and butterfly valves. For this part it is used default families in some parts since they were corresponded to the needs of the project and for some parts they are obtained by modifying a default Revit family. Pipe accessories are listed below: (Figure 36 and 37)



Figure 36: Project Browser, Revit

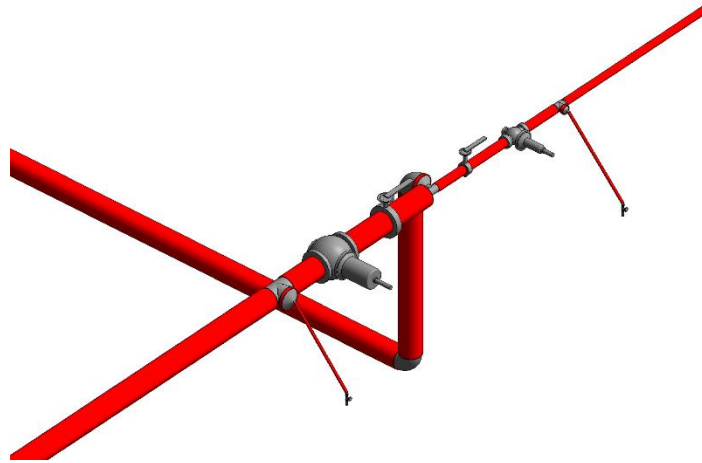


Figure 37: Pipe Accessories, Revit

3.4.5. Sprinklers

Fire Protection Systems save lives in the event of a fire. A well-maintained fire sprinkler system, in conjunction with other fire protection measures, can help suppress smoke and flames and lessen the spread of the fire, reducing damages and giving everyone time to exit the building while fire services arrive. At the moment of fire, the sprinkler nozzle causes outflow of water and results in a quick intervention of fire. The sprinklers have different types. In this project it is used a default family of Revit for the sprinklers.

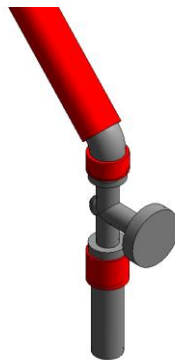


Figure 38: Sprinklers, Revit

3.4.6. Result

In conclusion at the end of the modeling phase, a three-dimensional information model of the Fire Protection System was obtained, with the data required for the exportation process as we will be seen.

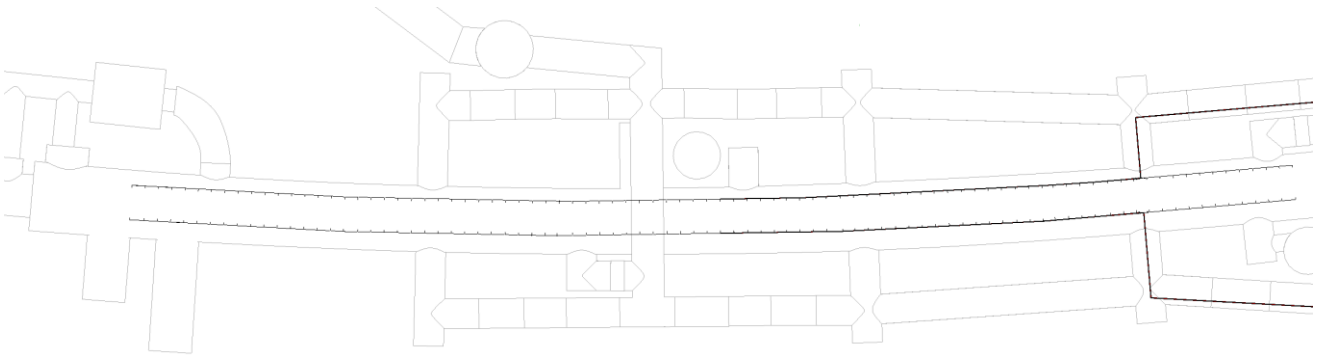


Figure 39: Top View of the Model, Revit

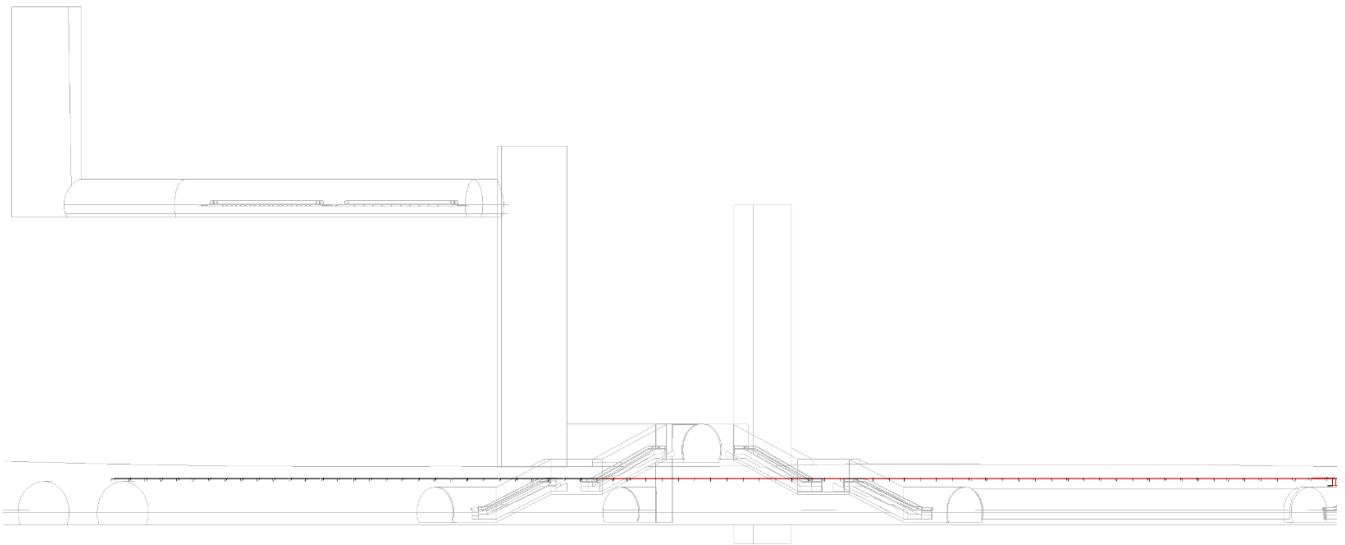


Figure 40: Front View of the Model, Revit

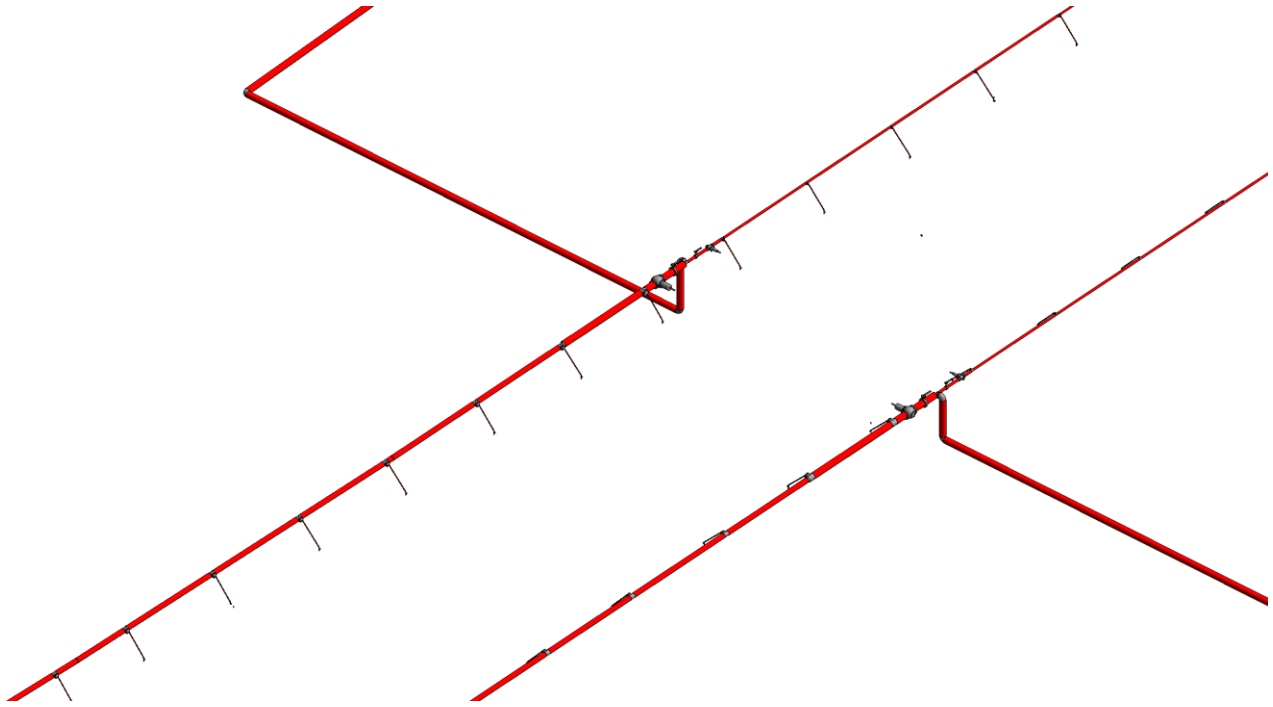


Figure 41: isometric View of the Model, Revit

3.5. Federated Model

BIM Model Federation is the most popular method of collaboration and the simplest to implement of the workflows. A BIM federated model is used in the design of coordination, clash detection and avoidance, approval processes, design development, estimating, and other processes [32]. Federated BIM models combine components from various disciplines onto a single data environment (CDE). This inter-disciplinary collaboration improves coordination, prevents information loss, reduces rework, and enables better project management. As per NBS, a Federated Model is “a combined Building Information Model that has been compiled by amalgamating several different models into one, or importing one model into another.” In a federated model, distinct individual models originating from multiple construction disciplines – architects, structural engineers, MEP engineers, contractors, sub-contractors, and suppliers can be seen on one tool. Even when individual multidisciplinary models are linked together in a federated model, they retain authorship, remain distinct, and cannot be modified by others without permission. Federated models lead to better design decisions by highlighting missing information, discrepancies, and insufficient resource allocation during the early stages of construction. The integration of multidisciplinary models into a single model improves seamless coordination, fosters a better understanding of design intent across disciplines, and increases transparency among stakeholders throughout the project life cycle [37]. For this project, a federated model was created

to host all the models developed about the project. Structural and HVAC models extracted from the Common Data Environment are also included. The inclusion is made by links.

