

POLITECNICO DI TORINO

Master of Science in Civil Engineering



THESIS OF MASTER DEGREE

BIM methodology analysis for model validation.

The case study of Torre Regione Piemonte

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Abstract

In the current digital era, a construction field becoming more complex and cost-effective we have ever seen before, due to fact that innovative methodologies and information technologies such as Building Information Modelling are developing rapidly. Any contraction design project involves different disciplines like structural, architectural, mechanical, electrical etc. A coordination between them is most important requirement, to achieving this aim a BIM methodology is a key.

This thesis aims at enhancing comprehension of mono-disciplined BIM model by means performing clash detection. As a case study parking area of the Piedmont Region Service Centre building research project were considered. Starting from an existing structural and architectural model of parking area of the building an electrical BIM model was created to perform clash detection of between firefighting and electrical systems. Finally, the result of clash detection and solution to eliminate possible issues at pre-construction stage.

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Index of acronyms and extensions

BIM - Building Information Model/ling

HVAC - Heating, Ventilation and Air Conditioning

LOD - Level of Development

LOG - Level of Graphic information

LOI - Level of Information

MEP - Mechanical Electrical and Plumbing

TRP - Torre Regione Piemonte

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Introduction

Nowadays it is hard to imagine any complex design project without clash detection, yet couple decades ago clash detection was not required at all. Engineers had to supervise during construction in the site and in case of occurrence any clashes or discrepancies e.g., structural beam collided with water supply pipeline, so pipeline design had to be refined or find other solutions on the spot. This could lead to unwanted delays and increasing cost of a project. Thanks to progress in information technology and new innovative methods which influence greatly design and construction fields gave the rise to Building Information Model/Modeling. BIM modelling engages creating a comprehensive master model that consists of different discipline models. Using Navisworks BIM software, allows to perform a more refined and careful analysis in all disciplines, anticipating design errors such as the overlapping of objects. As a result, design errors are minimized without even starting to build a project, thus allowing to save time and money.

Unfortunately, there are still some conservative design and construction companies which do not recognize obvious advantages of this methodology and keep using traditional 2D CAD drawings. The CAD projects were good in 60s-70s when it represented to the world, yet since then design field has changed a lot and keeps evolving day by day. One of the main drawbacks of this traditional tool is, all disciplines are created separately and manually, which means if there will be a change in one drawing, all other drawings must be changed manually. While computer-aided design with BIM methodology avoids such issues automatically. However, companies dealing with expensive and significant projects already realized the fundamental role of BIM in the design phase and trying to adopt it, even if they do not want to leave their CAD projects. Otherwise, these companies will face bankruptcy and be driven out of the market by others.

The main objective of this thesis is to explore clash detection that allows to speed up the construction process, avoiding problems and corrections on site, thus simplifying the assembly phase and saving both on materials and construction budget.

It was decided to work on the MEP model of the underground Parking Area of the Piedmont Region skyscraper, starting from an existing structural and architectural model, an electrical model was created in order to perform clash detection between the firefighting system and electrical models.

1. Case study

1.1. Case study: Skyscraper of the Piedmont Region (La Torre Regione Piemonte)

The current thesis is part of a research project launched between the Polytechnic of Turin and the Piedmont Region. The project involves numerous students and researchers who through their work are trying to develop a unique model of entire project with all disciplines. This project was born from the necessity to collect all the public offices of the Piedmont region in one building, due to fact that all of them are spread in different location and in most cases being in rent made up a large portion of the expenses.

The Tower was designed by an italian architect Massimiliano Fuksas in 2007 and construction work began at the end of 2011 in Turin city, Piedmont region, Italy and still in execution due to various delays and legal issues. The area for construction was chosen Nizza Millefonti district which was already used by the Fiat Avio company and consist of 70 000 m². The tower made entirely of reinforced concrete and glass with a high of two hundred and five meters. The skyscraper, the third tallest in Italy after the 231-meter Unicredit Tower and the Isozaki Tower (Allianz) of 209.20 meters both located in Milan.



Figure 1. Real 3D model of Piedmont Region Tower ^[1]

The top floor of Tower will be used as an open-air hanging forest accessible to the public, with the possibility of catering and observation of the Piedmont panorama. The forty-one floors above ground will serve as public offices for around 2600 employees and two underground floors will be oriented for functions and service of the tower.

Next to the tower, there is Service Center building with five-story made by steel and glass connected to the Tower by a suspended glass tunnel. which can accommodate various activities for the community like kindergarten for 75 beds, with rest and dining rooms, spaces for common activities, hall, conference rooms, library, a cafeteria and a pediatric clinic.

Finally, there is three-storey underground parking that can accommodate 1138 cars. The minus third floor of the parking is intended only for employees of the Tower and can house 136 parking spaces while minus second and first floors for both public and employees with around 1002 spaces for cars.

The whole project costs in total 262 million euro together with the urbanization works.

1.2. Framework of the Thesis

This thesis concentrates not only development of 3D parametric model of electrical system with respect of project regulations, but also performing clash detection between different disciplines of underground parking area of the Skyscraper of the Piedmont Region.

Due to fact that the current thesis is part of a research project which is launched several years ago, some considerations were already made and cannot be changed. One of them is BIM modelling software Revit 2019 which allows not only creation geometrical and parametric models, but also Federated modelling for work sharing. Which is a crucial tool to cope with the complex building where each discipline can be developed separately from others.

Following three figures illustrate 2D drawings of the Electrical part of underground parking area of all three floors provided by technical office of the Piedmont region authority.

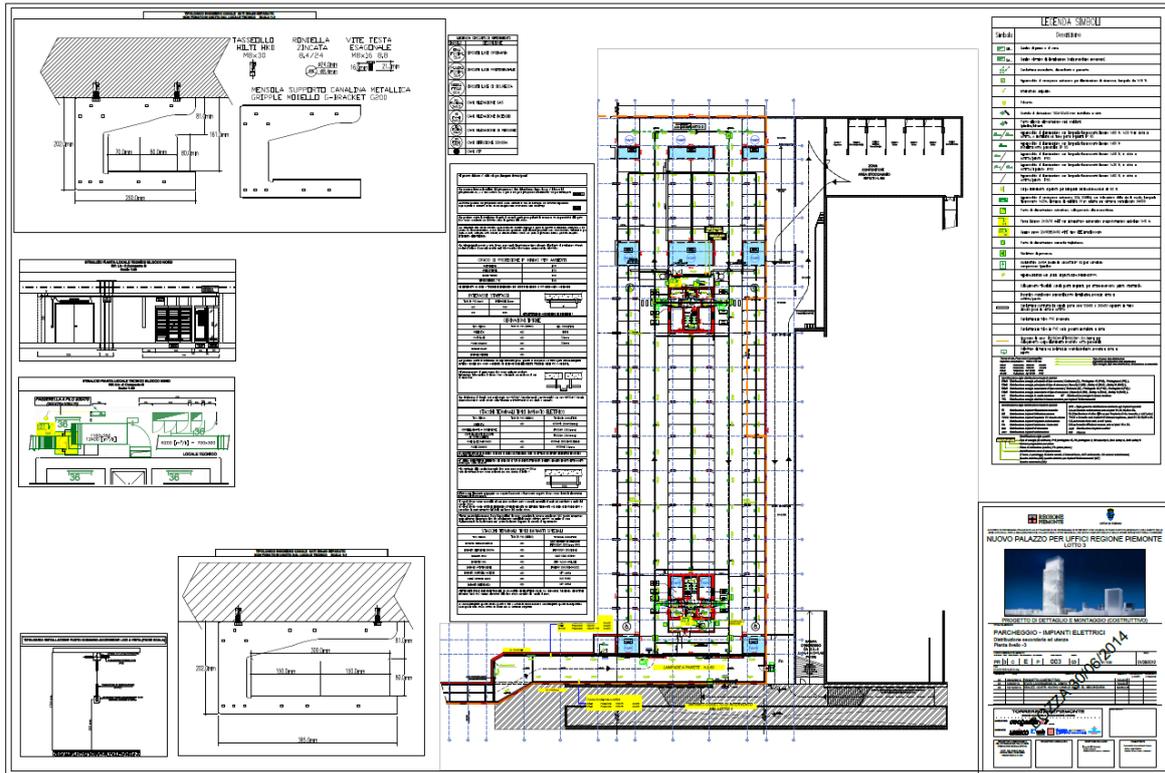


Figure 2. 2D drawing of the Electrical part of underground parking area at level -3
 [Source: Technical office of the Piedmont region authority]

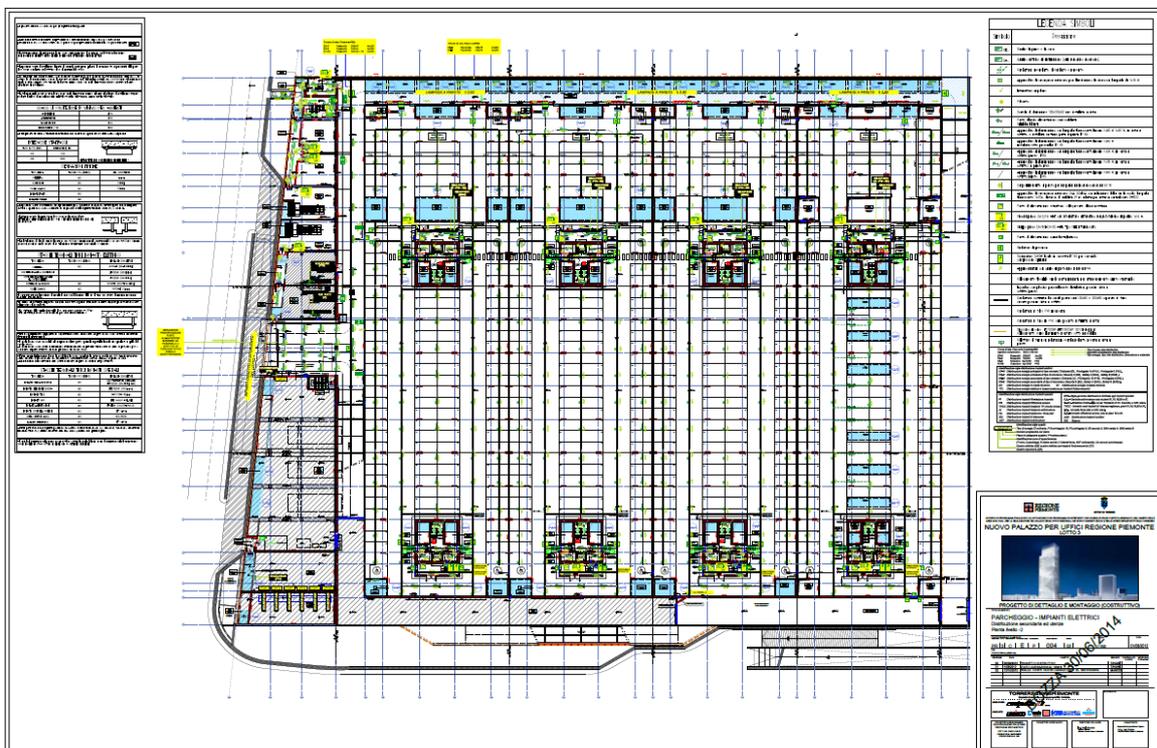


Figure 3. 2D drawing of the Electrical part of underground parking area at level -2
 [Source: Technical office of the Piedmont region authority]

