POLITECNICO DI TORINO

Master's Degree in Civil Engineering

Master's Degree Thesis

4D BIM for Construction Management:

The Case Study of Torre Regione Piemonte High-Rise

Supervisors

Prof. Anna OSELLO

Eng. Matteo DEL GIUDICE

Candidate

Ibarhim ALADGHAM

October 2021

Abstract

Nowadays Constructions projects are getting more complex and contain different disciplines, Coordination between these disciplines in the design phase is a key aspect in order to avoid conflicts therefore minimizing potential problems that may arise in construction phase. This imply saving money and time for the project. This thesis points out how important is the adoption of ***BIM*** methodology in the design phase as it allows more easier and efficient coordination between the different designing disciplines throughout different sharing information methods and carrying out clash detection analysis between the different disciplines' models.

The case study of this thesis is Piedmont Region High-Rise, a mechanical 3D parametric model for the underground parking area was developed starting from existing architectural and structural models, this phase was divided into two main steps the first one is the geometrical modelling and the second one was about the alphanumeric codifications, after finishing the model a clash detection analysis was carried out in order to figure out the conflicts between the different disciplines. Based on this type of analysis results, conflicts can be solved before starting construction phase.

Keywords

Building Information Model/Modelling, Interoperability, Revit, Navisworks, BIM Validation, Clash Detection

INDEX

Index of Figures

Index of tables

Acronyms

BIM

Building Information Model/Modelling

LOD

Level of Development

TRP

Torre Regione Piemonte

AEC

Architecture, Engineering, and Construction

MEP

Mechanical, Electrical and Plumbing

HVAC

Heating, Ventilation, and Air Conditioning

Chapter 1

1 INTRODUCTION

Clash detection has a fundamental role in the designing process when it is necessary to execute an automatic checking of clashes between the different disciplines. In the designing process ***BIM Tools*** can be used to help in this manner such as ***Navisworks*** which allow to carry on clash detection analysis giving the ability to know the potential conflicts between objects and errors of designing.

Clashes can be defined in three main ways:

- **Hard clashes:** it is the clash where two objects occupy the same space.
- **Soft clashes:** when the two objects are extremely near to each other.
- **Workflow clashes:** clashes that happen in the time schedule of different activities of project construction process.

This methodology has several advantages, one of the most important of them is that it gives the designers the ability to minimize the errors of designing even in the preliminary design phase, therefore it will help to minimize the loss of money and time. It was chosen to work on the MEP model of the underground parking zone of the project Torre Regione Piemonte which is a high-rise building located in city of Turin, starting from the existing structural and architectural models, the aim is to create a 3D parametric model to be as completed as possible to have a reliable results at the verification and validating process.

For this analysis, ***Navisworks*** a product of Autodesk company will be adopted. First Interoperability analysis between the softwares will be carried out by checking out elements and parameters quantities to check if there is any missing data, after that the clash detection analysis will be carried out. Clash detection should be applied to each project allowing an easy control of all construction process. Thanks to that it can be avoided the errors in the construction site during the construction process and to verify if the space between the elements and objects are sufficiently enough to allow the maintenance process and access to all the zones and elements of the project.

1.1 Objectives

The main objectives of this thesis is to test and validate the integrity and correctness of the created 3D parametric model by exporting ***BIM*** content in a format that maintains the integrity of the created objects in the 3D parametric model, not only from a geometric point of view but also from a data and informations point of view, after which to carry out an analysis to identify the conflicts between the different disciplines taken into consideration, in this case the architectural, structural and the mechanical one. In order to obtain a consistent and as complete as possible data integrity, it was necessary to establish from the early stages of the project which types of parameters were needed.

During modeling, all elements were created to simulate reality as close as possible, with assigned information to each element in form of parameters. Specifically, it was necessary to create a unique code for each element, called ***identification code (codice identificativo)*** necessary for faster identification in the checking phase.
After completing the modeling, the models were exported in different formats, to check and verify if there was any missing data, to compare between the different methods of data transfer between the different platforms.

Subsequently, a software was considered (***Navisworks***) and through some rules and filters, it was possible to verify the quantities and conflicts based on the parameters initially defined in the rules.

With this method it is possible to identify the problems, conflicts, clashes and errors that could be exist between the various disciplines, therefore, by solving these conflicts in early stage it helps making the workflow more efficient and preventing conflicts to appear during the construction phase.

1.2 What is BIM?

It is of fundamental importance to give more information on the ***BIM Methodology*** in order to better understand the information regarding this thesis. The main purpose of ***BIM*** is to create an overall digital representation of a project through all its entire life cycle.

In recent years, in the world of construction, construction techniques and construction documentation have undergone a radical change in the methods of representation, especially the information coming from different disciplines.

To describe the different building components, a digital model is used where it can contain the main characteristics and information of the object. Sharing informations is not limited only for the geometry and dimensions of elements, but also the non-geometrical information assigned to the model objects that makes the model more complete, easy to navigate through and clear to describe.

Building Information Modeling (BIM) is the holistic process of creating and managing information for a building project. Based on digital model and created by a ***BIM*** platform, ***BIM*** integrates structured, multi-disciplinary data to produce a digital representation of a project through its lifecycle, from planning and design to construction, operating and maintenance.

"BIM simulates the construction project in a virtual environment. With BIM technology, an accurate virtual model of a building, known as a building information model, is digitally constructed. When completed, the building information model contains precise geometry and relevant data needed to support the design, procurement, fabrication, and construction activities required to realize the building" [1]

Adopting ***BIM*** methodology benefits to a great degree all the parties concerned with the project, starting with the different designing teams as it enhance the collaboration between them, minimizing the errors that results if each team worked separately without sharing information about their work, it also helps to have a fast and correct design process as the checking process will be in all disciplines combined in one model so conflicts can be detected before construction starts. For the owners with complete ***BIM*** model, it is easier to operate and apply maintenance to the project.

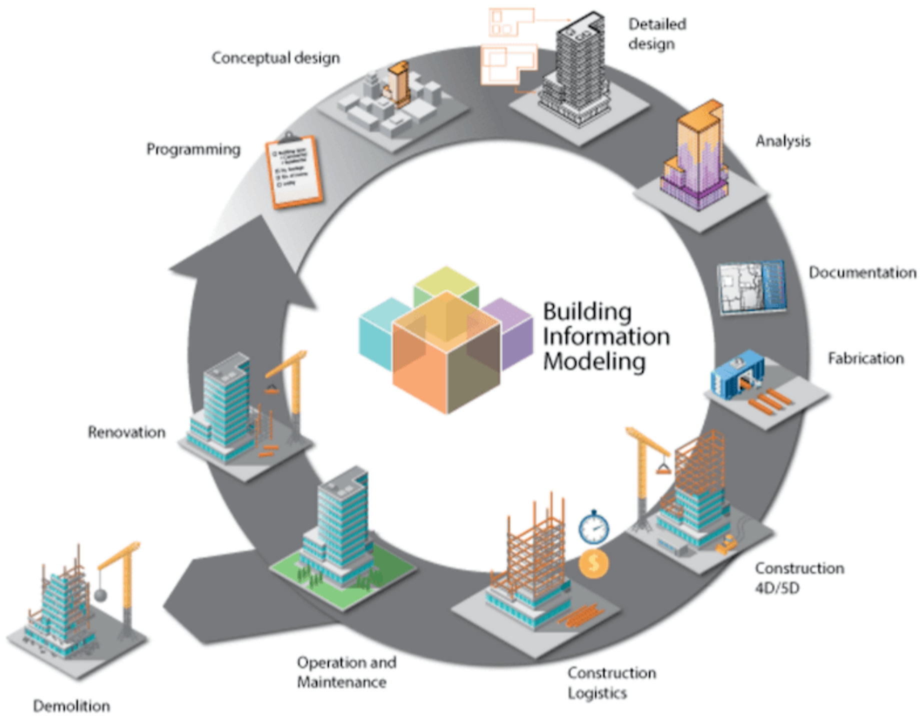


Figure 1: Project management with the BIM methodology [source: https://BIMmda.com/en/what-is-BIM]

"*BIM can be viewed as a virtual process that encompasses all aspects, disciplines, and systems of a facility within a single, virtual model, allowing all design team members (owners, architects, engineers, contractors, subcontractors, and suppliers) to collaborate more accurately and efficiently than using traditional processes. As the model is being created, team members are constantly refining and adjusting their portions according to project specifications and design changes to ensure the model is as accurate as possible before the project physically breaks ground*" [2]

1.3 Why BIM?

"*In the last years, the use of Building Information Modelling (BIM) has grown significantly as an optimizing factor of the whole building sector, supported by innovation technology. As a methodology, BIM allows the different parties involved AEC industry to share information through interoperability, improving data transfer and updating through the development of a 3D parametric model able to collect all the information needed for a project."* [3]

Nowadays projects have become more complicated and contains a vast amount of informations comparing to the traditional ways of paper-based design methods. These traditional methods allowed a major amount of errors and omissions to emerge as every discipline was completing his work apart from the other disciplines, the manual review process was not always accurate due to the human factor, it required much amount of time and effort to do it and the result was not always satisfying as many errors still appear when the construction phase starts, this would imply waste of time and delays of the project schedule in addition to their cost implications.

Shifting from the traditional ways of paper-based designing to the digital methods of design was a demand to avoid all the disadvantages of traditional ways, moving towards exploiting the new technologies of computers, it started with ***CAD*** softwares (Computer Aided Design). The different CAD applications provided a new way of representing the design, it also provided a very fast way for designers to accomplish their work as it contained blocks of predesigned objects that designers can use directly instead of drawing it from scratch. However, it remained in a certain level as the softwares read these designs just as lines and curves, no additional data was assigned to these drawings to explain them, this also created problems whenever it was needed to transfer data form one application to another and to carry out a checking analysis.

The idea starts to develop starting from creating 3D parametric model that describes the geometry of the project with the ability to extract 2D plans and cross-sections from it, Then the next step of ***BIM*** development was to assign additional information to the elements inside the 3D model therefore each object will not just have information about its geometry but to assign information, attributes, classifications, and codifications. Such information will facilitate the processes of designing, construction, operating and maintenance of the project.

"*Designing a building that contains a hundred thousand or more objects would be impractical without a system that allows for effective low-level automatic design editing*." [1]

1.4 BIM Dimensions

The ordinary mistaken idea about ***BIM*** is that it is only about representing the project in 3D model, this idea is completely wrong as ***BIM*** extends to furthermore dimensions for representing various features of the project, each dimension of ***BIM*** concerns about incorporating new type of information to the model.

"BIM involves more than just 3D modelling and is also commonly defined in further dimensions such as 4D (time), 5D (cost) and even 6D (as-built operation). 4D links information and data in the 3D object model with project programming and scheduling data and facilitates the simulation analysis of construction activities. 5D integrates all of this information with cost data such as quantities, schedules, and prices." [4]

The different ***BIM*** dimensions can be summarized as the following:

- **4D BIM**

  It is the process of linking time schedule of constructions activities to the 3D digital model, in this way it is possible to generate a real-time graphical representation or simulation of the construction different phases.

- **5D BIM**

  It is the process of incorporating and integrating the cost allocated to the different construction activities with the 4D ***BIM*** dimension, it has numerous advantages as it helps to generate financial representation of the model against time.

- **6D BIM**

  Incorporating sustainability components and energy estimations to ***BIM*** model, which enables designers to analyze energy consumption in early stage for all the project life cycle.

- **7D BIM**

It is the process where it allows to extend ***BIM*** use to facility management,

This phase concerns the building managers and owners as this dimensions is used to provide data such as building status, operating, maintenance, and warranties.

Figure 2:BIM Dimensions [Source: https://biblus.accasoftware.com/en/bim-dimensions/]

1.5 Level of Development LOD

When Building Information Modeling (***BIM***) is used in construction, the level of development could be varied from different geometric representations to an accurate as-built model depending on phase requirements. The Level of Development (***LOD***) framework is used to specify how much the elements within the model has been developed in terms of associated informations. The term “Level of Detail” is also used, but it could be misleading. For example, a model with a high level of graphical details but without technical specifications is still preliminary, therefore Level of Development is preferred because it gets associated with graphical or physical characteristics beside the associated informations such as technical specifications or fabrications informations to the objects.

The American Institute of Architects (***AIA***) defines six levels of development in its ***E202-2008*** Building Information Modeling Protocol (AIA 2008).

Figure 3: Level of Development LOD [Source: https://www.hitechcaddservices.com/bim/support/level-of-development-lod/]

These six levels of ***LOD*** can be summarized as the following:

- ***LOD 100***: it is used in the pre-design phase or conceptual design where the objects are represented with generic shapes just to give an understanding of the project size and its requirements.

- ***LOD 200***: used in schematic design phase with utilization of approximate geometry, size, shape, location and orientation, non-graphical informations may be attached to elements.
- ***LOD 300***: used in design development phase and is similar to construction document, precise and accurate geometry is used with information about fabrication and installation, it can be used in construction phase
- ***LOD 350***: used for construction documents phase, precise geometry with connections and interfaces between different systems and components in the model, it shows how different systems interact with each other.
- ***LOD 400***: used in construction and fabrication phase, the model contains information and specifications can be provided to suppliers to be used for fabrication.
- ***LOD 500***: as-built, contains all information to support building operating and maintenance processes in the building lifecycle.

In this way Level of Development ***LOD*** creates a standardized definition for requirements of completeness of each phase of building lifecycle starting from conceptual design to operating and maintenance phase, by using ***LOD*** it is easier and clearer for different disciplines teams to communicate and cooperate.

"The Level of Development (LOD) Specification is a reference that enables practitioners in the AEC Industry to specify and articulate with a high degree of clarity the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process." [5]

Several countries have developed their ***LOD*** classifications and ***BIM*** guidelines based on ***AIA*** Protocol such as Australia, Canada, Singapore, China, Taiwan, Germany and France. Other countries have developed their own classification systems such as New Zealand and Denmark.

For the Italian ***BIM*** *standards* and regulations ***UNI 11337-4 of 2017***, a general ***LOD*** levels has been defined with subsequent examples of the most significant construction systems.

General levels:

- **LOD A (SIMBOLICO):** symbolic object representation.
- **LOD B (GENERICO):** generic object representation.
- **LOD C (DEFINITO):** defined object representation.
- **LOD D (DETTAGLIATO):** detailed object representation.
- **LOD E (SPECIFICO):** specific object representation.
- **LOD F (ESEGUITO):** as-built object representation.
- **LOD G (AGGIORNATO):** updated object representation.

there are two additional terms in subcategory of **LOD**

- **LOG**: Refers to level of development of objects in terms of geometric attributes.

- **LOI**: Refers to level of development of objects in terms of informatic attributes.

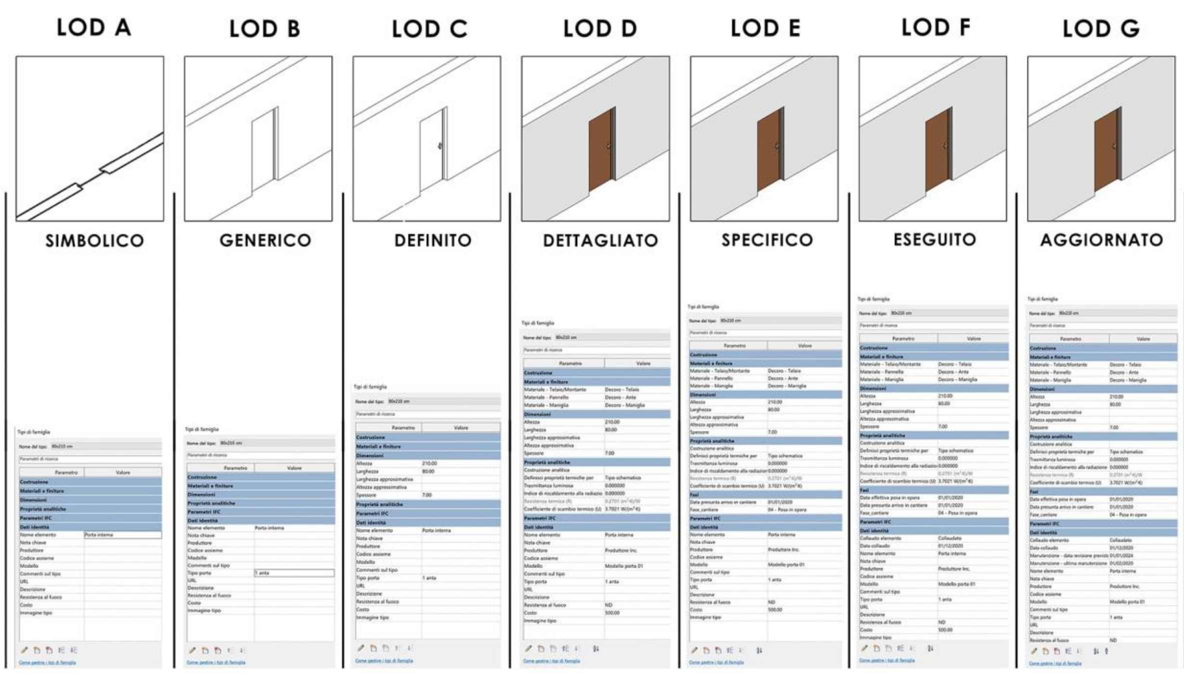


Figure 4: Italian Classification of LOD [Source: https://4mgroup.it/blog/i-lod-del-bim-spiegati-bene]

1.6 Interoperability

As it was mentioned before, in the last few decades, the ***AEC*** industry witnessed a huge development in the applied technologies, many designing platforms appeared and some of them is specialized for one or more discipline, for example ***Autodesk Revit*** for architectural, structural and ***MEP*** modelling, ***Tekla*** for steel structures. Due to the fact of existing of different ***BIM*** tools and different designing disciplines and every ***BIM*** tool has its own file extension, when it is needed to integrate all the teams work the issue of transferring data between the different platforms appears. ***Interoperability*** is a key aspect in Building Information Modelling as it is essential to maintain high integrity of transferred information between the different tools in order to finally achieve as complete and correct model as possible.

"*Interoperability is the ability to exchange data between applications, which smoothes workflows and sometimes facilitates their automation*." [1]

Losing data when transferring the work between the different tools would create many problems, the problem of losing of data is almost negligible when the different tools belong to the same manufacturer such as Autodesk different ***BIM*** products but it becomes more clear when transferring data between tools that are from different manufacturer, a lot of efforts were localized in order to minimize and overcome of this problem, in the late 90s the International Alliance for Interoperability (***IAI***) -now known as ***BuildingSMART***- was established by Autodesk including other ***BIM*** platforms manufacturers, this association main scope was to develop standards, norms, and tools supporting the flow of information between the different platforms.

The ***.ifc*** (Industry Foundation Classes) extension was introduced to work as shared neutral exchange format that it is not the format the software is working by it, but it works as a link between the different platforms to transform the data, there for each platform that has this built-in feature can export and import all the data and geometry of the model in ***.ifc*** extension.

"IFC or Industry Foundation Classes is a global standard for describing, sharing and exchanging information on building and facility management. It is a non-proprietary, neutral

data format. IFC provides a set of definitions for all types of object elements encountered in the construction industry and a text structure to store such definitions in a data file." [6]

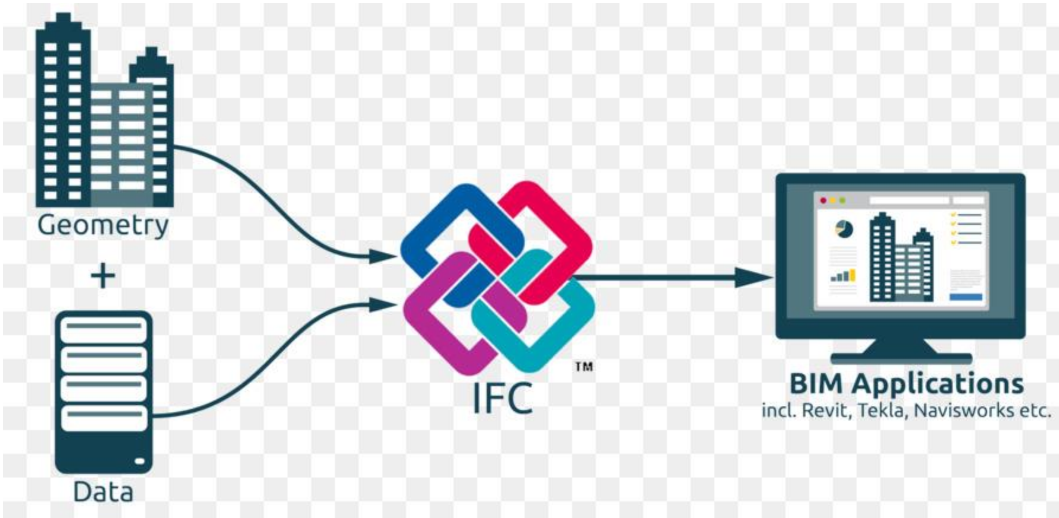


Figure 5: IFC file includes both, geometry and data [source: https://www.BIMcommunity.com/news/load/910/ifc-why-now]

The International Alliance for Interoperability (**IAI**) now known as ***buildingSMART***, since it has released the first edition of the ***.ifc*** exchange format has made it go through multiple updates in order to improve its quality for data exchange to keep it in pace with the rapid increase of AEC technology development and the appearing of new tools.