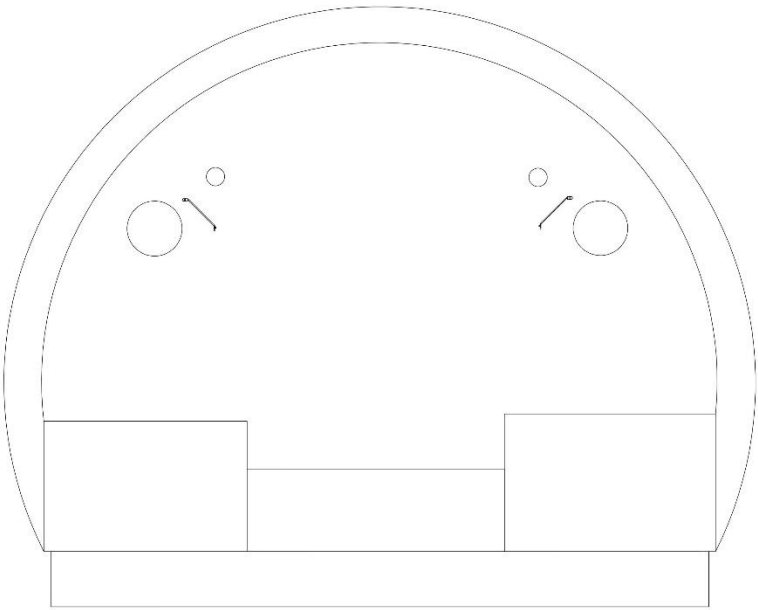


Figure 42: Federated Model – Section T2-T2, Revit

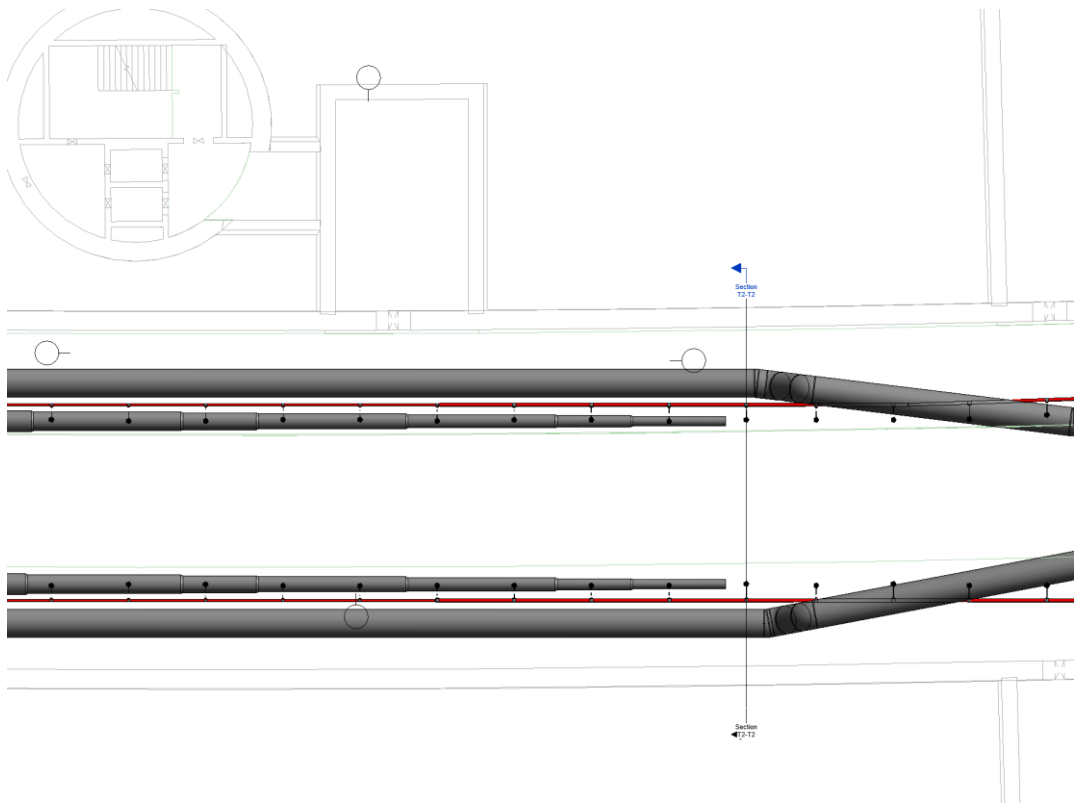


Figure 43: Section T2-T2 from the plan, Revit

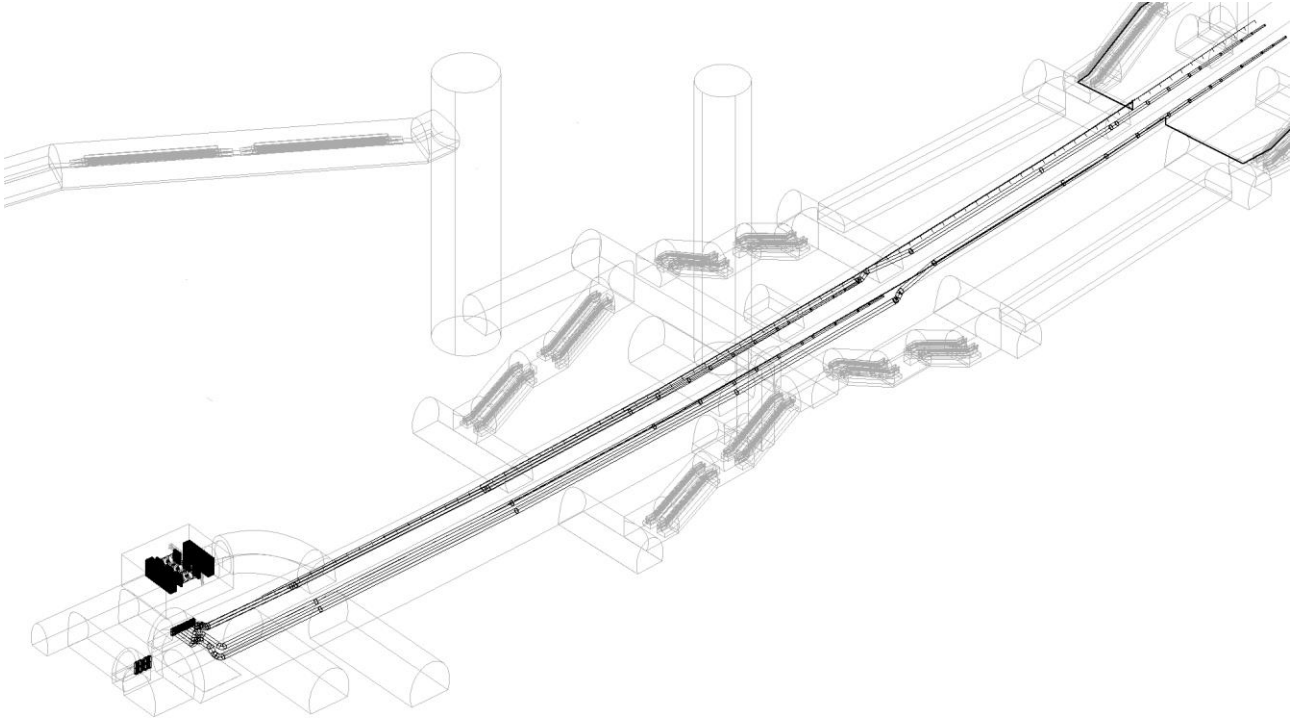


Figure 44: Federated Model - Isometric View, Revit

Chapter 4

Information Delivering

4.1. Interference Check

Engineering design is a dynamic field that needs effective coordination among various stakeholders in order to achieve the desired results. Architects, structural engineers, MEP engineers (HVAC, electrical, and plumbing), environmental engineers, and other professionals work individually to create design models. The clash detection process identifies where the independent models clash with each other- finding where elements from one model overlap the elements of models from other architect-engineering design disciplines. Clash detection ensures that all aspects work together and that nothing is incompatible. Without clash detection at the design stage with the help of integrated models, completing projects in this era is next to impossible. Interference and clashes can cause losses, delays, and other issues during the construction stage, and can even result in a total design failure in terms of compliance. With clash detection, mistakes that would normally be discovered on-site (with high cost and schedule implications if corrected at that stage) can be seen in the earliest stages of design, resulting in a faster project and a lower budget [38].

4.1.1. Data Collection

Advanced clash detection and design review software, such as Navisworks, makes it easier for architects and building designers to divide larger models into subsets for focused clash detection. Clash report is always generated between two design models using Autodesk's Navisworks. Once three-dimensional models have been obtained, each model can be exported from Revit in NWC format to open in the Navisworks. For doing this click on File > Export > NWC and set correct parameters to obtain the model in NWC (Figures 45-47).