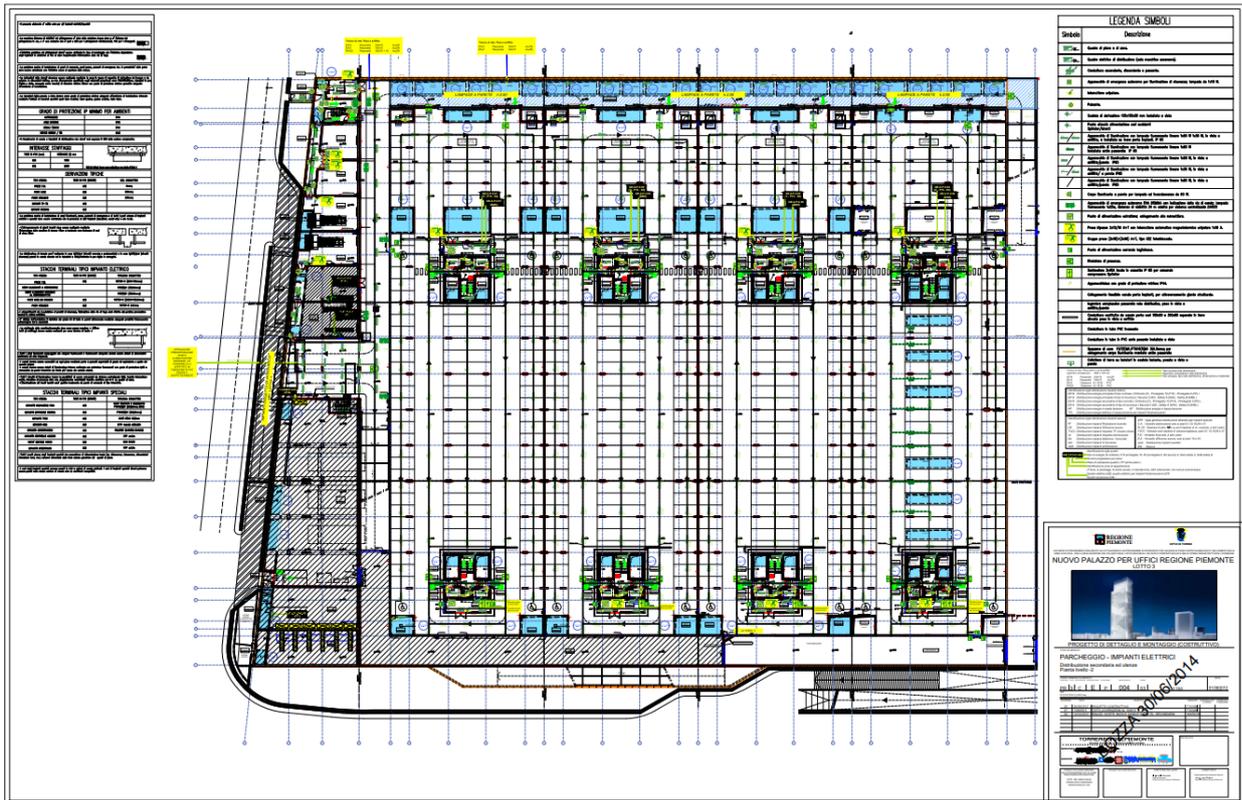


Figure 4. 2D drawing of the Electrical part of underground parking area at level -1
[Source: Technical office of the Piedmont region authority]

1.3.Objective of the thesis

The main objective of this thesis using BIM methodology analysis for model validation on the base of existing building under construction which was introduced previously. To achieve this aim, first 3D model was created only on the base of design drawing with particular emphasis on requirements of project for coding regulations and local standards. Second step was BIMuse with clash detection for defining of inconsistencies in model. Last step was independent real-world observations of building for comparison with the model.

2. BIM

2.1. What is a BIM?

The abbreviation BIM stands for Building Information Model or Modelling, these two concepts may seem similar however, they are totally different concepts. The main differences are that BIM model an object while BIM modelling is a method.

In more detail BIM model is three-dimensional graphical representation of building with some additional information about it. In other words, it is a digital model with database of the building or structure where all users can search, add and edit interested information during whole life cycle of the building. It allows not only to optimize and speed up design and construction processes in each phase, also monitor and maintain building during exploitation.

On the other hand, BIM modelling is a method allowing to create, manage and share information about building model among all actors involved in the entire process to ensure quality and efficiency of building. Such actors are not just architects, engineers of all disciplines, but also vendors of equipment, material suppliers and building maintain staff.

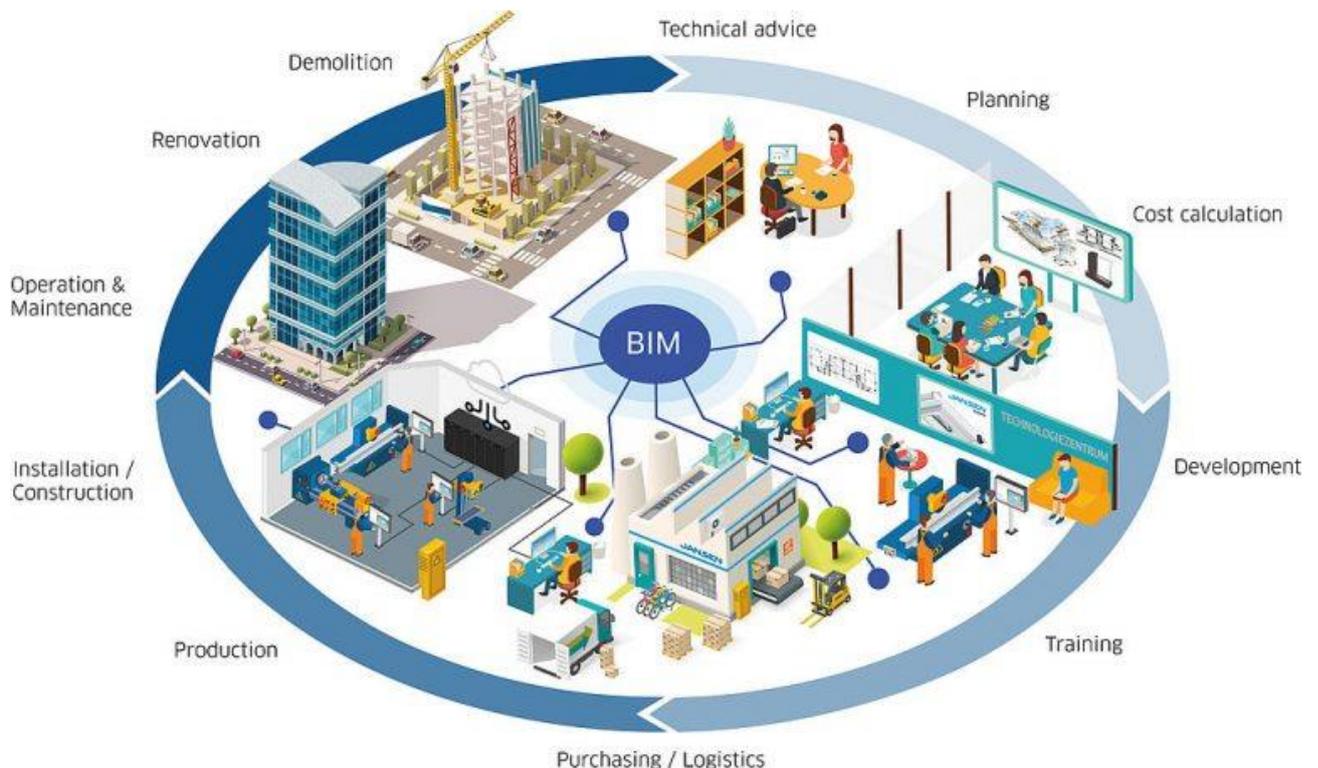


Figure 5. BIM (Building Information Modeling) ^[1]

According to John I. Messner (2017) *"The stark reality is that BIM will continue to significantly change the construction business environment and product manufacturers who are not willing to adapt to support BIM process will face the reality that they will cease to remain competitive in the marketplace."* [2]

2.2. Inteoerability

A process of a design, construction and maintenance of a building or structure have been changed gradually for last 50 years and keep changing due to digitalization process. Wide variety of software are provided for each type disciplines to work with BIM. All actors involved in Building information modelling can use different workflow and software related to their activity during life cycle of a building. However not all software can interact with each other, due to fact that all of them use most of the cases different file extensions, interoperability is a key for this kind of issues.

"the term interoperability is used to describe the capability of different programs to exchange data via a common set of exchange formats, to read and write the same file formats, and to use the same protocols" [3]

This is one of the definitions that could be found in internet, in general interoperability is an ability to transfer data from one software to another with acceptable level of data lost.

In this thesis all main softwares were used like AutoCAD, Revit and Navisworks manages belongs to one manufacture Autodesk, so there is no any problems with interoperability or data lost. It is good way to start and learn how to work with BIM, however Autodesk in not only manufacturer who produce BIM tools in the market. Interoperability is one of the challenging issues in BIM environment. To overcome this interoperability problems, a IFC (Industry Foundation Classes) format was introduced in 1997.

"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." [4]

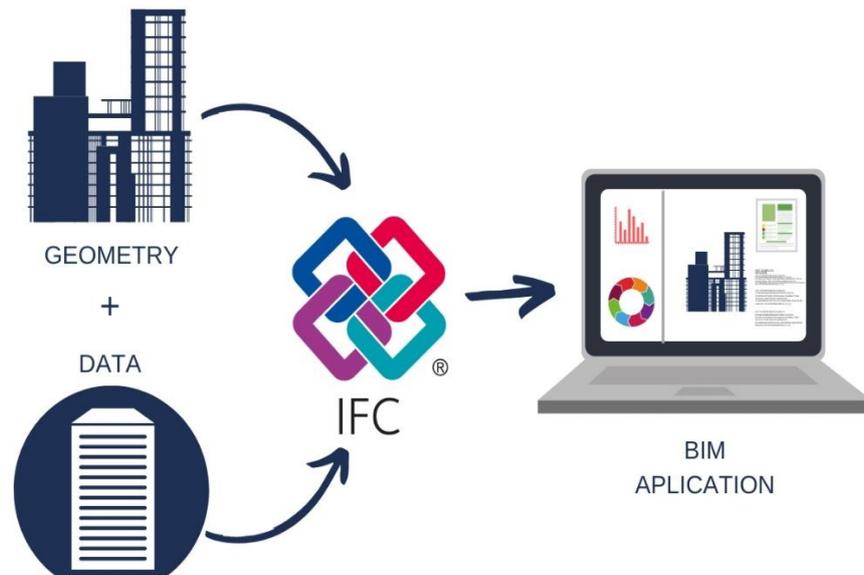


Figure 6. IFC file ^[4]

Probably this is one of the complete definition of IFC format with illustration in figure 6. Which says IFC file includes not only a data but also geometry of the object. It must be mentioned that not always ifc file provide interoperability between software or may cause of data lost. It depends on software manufacturers, do their products support this type of file. Also before converting into IFC files, we must perform interoperability tests and understand what is the purpose of transferring this file and which part of information can be lose.

It is useful to know that IFC is not only unique solution for interoperability applications, there are a lot of other less famous alternatives which are in some specific cases can solve more efficient IFC. So, it is huge topic for develop and more deeper knowledge are required, which is not objective of this thesis.

2.3. Methodology

Building information modelling methodology is totally different from traditional CAD-projects. There is no need for drawing, checking or updating drawings manually, wasting tons of time and money. Traditional method for design maybe faster, but it is for sure not cheaper. CAD-projects require less time for design however contain lot of uncertainties and discrepancies compare to BIM-projects. It is due to fact that 2D drawings created independently from other disciplines are used in traditional projects while BIM require use of 3D models with work and data sharing. One of the expensive parts of any project is a clash, nowadays depending on type and complexity of a project, each clash cost about 20 000 euros in construction phase. Which leads to delay and increasing cost of the project. Of course, with 2D drawings it is possible to detect a clash, however it is a very difficult task. Even if by detecting clash in CAD-project must be updated in all disciplines manually. The advantage of using BIM-project is that it allows to create parametric model of whole structure which connected with all players project of before starting the construction. As a result, all issues detected design phase can be eliminated.