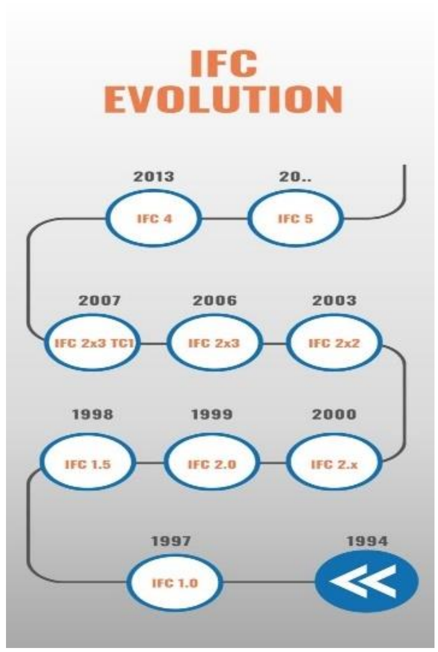


Figure 6: IFC file evolution [source: https://BIMcorner.com/everything-worth-knowing-about-the-ifc-format/]

1.7 BIM standards and regulations

The application of ***BIM*** in construction project includes the digital representation of its components, this representation includes physical and functional attributes. The digital model of the project facilitates the process of decision-making process in the whole project life cycle, and ***BIM*** adoption implies other benefits such as:

- Reducing the project delivery time.
- Improving the cooperation and collaboration between the different involved parties.
- Reducing the total cost for the project.
- Reducing the errors and omissions in design and construction.

Since ***BIM*** technology was first applied in the USA it started rapidly spreading in other countries all over the world specially the countries that have a large constructions market, the need of organizing the use of ***BIM*** has emerged in these countries. therefore, some of these countries began to release legalizations that make the use of ***BIM*** mandatory and standards that organize its use.

"The use of BIM is in rapid growth in the largest construction markets and many countries worldwide have already institutionalized trough mandatory implementation in all public works. Although the USA was the first country to adopt BIM, the highest success rates of BIM are recorded in countries where BIM is required, such as the United Kingdom, based on specific standards and procedures." [7]

National standards exist in many products we use in our daily life, it can be clearly viewed how it facilitates the quality, efficiency and reliability of these products, the idea of applying standards on ***BIM*** in the ***AEC*** industry is not excluded and would contributes in making the use of ***BIM*** more developed and more efficient. In the UK the ***National BIM Standards*** was developed in order to organize and facilitate the ***BIM*** use, these standards refer in clear and in detail way to the whole stages of ***BIM*** use and contains a large number of documents that illustrate procedures, roles, etc. likewise, other countries such as Italy, Norway, Finland and Singapore developed their own national ***BIM*** standards, whereas the other countries are planning to release their own standards in the near future. In the countries that yet has not developed its own national ***BIM*** standards, many private and public entities are developing initiatives to create their standards for the implementation of ***BIM***, not having a united ***BIM*** standards will result in making it more difficult for engineers, owners, and contractors as they will have the need of learning different ***BIM standards*** with every different type of project.

Due to globalization that it is for certain also affecting the construction industry, there is continuous increase of international projects and collaborations between countries, since each country has its own ***BIM*** standards it is difficult to reach out a common international ***BIM*** standards. In seek of overcoming these obstacles, ***ISO-19650*** standards were developed and published on December 2018 to regulate the use of ***BIM*** on international basis, ***ISO-19650*** is based on the English standards ***BS-1192*** and aim for closing the gap between the different national standards.

In Italy, the regulations for ***BIM*** came a little late, after undergoing countless changes and updates, compared to other countries of the European Union which, on the other hand, had already introduced a policy on digitalization in the construction industry. In Italy, starting from the decree no 50/2016 then decree 560/2017, in august 2021 the new Ministerial Decree has been published by the Ministry of Infrastructure and Transport. which amends and updates the Decree of 1 December 2017, n. 560 which establishes the methods and times for the gradual introduction of digital modeling methods and tools for buildings and infrastructures.

1.8 Case study: Torre Regione Piemonte

The forty-two stories skyscraper was designed in 2007 by the Italian architecture ***Massimiliano Fuksas*** and the construction operations started by the fall of 2011, the project aimed to contain all the public-service offices which is scattered all over the city in order to facilitate for the citizens to reach it in one place. The project is located in Turin the capital city of the Piedmont region in Nizza district in the southern part of the city, the skyscraper is constructed above area of 70.000 m^2 with reinforced concrete structural system to reach a total height of 205 m to be the third highest building in Italy.

The project consists of three main parts:

- The Tower
- The Service Center Building
- The Underground Parking Area

The tower consists of forty-two stories, forty-one stories for the offices that is anticipated to reach a capacity of 2600 employers and the top floor is designed to be an open-air area accessible by the public where they can enjoy the panoramic view besides the multiple services to be presented such as catering, there is two underground floors aimed for functions and services of the tower. The service center building -located next to the tower- consists of five floors and is connected to the main tower by suspended glass tunnel, it is designed to contain public services for the community such as kindergarten, spaces for common activities, conference rooms, library and cafeteria. The third part is the under-ground parking area consists of three underground floors with full capacity of 1138 parking spaces the third floor which contains 136 parking spaces is dedicated only for the tower employees whereas the other two floors are available for public and employees.

An agreement was reached between the administration of Piedmont region and Politecnico di Torino university aimed to create a 3D parametric model for the whole project containing all its details and information in order to facilitate and accelerate the construction process and for the operating and maintenance of the project in the future. The process involves numerous numbers of researchers and students, this thesis is a part of this process and it's focused on developing MEP model for the underground parking area with all its details and checking its consistency with the other models of the same part in order to detect and anticipate the possible clashes and conflicts.

Figure 7: Piedmont Region Highrise

Chapter 2

2 METHODOLOGY

2.1 Methodology

BIM methodology is different than traditional design methods such as paper-based design and CAD design methods, ***BIM*** allows for more collaboration and organization between different design teams, ***BIM*** is also more effective and fast in the process of checking and update, the old traditional methods although it is faster in drawing and in finalizing the project but it usually results with many errors and omissions as every discipline is working independently, the checking process in the traditional methods was carried on manually therefore consuming much time and not very effective, the errors was to be discovered during construction resulting in cost increase and delay of project delivery schedule. In the contrary the revolutionary ***BIM*** method allowed for gathering all the teams works in one model therefore the errors and clashes detection was in the design process avoiding them to happen in construction phase, saving money and accelerating project delivery time.

The process of developing of ***BIM*** model starts with choosing the right platform to work on, here the ***Revit*** was chosen, it allows various methods for data sharing and work sharing such as ***Integrated model*** and ***Federated model***.

The Integrated model allows to gather and merge all the mono-disciplines models such as architecture, structural and MEP models in one unique model where it merges all the characteristics of these different models in one database, whereas the Federated model is only making link between these models. The federated model was chosen to work with in this project with the consideration of ***ISO-19650*** standards which regulates the process of data merging and sharing.

Figure 8 illustrates how the federated model works and what is its components.

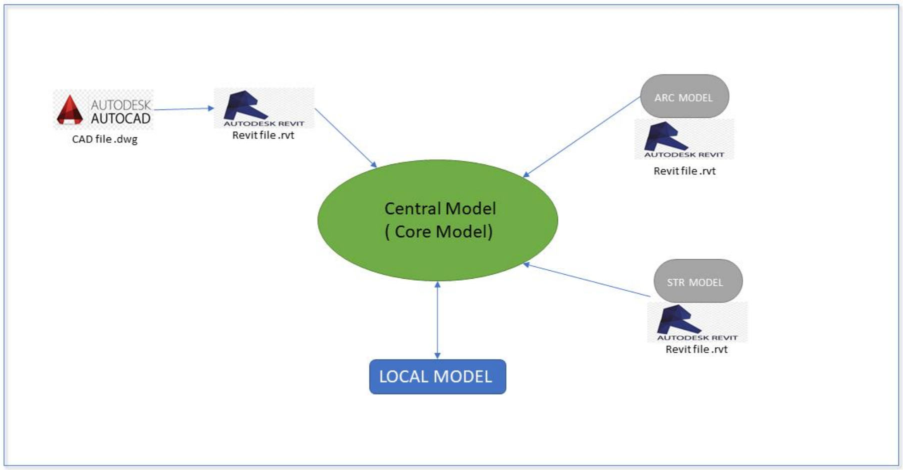


Figure 8: Central Model creation scheme

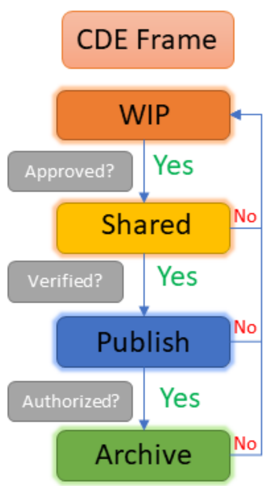


Figure 9: CDE Frame components

The term ***CDE*** stands for Common Data Environment, it is sort of database for all the project documents where it is divided to main four folders, each folder has different type of accessibility. The folders are:

- **WIP (Work In Progress)**: in this folder all users from all disciplines are allowed to access, create and work.

- **Shared**: this folder contains documents that has been checked and approved by the head engineer.
- **Publish**: contains documents that have been checked, issued, and accepted by the owner.
- **Archive**: this folder is for the owner where it is used as storage for all the project documents that have been accepted by the owner.

Only the owner has the accessibility for all the folders, ***WIP*** folder can be accessed by the different disciplines modelers, Archive is accessed only by the owner, finally the shared and publish folders their access is granted by the owner.

The work starts with collecting the structural and architectural models from the ***shared area*** then start creating and developing in the ***working area*** the mechanical model for the parking area. After finishing and validating, it was uploaded and added to the core model.

2.2 Methodology scheme

Any ***BIM*** project must have its own workflow which determines the sequence of its steps and the utilized tools in each one, it could be different from one project to another depending on the nature of the project, its requirements and the needed final results. Nevertheless, this workflow for any project must have main points that determine the needed tools, these points are Input data, BIM tool and Output data, *Figure* 10 illustrates the workflow that was utilized in order reach the final outputs.

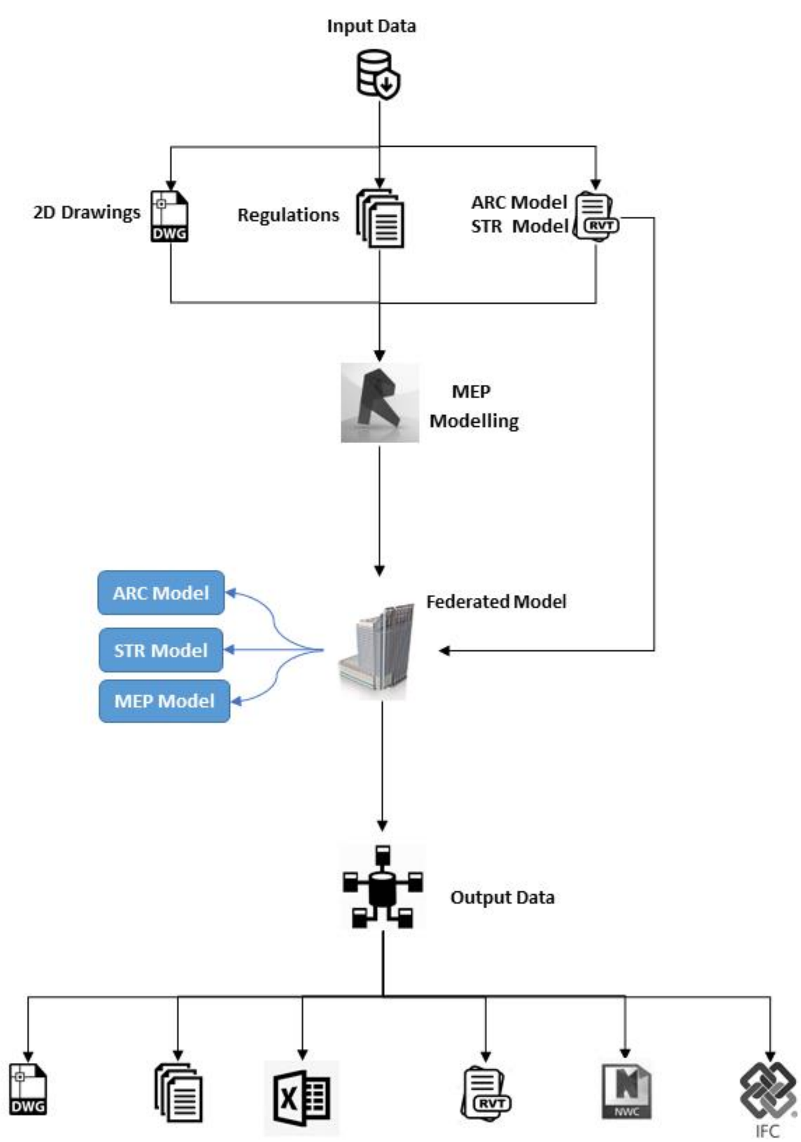


Figure 10: Workflow Scheme

In our case in order to create and develop mechanical model for the underground parking area, for the input data we have 2D CAD drawings, regulations documents and 3D model for the Architectural and structural components combined together as the parking area is not complicated as the main skyscraper. The 2D Cad drawings was provided by the technical office of the Piedmont region authority, they are three AutoCAD files that contains detailing planes and cross-sections drawings for the mechanical ventilations systems in addition to schedules of quantities and manufacture informations as types, dimensions and technical characteristics. the regulations files are developed by ***Drawing to the future*** team of ***Politecnico di Torino***, these files regulate the compilation of the alpha-numerical part of modelling in terms of naming of families, types, sheets and schedules. It also put the rules to be followed by all teams for the codifications process of all the model components. One of the biggest advantages of the applied method that it is based on already created models therefore it minimizes the risk of errors and clashes between them.

For ***BIM*** design tool ***Revit 2019*** was chosen in order to have all models created with the same version and avoid problems that rise from using different versions, for the modeling phase the first step was to determine the level of details **LOD** of the model components and objects following the project requirements. After that developing the model starts by creating new families for objects that doesn't exist in the default system families in Revit library, all the characteristics needed to be assigned to families were taken from the 2D CAD drawings and if they are not included a reasonable assumption was made for them.

The regulations were followed in the step of creating and compiling the codifications for each component in the model, the last step after finishing all the work in Revit environment is to export the model to Navisworks in order to validate the interoperability level between the two softwares and to carry out clash detection test with the other models and from there it was possible to have the analysis output data in form of tables and reports.

2.3 Documents collection

Starting from 2D CAD files that provided all the necessary information for the mechanical HVAC system whih includes mechanical equipments, ducts, air terminals with detailed information about their characteristics such as dimensions, elevations, materials, and air flow capacity that would help to create the 3D parametric model in Revit to be as close as possible to reality.

In addition to CAD drawings, it was provided Revit 3D architectural-structural model, this model was a start point for creating the mechanical HVAC system, by building on previous models we can ensure that the model coordinates are coinciding therefore conflicts with these previous models while creating the new model can be minimized. *Figure 11* shows CAD drawing of the first underground parking level (level -1).

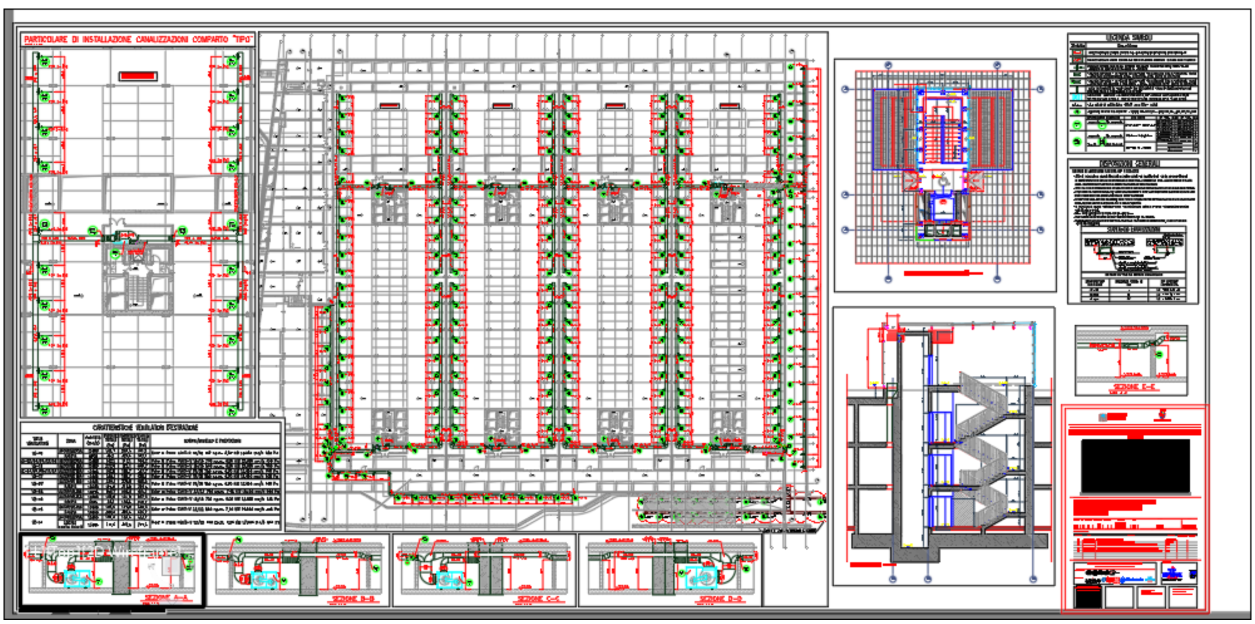


Figure 11: 2D drawing of the mechanical HVAC system part of underground parking area

2.4 Model file creation

For the creation of digital model Revit 2019 was chosen to be aligned with all members of the teamwork in order to avoid the multi-disciplinary interoperability problems in case of data exchange or merging the models into one federated model. The creation of the model is based on design classification ***As-built*** which its scope is to represent the work as it was constructed, sometimes the actual executed work could be different to the original design for variety of causes such as discovering errors in design while constructing or the original designs are very difficult to be executed in reality, having the digital model will allow the continues update of the design based on the changes that was made in the construction site. All the provided CAD drawings of the underground parking zone was As-built type.

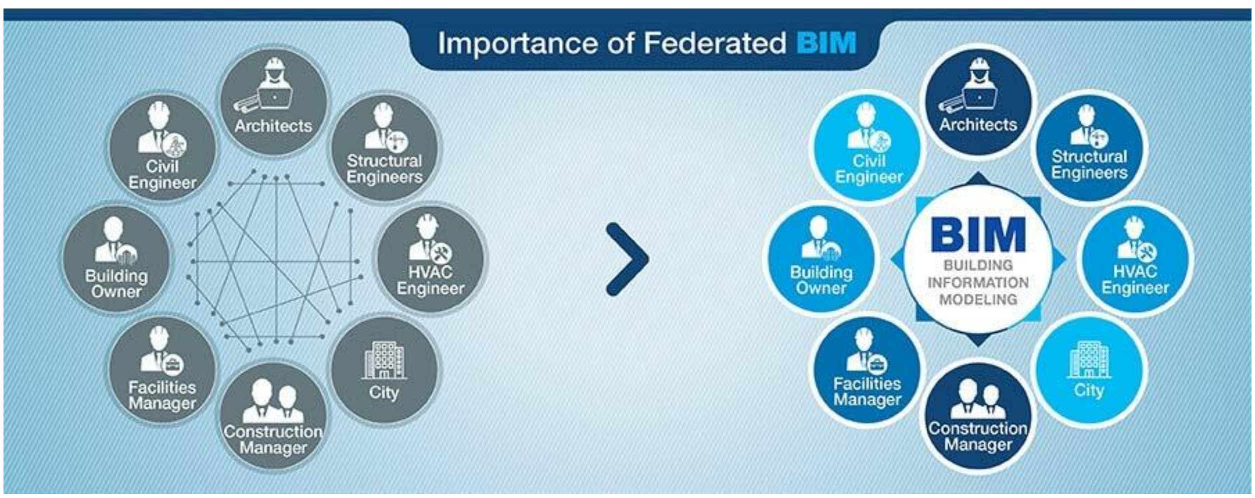


Figure 12: Importance of Federated model in BIM [source: https://www.hitechcaddservices.com/news/importance-of-federated-bim/]

The CAD files were imported into Revit, organized and assigned for each underground level which allow easy interpretation and better control. These files were provided as input data as well as ARC/STR Revit files, these files of input are extremely important for having an accurate creation of the model, they allow a correct check and control to figure out if the elements are placed in the correct position and to avoid errors and conflicts.