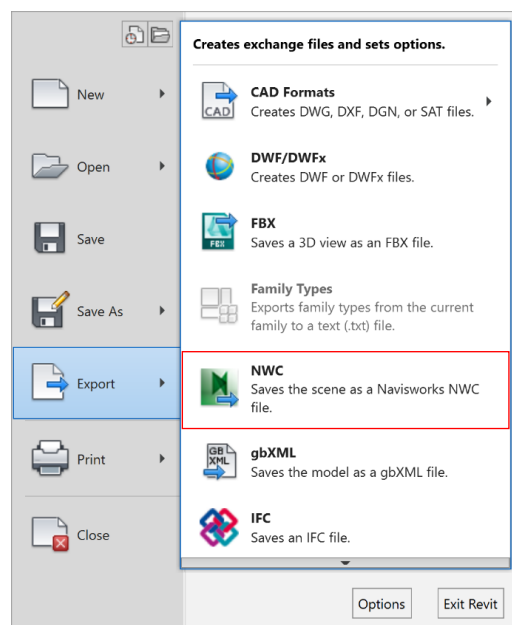


Figure 45: Export NWC Format, Revit

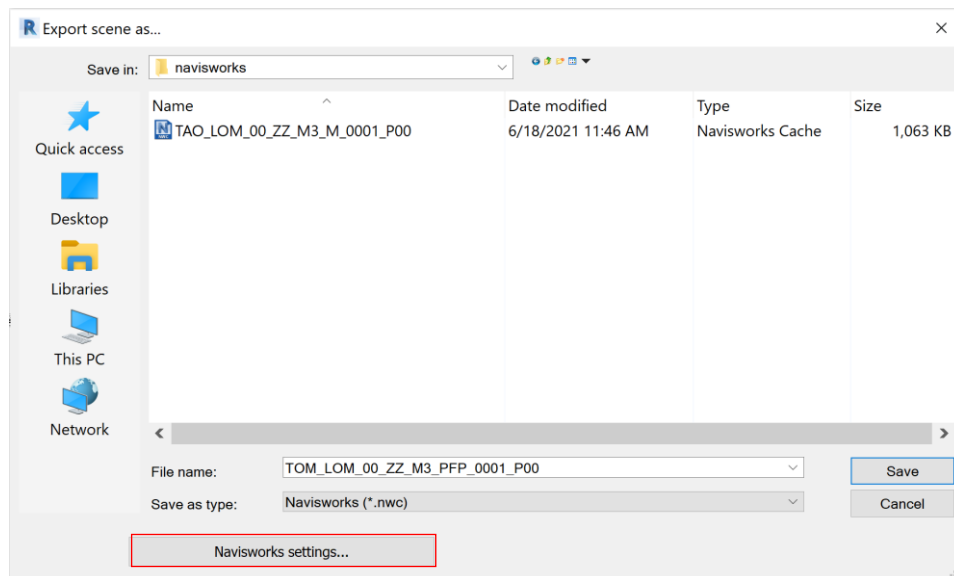


Figure 46: Export NWC Format, Revit

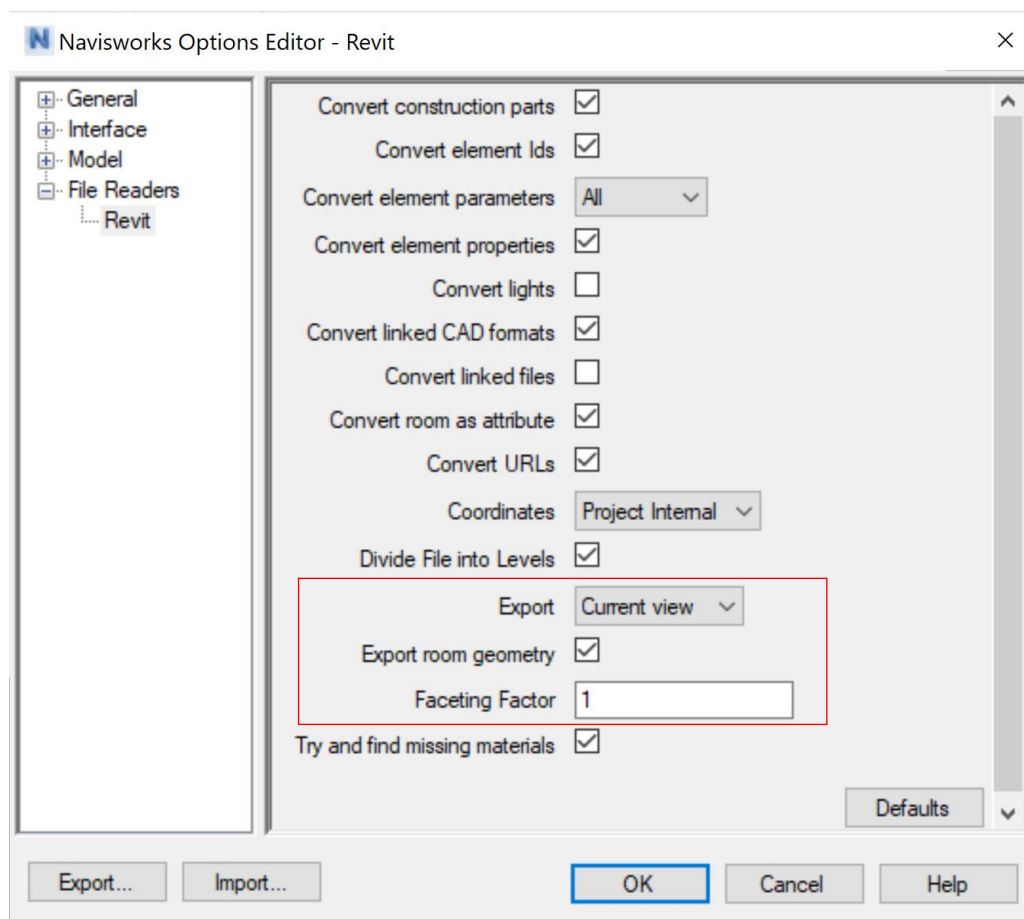


Figure 47: Navisworks Option Editor - Export NWC, Revit

4.1.2. Software

For static and dynamic interference checking, the Autodesk Navisworks Manage software, in the 2020 version. This program allows the identification and management of problems caused by conflicts and interference before the construction of the work.

4.1.3. Import of Disciplinary Models

To do the clash detection in Navisworks we need to import the disciplinary models which we converted before from Revit to NWC format by clicking on Start > Append and then selecting the desired file (Figure 48).

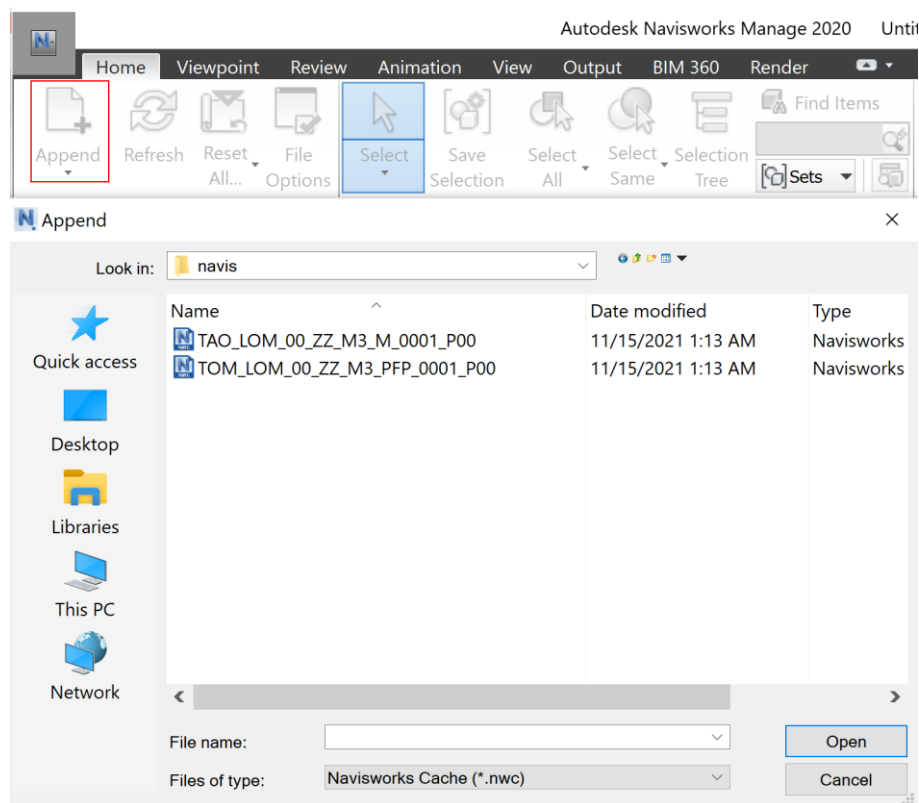


Figure 48: Append NWC, Navisworks

4.1.4. Check for Duplicates - Level 1 Validation

The first step to controlling the validation of the models is to check for duplicates. This option allows the clash test to detect duplicate geometry. This type of clash test is useful to check the model against itself to ensure the same part has not been drawn, or referenced twice, for example. To do this, you must then select Add test and choose the "duplicates" type from the drop-down menu (Figure 49-51).