The development of a BIM model starts for the selection of the right BIM authoring platform. Since the project already started and Revit software were chosen.

Revit Software offers different methodologies for **worksharing** and **datasharing**, like Integrated model which collects several Mono-Discipline models into one. It merges all properties of individual models into a single database. On the other hand, Federated model just links several Mono-Discipline models together.

Due to this reason **federated model** was chosen for Piedmont Region Tower according with ISO 19650. This is an international standard for managing all data related to any structure with help of building information modelling. Following figure 7. illustrates federated model in the project and how I used it. I took STR and ARCH models form shared area and created mechanical model in working area, as soon as model was ready upload it to shared area from where it is loaded to **COOR** (core model).

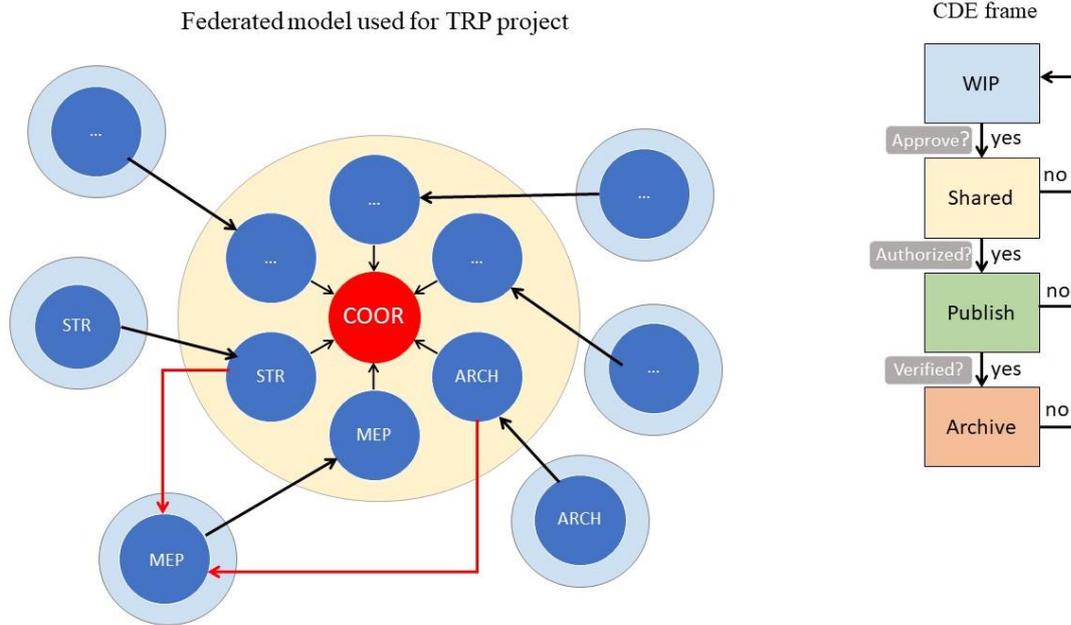


Figure 7. Federated model

CDE means Common Data environment came from British standard, CDE frame can be seen as a storage for all project documents where they are saved, manipulated and approved.

There are four folders:

- **WIP** folder means Work in Progress, allows to users of all discipline create, work on their documents without any restriction.
- **Shared** folder, only after approvement by a head engineer, a finished document or file allowed to transfer this folder.
- **Publish** folder, the documents already checked, issued with specific date and waiting acceptance of customer.
- **Archive** folder, used as history of project with all documents which were accepted by owner.

However not all users have privilege to manage the folders, only owner of the project has all access for these folders. While WIP folders are private area for each specialist, Archive folder is private area only for owner, however shared and publish are shared area which access controlled by the owner.

2.4. Workflow

Any project in BIM has their workflow, it can be different from one project to another. However, it must contain main point like input data, BIM tool and output. The following figure 8 illustrates the workflow followed in this thesis work. To start modelling the electrical system, some input data were required. 2D CAD drawings of modelling system with cross section and dimensions, regulations of project like standards, TRP guidelines which were developed by Drawing to future team and a STR mode from shared area where possible to

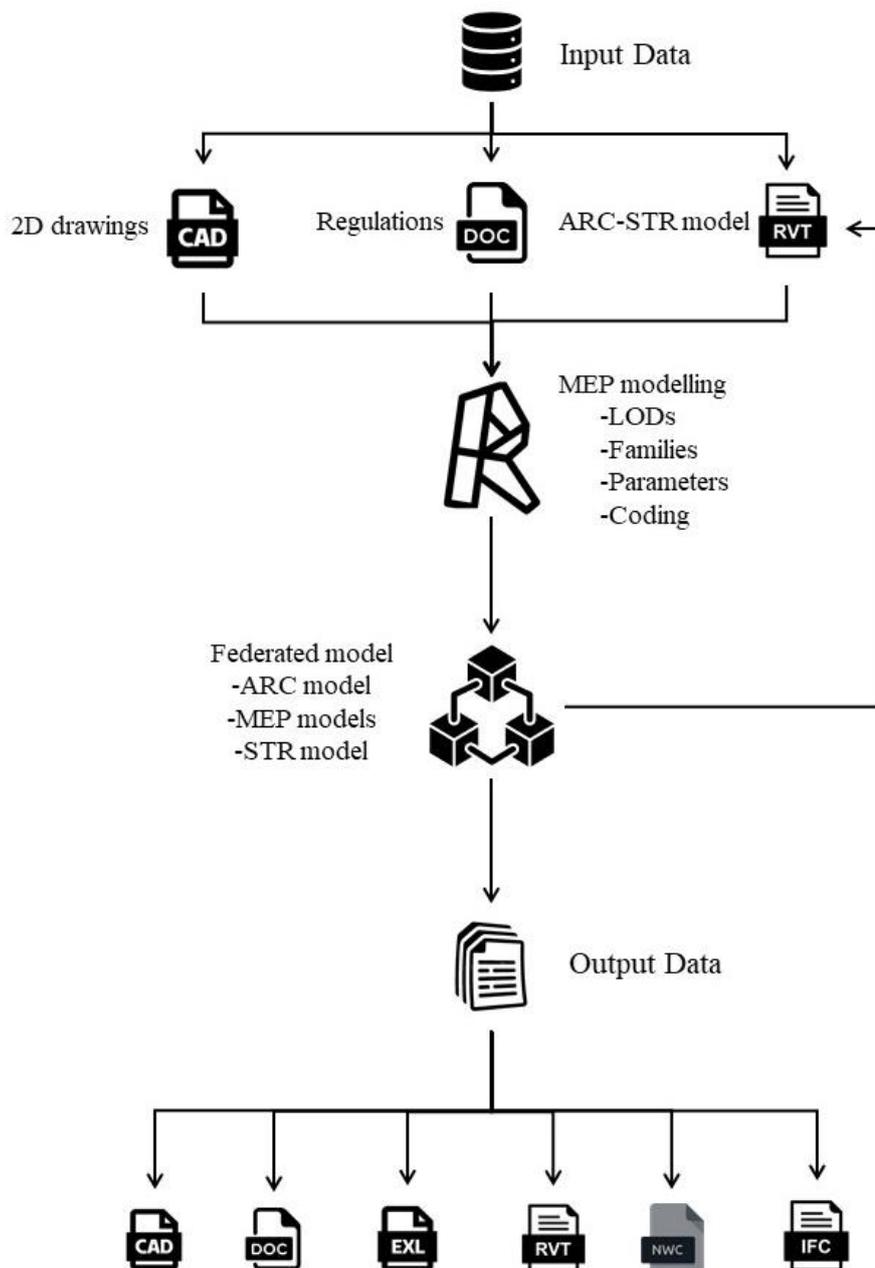


Figure 8. Workflow scheme

create electrical model. The advantages this workflow is that it allows to create you model in on the base of other already made models. In this way the possibility of errors between disciplines are decreases. In the case of underground parking area, architectural and structural models were not complex as a main skyscraper, so it was decided to combine both these disciplines in one. As it can be observed from figure 8, ARC-STR model were taken as starting file for electrical system.

As regards BIM modelling tool, the Revit software were chosen with 2019 edition to avoid any issues between models. In MEP modelling phase, first level of detail of elements must be defined according to project requirement. Next step was creation family and type of electrical systems. The due to fact there was not essential system families in Revit library, it was required to created loadable annotation and object families, then upload annotaion family to object family only after upload it project model as shown in following figure 9.

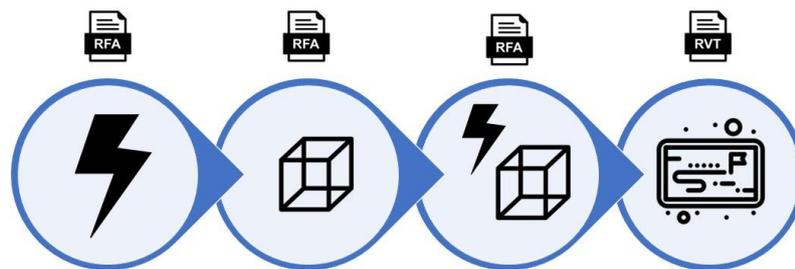


Figure 9. Creation workflow of electrical loadable family with annotation

All parameters to assigned to families according to the 2D drawing, if there is not mentioned any information, the assumptions were made. Strict coding and regulations were followed for naming each instance, creation and filling schedules of the project.

Clash detection between different disciplines were performed and models, results, tables and reports were created as output data.

3. MEP modelling

3.1. Annotation Families

The due to fact that our TRP is complex project and system families containing revit library is not enough, it is required to created loadable families. In electrical system of project drawings also exist annotations of electrical devises. So first we have to create Annotation family of each element. In revit sowftware go to File, New and Family as illustrated in figure 10

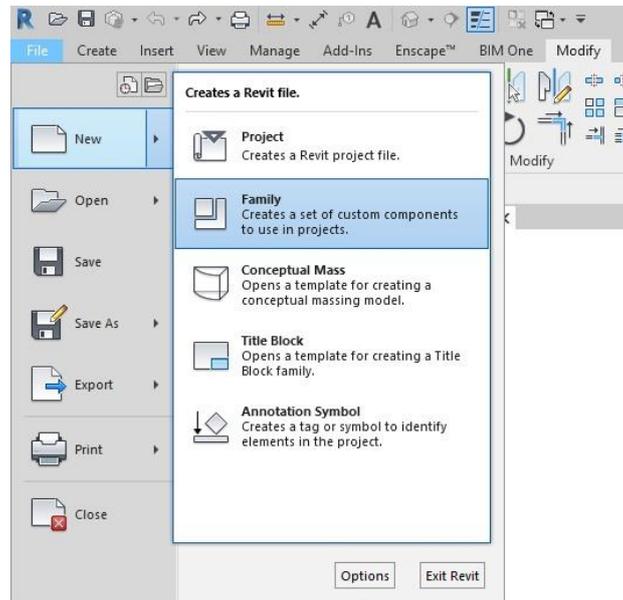


Figure 10. Family annotation of electrical box created in revit 2019

The folder with family templates will be open, we must open folder named Annotations, we must choose annotation type we are interested. In our case it is Metric Electrical Equipment Tag.