For the realization of the model the very first step was to start from an empty Revit file, then the next step was to link the provided previous ARC/STR model with the new model, this process allow to merge more than one model in the same place but the linked models will have only some graphical representations therefore it will not make the new file very heavy, after this step it is easy to match the coordinates of the new file with those of the linked models therefore we can be sure about the placement of the new elements in the correct position, *Figure 13* illustrates the step of linking other models to the new model, after clicking on add a new window appear that allows to choose the location of .rvt file of the targeted model with options of positioning, it is important in this step to choose the adequate one in order to make the coordinates coincide with each other, Auto – origin to origin was chosen for that purpose.

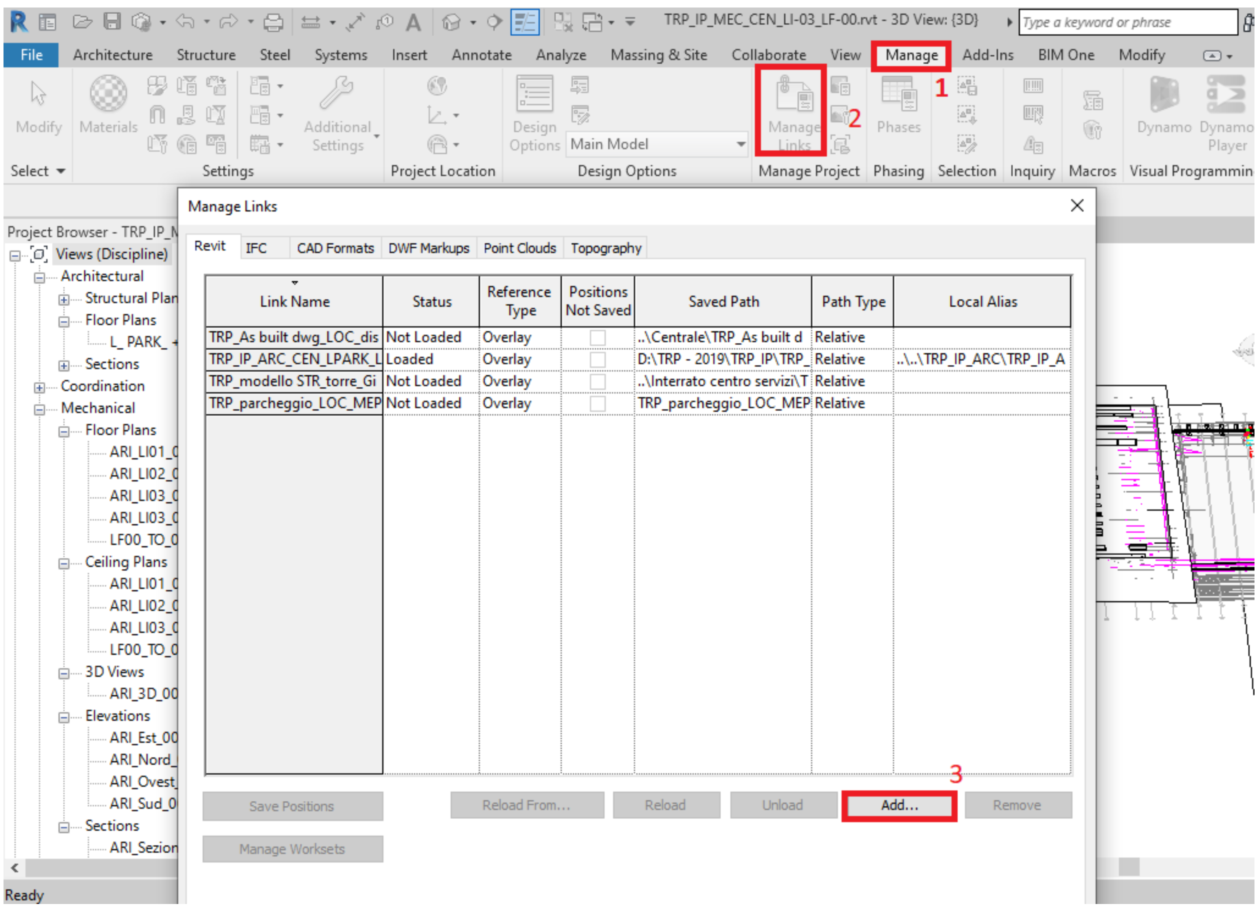


Figure 13: process of link models to Revit

After that it is possible to align the coordinates of the new model with the linked model from mange tab and acquire coordinates option as shown in *Figure 14*, after clicking on Acquire Coordinates as highlighted on the figure, it can be chosen which link to acquire coordinates from.

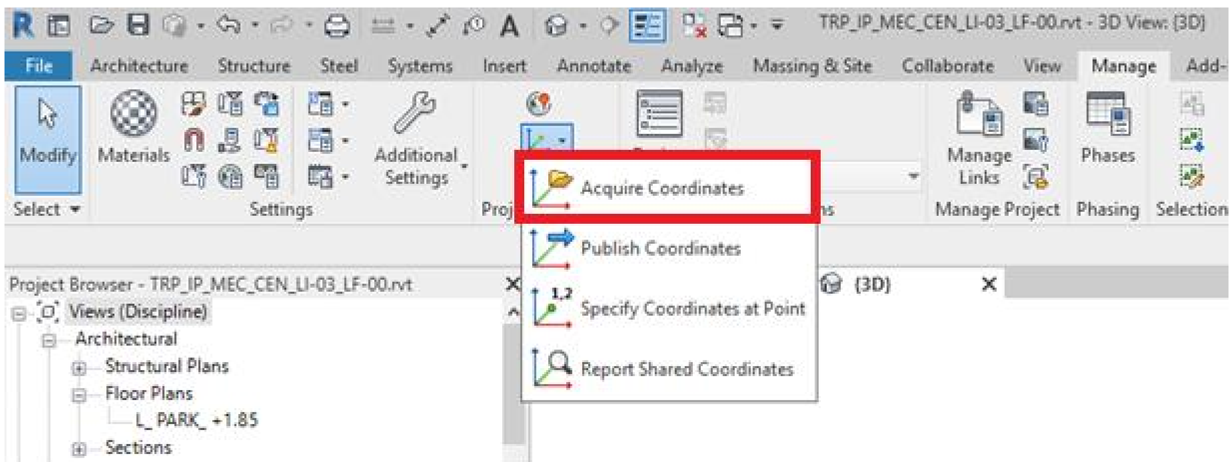


Figure 14: Acquiring coordinates for the model

Now it is possible to save the file as local model giving it a name that follows the guidelines, this name contains codes of project name, zone of modelling, discipline, model type, first level and last level.

Following the guidelines, the file name in our case was created to be **TRP_IP_MEC_CEN_LI-03_LF00.rvt**

Where:

- **TRP**: refers to project name (Torre Regione Piemonte)
- **IP**: refers to zone of modelling (Interrato Parcheggio)
- **MEC**: refers to Mechanical discipline of modelling
- **CEN**: refers to model type (Central)
- **LI-03:** refers to third underground level of parking zone (Livello interrato)
- **LF-00**: refers to ground level

2.5 Creation of parametric model

2.5.1 Insertion of families

Revit has a large group of predefined families , but first of all we need to define what is the meaning of object family and what are its different types.

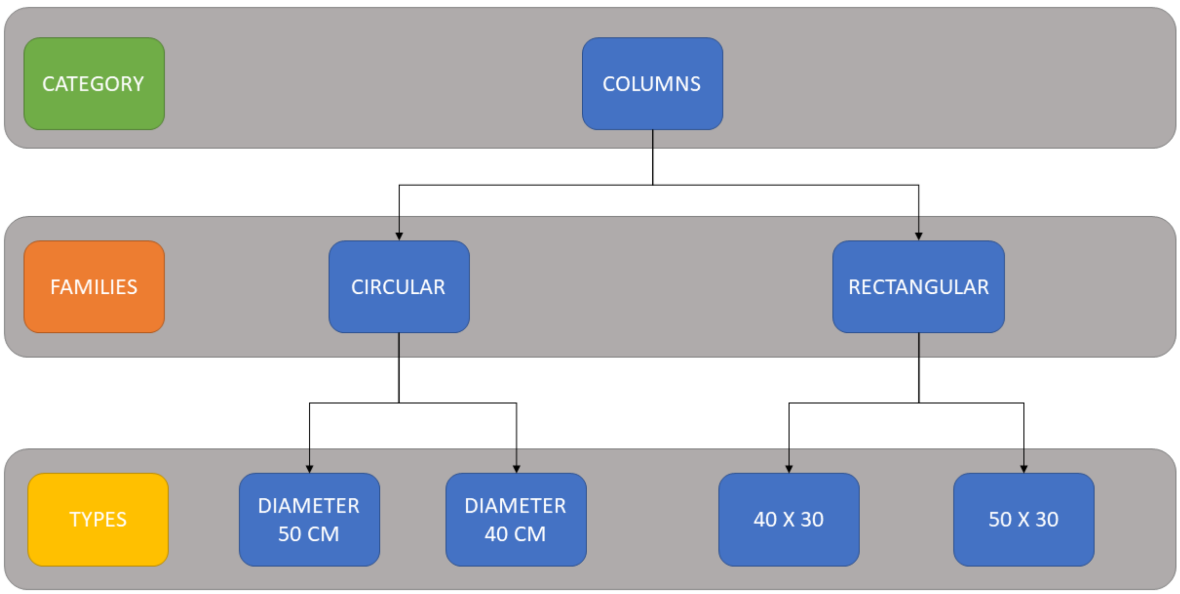


Figure 15: Hierarchy of Revit elements

All elements in Revit is a part of family, *Figure 15* illustrates the hierarchical definition of these elements inside Revit, at the top level there are categories which are predefined within the software and can't be added, deleted or renamed, there are a large group of categories and are distributed according to each discipline and within each discipline to different overall master groups, for example in Structure discipline there are categories of Beam, Wall, Column and Floor as shown in *Figure 16*.

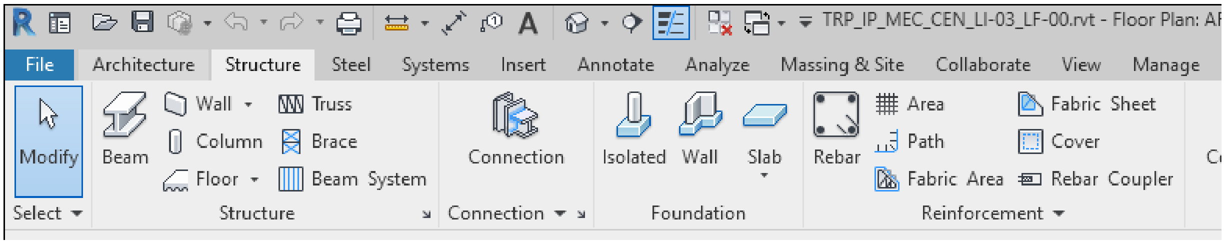


Figure 16: categories example in Revit

These categories are not enough to include all required modelling elements in that general way as some of these elements even though they belong to the same category but they come with different shapes and sizes as columns therefore there was the need to have another level for these elements, this level is defined as families

"All Revit elements belong to a family. Families are best thought of simply as a collection of like items sharing the same overall look and behavior. Revit includes many families such as the "Basic Wall" wall family, the "Single-Flush" door family and many annotation families like "Text" or "Linear Dimension Style." Even the views themselves like floor plans and sections are system families in Revit." [8]

Families are divided into two main kinds, System families and Loadable families. System families are the kind of family that are predefined in the Revite and cant be modified by the user, it can includes model components such as walls, floors, ducts, beams and ect. It can also include important elements such as levels, project data and floor planes. System families cant be created or deleted and their proprieties are pre-defined in the software. Loadable families are the families that are created by the user or downloaded from other online liberaries, one of the most powerful advantages of Revit is the ability to creat these new families that allow the user to complete his modle in the most clear and correct way.

	System families	Loadable families
Ducts	✓	-
Fire dumbers	-	✓

Table 1:Examples of system and loadable families.

Most of these families can have more than one type, ***Type*** is the next level of elements herraricy levels in Revit, types are represents the differencies in dimensions, shapes, materials and technical characteristics that exist in the same family.

System families can be found in Revit interface, for inserting Loadable families, as shown in *Figure 17*, from file menu choose open then family, a new dialuge window will appear from wich it is possible to choose the location of the loadable family and import it to the software.

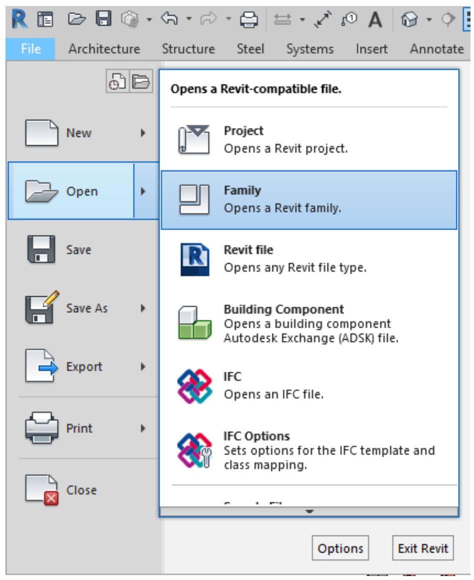


Figure 17: Inserting families in Revit

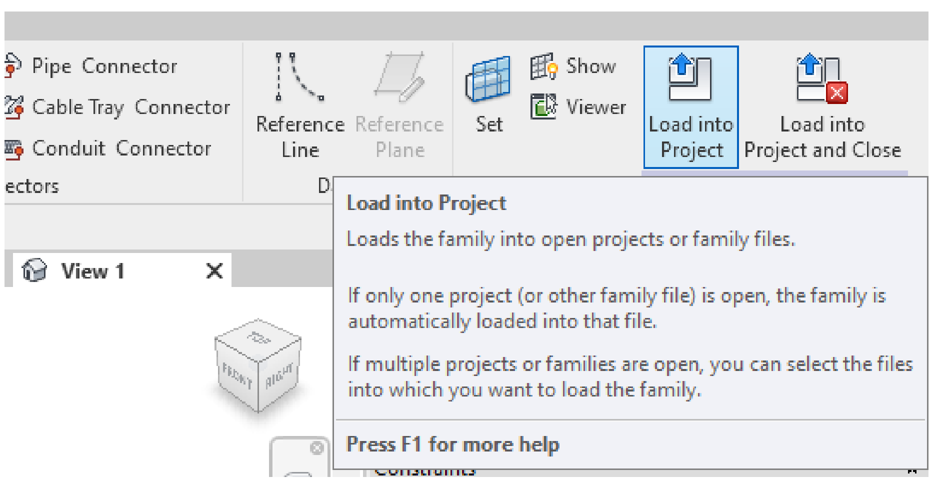


Figure 18: Load family to project model

After opening the family, it can be loaded to project in order to use it inside the model as shown in *Figure 18*.

2.5.2 Creating new families

The process of creating new family is needed when the library of system families does not contain the objects that we need to model, Revit give the possibility to create new objects family, this process is similar to usual modelling process in Revit as it includes defining levels and reference levels, the process can be started from ***File menu*** and then choose Family as shown in *Figure 19*.

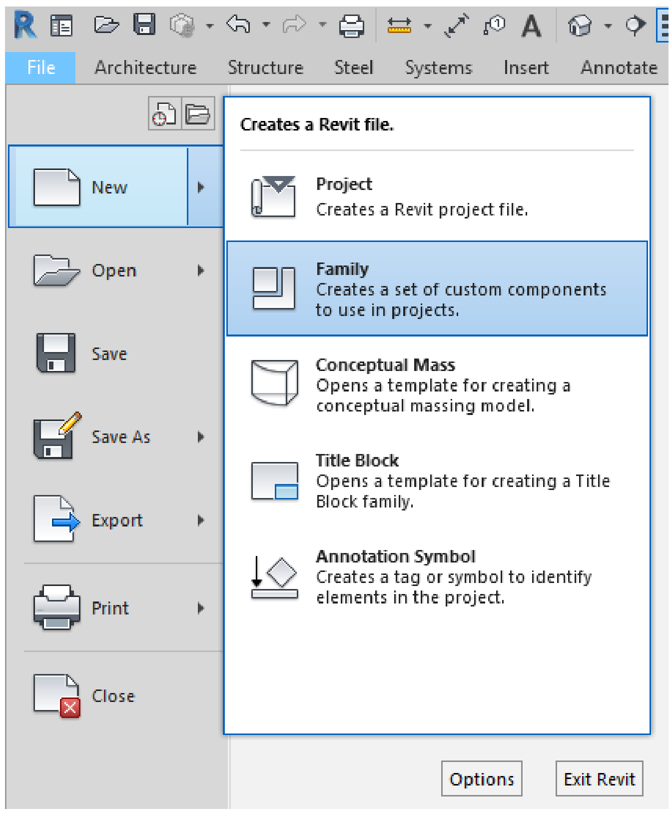


Figure 19: Create new family in Revit

A dialouge window will open, from it we can choose the location of family template, Revit liberary gives a wide variaty of options and pre-defined templates for creating families, the choosing of the suitable template file depend on the kind of object we need to creat, for instance if the new object is a mechanical equipment we can start with mechanical equipment template file in order to have some predefined refrence levels that facilitate the process, otherwise we can start from a generic template file that only contain two reference levels as shown in *Figure 20* .

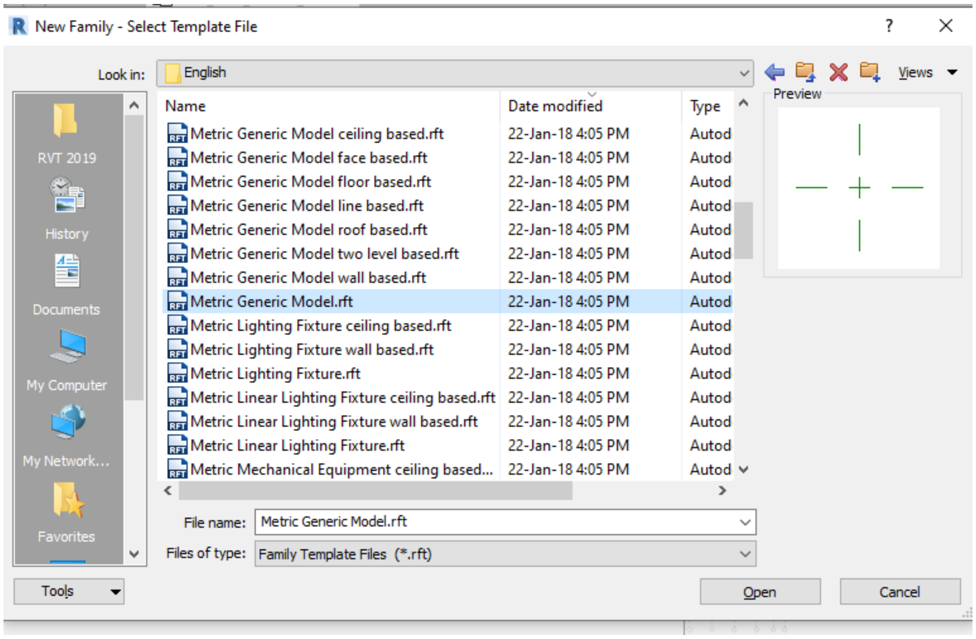


Figure 20: family template file

Revit gives various options in the process of creating new object family from crating regular 3D shapes to variable unregular shapes as shown in *Figure 21*, Revit gives also the possibility of assigning parameters to the object, this parameters can be in form of fixed values or calculated through formula , in this way changing the value of this parameters value it is possible to edit family geometrical characteristic during modelling such as dimensions or technical characteristics such as air flow rate.

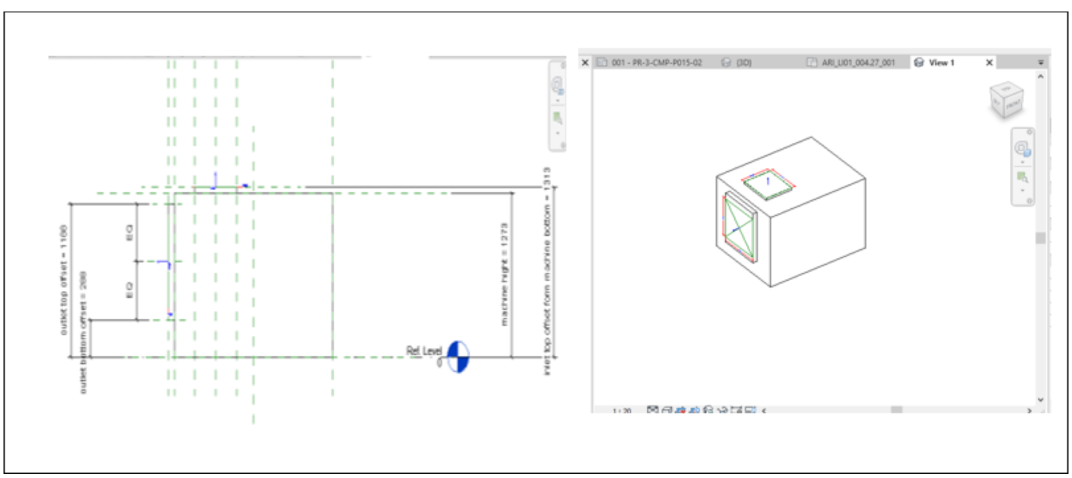


Figure 21: Modelling new family

2.5.3 Creating HVAC Systems

The modelling process starts with defining the levels and views to work on such as planes and elevations, starting from the CAD files it is possible to know each system components with all the details about their dimensions, positions, orientation, and technical characteristics. It was better to start with the main mechanical equipment of each system as it is the main source for the duct lines and the several duct fittings that are attached to it. These mechanical equipment is an air ventilators all with same size but with different technical characteristics such as air flow rate and size of openings for duct to be attached to it, it was necessary to create new family for this equipment with several types that matches the characteristics indicated in CAD drawings.