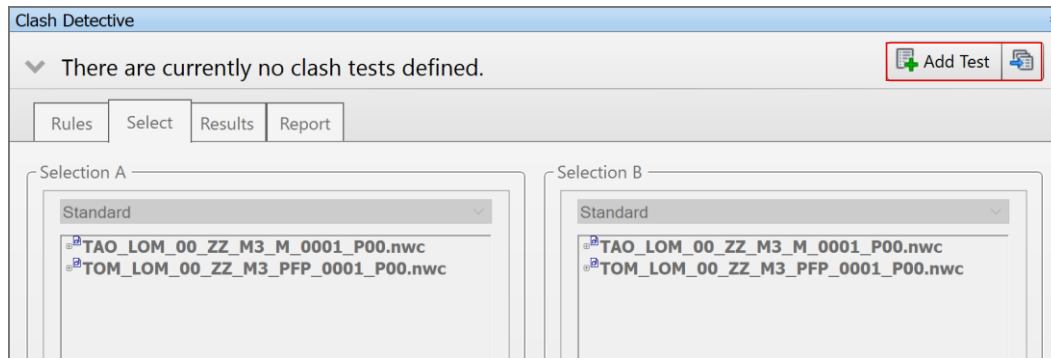


Figure 49: Add Duplicate Test, Navisworks

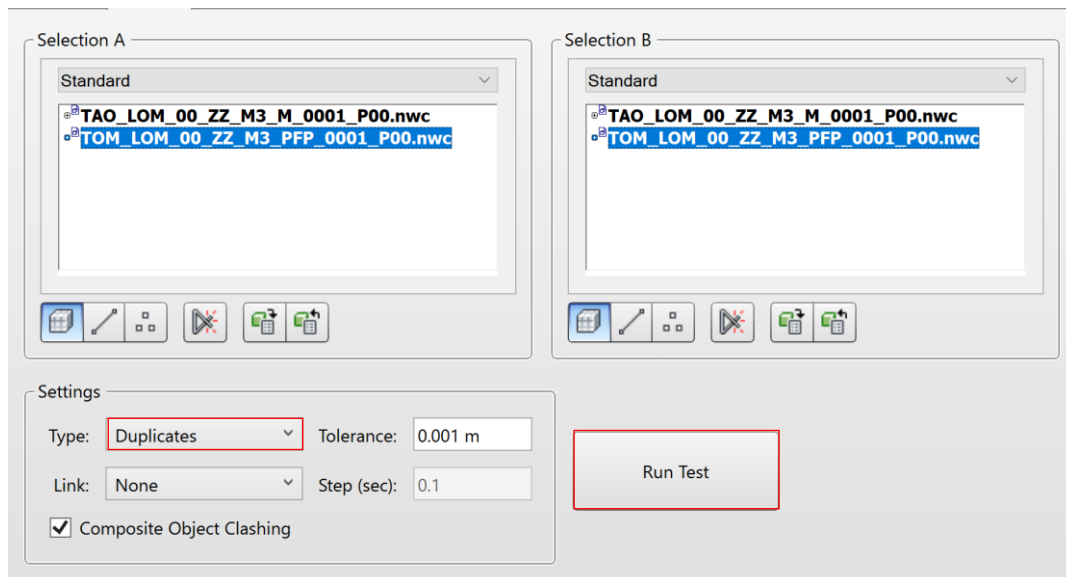


Figure 50: Duplicate Check Setting, Navisworks

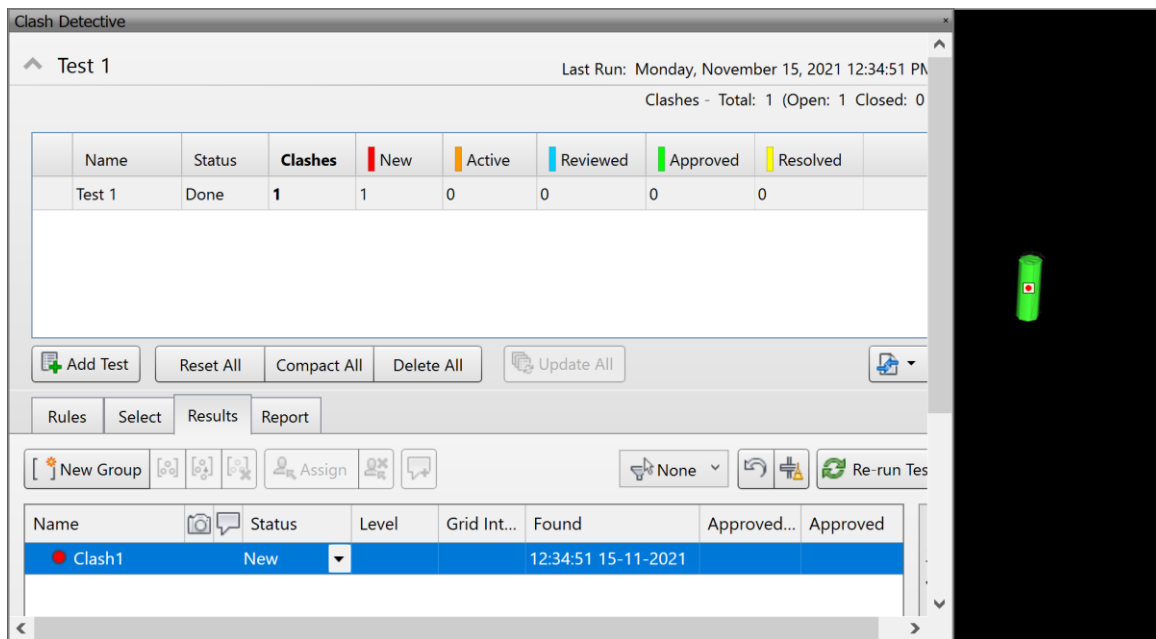


Figure 51: Duplicate Check Results, Navisworks

4.1.5. Hard Clash detection - level 2 validation

The next level of validation of the model is at the coordination level. This type of clash test allows detecting actual intersections between geometry. It is necessary to follow the following steps: Rename the test (for example “PFP vs M” corresponds to the control of the interference between the pipe model and the ventilation one); select the two files you want 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; In this section, we just need to modify the settings to change the type from duplicate to hard and then run the test (Figure 52).

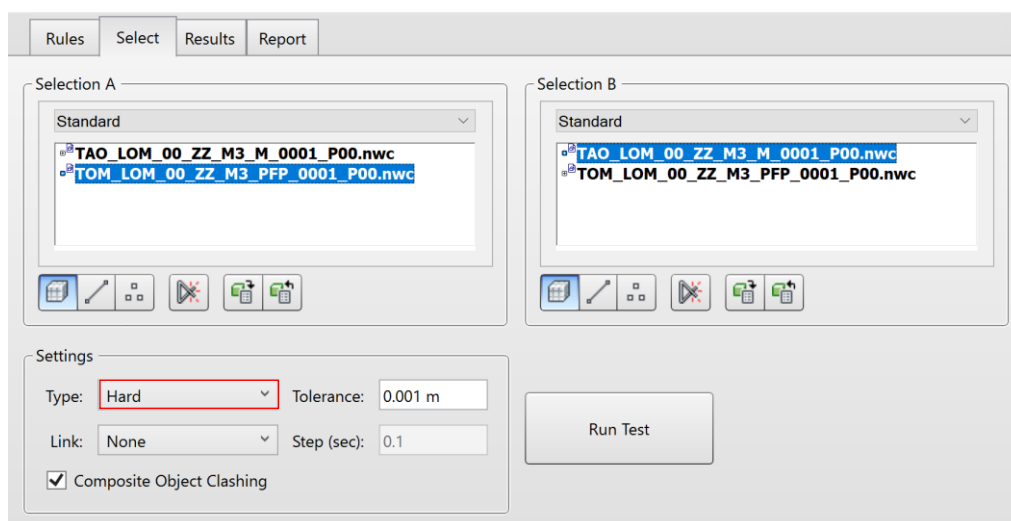


Figure 52: Hard clash detection Check Setting, Navisworks

As can be seen from the results these interferences turn out to be all of the Hard type (Figure 53 and 54). Interferences occur when two objects come into physical contact with each other. These types of conflicts must be resolved quickly by moving or replacing the elements that cause the conflict.