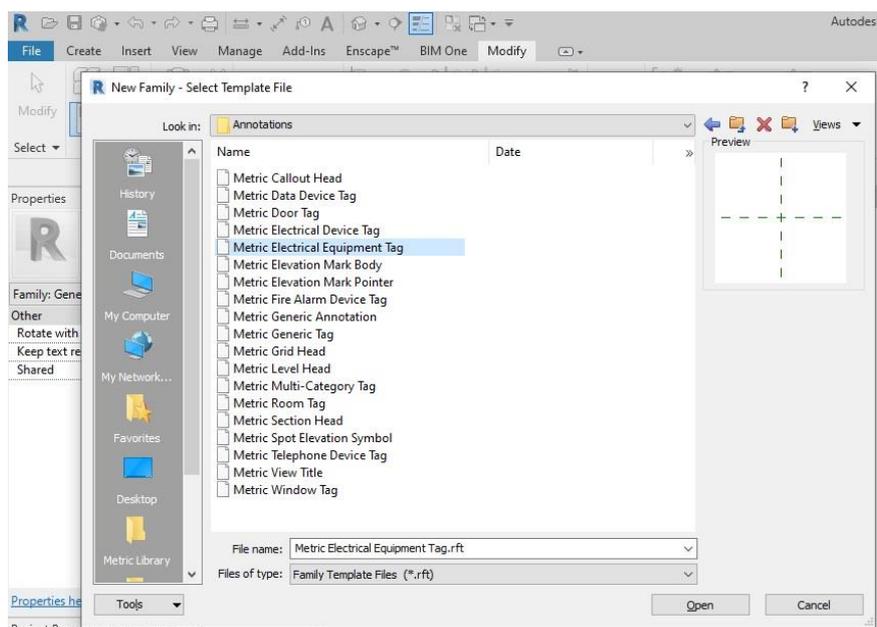


Figure 11. Family annotation template file in revit 2019

Open empty annotation template with axes of coordinates, it better if we will create our annotation in centre of coordinate system for farther manipulation. The interface of the Revit software for creation family annotations are user-friendly and intuitive. In our case in order create electrical box annotation, we go to Masking area Region

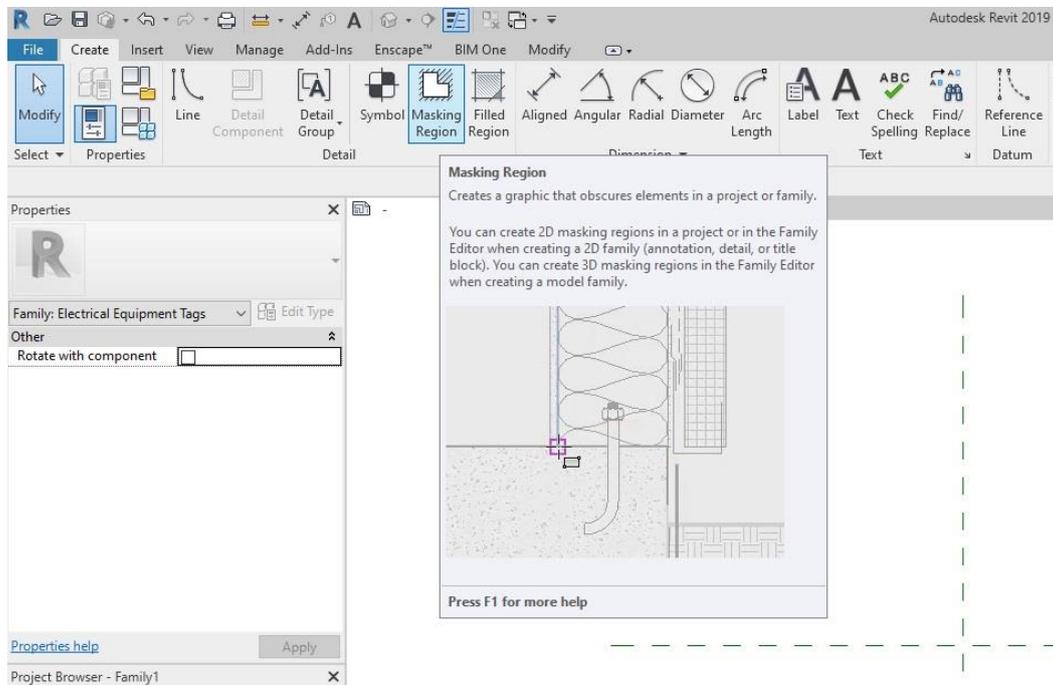


Figure 12. Family annotation marking region

And select Rectangular and draw it with diametions 5mm x 8mm this small diamention are required, because when we will print the shop drawing in scale 1:100, the annotaion with greater size will cover other elements in drawing and having unaesthetic appearance.

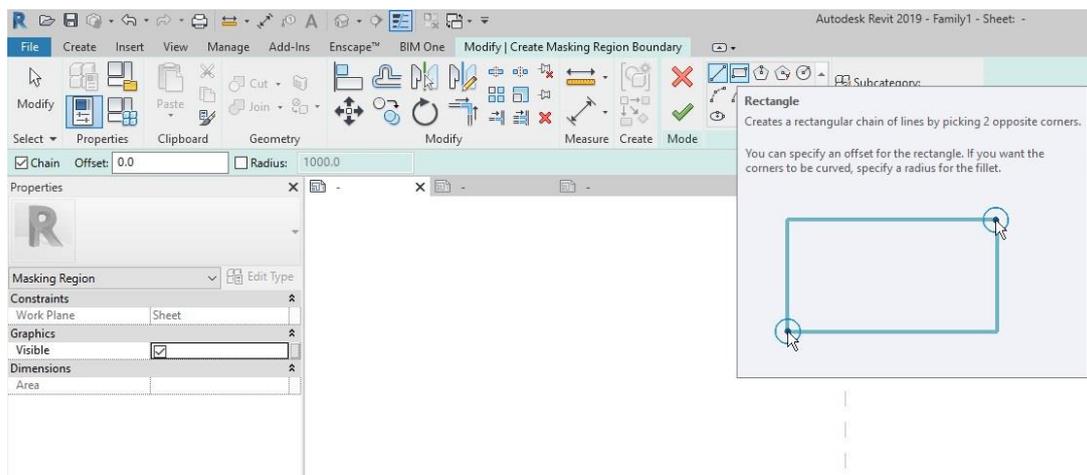


Figure 13. Family annotation creation

As soon as we will have rectangular, we go to Filled Region and this time draw triangle inside our rectangle

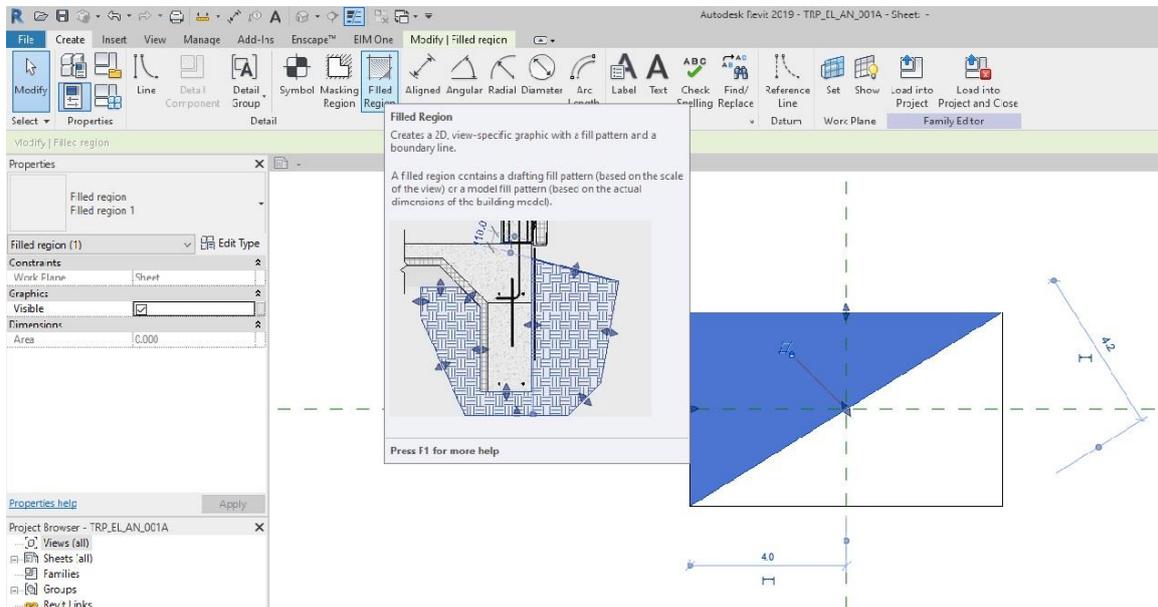


Figure 14. Family annotation filled region

Last step is adding Text to our annotation and save it. Depending on the difficulty of annotation we want the steps may vary, however general step are these.

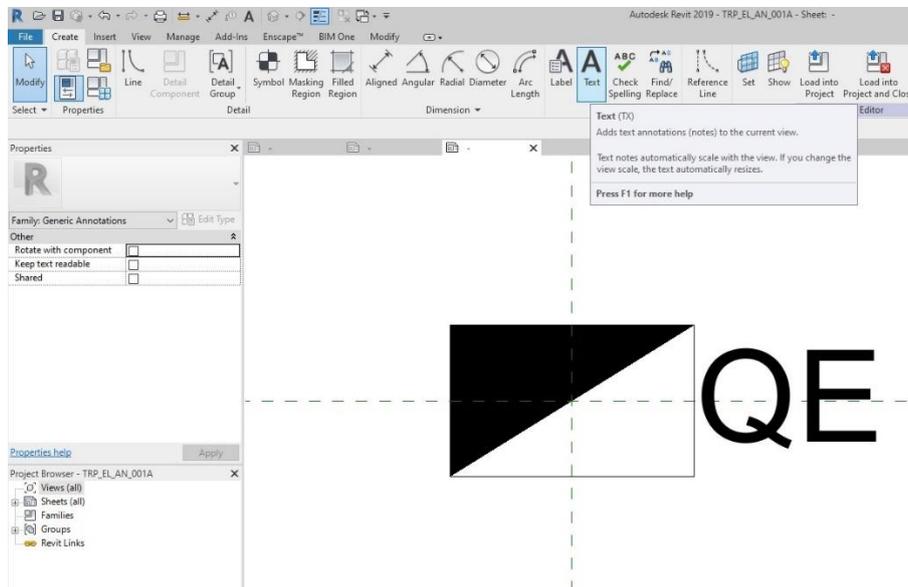


Figure 15. Family annotation text cration

Now we create family objects, the procedure is similar to the creation of family annotations however there is some differences.