Before creating the duct lines, it is necessary to adjust duct routing preferences, this option allows to choose which type of duct accessories and fittings to be used during creating the duct lines such as which type of elbows and transitions, this option can be found by opening duct Edit type menu as shown in *Figure 22*.

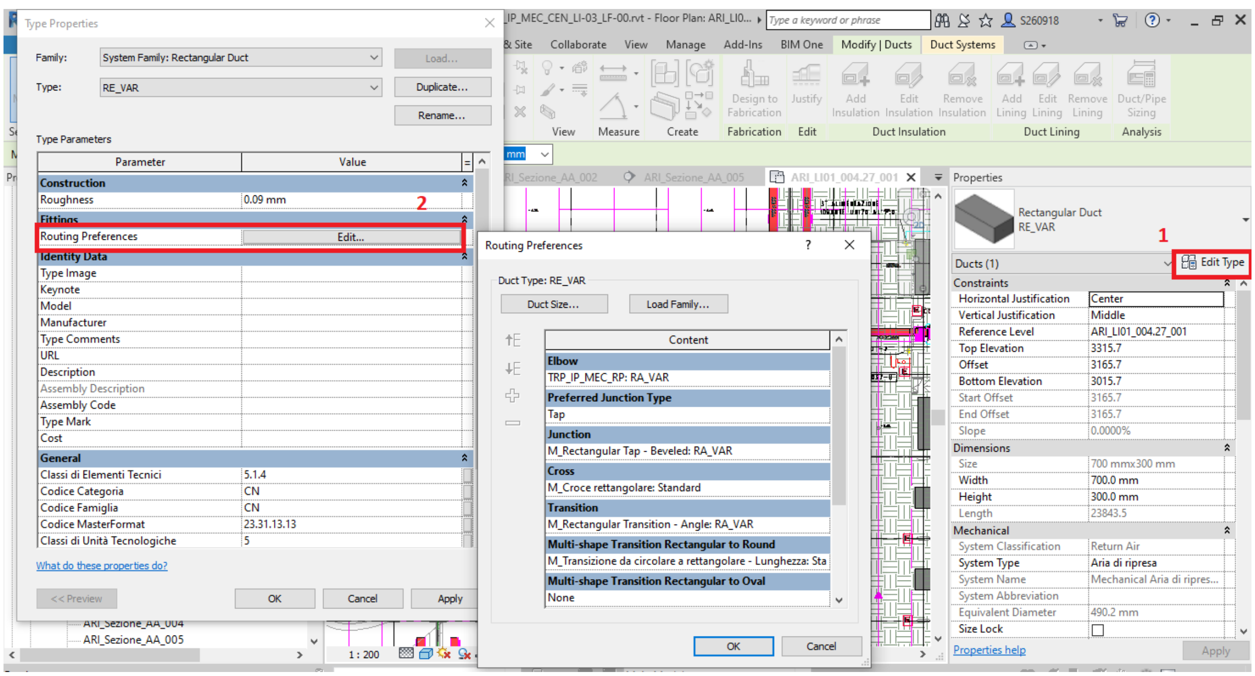


Figure 22: Duct routing preferences

Then it is possible to start creating the duct lines following the CAD files, after that duct accessories such as fire dumpers could be added in their correct possitions along the duct lines.

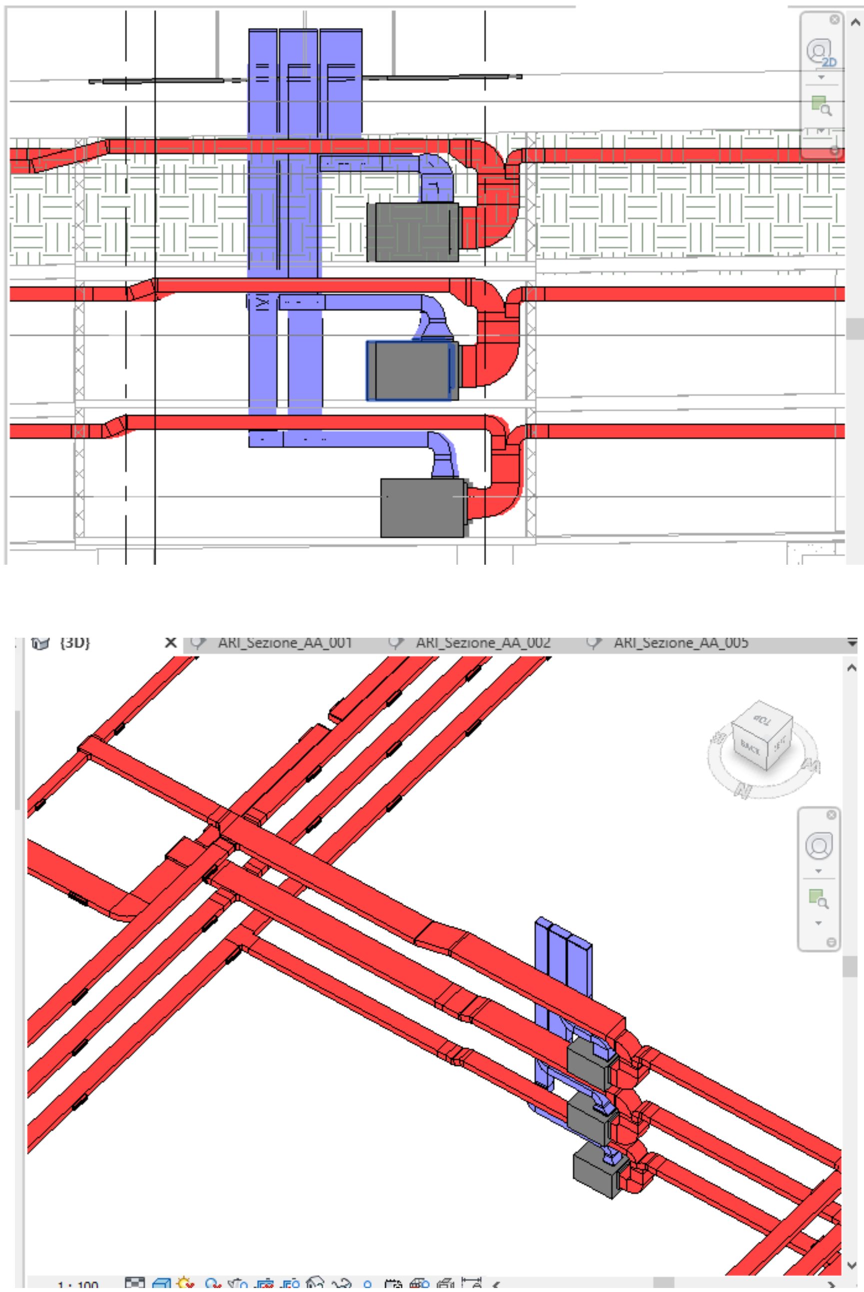


Figure 23: HVAC Model of underground parking zone.

2.5.4 Managing system browser

System browser is an built-in tool in Revit that allows to view all the created systems within the model, it also allows to view all the unconnected objects to these systems therefore it is an early step of validating the correctness of the created model before moving towards integrating it with other models or share it with other designing teams.

To open the system browser in Revit. from View tab, Windows panel, User Interface drop-down. As shown in *Figure 24*.

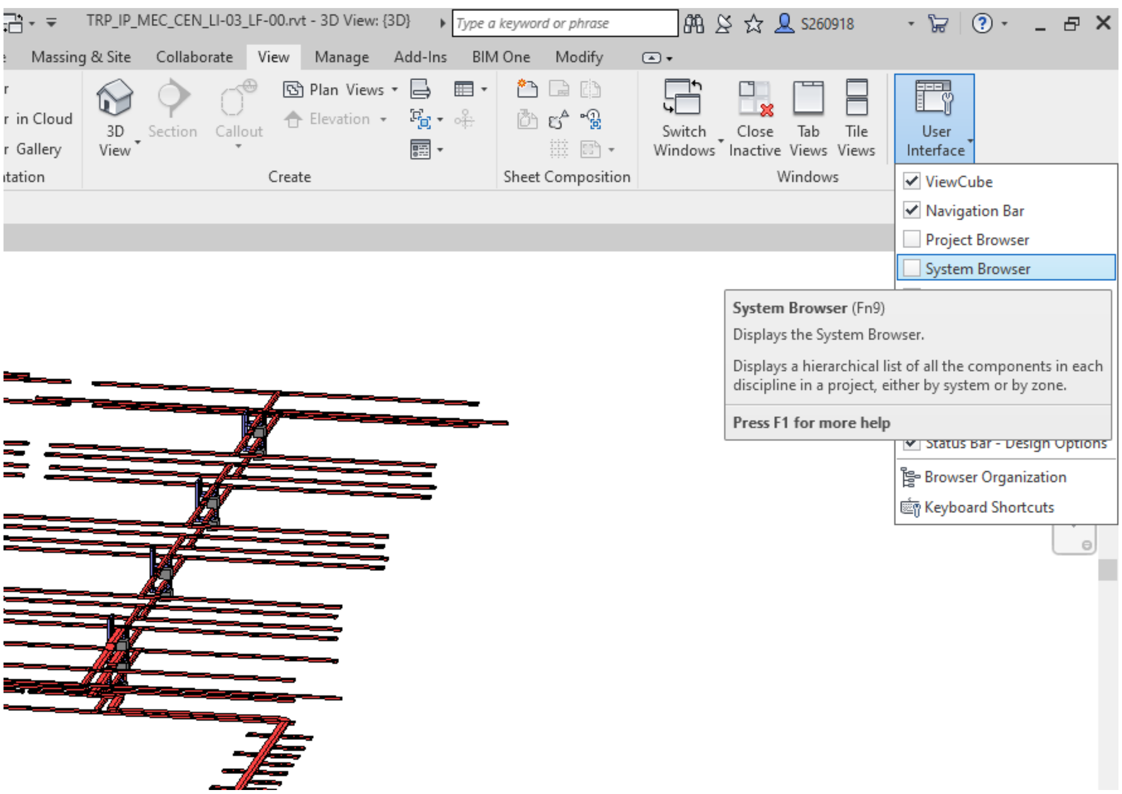


Figure 24: opening system browser in Revit.

As it is shown in *Figure 25*, it can be seen that this browser views the different created systems with it is assigned characteristics such as flow or size. In addition, it shows the unassigned items therefore the modeler can go back and connect them to their correct system.

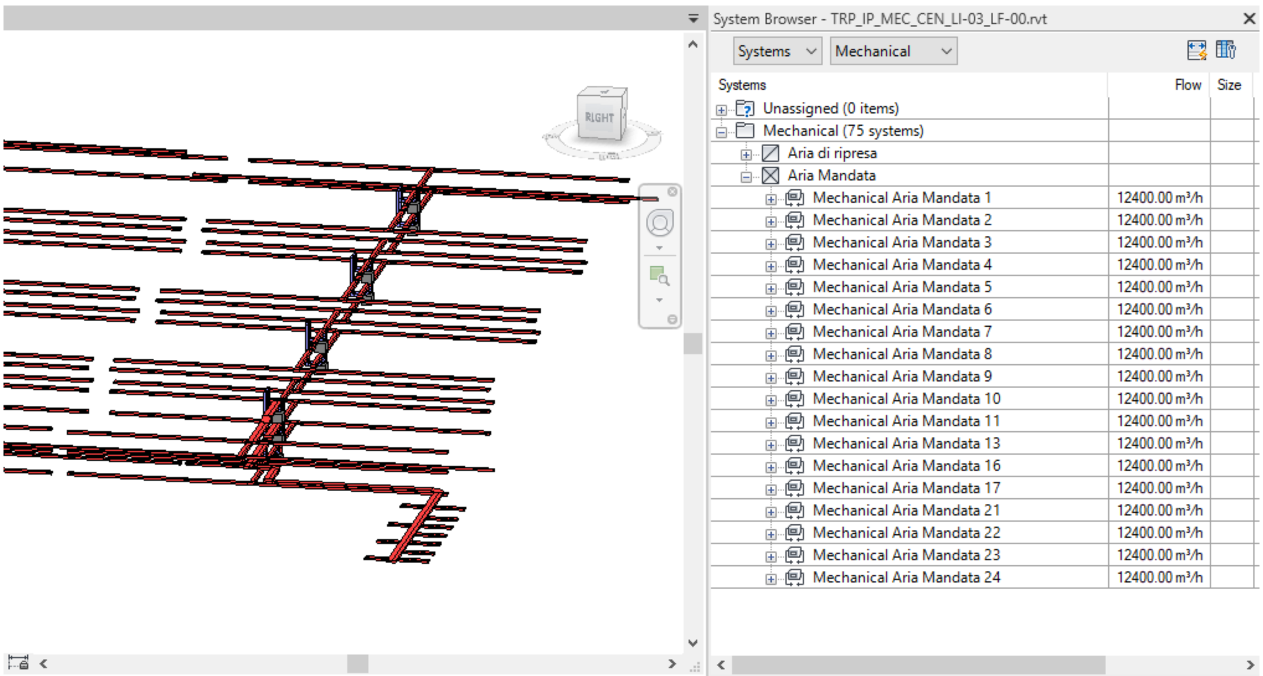


Figure 25: System browser in Revit.

2.6 Alpha-numerical compilation

the International Organization for Standardization (**ISO)** define that the alphanumeric term refers to the data that consist of digits, letters and other characters beside the processes that use those data. This phase in the process of creating parametric model that is valid for the next steps and ***BIM*** uses such as clash analysis and maintenance process is fundamentally essential as it allows to assign for each element has been modelled a unique name beside the compilation of several parameters in form of codes that are assigned to these elements , these parameters could be existing codes given to objects during the designing phase or classification codes and names such as Masterformat classifications.

2.6.1 Nomenclature of families and types

2.6.1.1 Families

As illustrated previously the families in Revit could be in two kinds, system or loadable families, in the case of system families it is not possible to rename it. Therefore, this process will be only for the loadable families, in order to go ahead in this step, the project guidelines was followed as it gives a clear instructions in this manner, according to the project guidelines the name of a family should follow a form that consist of four different fields written in uppercase letters and separated by underscore character (**_**).

- The first field is the project code consist of three letters **(TRP)**
- The second field is the building code, consist of two letters **(IP)**
- The third field is the discipline code, consist of three letters **(MEC)**
- The fourth field is the family code consist of two letters

2.6.1.2 Types

For the naming of types the project guidelines indicates that the name should follow the form that consist of two fields of uppercase alphanumeric characters separated by underscore character (_).

- The first field is the ***function code***, formed of two letters
- The second field is the ***characteristic code.***

The ***function code*** represents what the object is used for or what it is role in the system such as Accessory, Terminal, Source, Network and Fittings.

In the other hand the ***Characteristic code*** is an alphanumeric code depend on the distinctive feature that can describe the object such as dimensions, typology, and air flow rate.

			FAMIGLIA										TIPO					
Categoria	Codice categoria	Tipologia di famiglia	Progetto	Codice Progetto	Edificio	Codice Edificio	Disciplina	Codice Disciplina	Famiglia	Codice Famiglia	Nomenclatura Famiglia	Funzione	Codice Funzione	Caratteristica	Codice Caratteristica	Nomenclatura Tipo
									Collettore pannelli radianti soffitto	CA	**TRP_TO_MEC_CA**				3M	**AC_3M**
									Collettore pannelli radianti soffitto	CF	**TRP_TO_MEC_CF**				4M	**AC_4M**
									TRP_TO_MEC_X1	CM	**TRP_TO_MEC_CM**			Derivazioni mandata	6M	**AC_6M**
									TRP_TO_MEC_X4	CO	**TRP_TO_MEC_CO**				5M	**AC_5M**
									TRP_TO_MEC_X6	CQ	**TRP_TO_MEC_CQ**				3M	**AC_3M**
									Collettore pannelli radianti soffitto	CG	**TRP_TO_MEC_CG**				3R	**AC_3R**
									Collettore pannelli radianti soffitto	CH	**TRP_TO_MEC_CH**				4R	**AC_4R**
									TRP_TO_MEC_X2	CN	**TRP_TO_MEC_CN**			Derivazioni ritorno	6R	**AC_6R**
									TRP_TO_MEC_X3	CP	**TRP_TO_MEC_CP**				5R	**AC_5R**
Accessori per tubazioni	AT	Caricabile	Torre Regione Piemonte	TRP	Torre	TO	Meccanica	MEC	TRP_TO_MEC_X5	CR	**TRP_TO_MEC_CR**	Accessorio	AC		3R	**AC_3R**
									Valvola di intercettazione	VA	**TRP_TO_MEC_VA**			Diametro	20	**AC_20**
															25	**AC_25**
									Valvola di sfiato	VB	**TRP_TO_MEC_VB**			Diametro	32	**AC_32**
															40	**AC_40**
															15	**AC_15**
									Valvola di taratura	VC	**TRP_TO_MEC_VC**			Diametro	20	**AC_20**
															25	**AC_25**
															30	**AC_30**
									Valvola RW213112P	VD	**TRP_TO_MEC_VD**			Diametro	20	**AC_20**

Figure 26: Examples of nomenclature for families and types

2.6.2 Shared parameters compilation

2.6.2.1 What are shared parameters

Shared parameters are parameters that can be added to families or projects and then share them with other families and projects. specific data can be added that has not been predefined in the family file or the project. If a shared parameter is created and added to the family categories, a schedule can be created with these categories. In Revit it is called a multi-category schedule. The families modeled in Revit contain in their properties a series of parameters, defined to enrich them with information and to be able to organize their hierarchical structure, if several families are connected to each other. The possibility of going back to a family hierarchy facilitates the analysis operations, during the management and maintenance phase of the parts of the project.

Shared parameters can be considered as information container that can be used in multiple families or projects. The list of shared parameters is stored in an independent text file (.txt) that can be saved in *Shared Area* therefore this allows to import it for any project. In our case a shared parameter file was created and to import it to the project a sequence of steps was followed as shown in *Figure 27* (*Manage tab* → *Settings panel* → *Shared Parameters* →*Browse* → *Select shared parameters file*).

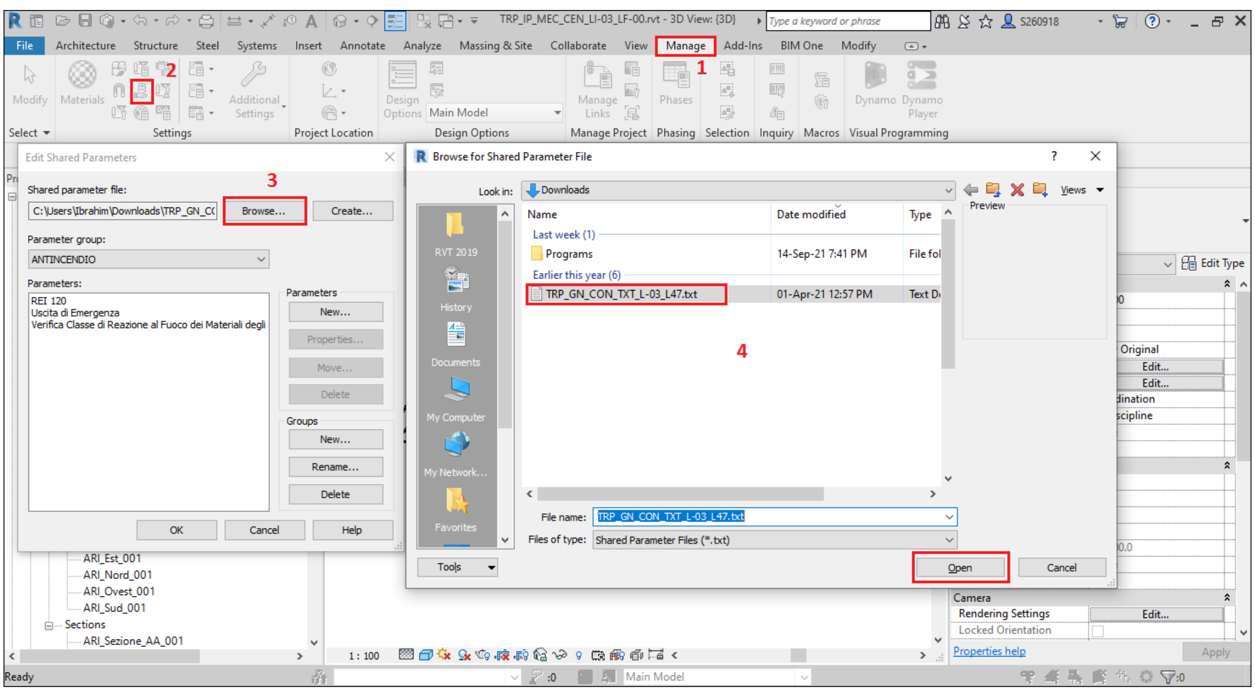


Figure 27: importing shared parameters file

For each family the information assigned to each shared parameter is applied only to that family and is not loaded automatically to other families. In the process of adding new shared pararmeter to projct parameters it is important to define *Parameter data,* for example choosing to make it *Type* or *Instance* parameter, in case of *Type* the information assigned to this paramaters will be assigned to all the objects created of that family, in the other hand *Instance* make the information assigned only to one object at a time.