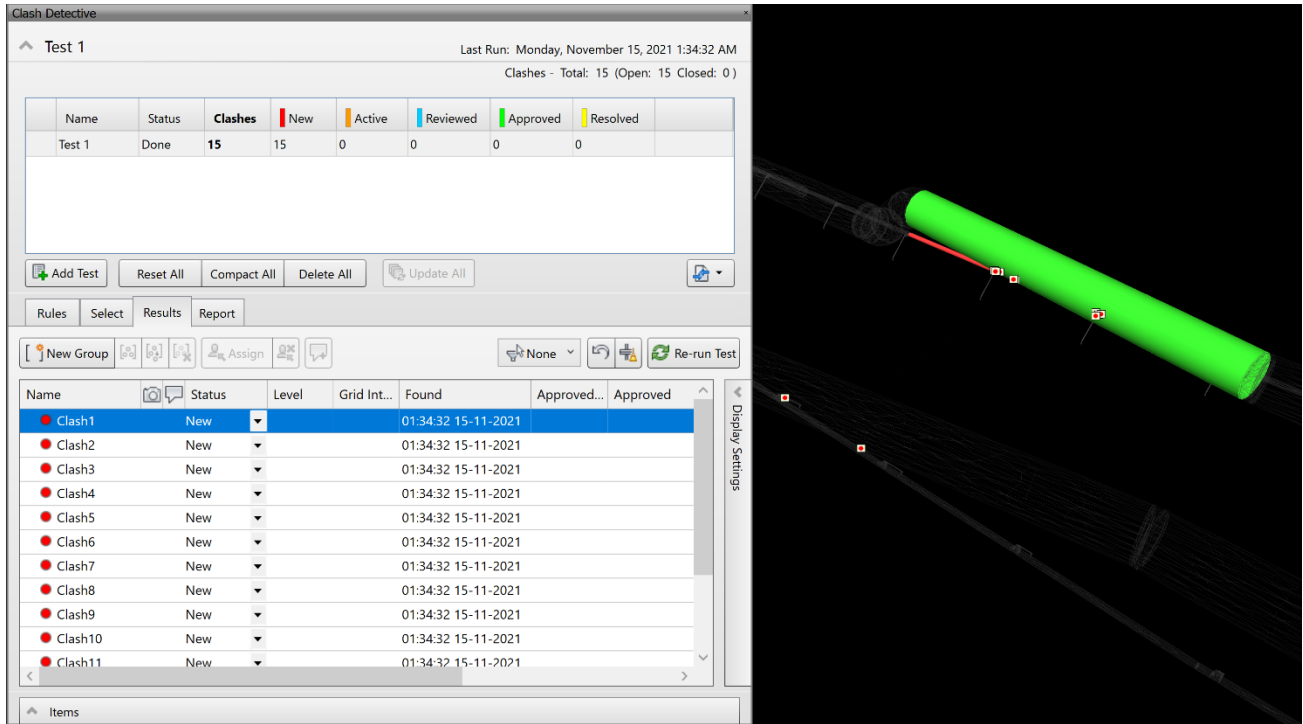


Figure 53: Clash Detection Results, clash1 – PFP vs M, Navisworks

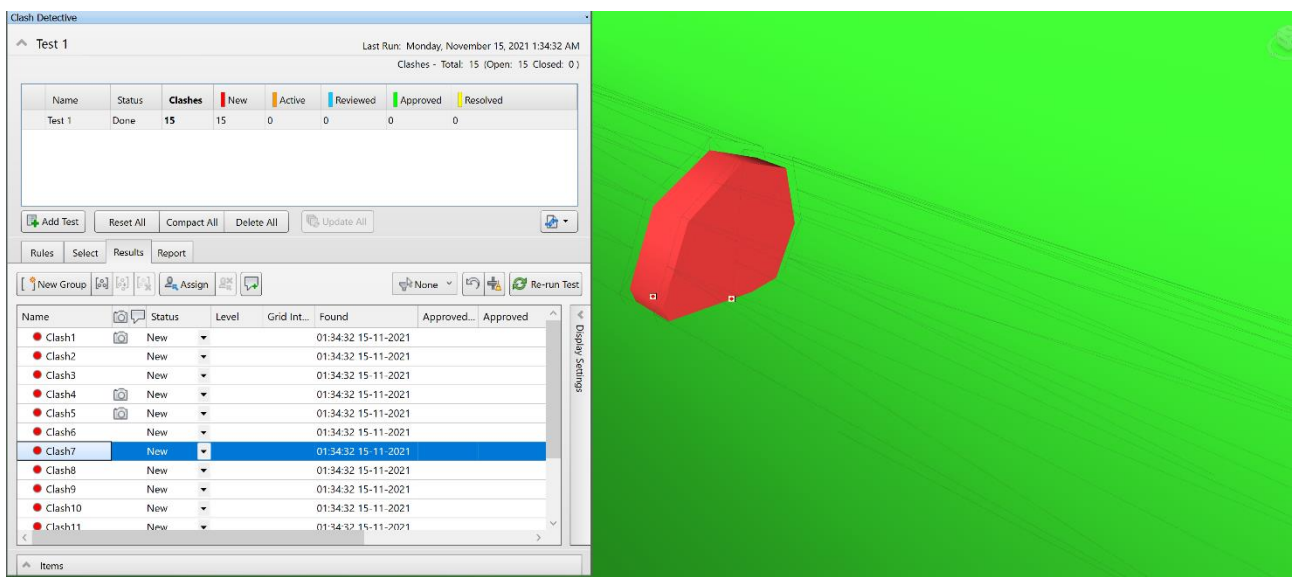


Figure 54: Clash Detection Results, clash7 – PFP vs M, Navisworks

Once the test has been completed and the results have been obtained, it is possible to download the report of the clash detection in HTML format by clicking on the write report. (see Figure 55). HTML will create an HTML file containing all the clashes and a jpeg of their viewpoints alongside their details. On choosing this option, you will need to select or create a folder for the files and enter a name for the HTML file. By choosing the current test as the report type it creates a single report for the current test only

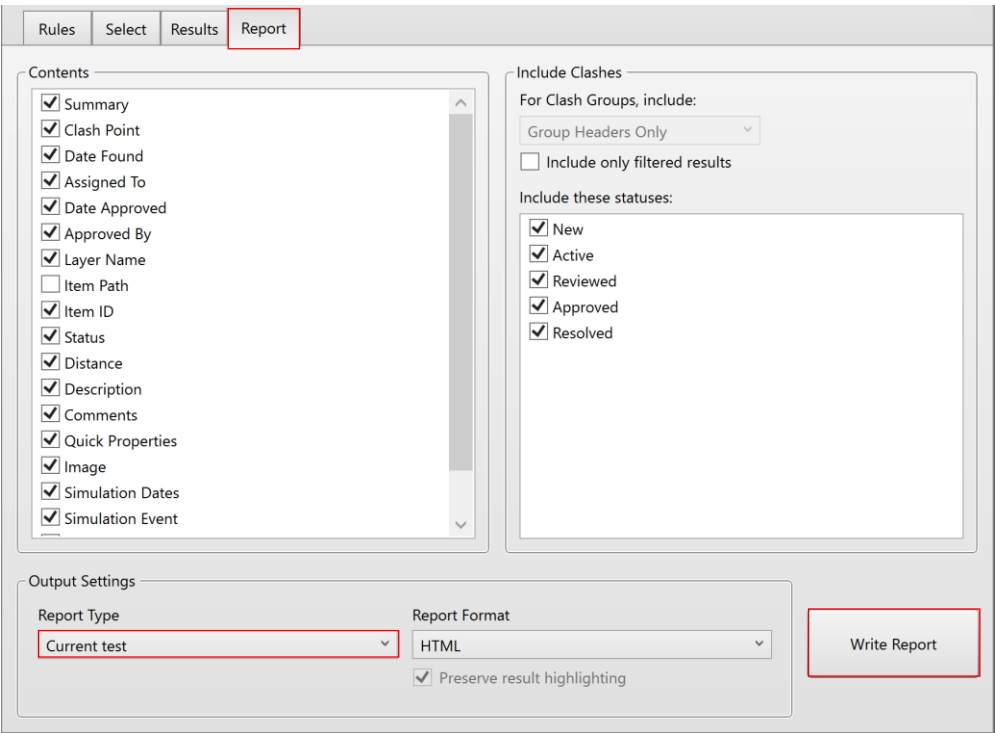


Figure 55: Interference Report, Navisworks

It is possible to enter comments relating to the interferences found and also BIM Coordinator can choose a person to assign the responsibility for the selected clashes (Figure 56 and 57). we can group the clashes for the better organization but they will be listed as a single clash in summaries and reports.

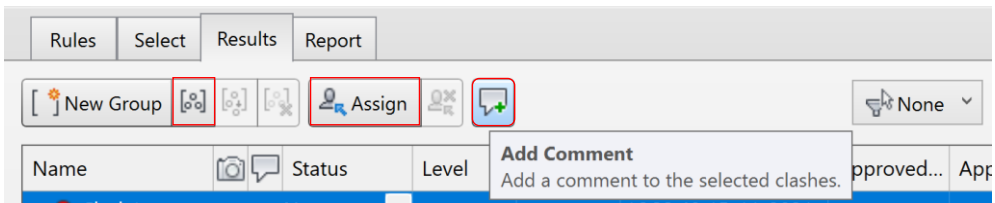


Figure 56: Add Comments, Navisworks

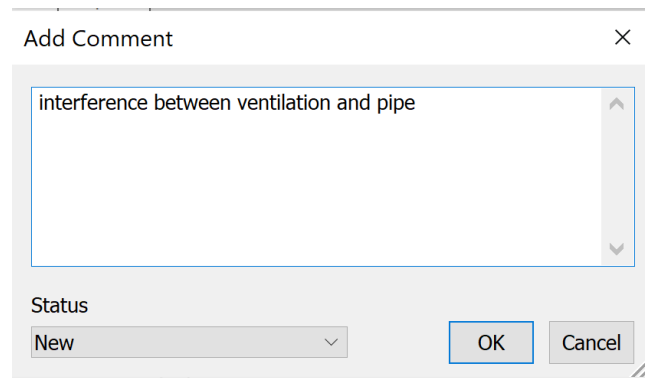


Figure 57: Comment Example – PFP vs Ventilation, Navisworks

4.1.6. Clashes statuses

An icon is displayed to the left of each clash name. It visually identifies a clash status as follows (Figure 58):

- **New:** A clash found for the first time in the current run of the test.
- **Active:** A clash was discovered in a previous run of the test and was not resolved. Clashes in this state are pending.
- **Reviewed:** A clash previously found and marked by someone as reviewed.
- **Approved:** A clash previously found and approved by someone.
- **Resolved:** A clash found in a previous run of the test and not in the current run of the test as a result of changes to the design file so the status will automatically change to resolved.