3.2.Object Families

In revit software go to File, New and Family as illustrated in the figure 16. this time we did not choose folder annotations, but just select Metric Electrical Equipment in current folder

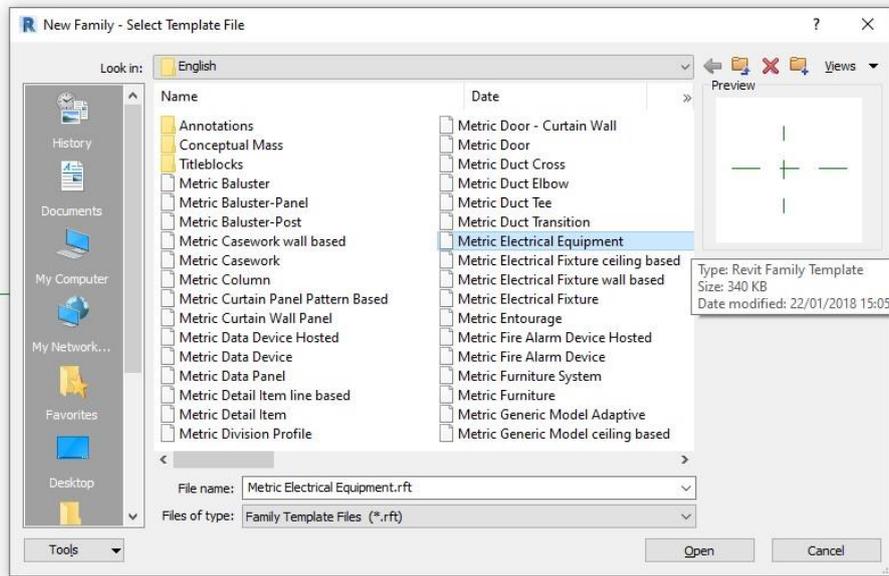


Figure 16. Family object Template file

Also, in this case will have family object template with axes of coordinates, one of the main obvious differences between family annotations and family objects is that annotations are 2D and objects are 3D.

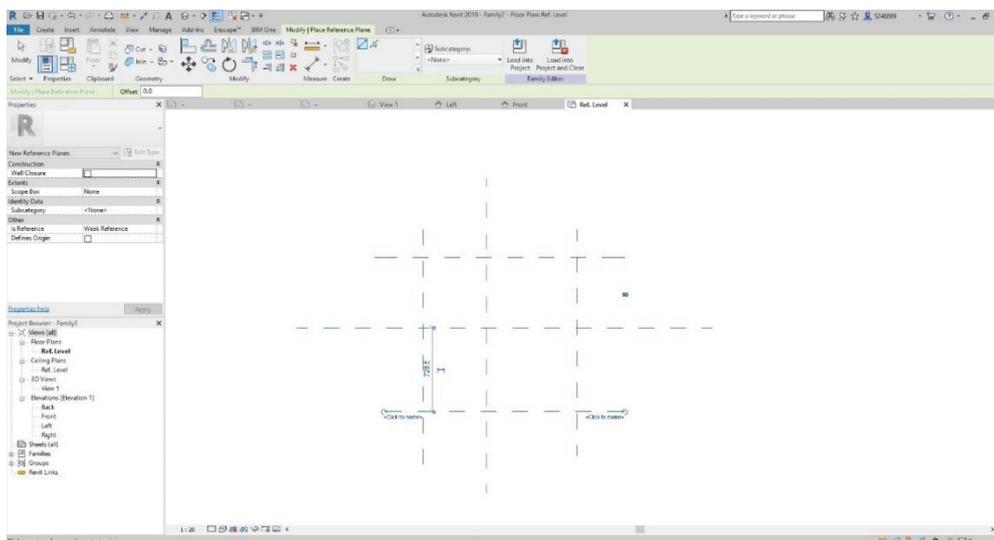


Figure 17. Reference planes

First select Reference Plane (or short cut RP can be used) and draw some reference planes on our axes.

Now we must constrain these reference planes, to do so we need dimension. Go to Aligned Dimension (or just use command DI) and select first one vertical reference plane and vertical axis and from vertical axis to another vertical reference plane. There will appear EQ (equal) emblem which makes your reference planes equidistant, we need also one dimension between two vertical and horizontal reference planes.

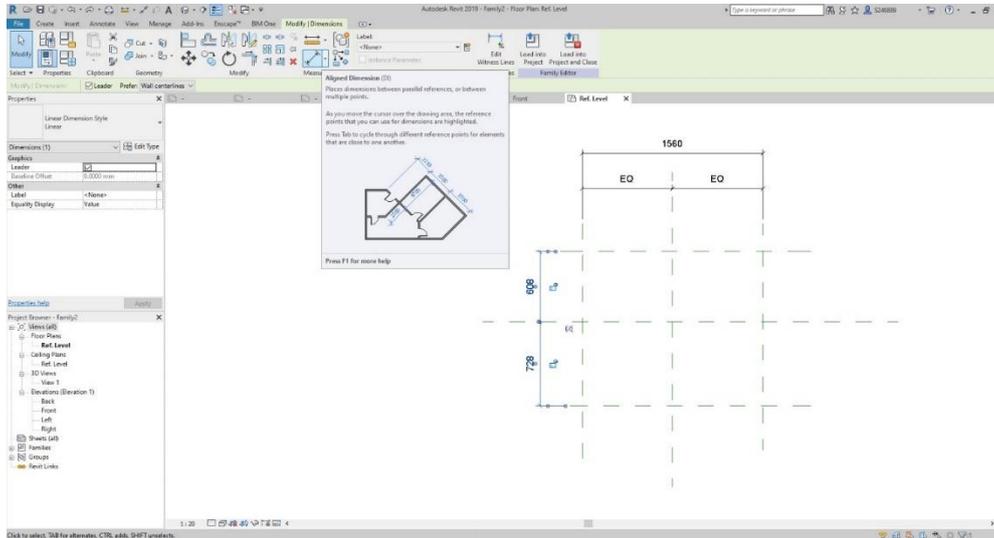


Figure 18. Reference plane dimensioning

Next step is creating a parameter go to the icon shown in the following figure. In the parameter properties window select family parameter, write name of parameter in our case it is length and choose Type.

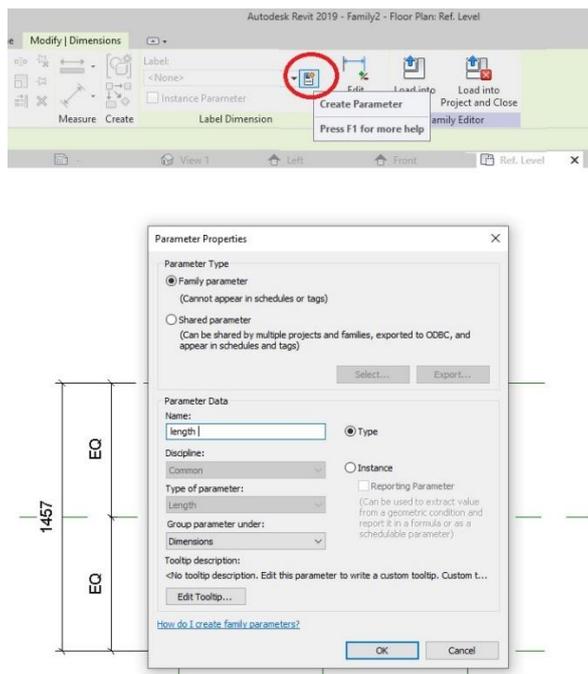


Figure 19. Parameter creation

It is important if we want to create in future different type of this family. After this crate with parameter in the same way as aforementioned.

In order to change these family types, we have to go Family types and in the section, values we change it.

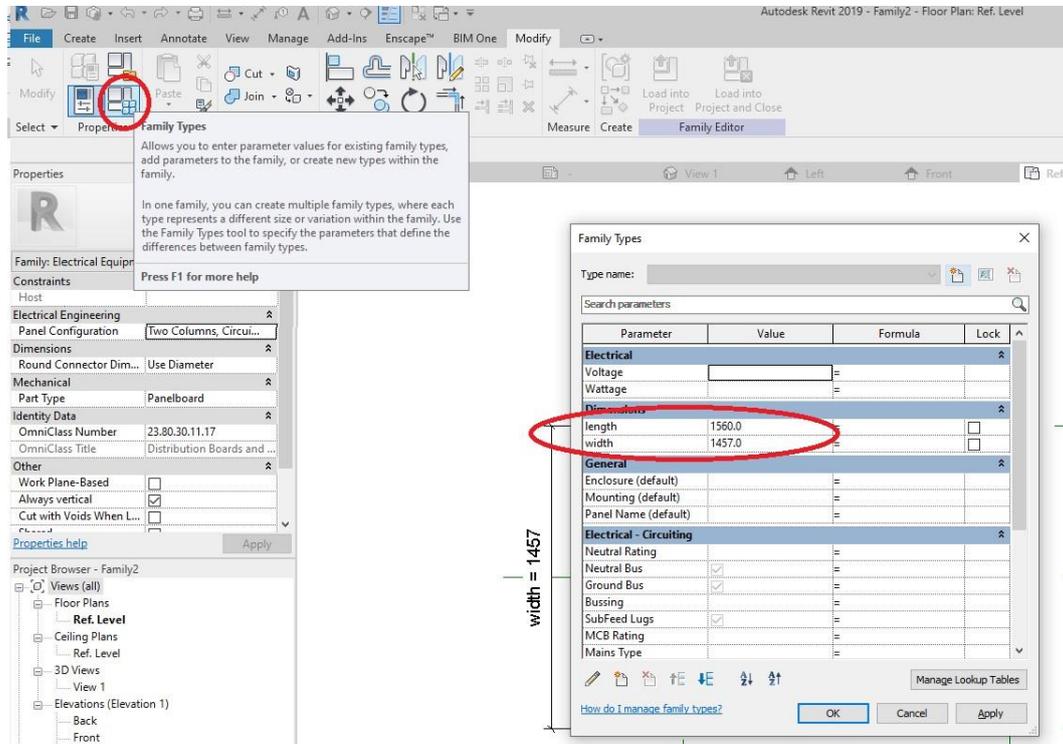


Figure 20. Family types

We need also add the hight parameter, we need go to Front elevation. We can see our reference level, so we need just one more Reference Plane above this reference level and constrain as we done previous steps. Now we will go back to reference level in floor plans and click Create, Solid Extrusion, Rectangular and draw it inside our reference planes.

After go to Align (or command AL) and select first any reference plane after corresponding side of the extruded rectangular. It will appear open lock symbol, if we click one time on it, it will close which means we connect our reference plane with 3D object. We have to connect all reference planes to your 3D model.

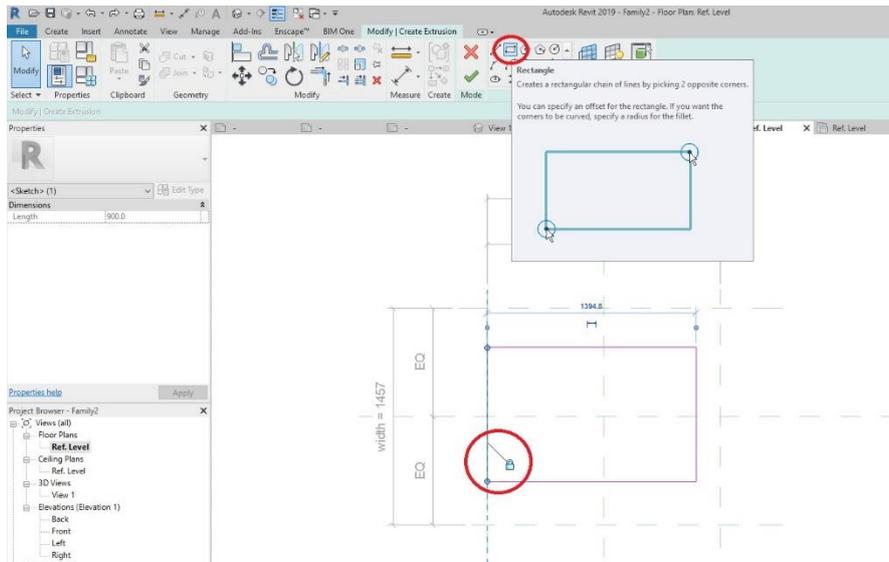


Figure 21. Constraining reference planes

We should give same value for start and end of extrusion in order we can see it height in front view and again align it with reference plane at the bottom and in the top.