In our case there were defined 14 shared parameters, in order to use them in the project after importing shared parameters file it is necessary to define each one of them as project parameter as shown in *Figure 28*.

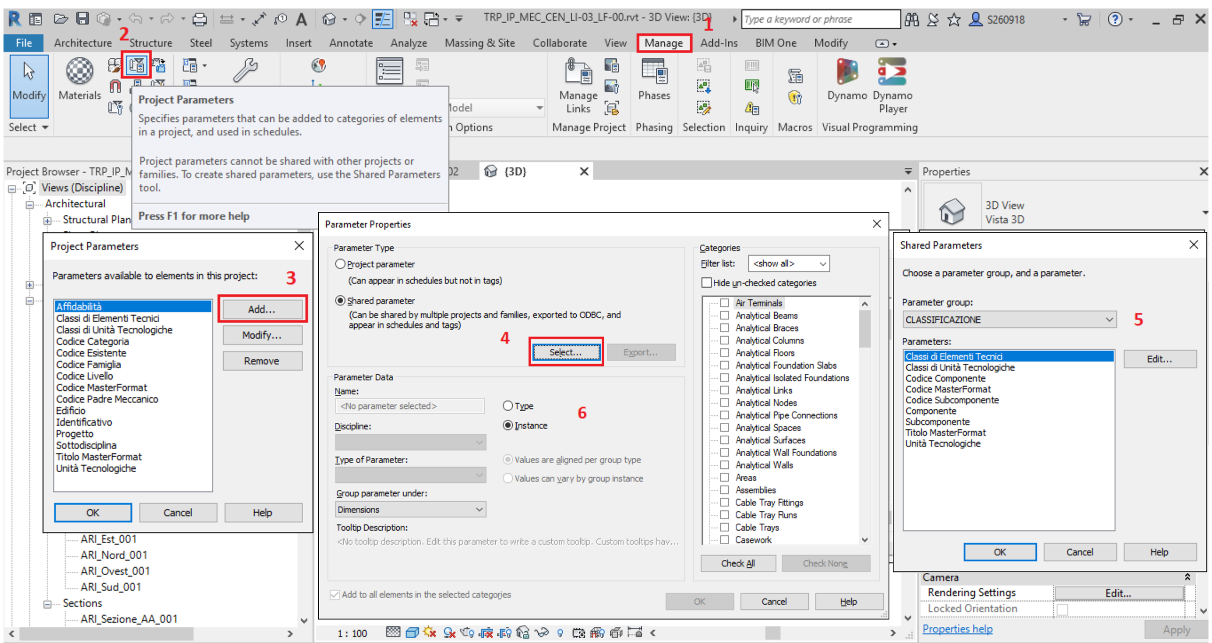


Figure 28: Defining new project parameter.

For compiling the Parameter data in correct way, the instructions of the project guidelines were followed where it indicates all the descriptions and characteristics of these parameters as shown in table 1

Parameter	Type of parameter	Type/ Instace	Group	Applied to	Parameter Description	Example
Progetto	Text	Instance	General	All model's categories	3-letter code (A-Z) representative of the project	TRP
Edificio	Text	Instance			2-letter code (A-Z) representative of parts of the project	IP
Classi di Unità Tecnologiche	Text	Type		All model's categories, except views	Class of homogeneous functional elements, grouped by prevailing function, physical and functional continuity (UNI 8290)	5
Unità Tecnologiche	Text	Type			Set of technical elements representing functions aimed at meeting the needs of users (UNI 8290)	5.1
Classi di Elementi Tecnici	Text	Type			Class of products performing functions specific to one or more technological classes (UNI 8290)	5.1.4
Codice MasterFormat	Text	Type			Numerical coding for functional elements defined by CSI CODE	23.33.13.16
Titolo MasterFormat	Text	Type			Text coding associated with Masterformat code for functional elements defined by CSI CODE	Fire Dampers
Codice Categoria	Text	Type			2 uppercase letters code used to identify the Category of an Instance	AC
Identificativo	Text	Instance			Unique characterization of each individual Instance present within the model. Following the form: CodiceFamiglia_CodiceTipo_Livello_Numero progressivo	TRP_IP_MEC_SE_AC_700x300_LI03_00001
Codice Padre	Text	Instance			Characterization of the reference source Instance, in the hierarchical structure of a discipline	TRP_IP_MEC_VE_AC_VE10_LI02_00001
Codice esistente	Text	Instance			Code detected by existing documentation to maintain information in the CAD to BIM phase	STF-02-D-Q3
Affidabilità	Text	Instance			Reliability class of a modeled Instance:	2
Codice Famiglia	Text	Instance			2-letter code (A-Z)	NA
Sottodisciplina	Text	Instance		Views	3-letter code (A-Z) representative of the disciplines included in the views.	ARI

Table 2: TRP Shared Parameters [Source: TRP Guidelines].

1-Progetto

This parameter is compiled by alphabetic letters which refer to the main project name, in our case **TRP** (**T**orre **R**egione **P**iemonte).

2-Edificio

This parameter is compiled by an alphabetic code which refers to certain part of the project, in this case **IP** which is acronym for the Italian word (Interrato Parcheggio) which means underground parking.

3- Codice Categoria

This parameter is compiled by an alphabetic code which refers to the category of the object, the project guidelines provide a code for each category, for example Mechanical equipments categories has the code **AM**.

4- Codice Famiglia

This parameter is compiled by an alphabetic code assigned for each family.

5- Affidabilità

This parameter is a representation of how much reliability of the modelled objects, it depend on from where the data about the object was driven and how much it is trusted.

Classes of modelling reliability

1: measurements on site

2: measurements from CAD drawings

3: hypothesized

6- Codice esistente

In case the object has an existing code in the 2D documents

7- Classi di Unità Tecnologiche

Extracted from **UNI8290** Standards.

8- Unità Tecnologiche

Extracted from **UNI8290** Standards**.**

9- Classi di Elementi Tecnici

Extracted from **UNI8290** Standards.

Classi di unità tecnologiche	Unità tecnologiche	Classi di elementi tecnici
5. Impianto di fornitura servizi (segue)	**5.4** Impianto di smaltimento aeriformi	**5.4.1** Alimentazione **5.4.2** Macchine **5.4.3** Reti di canalizzazione
	5.5 Impianto di smaltimento solidi	**5.5.1** Canne di caduta **5.5.2** Canne di esalazione
	5.6 Impianto di distribuzione gas	**5.6.1** Allacciamenti **5.6.2** Reti di distribuzione e terminali
	5.7 Impianto elettrico	**5.7.1** Alimentazione **5.7.2** Allacciamenti **5.7.3** Apparecchiature elettriche **5.7.4** Reti di distribuzione e terminali

Figure 29: UNI8290 classifications levels.

UNI8290 Norm:

It is Italian regulations used for classification and subdivide the different component in building systems. It has three main levels of classifications:

1. Classi di unità tecnologica (Classes of technological units).
2. Unità tecnologiche (Technological units).
3. Classi di elementi tecnici (Classes of technical elements).

10- Codice MasterFormat

Extracted from **CSI CODE MasterFormat.**

11- Titolo MasterFormat

Extracted from **CSI CODE MasterFormat.**

23 30 00	**HVAC Air Distribution**
23 31 00	**HVAC Ducts and Casings**
23 31 13	Metal Ducts
23 31 13.13	Rectangular Metal Ducts
23 31 13.16	Round and Flat-Oval Spiral Ducts
23 31 13.19	Metal Duct Fittings
23 31 16	Nonmetal Ducts
23 31 16.13	Fibrous-Glass Ducts
23 31 16.16	Thermoset Fiberglass-Reinforced Plastic Ducts
23 31 16.19	PVC Ducts
23 31 16.26	Concrete Ducts
23 31 19	HVAC Casings

Figure 30: CSI CODE MasterFormat

MasterFormat is a standard for organizing specifications and other written information for commercial and institutional building projects in the U.S. and Canada.

12- Identificativo

This parameter is filled out following a form that contains five fields separated by underscore character (_), e.g.

Progetto_Edificio_CodiceFamiglia_CodiceCategoria_CodiceTipo_Livello_Numero progressivo

The progressive number (***Numero progressivo***) is a unique numerical code of five digits for each object in the model, the used technique for coding objects was to start with **00001** and go on with other objects in sequential mode, the objects were ordered in a mode that guaranties objects of same family, type and level to be grouped with each other in sequential way through out Sorting/Grouping option in Revit schedules as shown in *Figure 31*.

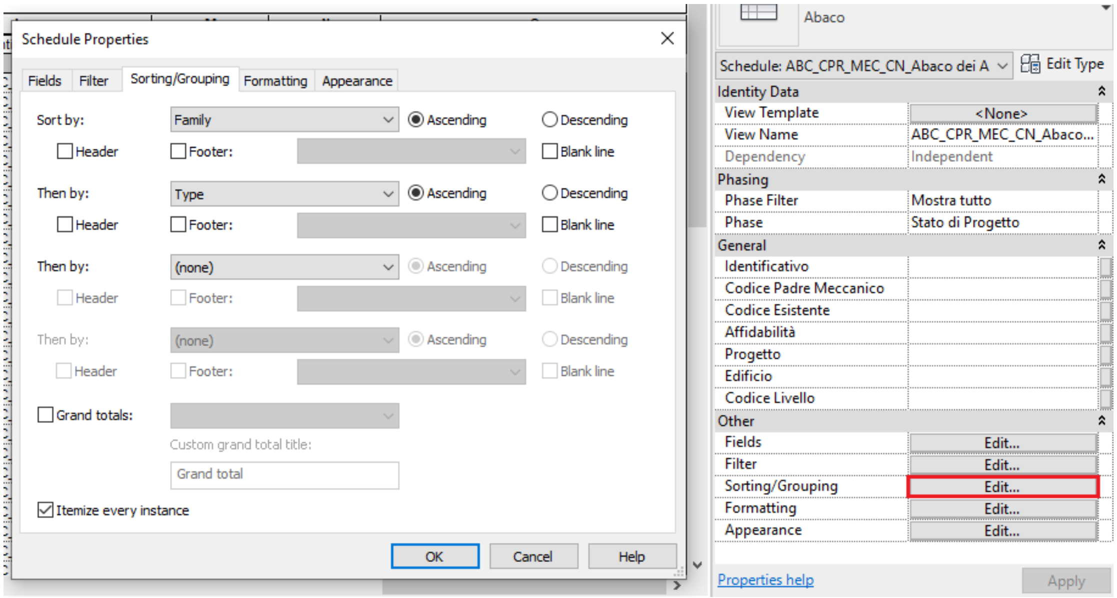


Figure 31: Sorting/Grouping schedules in Revit

13- Codice Padre

It is the (***codice Identificativo***) of the source object in each system inside the model, therefore all the objects which belong to the same system have the same ***codice padre.***

14- Sottodisciplina

This parameter is filled out by a code that represent an acronym for the name of disciplines that are included in the created views in Revit.

e.g., ***ARI (Componenti Aeraulici***) which stands for air distribution systems and components under mechanical discipline.

2.6.2.2 Filling out the parameters

The way to fill out the parameters' information depends on the predefined parameter data if it is ***Type*** or ***Instance.***

For the first one, we select the targeted object, from its *Properties menu* we click *Edit Type, Type proprieties* window appears from there we can scroll down to General section and fill out the data as shown in *Figure 32.* These data will be applied automatically to all objects of this family.

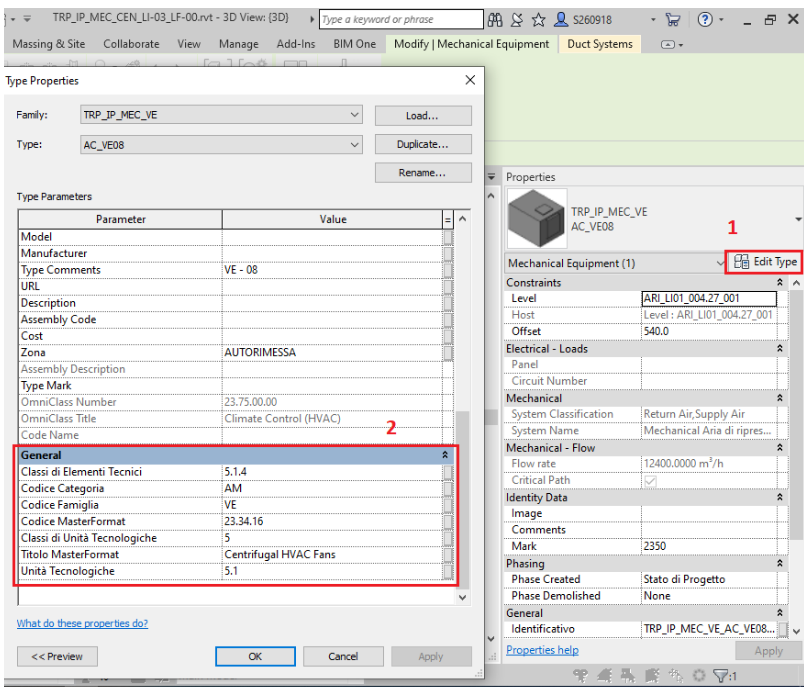


Figure 32: filling out (Type) Parameters.

For the second one ***Instance***, from the object ***Properties menu,*** we scroll down to the section of ***General,*** from there the data can be filled out as shown in *Figure 33*. These information will be applied only for the selected object and all the similar parameters of ***Instance*** kind will need to be filled out object by object, this would imply consuming too much time for this step but that can be avoided by using Revit Schedules to facilitate this step.

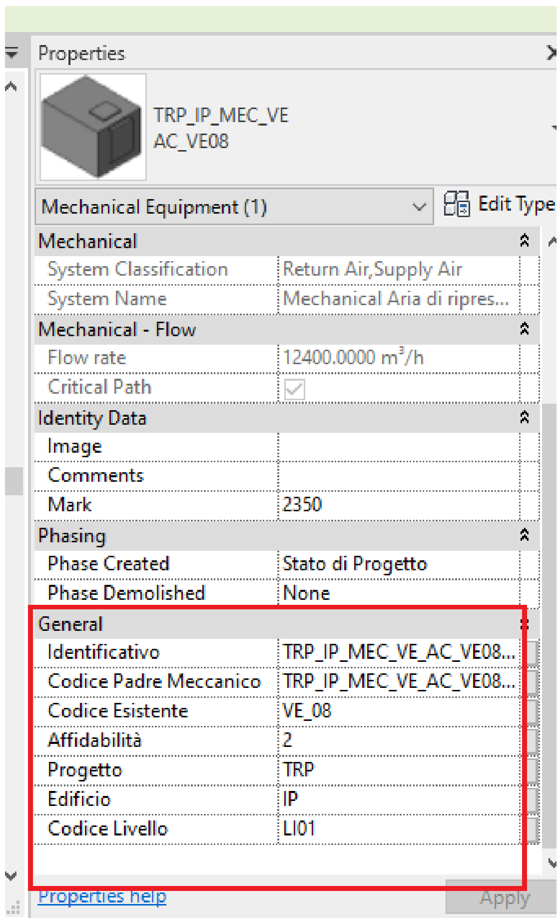


Figure 33: Filling out (Instance) Parameters

2.6.3 Schedules

Schedules in Revit are spreadsheets that can be created at any point during modelling, these schedules are directly connected to the model in a way that if any modifications made to elements or their proprieties in the model, schedules updates automatically and vice versa.
There are several types of schedules can be created in Revit such as:

- Quantities of elements
- Material takeoff
- Revision schedules

"*A schedule is a tabular display of information, extracted from the properties of the elements in a project. A schedule can list every instance of the type of element you are scheduling, or it can collapse multiple instances onto a single row, based on the schedule's grouping criteria*" [9]

Schedules are used to have clear, detailed and easy for reading visualization of model elements and information assigned to them, this would facilitate the process of verifying or modifying these information, in our case schedules were used in order to verify and modify some of the objects' parameters illustrated in the previous section such as (***Codice Identificativo***).

During the process of creating new schedules, it can be chosen the category of required schedule which determine what elements would be included in it. After creating it the fields included in the schedules can be chosen.

The fields used to create the schedules are as follows:

- Family
- Type
- Progetto (Project)
- Edificio (Building)
- Codice categoria (Category Code)

- Codice famiglia (Family Code)
- Classi di Unità Tecnologiche (Classes of Technological Units).
- Unità Tecnologiche (Technological Units).
- Classi di Elementi Tecnici (Classes of Technical Elements).
- Codice MasterFormat (MasterFormat Code).
- Titolo Master Format (MasterFormat Title).
- Identificativo (Identifier Code).
- Codice esistente (Exisiting Code).
- Affidabilità (Reliability).
- Codice Padre Meccanico (Mechanical Father Code).
- Livello (Level).

There are several Add-Ins that can be added to Revit that facilitate working on schedules for example there are add-ins that allow exporting or importing them to or from Microsoft Excel.

Figure 34 shows the created schedule for the mechanical equipments.

<ABC_CPR_MEC_CN_Abaco dei Attrezzature meccaniche>

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Family	Type	Progetto	Edificio	Codice Categoria	Codice Famiglia	Classi di Unità Tec	Unità Tecnologiche	Classi di Elementi T	Codice MasterForm	Titolo MasterForma	Identificativo	Codice Esistente	Affidabilità	Codice Padre Meccanico
TRP_IP_MEC_SE	AC_500x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_500x300_LI02_00001	STF-01-A-Q2	2	TRP_IP_MEC_VE_AC_VE10_LI02_00001
TRP_IP_MEC_SE	AC_500x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_500x300_LI01_00001	STF-01-A-Q1	2	TRP_IP_MEC_VE_AC_VE01_LI01_00001
TRP_IP_MEC_SE	AC_500x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_500x300_LI01_00002	STF-01-A-Q1	2	TRP_IP_MEC_VE_AC_VE01_LI01_00001
TRP_IP_MEC_SE	AC_600x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_600x300_LI02_00002	STF-07-D-Q2	2	TRP_IP_MEC_VE_AC_VE15_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00001	STF-02-C-Q2	2	TRP_IP_MEC_VE_AC_VE14_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI01_00001	STF-02-C-Q1	2	TRP_IP_MEC_VE_AC_VE06_LI01_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI01_00002	STF-02-C-Q2	2	TRP_IP_MEC_VE_AC_VE06_LI01_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00002	STF-02-C-Q2	2	TRP_IP_MEC_VE_AC_VE14_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00003	STF-02-D-Q2	2	TRP_IP_MEC_VE_AC_VE16_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI03_00001	STF-02-D-Q3	2	TRP_IP_MEC_VE_AC_VE18_LI03_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI01_00003	STF-02-D-Q1	2	TRP_IP_MEC_VE_AC_VE08_LI01_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI03_00002	STF-02-D-Q3	2	TRP_IP_MEC_VE_AC_VE18_LI03_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI03_00003	STF-02-D-Q3	2	TRP_IP_MEC_VE_AC_VE17_LI03_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI03_00004	STF-02-D-Q3	2	TRP_IP_MEC_VE_AC_VE17_LI03_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00004	STF-02-D-Q2	2	TRP_IP_MEC_VE_AC_VE15_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00005	STF-02-C-Q2	2	TRP_IP_MEC_VE_AC_VE13_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI01_00004	STF-02-C-Q1	2	TRP_IP_MEC_VE_AC_VE05_LI01_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00006	STF-02-C-Q2	2	TRP_IP_MEC_VE_AC_VE13_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI01_00005	STF-02-C-Q1	2	TRP_IP_MEC_VE_AC_VE05_LI01_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI01_00006	STF-02-B-Q1	2	TRP_IP_MEC_VE_AC_VE03_LI01_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00007	STF-02-B-Q2	2	TRP_IP_MEC_VE_AC_VE11_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI01_00007	STF-02-B-Q1	2	TRP_IP_MEC_VE_AC_VE03_LI01_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00008	STF-02-B-Q2	2	TRP_IP_MEC_VE_AC_VE11_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI01_00008	STF-02-A-Q1	2	TRP_IP_MEC_VE_AC_VE01_LI01_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00009	STF-02-A-Q2	2	TRP_IP_MEC_VE_AC_VE09_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00010	STF-02-A-Q2	2	TRP_IP_MEC_VE_AC_VE09_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00011	STF-02-D-Q2	2	TRP_IP_MEC_VE_AC_VE15_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00012	STF-02-D-Q2	2	TRP_IP_MEC_VE_AC_VE16_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00013	STF-02-D-Q2	2	TRP_IP_MEC_VE_AC_VE16_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00014	STF-02-A-Q2	2	TRP_IP_MEC_VE_AC_VE10_LI02_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI01_00009	STF-02-A-Q1	2	TRP_IP_MEC_VE_AC_VE02_LI01_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI01_00010	STF-02-A-Q1	2	TRP_IP_MEC_VE_AC_VE02_LI01_00001
TRP_IP_MEC_SE	AC_700x300	TRP	IP	AC	SE	5	5.1	5.1.4	23.33.13.16	Fire Dampers	TRP_IP_MEC_SE_AC_700x300_LI02_00015	STF-02-B-Q2	2	TRP_IP_MEC_VE_AC_VE12_LI02_00001

Figure 34: Mechanical Equipment Schedule.