Name	Status	Clashes	New	Active	Reviewed	Approved	Resolved
Test 1	Done	15	15	0	0	0	0

Add Test		Reset All	Compact All	Delete All	Update All
----------	--	-----------	-------------	------------	------------

Rules	Select	Results	Report
-------	--------	---------	--------

New Group	Assign
-----------	--------

Name	Status	Level	Grid Int...	Found	Approved...	Approv
Clash1	New			17:55:55 15-11-2021		
Clash2	New			17:55:55 15-11-2021		
Clash3	Active			17:55:55 15-11-2021		
Clash4	Reviewed			17:55:55 15-11-2021		
Clash5	Approved			17:55:55 15-11-2021		
	Resolved			17:55:55 15-11-2021		

Figure 58: Clashes Status, Navisworks

4.1.7. Result

The model is modified on the basis of the clashes that found in the clash detection test. as a result there is no more clashes are found in the new run of the test (Figure 59):

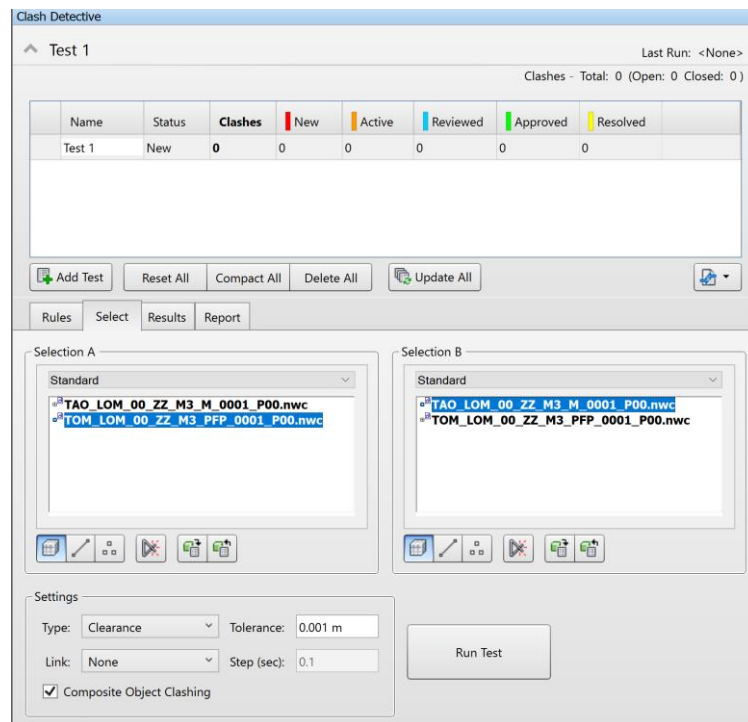


Figure 59: Clash Detection Result Test, Navisworks

4.2. EXPORTING PROCESS

The next step is exporting the Revit model in to the JSON format using Dynamo.

4.2.1. DYNAMO

From its origins as an add-on for Building Information Modeling in Revit, Dynamo has matured to become many things. Above all, it is a platform that allows designers to explore with visual programming, solve problems, and create tools. Dynamo is available for free download and aims to be accessible to both non-programmers and programmers. It allows users to visually script behavior, define custom logic, and script using various textual programming languages via visually script code blocks. This allows the users to manipulate elements, data, and geometry in Revit by coupling script nodes. Nodes are the objects which are connected to form a graph or (visual program). The language used to write the codes is in Python and each node performs simple or complex operations to complete a calculated task in Revit. Most Nodes in Dynamo are composed of five parts. While there are exceptions, such as Input Nodes, the anatomy of each Node can be described as follows:

1. Name of the node;
2. The main body of the Node. Right-clicking here presents options at the level of the whole node;
3. The in and out ports. The receptors for Wires that supply the input data to the Node as well as the results of the Node's action;
4. Lacing Icon. Indicates the Lacing option specified for matching list inputs;
5. Default Value. Right-click on an input Port, some Nodes have default values that can be used or not used.

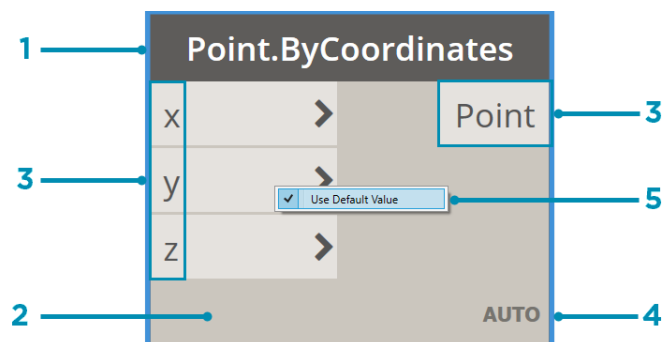


Figure 60: Anatomy of a Node, Dynamo

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

The Inputs and Outputs for Nodes are called Ports and act as the receptors for Wires. Data comes into the Node through Ports on the left and flows out of the Node after it has executed its operation on the right. Ports expect to receive data of a certain type. Data is the stuff of Dynamo. It travels through Wires, supplying inputs for Nodes where it gets processed into a new form of output data. Data is a set of values of qualitative or quantitative variables. The data is needed to add to the input Ports of Dynamo's Nodes – It is possible having data without actions but we need data to process the actions that our Nodes represent. When we've added a Node to the Workspace, if it doesn't have any inputs supplied, the result will be a function, not the result of the action itself [39].

4.2.2. Dynamo for Exporting Data

The first step for extracting information from the Revit model through Dynamo is by inserting a node which is named 'Categories'. Then we have to select the desired category. To do this clicking on Revit > Selection > Categories. After selecting the desired category, we have to insert another node 'All Elements of Category' to select all elements and connect these nodes with a wire. Wires connect the output Port from one Node to the input Port of another Node. This directionality establishes the Flow of Data in the Visual Program [39]. Then it is possible to create a group by selecting both nodes and Right Click > Create Group (Figure 61) and name it 'List of all Elements for a Specific Category'.



Figure 61: Selecting all Elements of the Revit Pipe Category, Dynamo

The next step is to create a list of parameters that we need to extract from elements by inserting a code block; Right Click > Code Block. There are two types of parameters as we mentioned previously. Instance parameters and type parameters. In this thesis, all the parameters extracted were instance parameters. The instance parameters in this workflow are divided into two groups of getting Parameters and Set Parameters (Figure 62).

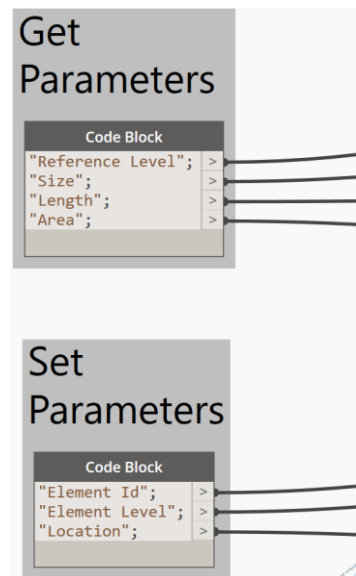


Figure 62: Pipe Category Parameters, Dynamo

Get parameters are the parameters that already exist in the Revit model. Set parameters are the parameters that don't exist and we need to create them for the element. For creating a new project parameter as mentioned in the previous chapter, go to the Revit > Manage > Project Parameters and create Element Id, Element Level, and, Location (Figure 63 and 64).

The screenshot shows the 'Parameter Properties' dialog box in Revit. The 'Parameter Type' section has 'Project parameter' selected. The 'Parameter Data' section shows 'Name: Element Id', 'Discipline: Common', 'Type of Parameter: Text', and 'Group parameter under: Data'. The 'Categories' section shows a list of categories with 'Air Systems' through 'Cable Trays' checked. The 'Add to all elements in the selected categories' checkbox is checked.

Figure 63: Creating New Project Parameters, Revit

For the location, the plan is divided into three different zones of A, B, and C, and the parameter is assigned to each element depending on where it is located in the plan.

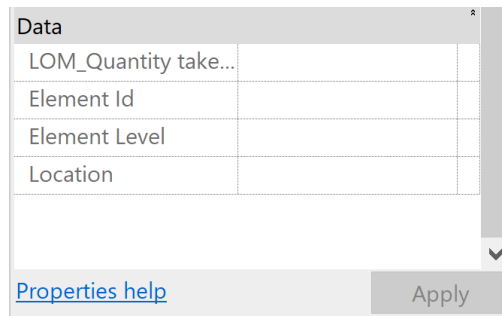


Figure 64: Element Properties – Data, Revit

Then we insert the Element Id and Element Name node and for the rest of the parameters which they don't have a node with their name in dynamo we have to obtain them by inserting 'Element.GetParameterValueByName'. after that, we can create a group for each parameter and subsequently, selecting those parameters from the code blocks and connect them to the parameter name input and from the other side connect the output of all elements of the category to the element input of each parameter group. For the set parameters, we have to insert another node 'Element.SetParameterparameterByName', and connect the output of each set parameter group which is a string to the input value of these nodes (Figure 65-67).