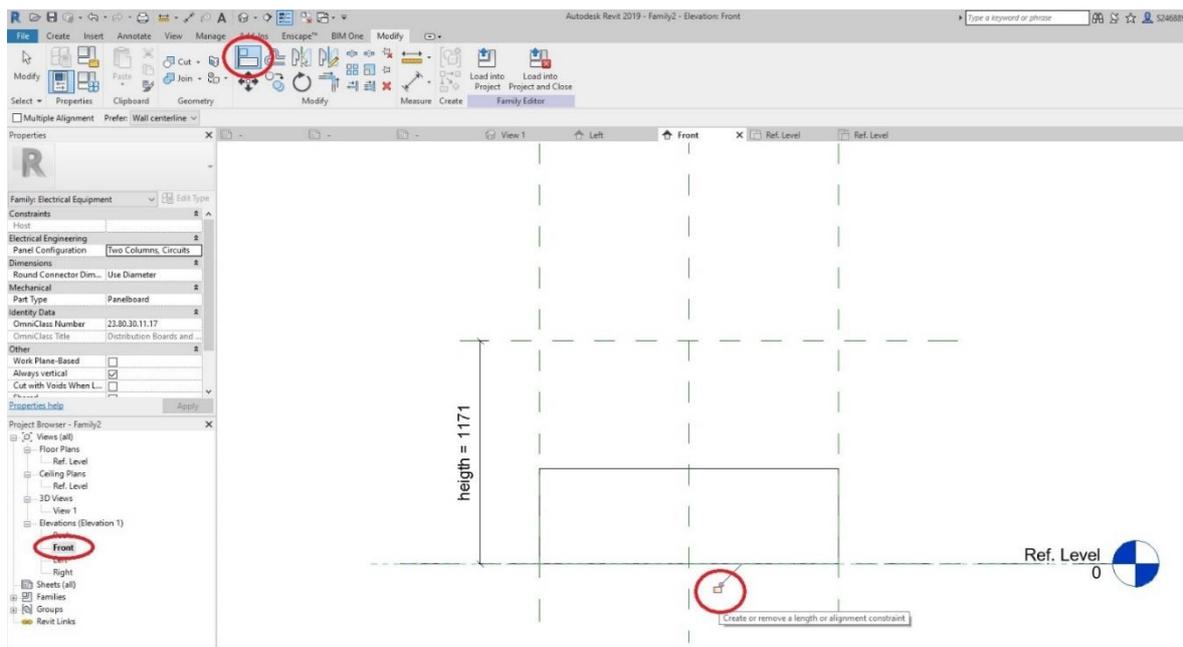


Figure 22. Vertical reference planes

Next step is to put connector, first you must have clear idea of what kind of family object are you creating. In our example we are crating electrical box and it is connector located in backside.

Go to 3D view, Create, Electrical Connector and choose the side of object where must be located the connector.

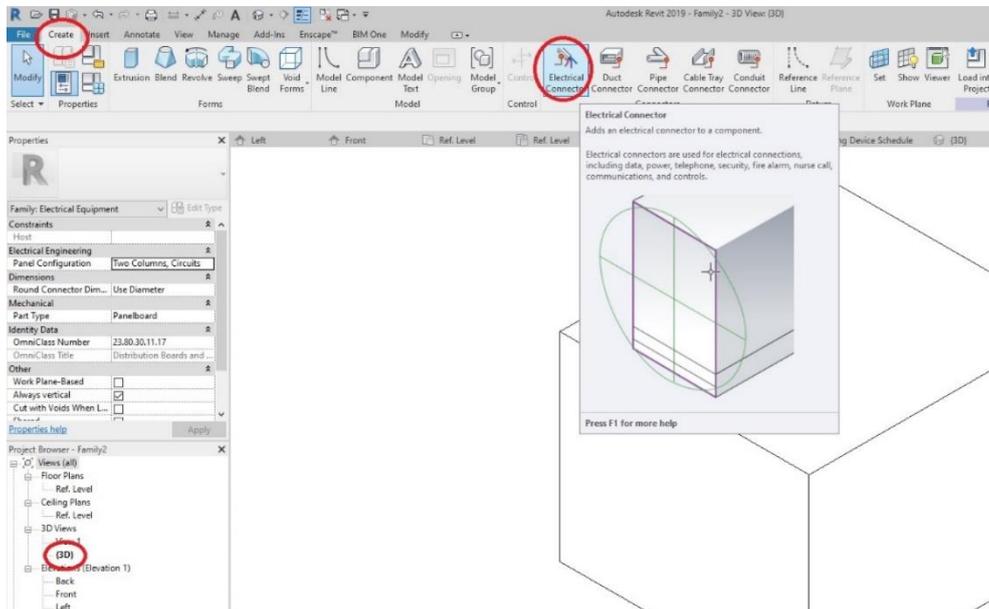


Figure 23. Connector creation

Now we can load family annotation to our family of object. Go to Floor Plans, Insert, Load Family and choose family annotation we created before.

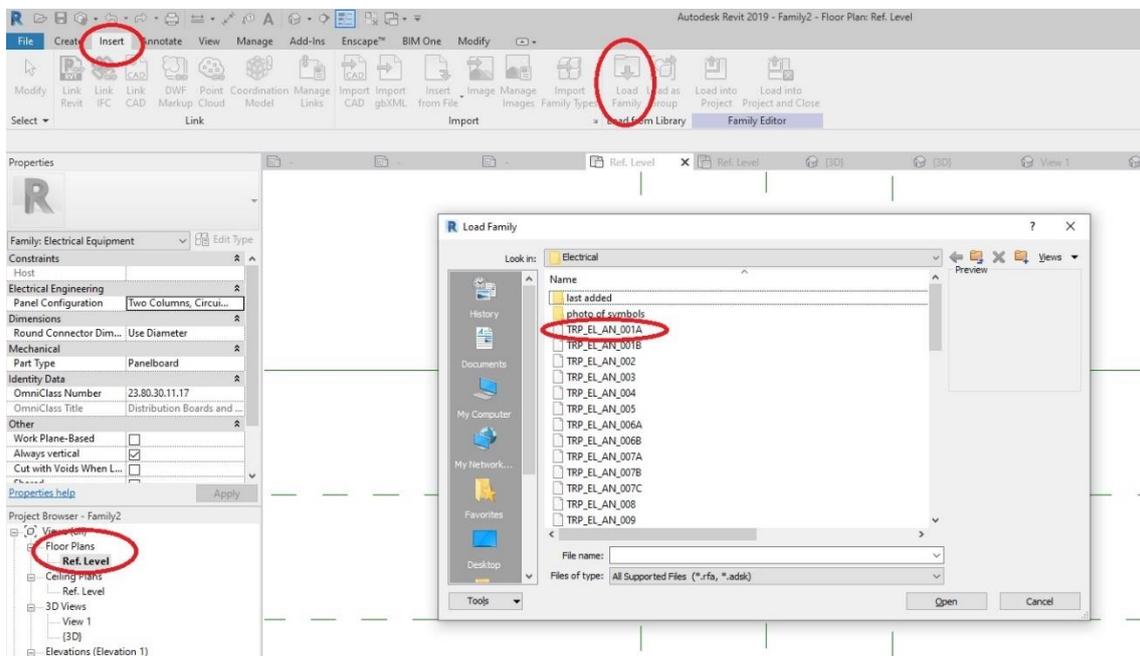


Figure 24. Annotation family loading

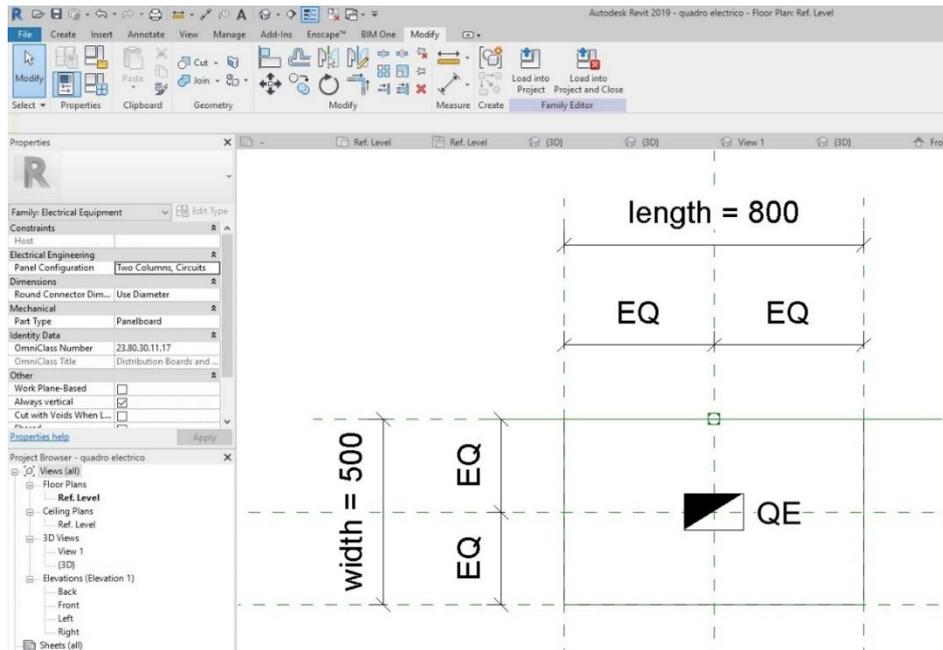


Figure 25. Family object with annotation

To give correct dimension of object we have to check 2D drawings provided by design company. In the drawing we have only length and width of electrical boxes, the height did not mentioned in sections or specifications. In this case we have to choose most real values for such kind of elements.

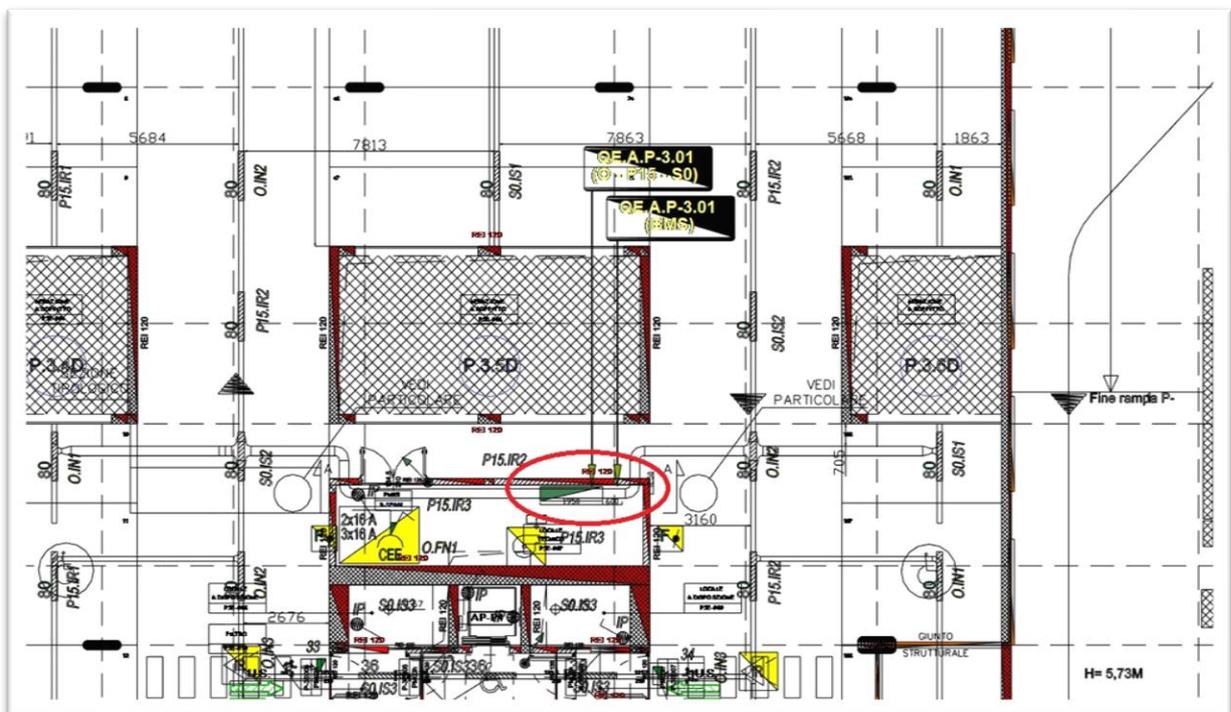


Figure 26. 2D drawing of the Electrical part of underground parking area at level -3 [Source: Technical office of the Piedmont region authority]

Due to fact that there are a lot of elements with same problems, we decided to construction site for take measurements of electrical system equipment and devices.