2.7 Level of Development in the model

As illustrated in the first chapter in the section about level of development and its importance, in the next tables are present examples of the reached level of development of the elements during modelling.

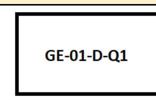
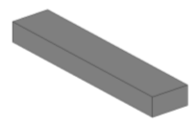
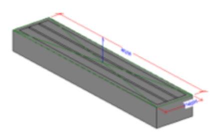
<table>
<tr><td colspan="2" rowspan="2">Discipline</td><td>Object name</td><td>TRP_IP_MEC_GA</td></tr>
<tr><td>Typology of family</td><td>Loadable</td></tr>
<tr><td colspan="2">Mechanical</td><td>Reached level of developement</td><td>C</td></tr>
<tr><td rowspan="4">LOG</td><td>Visualisation level</td><td>Visualisation description</td><td>Graphical representation</td></tr>
<tr><td>Low</td><td>2D element</td><td>
</td></tr>
<tr><td>Medium</td><td>Approximate 3D element</td><td></td></tr>
<tr><td>High</td><td>Defined 3D element</td><td></td></tr>
<tr><td rowspan="14">LOI</td><td colspan="2">Parameter</td><td>Parameter code</td></tr>
<tr><td colspan="2">Progetto</td><td>TRP</td></tr>
<tr><td colspan="2">Edificio</td><td>TO</td></tr>
<tr><td colspan="2">Classi di unità tecnologiche</td><td>5</td></tr>
<tr><td colspan="2">Unità tecnologiche</td><td>5.1</td></tr>
<tr><td colspan="2">Classi di elementi tecnici</td><td>5.1.4</td></tr>
<tr><td colspan="2">Codice MasterFormat</td><td>23 36 16</td></tr>
<tr><td colspan="2">Titolo MasterFormat</td><td>Constant Air Volume Unit</td></tr>
<tr><td colspan="2">Codice Categoria</td><td>BO</td></tr>
<tr><td colspan="2">Identificativo</td><td>TRP_IP_MEC_GA_AC_500x200_LI01_00009</td></tr>
<tr><td colspan="2">Codice Padre</td><td>TRP_IP_MEC_VE_AC_VE07_LI01_00001</td></tr>
<tr><td colspan="2">Codice esistente</td><td>GE-01-D-Q1</td></tr>
<tr><td colspan="2">Affidabilità</td><td>2</td></tr>
<tr><td colspan="2">Codice Famiglia</td><td>GA</td></tr>
</table>

Table 3:LOD of modeled Air Vent

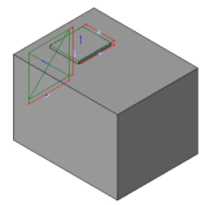
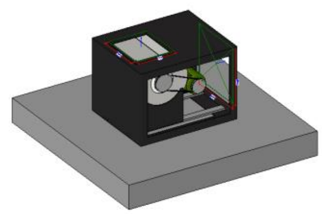
<table>
<tr><td colspan="2" rowspan="2">Discipline</td><td>Object name</td><td>TRP_IP_MEC_VE</td></tr>
<tr><td>Typology of family</td><td>Loadable</td></tr>
<tr><td colspan="2">Mechanical</td><td>Reached level of developement</td><td>D</td></tr>
<tr><td rowspan="4">LOG</td><td>Visualisation level</td><td>Visualisation description</td><td>Graphical representation</td></tr>
<tr><td>Low</td><td>2D element</td><td>
</td></tr>
<tr><td>Medium</td><td>Approximate 3D element</td><td></td></tr>
<tr><td>High</td><td>Defined 3D element</td><td></td></tr>
<tr><td rowspan="14">LOI</td><td colspan="2">Parameter</td><td>Parameter code</td></tr>
<tr><td colspan="2">Progetto</td><td>TRP</td></tr>
<tr><td colspan="2">Edificio</td><td>TO</td></tr>
<tr><td colspan="2">Classi di unità tecnologiche</td><td>5</td></tr>
<tr><td colspan="2">Unità tecnologiche</td><td>5.1</td></tr>
<tr><td colspan="2">Classi di elementi tecnici</td><td>5.1.4</td></tr>
<tr><td colspan="2">Codice MasterFormat</td><td>23 34 16</td></tr>
<tr><td colspan="2">Titolo MasterFormat</td><td>Centrifugal HVAC Fans</td></tr>
<tr><td colspan="2">Codice Categoria</td><td>AM</td></tr>
<tr><td colspan="2">Identificativo</td><td>TRP_IP_MEC_VE_AC_VE07_LI01_00001</td></tr>
<tr><td colspan="2">Codice Padre</td><td>TRP_IP_MEC_VE_AC_VE07_LI01_00001</td></tr>
<tr><td colspan="2">Codice esistente</td><td>VE-07</td></tr>
<tr><td colspan="2">Affidabilità</td><td>2</td></tr>
<tr><td colspan="2">Codice Famiglia</td><td>VE</td></tr>
</table>

Table 4: LOD of modeled ventilator

Chapter 3

3 BIM MODEL CHECKING

3.1 Model checking

BIM is based on data exchange between the different involved actors during all the project phases, therefore it is of significant importance to verify these data in order to guarantee reliable results in the next phases such as analysis, operating and maintenance. The checking process includes all the different data implemented in the digital model either geometrical or non-geometrical information by testing the ***BIM*** model thorough validation domains.

There are three main phases to carry out model checking process, each one is concerned about specific type of model testing, *Figure 35* shows these three phases.

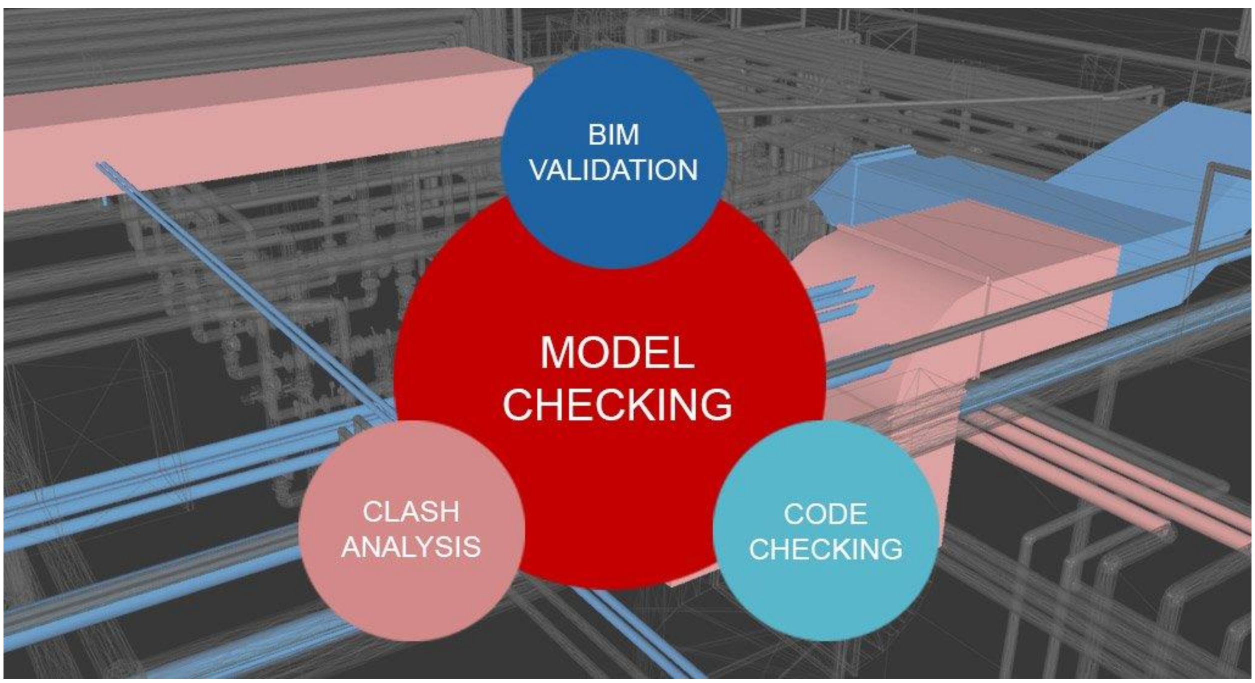


Figure 35: BIM Model Checking Phases.

There are several platforms and tools to do such important phases of ***BIM*** such as:

- usBIM.Checker
- Solibri Model Checker
- Autodesk Navisworks

3.1.1 BIM Validation:

The aim of this phase is to analyze the integrity of the information content assigned to the parametric objects inside the model, this allows to control the level of quality and internal consistency of the model, it includes checking that all elements have been named and classified correctly, also controlling the actual presence and correct compilation of project parameters, all of the previous results in supporting correct flow of information between the different parties involved in the project.

3.1.2 Clash Analysis

As ***BIM*** validation phase is concerned about the informatic content inside the parametric model, the clash analysis phase is used to verify the geometric data by detecting if there are spatial conflicts between the different disciplines according to pre-defined criteria. There are several tools designated to carry out this type of analysis.

3.1.3 Code Checking

This phase is concerned about verifying compliance of assigned informations and classifications with the standards and regulations.

3.2 Clash Detection

One of the main objects of ***BIM*** is to achieve cooperation and coordination between different parties involved in project life cycle such as engineers, contractors and owners. Large construction projects contains different design disciplines architectural, Structural and MEP, before developing the ***BIM*** technology in the conventional methods of design, designers had to review their work manually by comparing between the different disciplines design to check compatibility level and discover conflicts between them, there was a big lake of efficiency in that approach beside it is time consuming not all the conflicts were detected during design and began to appear during constructing which resulted in delaying in project delivery schedule and big losses of resources.

BIM methodology provided a key component within its procedure which is clash detection analysis, it can be carried out when combining the different disciplines design models in one central or federated model, therefore with some predefined rules and filters the different types of clashes can be detected.

There are three main types of clashes that can be found in clash analysis which are:

- **Hard Clashes**

  It happens when two objects or elements occupy the same space in the model or intersect with each other, this type of clashes if not solved before construction begins, they will have a great impact in project cost and time.
- **Soft Clashes**

  It happens when objects or elements don't have enough surrounding space or tolerance that is essential for safety, operating, maintenance reasons.
- **Workflow Clashes**

  It is also called 4D clashes as it is concerned about clashes that happen in the time schedule of different activities of project construction process.

Clash detection phase is very essential as it affect the process of decision making, Different disciplines designers during coordination meetings will have to decide how to resolve the detected clashes and which disciplines will have to modify its own work.

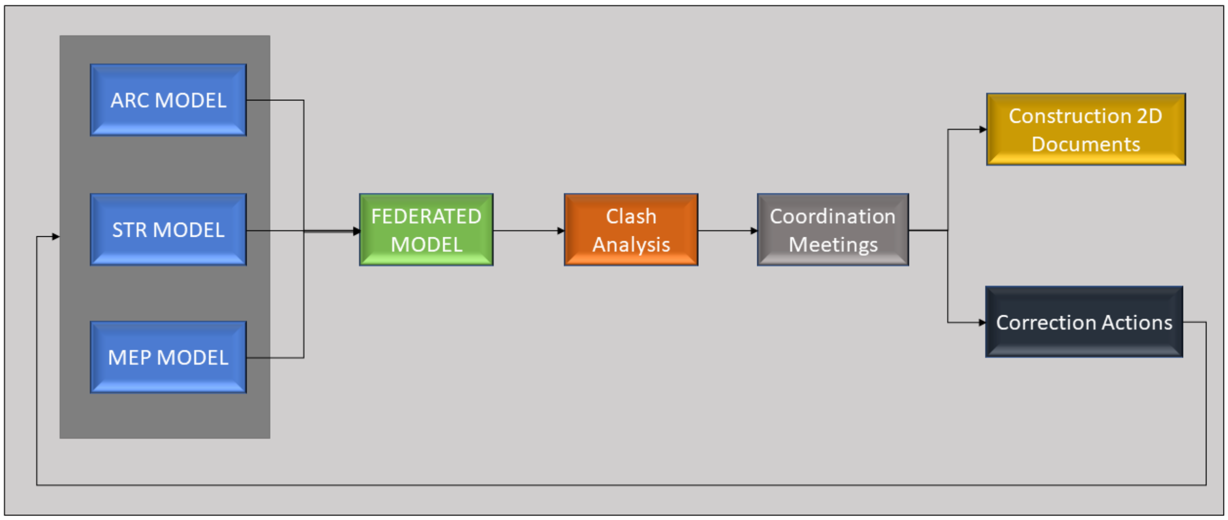


Figure 36: Decision making process

3.2.1 Navisworks

Navisworks is a software that belongs to Autodesk softwares family as Revit, it can be used for several analysis and check operations that follows the 3D design of the construction project. Navisworks allows to combine different disciplines models and by setting some rules and filters those operations can be carried out such as:

- Clash detection
- Time Simulation (4D BIM)
- Cost Planning (5D BIM)

3.2.1.1 Model Creation for Interoperability

For the models created on Revit there are different ways to transfer them to Navisworks, first one is to use the option provided in Revit to export the model file as ***.nwc*** which is the extension of Navisworks files as shown in *Figure 37.*

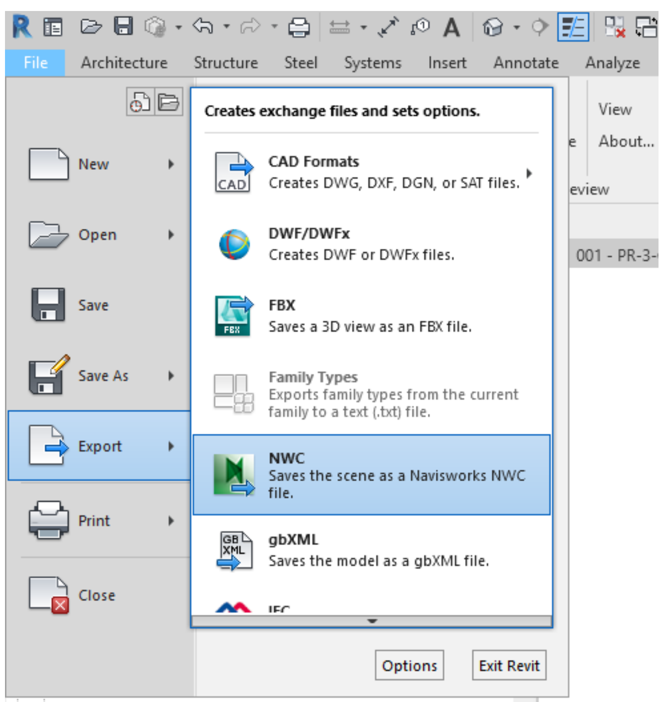


Figure 37: Exporting to Navisworks.

The second method is to transform the Revit model file to ***.ifc*** extension (Industry Foundation Classes) as shown in *Figure 38*.

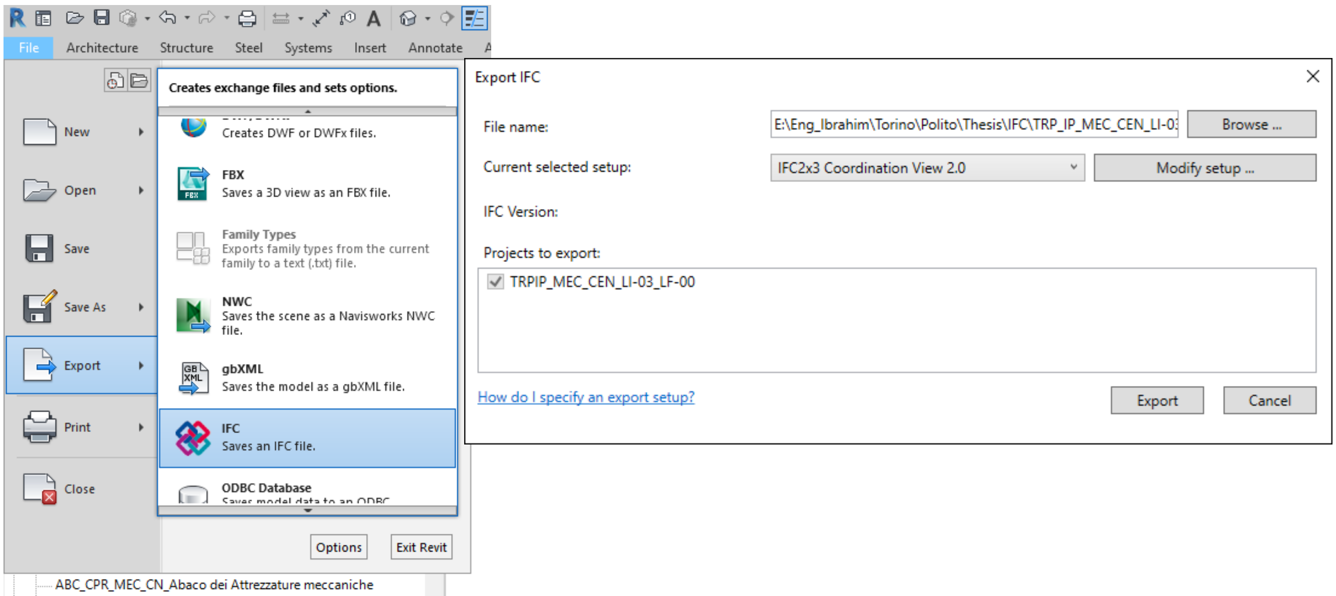


Figure 38: Exporting as IFC file

IFC2x3 Coordination view 2.0 was chosen as exporting setup which contains instructions for the transformation process.

The last method is to open the model file in Navisworks with its original extension ***.rvt*** and the software makes the transformation.

3.2.1.2 Verifying quantity of elements

In order to know which exporting method is more efficient the key aspect in this manner is how much information were lost from the original 3D model for each method.

Firstly, a schedule of elements quantity was made in Revit and exported to excel to know how much elements were created in the model which turned out to be 1275 element.

	C	D	E	F	G	H
3	Family	Type	Progetto	Edificio	Codice Categoria	Codice Fami
4	ElementId	ElementId	Text	Text	Text	Text
326	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
327	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
328	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
329	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
330	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
331	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
332	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
333	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
334	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
335	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
336	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
337	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
338	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
339	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
340	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
341	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
342	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
343	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
344	Rectangular Duct	RE_VAR	TRP	IP	CN	CN
345						
346						

ABC_CPR_MEC_CN_Abaco dei Att001 | ABC_CPR_MEC_CN_Abaco dei con00

Figure 39: quantity of rectangular metal ducts.

3	Family	Type	Progetto	Edificio	Codice Categoria	Codice Famiglia
4	ElementId	ElementId	Text	Text	Text	Text
477	TRP_IP_MEC_GA	AC_800x200	TRP	IP	BO	GA
478	TRP_IP_MEC_GA	AC_800x200	TRP	IP	BO	GA
479	TRP_IP_MEC_GA	AC_800x200	TRP	IP	BO	GA
480	TRP_IP_MEC_GA	AC_800x200	TRP	IP	BO	GA
481	TRP_IP_MEC_GA	AC_800x200	TRP	IP	BO	GA
482	TRP_IP_MEC_GA	AC_800x200	TRP	IP	BO	GA
483	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
484	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
485	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
486	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
487	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
488	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
489	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
490	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
491	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
492	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
493	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
494	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
495	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
496	TRP_IP_MEC_GA	AC_1000x200	TRP	IP	BO	GA
497						

... | ABC_CPR_MEC_RC_Abaco dei Rac001 | ABC_CPR_MEC_BO_Abaco dei Boc001 | Legend

Figure 40: quantity of created air vents.