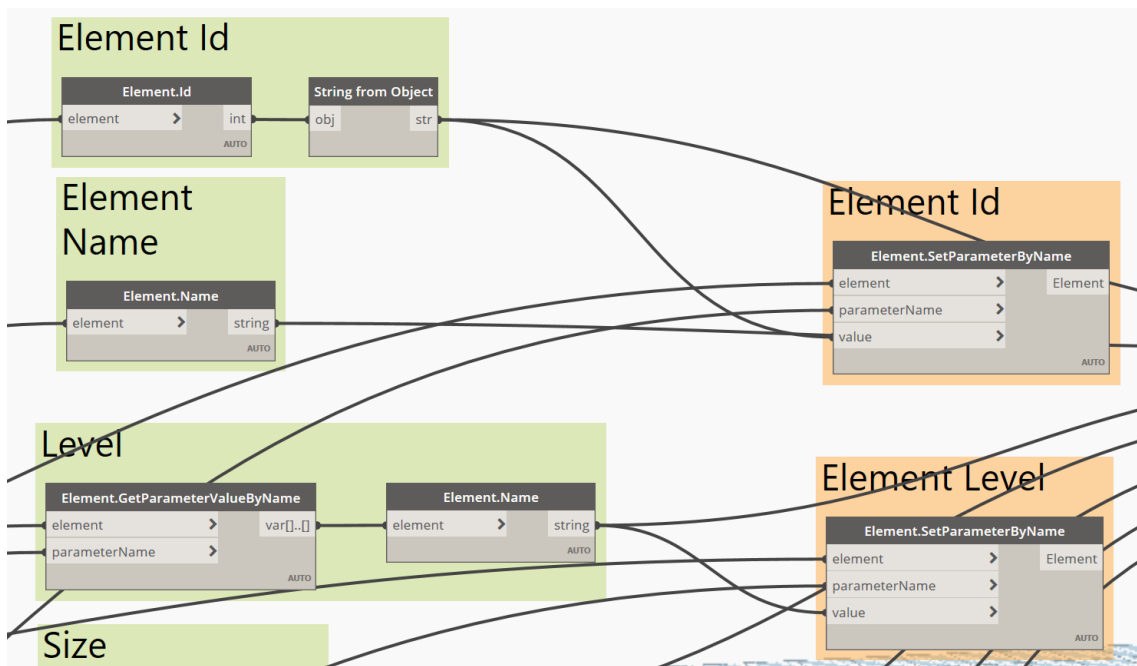


Figure 65: Parameter Groups, Dynamo

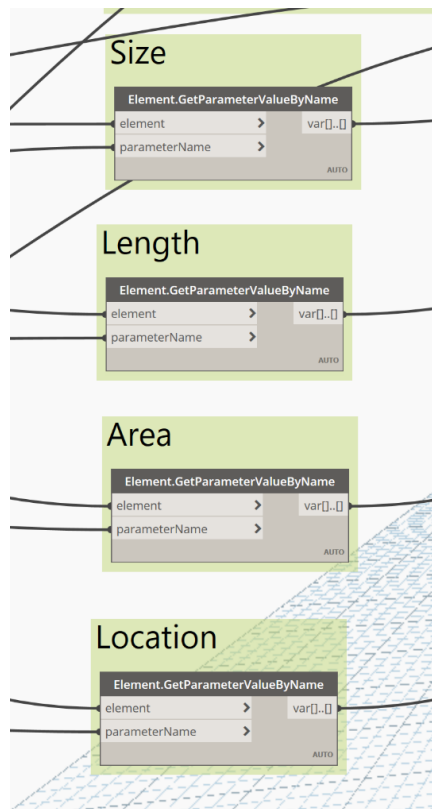


Figure 66: Parameter Groups, Dynamo

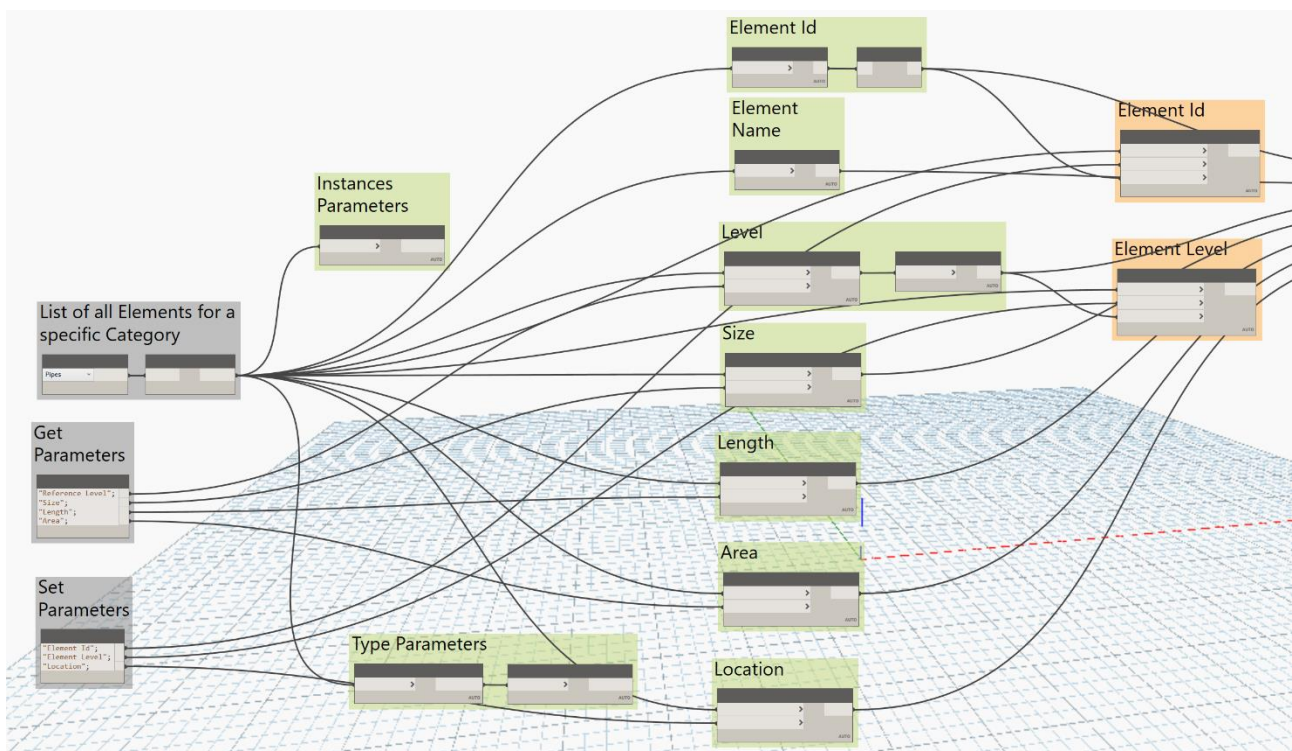


Figure 67: Dynamo Workflow, Dynamo

At this step, we have all the information that we need to extract from the model and we have to create a list from them by inserting the node 'List Create' and connecting the output of each parameter to this list.

4.3. JSON Format

The last step is to export the data in JSON format. JSON stands for JavaScript Object Notation is a lightweight popular format for storing and transporting data. As the name suggests, JSON is derived from JavaScript but later embraced by other programming languages. JSON is "self-describing" and easy to understand and it is often used when data is sent from a server to a web page. JSON file ends with .json extension but it is not compulsory to store the JSON data in a file. It is faster, needs very less formatting, and has a higher parsing efficiency than XML and due to the inadequacies of XML, JSON has been widely used in Web applications. XML and JSON are two different data serialization formats used in web applications. JSON data is stored as key-value pairs similar to JavaScript object properties, separated by commas, curly braces, and square brackets. A key-value pair consists of a key also called name (in double quotes), followed by a colon (:), followed by the value (in double-quotes) [40], [41]. For exporting the report to JSON format we need to download packages for JSON by clicking on Packages > Search for a Package and then write the name of desired package (Figure 68 and 69).

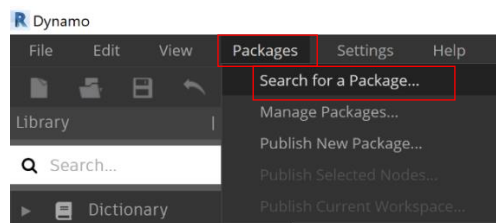


Figure 68: Dynamo Packages, Dynamo

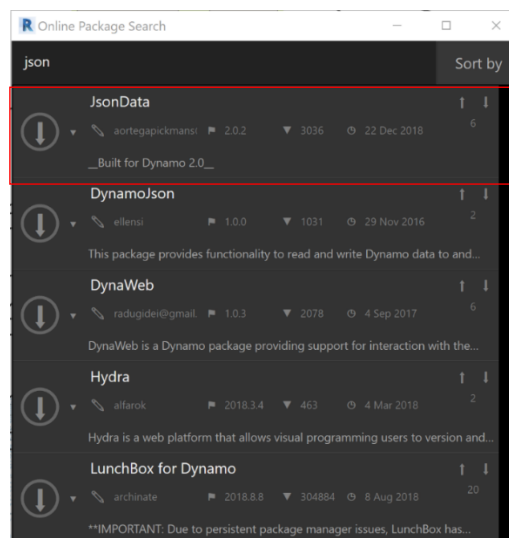


Figure 69: Dynamo online search package for JSON, Dynamo

In this project, the JsonData package is used for exporting to JSON. After downloading the package clicking on JsonData > JsonObject and select the node 'By.KeysandValues' (Figure 70).

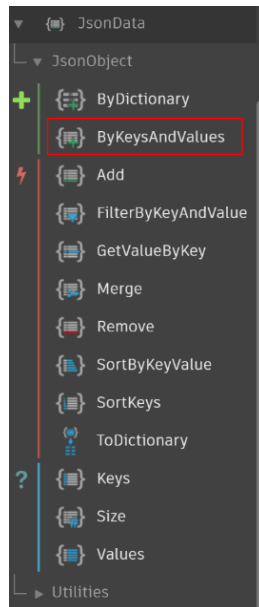


Figure 70: JSON Package, Dynamo

At this point, two lists of data need to be created for the parameters name and their related value for the Keys and Values input. The values output must be connected to the values input using the 'List.Transpose' node (Figure 71).