Figure 27. Photo of an electrical box of the underground parking area [Source: photo made during the visit of the site 05/26/2021]

Now we have all dimensions to complete our family of object, go to Family Types, dimensions parameters of connectors for electrical elements must be defined according to the design drawings of the project.

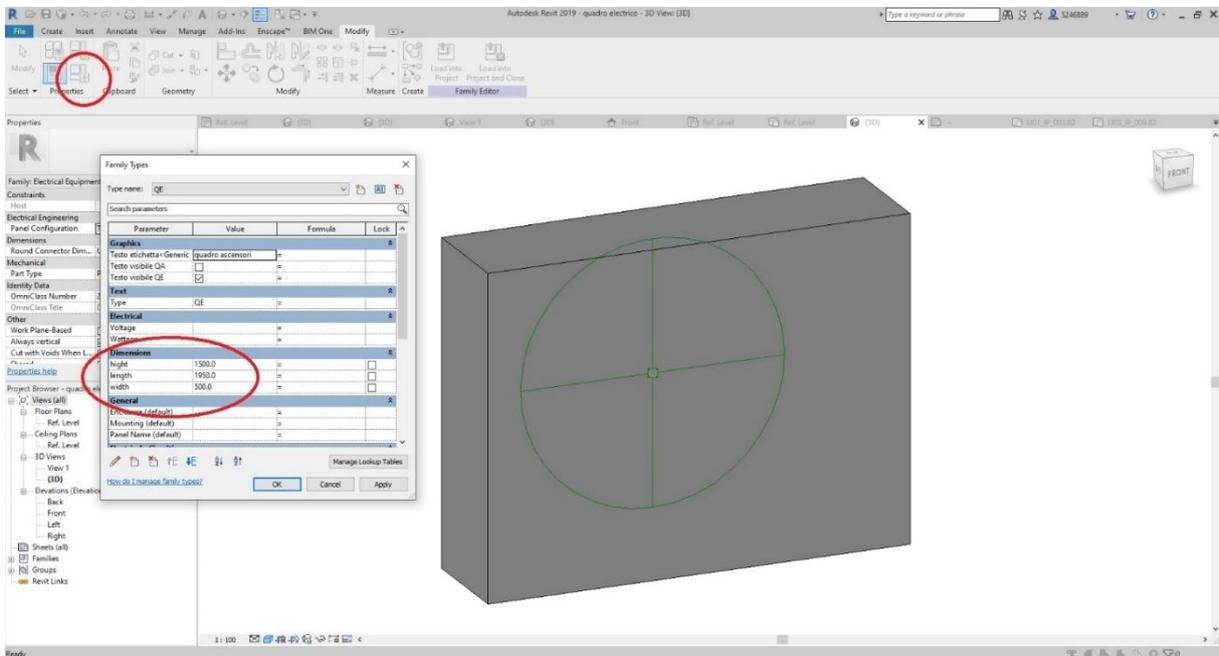


Figure 28. Dimensioning of 3D Electrical box

One of families objects ready to upload to the project. Go to Load into Project, select the project.

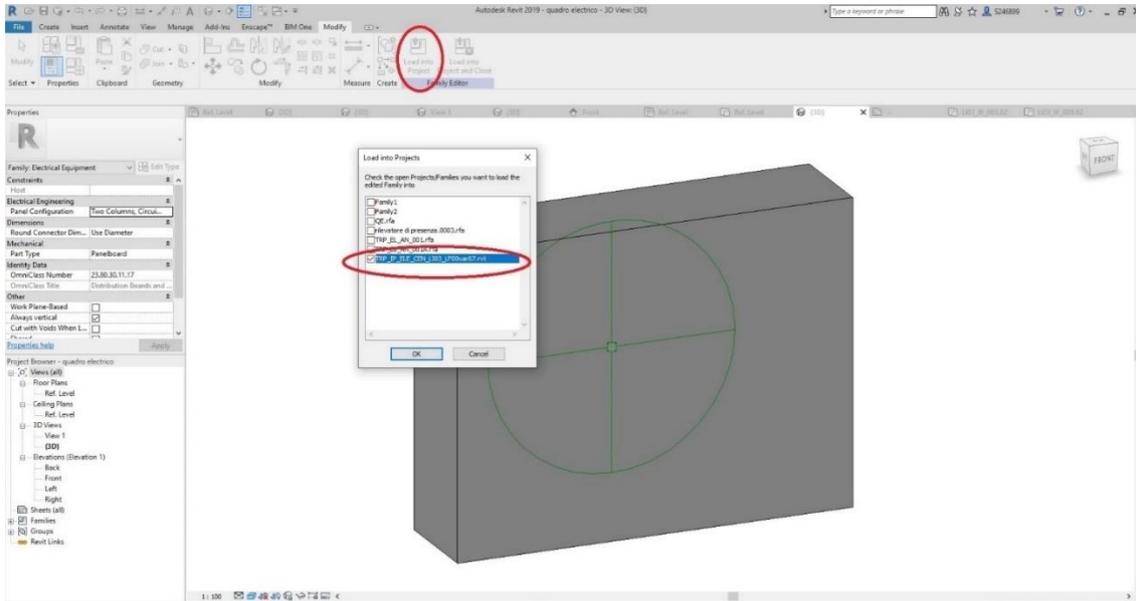


Figure 29. Uploading ready family object to the project

Next step is create electrical cable trays with all electrical components, final electrical models can be seen in following figure 30

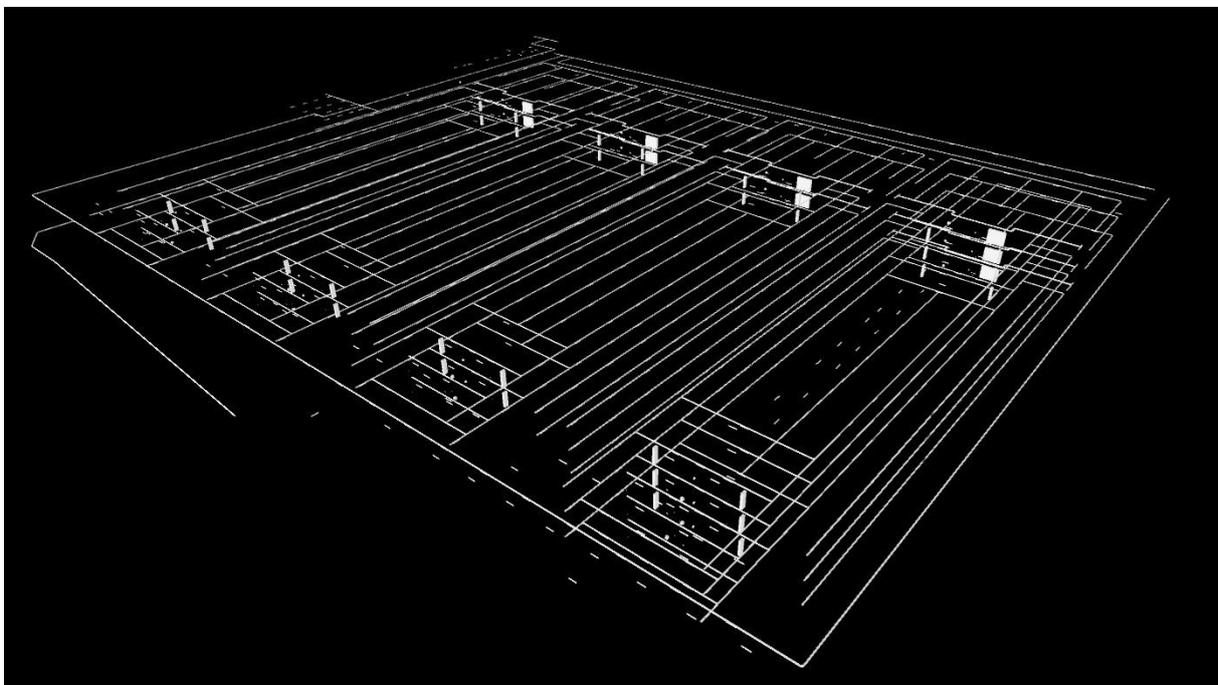


Figure 30. 3D model of the Electrical system

3.3. Circuits of the system

Revit software allows to create circuits for electricity systems, it is like connecting any electrical devices and equipment to establish an electrical system as in real life. Advantages of creating circuits are check the compatibility of electrical components and calculation wire length required for the entire electrical system. Also, it is possible to locate the cable in order to define in advance either the wires will be inside a wall or not.

The creating of lighting systems circuit was chosen for describing the procedure, which is same for other electrical components.

Before creation of the system circuit, adding **voltage definition** and distribution systems values are required in electrical settings. Since each lighting fixtures and electrical panel will be assigned with distribution system value one by one. If voltage is not defined or differ from one element to another one, it is not allowed to create circuit between two elements.

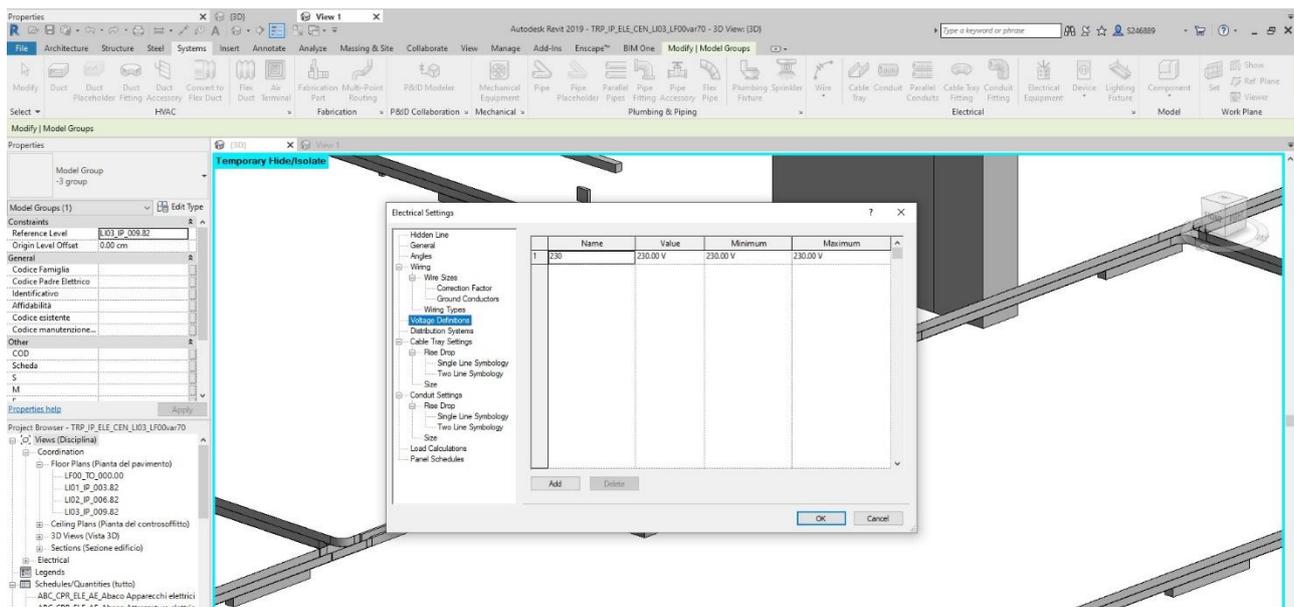


Figure 31. Electrical settings window

Now by selecting any element of the system, **power** and **switch** options for create circuit for electrical devices and switch systems for lighting fixtures respectively will appear. The import point is that, the element intaking electricity must be select first and then the element supplying electricity. Which means the creation electrical circuit starts from the lighting fixtures and end up with energy source. The software automatically calculate the length and size of wire to avoid voltages drop less then 3%.