	Family	Type	Progetto	Edificio
4	*ElementId*	*ElementId*	*Text*	*Text*
362	TRP_IP_MEC_RW	RA_600x700	TRP	IP
363	TRP_IP_MEC_RW	RA_600x700	TRP	IP
364	TRP_IP_MEC_RW	RA_600x700	TRP	IP
365	TRP_IP_MEC_RW	RA_600x700	TRP	IP
366	TRP_IP_MEC_RW	RA_600x700	TRP	IP
367	TRP_IP_MEC_RW	RA_600x700	TRP	IP
368	TRP_IP_MEC_RW	RA_600x700	TRP	IP
369	TRP_IP_MEC_RW	RA_600x700	TRP	IP
370	TRP_IP_MEC_RW	RA_600x700	TRP	IP
371	TRP_IP_MEC_RW	RA_600x700	TRP	IP
372	TRP_IP_MEC_RW	RA_600x700	TRP	IP
373	TRP_IP_MEC_RW	RA_600x700	TRP	IP
374	TRP_IP_MEC_RW	RA_600x700	TRP	IP
375	TRP_IP_MEC_RW	RA_600x700	TRP	IP
376	TRP_IP_MEC_RW	RA_800x700	TRP	IP
377	TRP_IP_MEC_RW	RA_900x700	TRP	IP
378	TRP_IP_MEC_RW	RA_900x700	TRP	IP
379	TRP_IP_MEC_RW	RA_900x700	TRP	IP
380				
381				
382				

... ABC_CPR_MEC_CN_Abaco dei con001 | **ABC_CPR_MEC_RC_Abaco dei Rac001**

Figure 41: quantity of created duct fittings.

AutoSave Off | TRP_IP_MEC_CEN_LI-03_LF-00_Schedules

File | Home | Insert | Page Layout | Formulas | Data | Review | View | Devel

Paste | Clipboard | Calibri | 11 | Font | Alignment | General

A1 | 53b2bb43-d279-4f9d-b8b0-d416e65248bd-005865ea

	Family	Type	Progetto	Edificio	Codice Categoria	Codice F
4	*ElementId*	*ElementId*	*Text*	*Text*	*Text*	*Text*
53	TRP_IP_MEC_SE	AC_1200x300	TRP	IP	AC	SE
54	TRP_IP_MEC_SE	AC_1200x300	TRP	IP	AC	SE
55	TRP_IP_MEC_VE	AC_VE01	TRP	IP	AM	VE
56	TRP_IP_MEC_VE	AC_VE02	TRP	IP	AM	VE
57	TRP_IP_MEC_VE	AC_VE03	TRP	IP	AM	VE
58	TRP_IP_MEC_VE	AC_VE04	TRP	IP	AM	VE
59	TRP_IP_MEC_VE	AC_VE05	TRP	IP	AM	VE
60	TRP_IP_MEC_VE	AC_VE06	TRP	IP	AM	VE
61	TRP_IP_MEC_VE	AC_VE07	TRP	IP	AM	VE
62	TRP_IP_MEC_VE	AC_VE08	TRP	IP	AM	VE
63	TRP_IP_MEC_VE	AC_VE09	TRP	IP	AM	VE
64	TRP_IP_MEC_VE	AC_VE10	TRP	IP	AM	VE
65	TRP_IP_MEC_VE	AC_VE11	TRP	IP	AM	VE
66	TRP_IP_MEC_VE	AC_VE12	TRP	IP	AM	VE
67	TRP_IP_MEC_VE	AC_VE13	TRP	IP	AM	VE
68	TRP_IP_MEC_VE	AC_VE14	TRP	IP	AM	VE
69	TRP_IP_MEC_VE	AC_VE15	TRP	IP	AM	VE
70	TRP_IP_MEC_VE	AC_VE16	TRP	IP	AM	VE
71	TRP_IP_MEC_VE	AC_VE17	TRP	IP	AM	VE
72	TRP_IP_MEC_VE	AC_VE18	TRP	IP	AM	VE
73						

Figure 42: quantity of created mechanical equipments.

To verify how many elements were found in the exported file to Navisworks, there is a tool in Navisworks which allows to calculate these quantites which is *Quantification Workbook.* As shown *in Figure 43.*

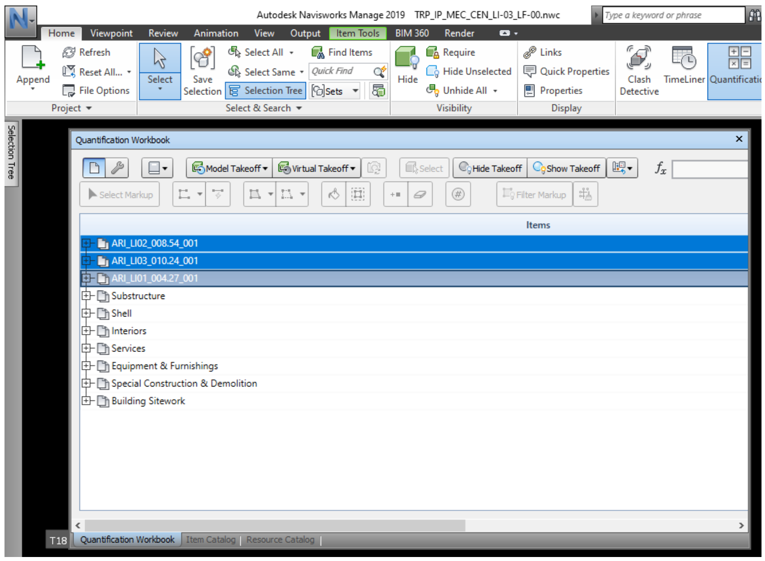


Figure 43: Quantification Workbook in Navisworks

by comparing the total number of elements found in .nwc file are 1266 out of 1275 elements were created in Revit which means there is a loss of data of 9 elements. For the IFC file the same method was applied and the total number of exported elements was also 1266 elements. As shown in *Figure 44*.

Row La	ModelLen	Length	Count	PrimaryQu
ARI_LI01_004.27_001				
Air Terminals		0	237	
Duct Fittings		0	173	
Ducts	4667.656	4667.656	145	
Mechanical Equi		0	30	
ARI_LI02_008.54_001				
Air Terminals		0	215	
Duct Fittings		0	168	
Ducts	4401.164	4401.164	162	
Mechanical Equi		0	32	
ARI_LI03_010.24_001				
Air Terminals		0	40	
Duct Fittings		0	30	
Ducts	877.2616	877.2616	28	
Mechanical Equi		0	6	
TOTAL			1266	

Figure 44: exported quantification table from Navisworks

3.2.1.3 Verifying Assigned Parameters

Another advantage given by Navisworks is the ability to check the number of assigned parameters to objects which was done during modelling in Revit, some of these parameters are important in clash analysis such as ***Identificativo*** code which is a unique code that was assigned for each created element by which it is easier to identify the element that is involved in the clash. The process to control these parameters can be done for each parameter alone then to be repeated for another one, in the following it is illustrated how this check was made for the ***Identificativo*** code.

To start such a process in Navisworks, form ***Home Tab*** we can choose ***Find Items***, a window appears where we can choose where to search in the model in terms of levels and then to define the search characteristics such as Category, property, condition, and value. After that we can export the search result as .xml file as shown in *Figure 45*.

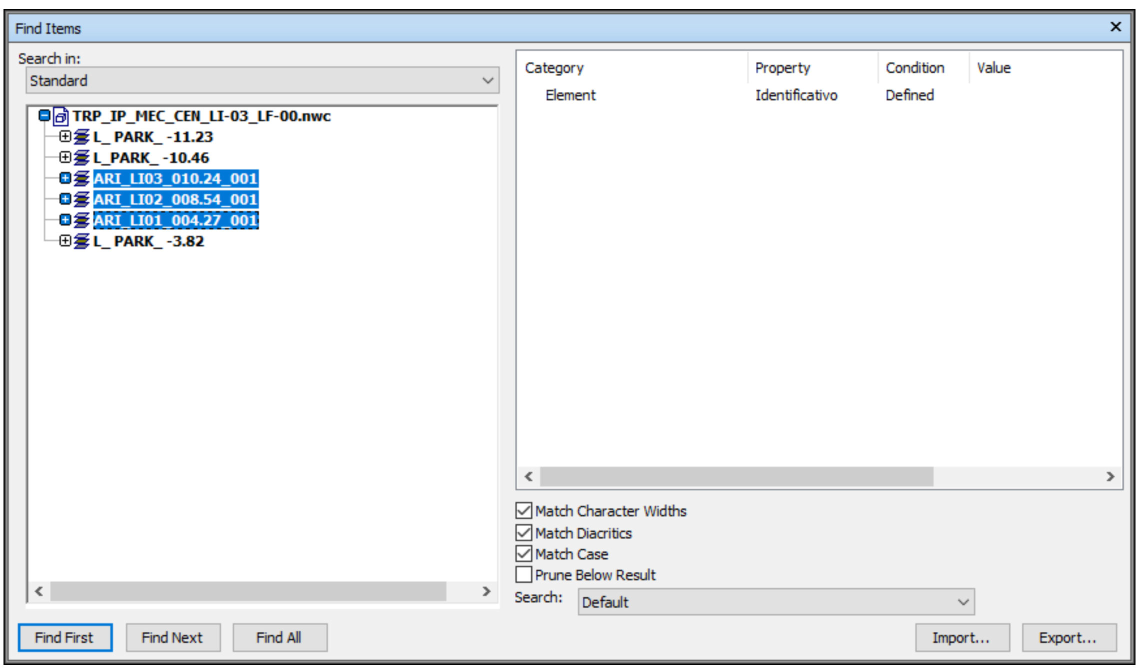


Figure 45: Find Items in Navisworks.

The results of this search showed that the .nwc file contained 1275 identificativo parameters which is the same number of this created parameter in Revit.

3.2.1.4 Clash Analysis

The first step to run clash analysis in Navisworks is to open the models which we want to check conflicts between them, to do that from *Home tab* in Navisworks we can choose *Append* and then choose the required models as shown in *Figure 46*.

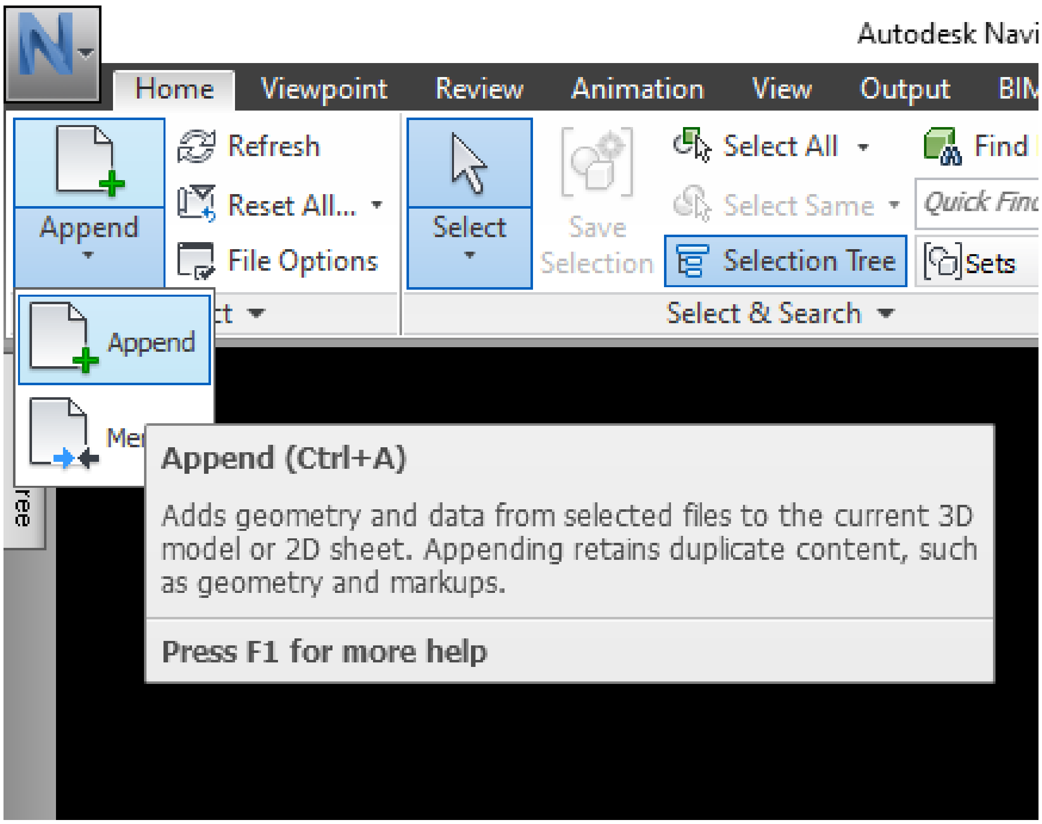


Figure 46: Adding different models to Navisworks.

Architectural-Structural and Mechanical models were opened after exporting each one of them form Revit as NWC files, *Figure 47* shows them in navisworks after merging them together.

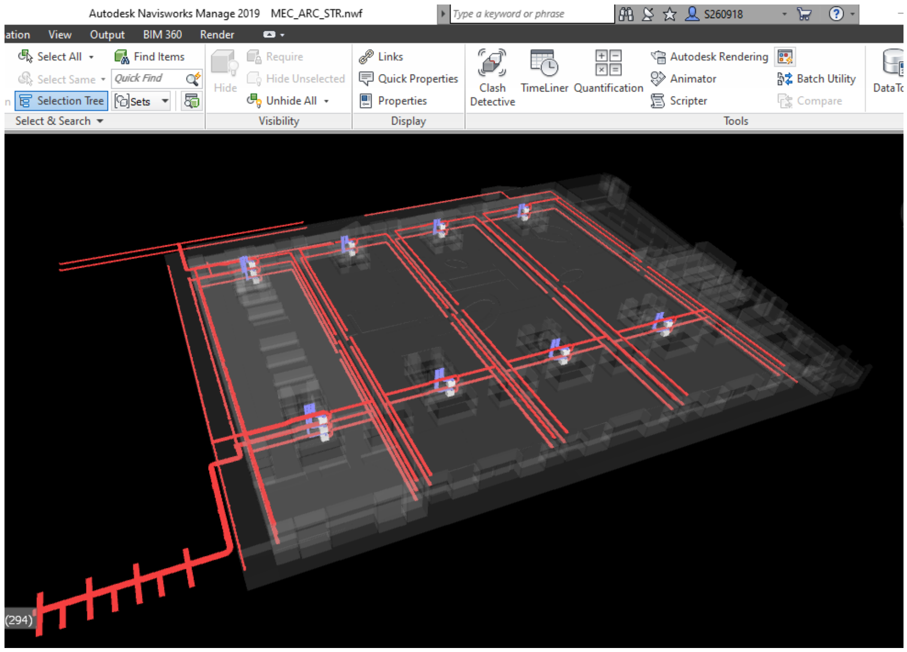


Figure 47: Architectural, Structural and Mechanical models merged in Navisworks.

To run the clash analysis, it is easy to click on *Clash Detective* icon which can be found in *Home ribbon* as shown in *Figure 48*.

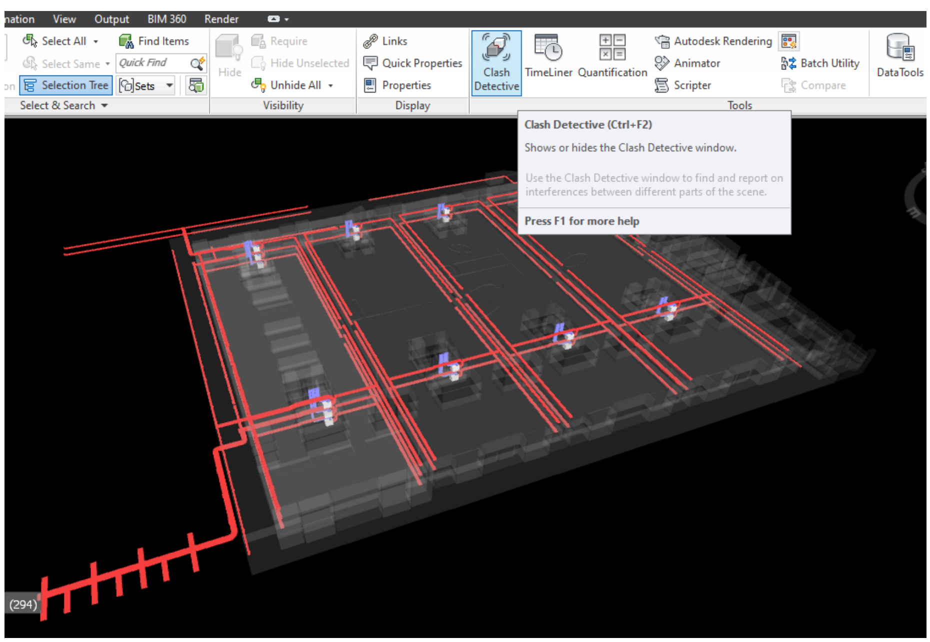


Figure 48: Opening Clash detective in Navisworks

After that Clash Detective window open where we can click on *Add Test*, then give it a name and chose the models we want to run the test between them.

In the bottom of the window there is the zone of clash test settings where we can define the rules of the test such as type and tolerance. It was chosen to run test between Architectural-Structural model and Mechanical model of the underground parking zone. It was chosen to run hard clash test with tolerance equals to 0.05 m as shown in *Figure 49*.

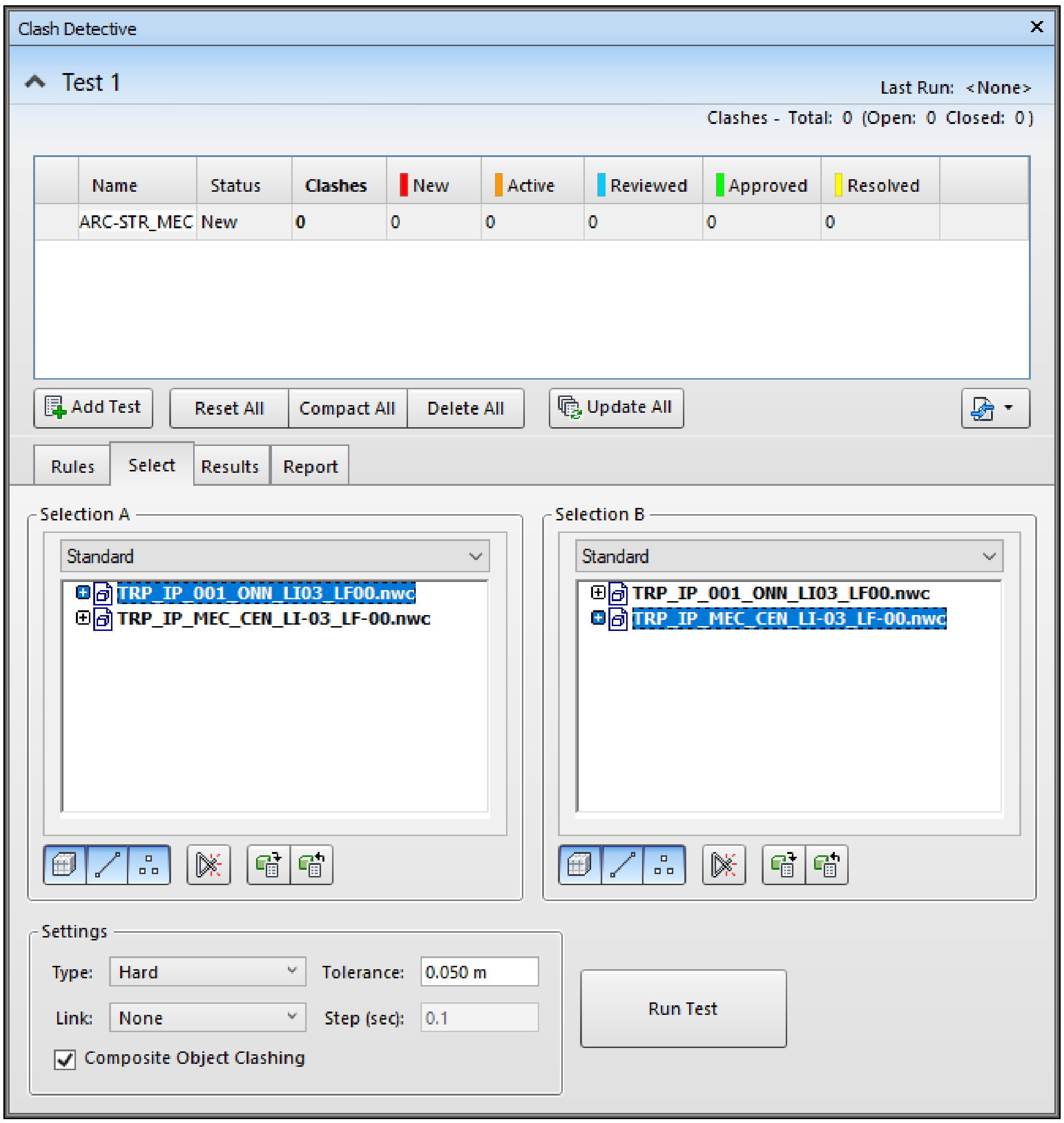


Figure 49: Defining rules for clash test in Navisworks.