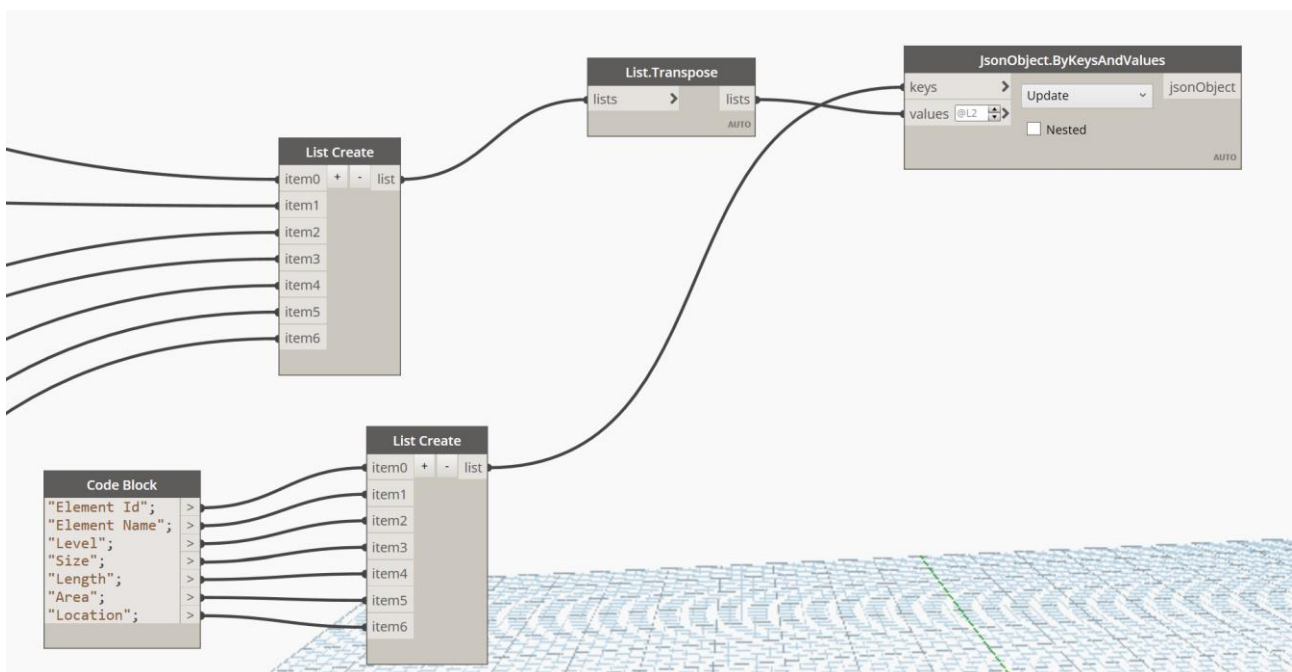


Figure 71: Dynamo workflow – Exporting to JSON Format, Dynamo

For converting the JSON object to the readable format we have to use another node 'WritetoJsonFile' by clicking on JsonData > Utilities > Write > ToJsonFile (Figure 72).

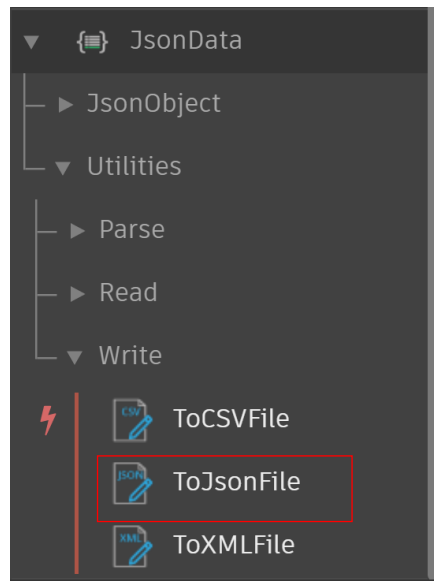


Figure 72: Write to JSON file, Dynamo

the last step of exporting the data is to define the file path by adding the node of File Path and clicking on brows (Figure 73). We have to save the name of the file with the .Jason extension. Then we can click the Run and export the JSON format (Figure 74).

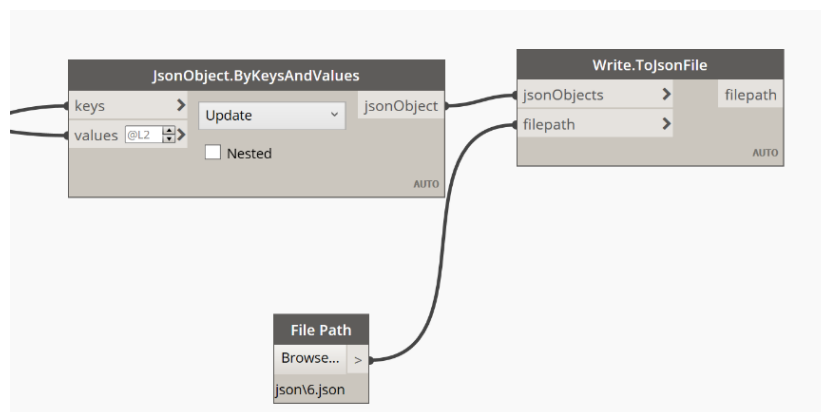


Figure 73: JSON File path, Dynamo

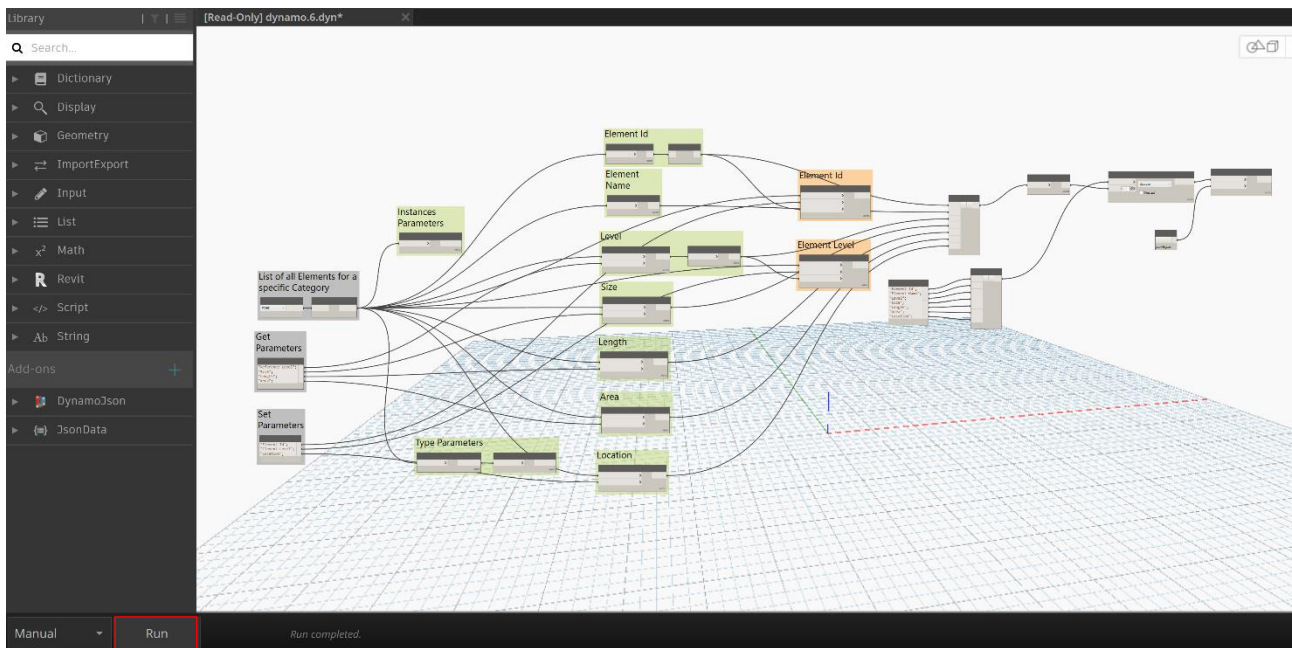


Figure 74: Dynamo Workflow Run, Dynamo

4.3.1. Result

At the end of the exporting process, a file with the JSON format is obtained. This file includes the data needs for all the elements of selected category which in this case was the pipe and the same process can be done for all the categories including in the Revit model (Figure 75).

```
[
  {
    "Element Id": "207601",
    "Element Name": "Default 2",
    "Level": "UGL109",
    "Size": "80 mmø",
    "Length": 0.48301791495901469,
    "Area": 0.12139564265499989,
    "Location": "A"
  },
  {
    "Element Id": "228438",
    "Element Name": "Default 2",
    "Level": "UGL109",
    "Size": "80 mmø",
    "Length": 3.6483177104243105,
    "Area": 0.916922249362443,
    "Location": "A"
  },
  {
    "Element Id": "239845",
    "Element Name": "Default 2",
    "Level": "UGL109",
    "Size": "80 mmø",
    "Length": 3.369956249999996,
    "Area": 0.84696238383350975,
    "Location": "A"
  },
  {
    "Element Id": "244625",
    "Element Name": "Default 2",
    "Level": "UGL109",
    "Size": "125 mmø",
    "Length": 0.43942500000002355,
    "Area": 0.17256179397547095,
    "Location": "B"
  }
]
```

Figure 75: JSON File

5. Conclusion

It is evident that as the construction industry expands and becomes more complex, new needs arise. On the other hand, technology is advancing at an incredible rate every day. Therefore, the construction industry must adopt new technologies to meet all the project needs. Since it emerged, BIM has revolutionized the construction industry and helped to optimize projects in different aspects. It reduces the costs and while speeding up the project increases its accuracy. Another benefit of using BIM is that the data will be managed properly and can be used for the maintenance phase of the project. These benefits make BIM an essential tool in complex projects such as infrastructure where maintenance and management can be a challenge due to the information accessibility issue which is a difficult and time-consuming process. This thesis aimed to take a step forward in improving the maintenance issue by exporting data from the BIM model in a format that can be used for facility management. The process involved obtaining a digital model of a fire protection system and verifying it in terms of conflicts with another MEP model of the project (HVAC System) and modifying the model based on the clashes. After that, the data is exported from the Revit model to JSON format using Dynamo. The JSON format can be used as a common language to make the communication between BIM and BMS through a platform. This creates a relationship between the physical and digital assets. If some problem or failure happens, the data will transfer from the sensors to this platform and from then will send back to the BIM model. In this case, the digital information model can be updated based on the data from the monitoring system. It can be possible after that to open a ticket for maintenance interventions.

all being said, exporting data from Revit to JSON is one of the first steps, following this idea as part of the future developments, there is a need to create a facility management platform for integrating BIM and BMS using JSON format for exchanging the data.

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