After setting the criteria for the test and then clicking on *Run Test*, the software takes some seconds and then shows the results of the test, for each detected clash, the software shows some informations about it in terms of level, grid, date and what are the elements which have the clash between each other as shown in *Figure 50*.

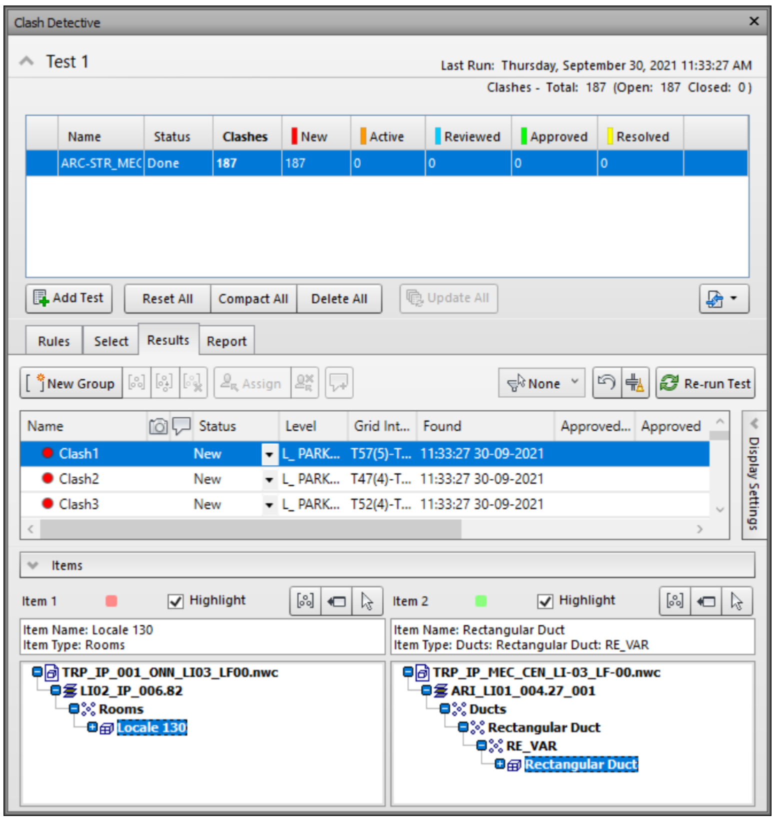


Figure 50:Clash Detecting results on Navisworks

The software also gives the possibility to highlight the clash in the model, it gives two distinct colors (green and red) for the clashed elements, in this way it is easier to visualize and to know the position of the clash in the model and the type of elements that has intersection between each other, as shown in *Figure 51*.

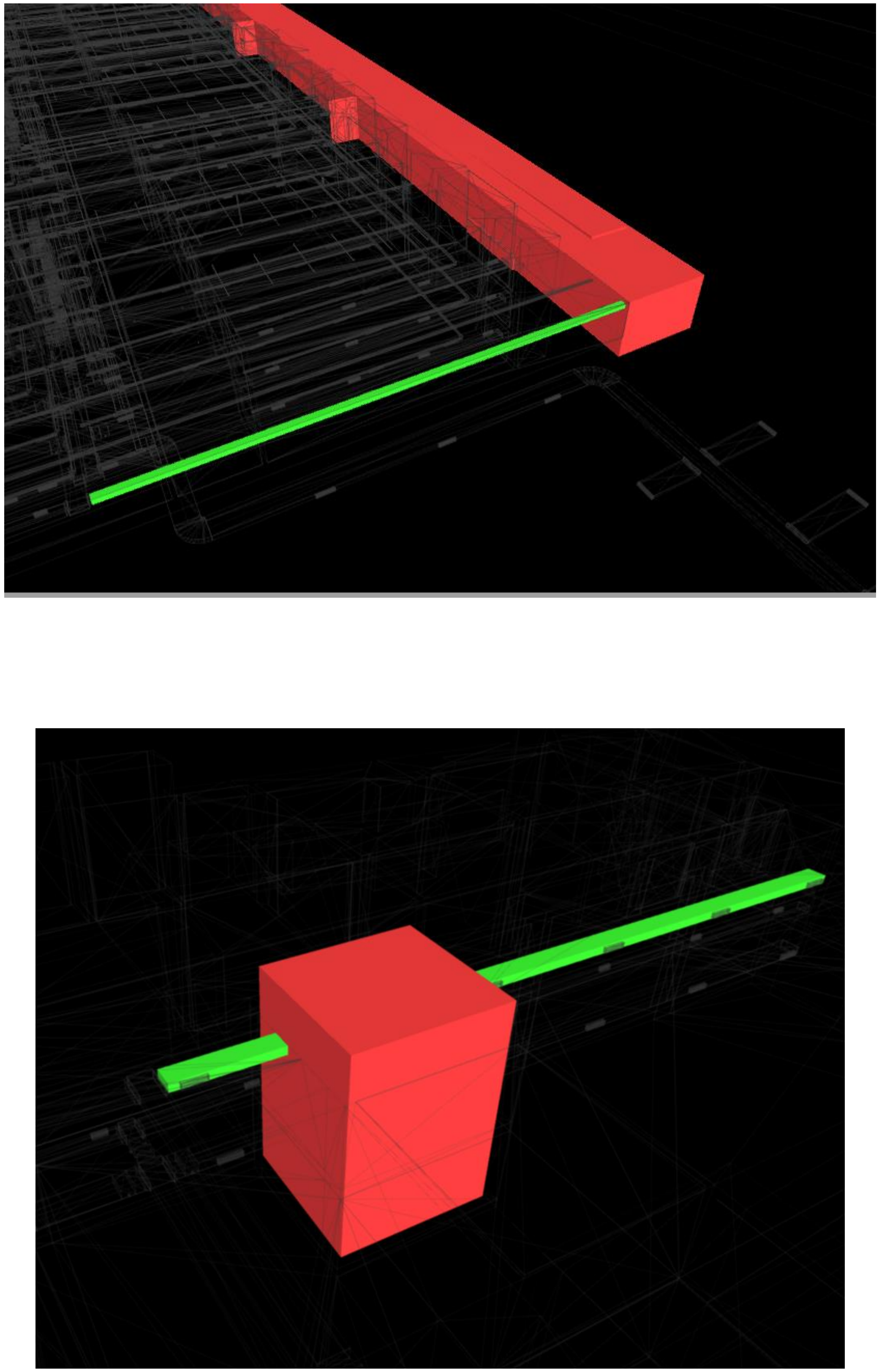


Figure 51: Navisworks highlighting the detected clashes.

It is possible after that to export a report of the detected clashes from Navisworks in a tabulated form including some detailed information about each clash such as description, item ID and clash group, as shown in *Figure 52*.

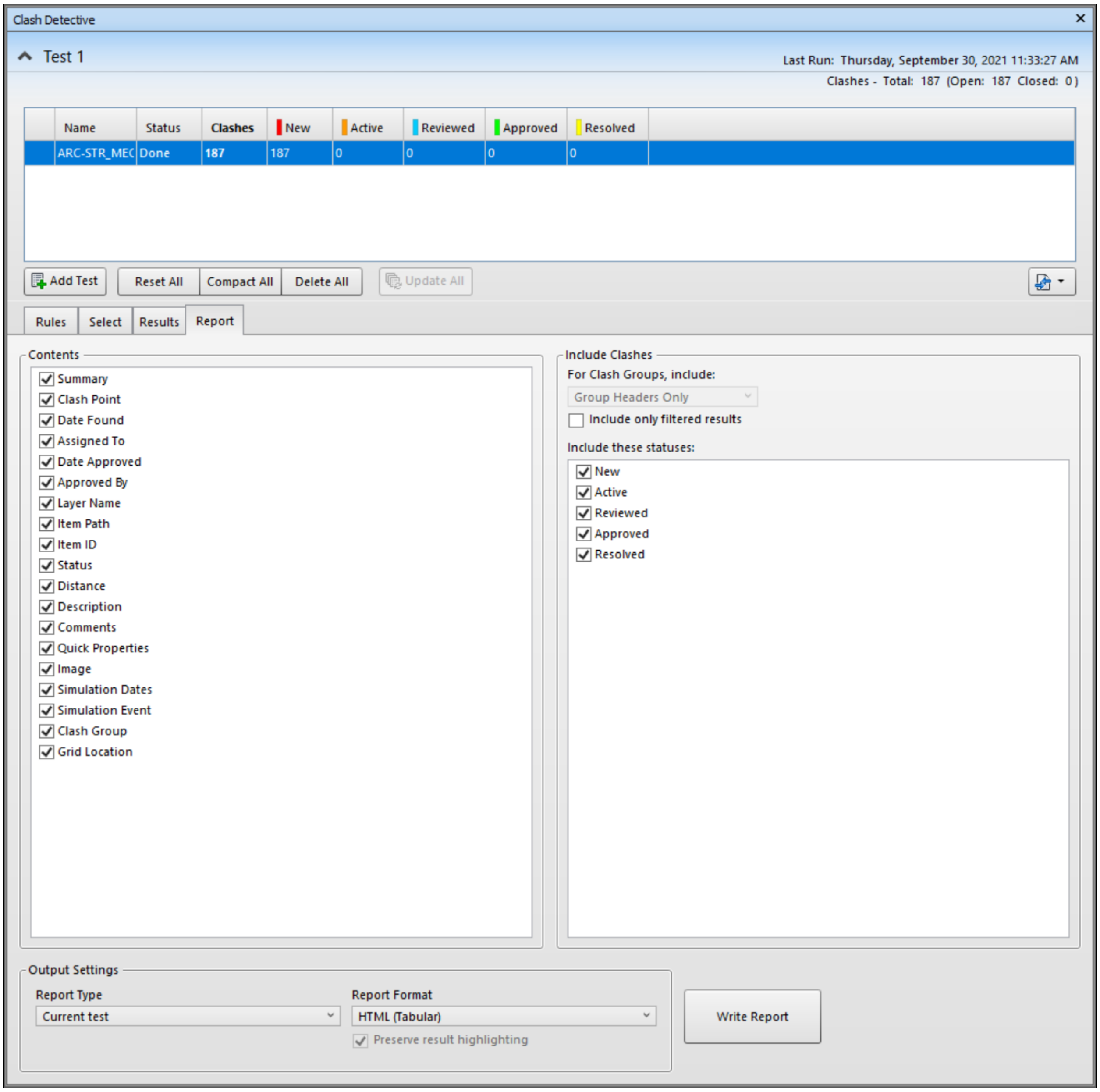


Figure 52: Exporting clash report in Navisworks.

In the repor extracted from navisworks each clash contains information about what objects produce it, the position of each items in terms of levels, items id , type of clash and position of the clash , as shown in *Figure 53*.

AUTODESK®
NAVISWORKS®

Clash Report

ARC-STR-MEC	Tolerance	Clashes	New	Active	Reviewed	Approved	Resolved	Type	Status
	0.050m	187	187	0	0	0	0	Hard	OK

Image	Clash Name	Status	Distance	Grid Location	Description	Clash Point	Item 1				Item 2			
							Item ID	Layer	Item Name	Item Type	Item ID	Layer	Item Name	Item Type
	Clash1	New	-3.74	T57-T68 : L_ PARK_ -1.75	Hard	x:-684.045, y:307.917, z:-0.262	*Element ID* : 5641681	LI02_IP_006.82	Locale 130	Solid	*Element ID* : 5722803	ARI_LI01_004.27_001	Aria di Ripresa	Line
	Clash2	New	-3.445	T47-T68 : L_ PARK_ -1.75	Hard	x:-482.976, y:249.265, z:-4.115	*Element ID* : 5641460	LI02_IP_006.82	Locale 128	Solid	*Element ID* : 5722685	ARI_LI01_004.27_001	Aria di Ripresa	Line
	Clash3	New	-3.445	T52-T68 : L_ PARK_ -1.75	Hard	x:-584.234, y:278.803, z:-2.559	*Element ID* : 5641693	LI02_IP_006.82	Locale 133	Solid	*Element ID* : 5722743	ARI_LI01_004.27_001	Aria di Ripresa	Line
	Clash4	New	-3.443	T42-T67 : L_ PARK_ -1.75	Hard	x:-376.756, y:235.267, z:-5.184	*Element ID* : 5574651	LI01_IP_003.82	Locale 34	Solid	*Element ID* : 5719812	ARI_LI01_004.27_001	Aria di Ripresa	Line
	Clash5	New	-3.443	T42-T67 : LI02_IP_006.82	Hard	x:-376.748, y:235.264, z:-15.026	*Element ID* : 5574651	LI01_IP_003.82	Locale 34	Solid	*Element ID* : 5704806	ARI_LI02_008.54_001	Aria di Ripresa	Line
	Clash6	New	-2.737	T47-T68 : L_ PARK_ -1.75	Hard	x:-483.282, y:248.312, z:-4.115	*Element ID* : 5757967	LI01_IP_003.82	Locale 1139	Solid	*Element ID* : 5722685	ARI_LI01_004.27_001	Aria di Ripresa	Line

Figure 53: Exported report of clashes

In this test there were detected 187 clashes between the mechanical model and the Architectural-Structural model, to solve these clashes will depend on the type of element in ARC-STR model, for instance if the clash is a wall with duct line it can be easily resolved by making an opening in the wall but if the clash is with structural element such as a column a decision has to be made in the coordination meetings to decide which discipline will modify his work in order to eliminate that clash.

Another clash test was conducted between the Mechanial model and the model of the fire fighting system, with the same criteria used in the previous test , the results of the test were detecting 87 clashes which can be solved by moving either one of the clashed objects.

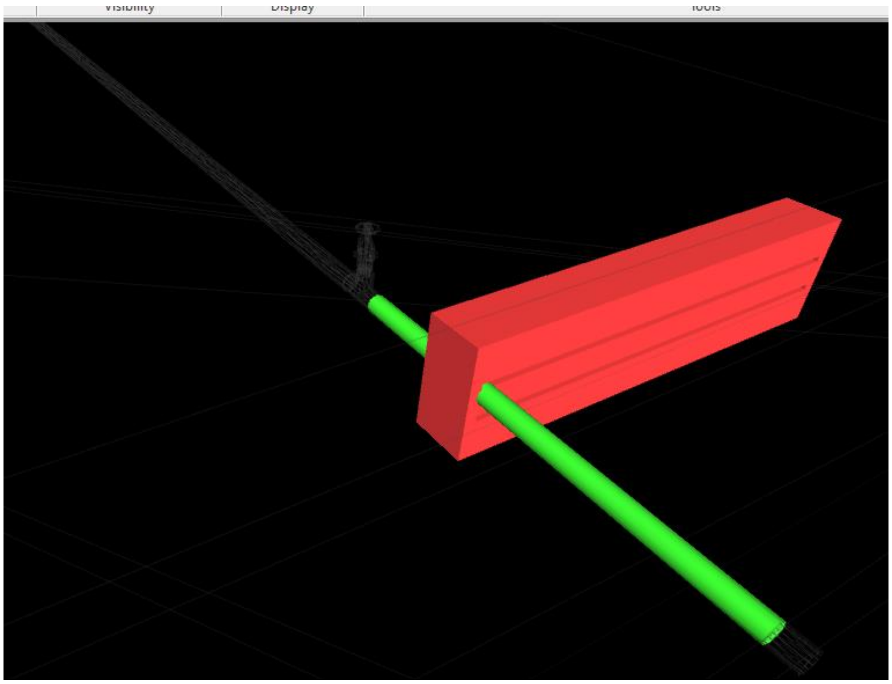


Figure 54: clashes between HVAC system and Fire Fighting system

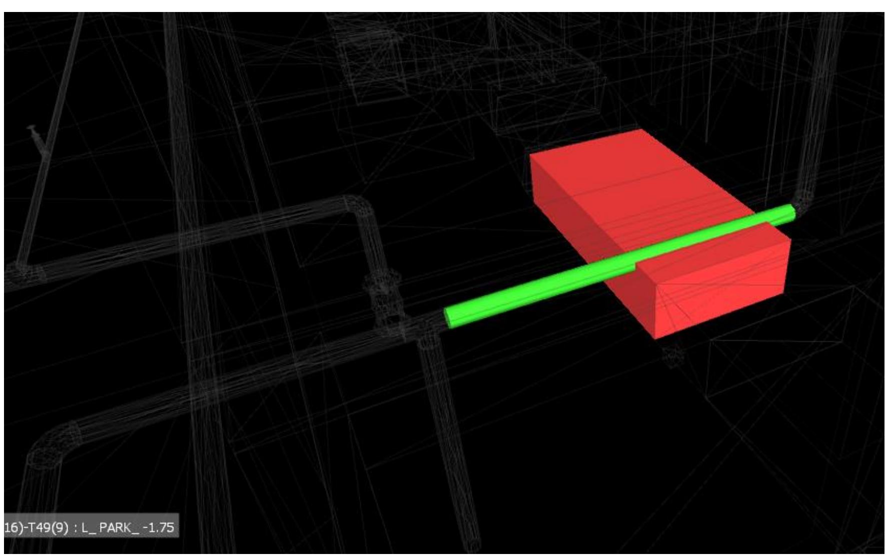


Figure 55:clashes between HVAC system and Fire Fighting system

4 CONCLUSION

In this thesis it was illustrated one of the applications of ***BIM*** methodology in the constructions industry, it has showed how much the application of this methodology in nowadays projects is important when the multidisciplinary design is applied and the need of data exchange between different teams appears, to test and verify the created modeled , to avoid the loss of information when transferring it, ***BIM*** has proved how powerful and useful it can be to all the parties involved.

The process of model checking by clash detection analysis shows a great potential in terms of finding out interventions and conflicts between different disciplines to resolve them before moving towards the next stages and construction.

The utilized tools for verifying and checking needs more developing in order to avoid in the future the current mistakes that the machine can do by remarking clashes that doesn't exist and to increase it is potential for example sorting and grouping the clashes, the possibility to return the results to the original model by automated way to indicate them where they exist not the users to do it manually therefore further human mistakes can be avoided.

Bibliography

[1] C. T. P. S. R. a. L. K. Eastman, BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors., New York: Wiley, 2008.

[2] J. a. I. K. Carmona, BIM: Who, what, how and why, Building Operating Management, 2007.

[3] M. Del Giudice, Il disegno e l'ingegnere, Torino: Levrotto & Bella, 2019.

[4] P. Smith, "Project Cost Management with 5D BIM," *Procedia - Social and Behavioral Sciences,* vol. 226, pp. 193-200, 2016.

[5] F. W. I. P. J. R. Jim Bedrick, in *Level of Development Specification part I*, BIM Forum, 2020, p. 272.

[6] J. Majcher, "Everything worth knowing about the IFC format," 2019. [Online]. Available: https://bimcorner.com/everything-worth-knowing-about-the-ifc-format/. [Accessed 31 08 2021].

[7] N. Panagiotidou, "The Need for BIM Standards in Digital Construction," [Online]. Available: https://www.gim-international.com/content/blog/the-need-for-bim-standards-in-digital-construction. [Accessed 01 09 2021].

[8] P. Aubin, "Revit Families: A Step-By-Step Introduction," [Online]. Available: https://www.autodesk.com/autodesk-university/article/Revit-Families-Step-Step-Introduction-2018. [Accessed 13 September 2021].

[9] A. Help, "About Schedules," [Online]. Available: https://knowledge.autodesk.com/support/revit/learn-explore/caas/CloudHelp/cloudhelp/2019/ENU/Revit-DocumentPresent/files/GUID-73090B70-8A13-4E12-909C-F25D724D5BA7-htm.html. [Accessed 22 09 2021].

[10] N. e. a. Azhar, Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry, Auburn, AL: Proc., 44th Associated Schools of Construction National Conference., 2008.

[11] B. a. M. D. Hardin, BIM and construction management: proven tools, methods, and workflows, John Wiley \& Sons, 2015.

[12] J. H. Hall, Top 10 Benefits of BIM in Construction, AUTODESK BIM 360, 2018, July 27.

Acknowledgments

I would like to express my sincere thanks and gratitude to Professor Anna Osello for giving me the opportunity to work under her supervision, it was a great honor to me.

I would like to thank professor assistant Matteo del Giudice for his guidance and help through the entire process.

I would like to thank researcher Emanuele Bussi the all the other members of ***Drawing To the future*** team as they always gave me the help and support.

Last but not least, I would like to thank my family and all my friends for their continues support and encouragement, I would not made it without you.

Sincerely,
Ibrahim Aladgham