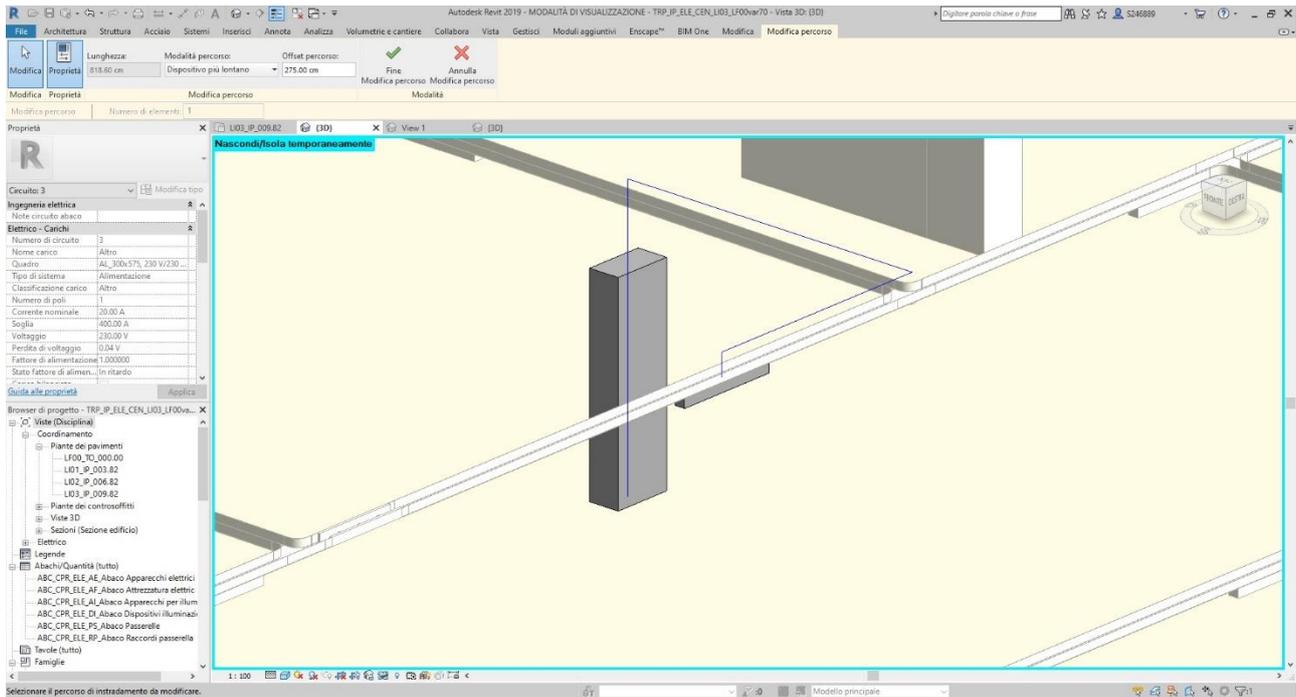


Figure 32. Circuit connection between lamp and electrical panel

As soon as the circuit is created with command **Edit path** it is possible only visualise the circuit connection, it does not mean that the wires or cables will follow exactly this path. Also, this command allows show one connection per a time it is not possible illustrate all connection at the same time. Once the circuit is created, it is possible to add or remove some electrical components from the system.

3.4. Schedules

For current project of the Piedmont Region, the TRP_Linee_Guida document was developed and provided by drawing to future team which contains a set of guidelines for the management of the project according to the BIM working methodology.

The CPR schedules must contain specific 15 parameters following a predetermined order, as shown in the table below:

Nº	Name of parameter	Translation
1	Famiglia	Family
2	Tipo	Type
3	Progetto	Project
4	Edificio	Building
5	Codice Categoria	Category Code
6	Codice Famiglia	Family Code
7	Classi di Unità Tecnologiche	Classes of Technological Units
8	Unità Tecnologiche	Technological Units
9	Classi di Elementi Tecnici	Classes of Technical Elements
10	Codice MasterFormat	MasterFormat Code
11	Titolo MasterFormat	MasterFormat Title
12	Identificativo	Identifier
13	Codice Esistente	Existing Code
14	Affidabilità	Reliability
15	Codice Padre ***	*** Father Code

Table 1. CRP schedule parameters ^[1]

First 6 parameters already discussed and further information can be found in the TRP_Linee_Guida file.

- **Classes of Technological Units, Technological Units and Classes of Technical Elements**

translates as Classi di Unità Tecnologiche, Unità Tecnologiche and Classi di Elementi Tecnici respectively, these parameters based on the UNI 8290 standard and these three levels of coding must follow the order.

CLASSIFICAZIONE E TERMINOLOGIA (NORMA UNI 8290 - 1981) (segue)		
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
	5.8 Impianto di telecomunicazioni	5.8.1 Alimentazione 5.8.2 Macchine 5.8.3 Reti di distribuzione e terminali
	5.9 Impianto fisso di trasporto	5.8.1 Alimentazione 5.8.2 Macchine 5.8.3 Parti mobili

Table 2. UNI 8290 Building elements - classification and terminology^[2]

This coding allows to divide any building or structure components into 8 group with three levels, as levels up more specific type of object mentioned. For example, if an electrical cabinet is considered, the group number 5 Service supply system must be selected for first level according to the table provided in UNI 8290. Service supply system is the set of technological units and technical elements of building system with the function of allowing the use energy like air conditioning, sanitary system, disposal networks and electrical systems etc. According to this table Electrical systems indicated with number 5.7 for second level technological units parameter. The last level of coding divides the system into supply, connections, electrical equipment, Distribution networks and terminals numbering from 1 to 4 respectively, depending on function of component. Due to fact the electrical cabinet supplies the electricity, it must be numbered as 5.7.1. In the following table some examples

Discipline	Name of objects	UNI 8290		
		Classes of technological units	Technological Units	Classes of Technical Elements
ELE	Quadro elettrico (electrical cabinet)	5	5.7	5.7.1
	Raccordi passerella (cable Tray with Fittings)	5	5.7	5.7.2
	Apparecchi di illuminazione (lighting fixtures)	5	5.7	5.7.4

Table 3. Building classification

- **MasterFormat Code and MasterFormat Title**

Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC) proposed a standard for organizing specifications named MasterFormat. The idea is to simplify communication between all actors involved in the project during whole life of the structure which will help to increase efficiency and respect the deadlines. The standard consists of a list with 8-digit numbering and titles in English language for each discipline of a building or a structure for schematizing information. The following figure illustrates Electrical part of the MasterFormat 2016 edition which was used the project.

MasterFormat® 2016 - Numbers and Titles		MasterFormat® 2016 - Numbers and Titles	
April 2016		April 2016	
25 51 00	Integrated Automation Control of Facility Equipment	26 05 13	Medium-Voltage Cables
25 52 00	Integrated Automation Control of Conveying Equipment	26 05 13.13	Medium-Voltage Open Conductors
25 53 00	Integrated Automation Control of Fire-Suppression Systems	26 05 13.16	Medium-Voltage, Single- and Multi-Conductor Cables
25 54 00	Integrated Automation Control of Plumbing	26 05 19	Low-Voltage Electrical Power Conductors and Cables
25 55 00	Integrated Automation Control of HVAC	26 05 19.13	Undercarpet Electrical Power Cables
25 56 00	Integrated Automation Control of Electrical Systems	26 05 19.23	Manufactured Wiring Assemblies
25 57 00	Integrated Automation Control of Communications Systems	26 05 23	Control-Voltage Electrical Power Cables
25 58 00	Integrated Automation Control of Electronic Safety and Security Systems	26 05 26	Grounding and Bonding for Electrical Systems
25 90 00	Integrated Automation Control Sequences	26 05 29	Hangers and Supports for Electrical Systems
25 91 00	Integrated Automation Control Sequences for Facility Equipment	26 05 33	Raceways and Boxes for Electrical Systems
25 92 00	Integrated Automation Control Sequences for Conveying Equipment	26 05 33.13	Conduit for Electrical Systems
25 93 00	Integrated Automation Control Sequences for Fire-Suppression Systems	26 05 33.16	Boxes for Electrical Systems
25 94 00	Integrated Automation Control Sequences for Plumbing	26 05 33.23	Switchgear for Electrical Systems
25 95 00	Integrated Automation Control Sequences for HVAC	26 05 36	Cable Trays for Electrical Systems
25 96 00	Integrated Automation Control Sequences for Electrical Systems	26 05 39	Underfloor Raceways for Electrical Systems
25 97 00	Integrated Automation Control Sequences for Communications Systems	26 05 43	Underground Ducts and Raceways for Electrical Systems
25 98 00	Integrated Automation Control Sequences for Electronic Safety and Security Systems	26 05 44	Sleeves and Sleeve Seals for Electrical Raceways and Cabling
26 00 00	Electrical	26 05 48	Poles for Electrical Systems
26 01 00	Operation and Maintenance of Electrical Systems	26 05 48.16	Vibration and Seismic Controls for Electrical Systems
26 01 10	Operation and Maintenance of Medium-Voltage Electrical Distribution	26 05 48.18	Seismic Controls for Electrical Systems
26 01 20	Operation and Maintenance of Low-Voltage Electrical Distribution	26 05 53	Identification for Electrical Systems
26 01 26	Maintenance Testing of Electrical Systems	26 05 73	Power System Studies
26 01 30	Operation and Maintenance of Facility Electrical Power Generating and Storing Equipment	26 05 73.13	Short-Circuit Studies
26 01 40	Operation and Maintenance of Electrical Protection Systems	26 05 73.16	Coordination Studies
26 01 40.13	Operation and Maintenance of Lighting Protection Systems	26 05 73.19	Arc-Flash Hazard Analysis
26 01 50	Operation and Maintenance of Lighting	26 05 73.23	Load Flow Studies
26 01 50.51	Luminaire Relamping	26 05 73.26	Stability Studies
26 01 50.81	Luminaire Replacement	26 05 73.29	Harmonic-Analysis Studies
26 05 00	Common Work Results for Electrical	26 05 78	Photometric Studies
26 05 05	Selective Demolition for Electrical	26 05 83	Wiring Connectors
		26 06 00	Schedules for Electrical
		26 06 10	Schedules for Medium-Voltage Electrical Distribution
		26 06 20	Schedules for Low-Voltage Electrical Distribution
		26 06 20.13	Electrical Switchboard Schedule
		26 06 20.16	Electrical Panelboard Schedule
		26 06 20.19	Electrical Motor-Control Center Schedule
		26 06 20.23	Electrical Circuit Schedule
		26 06 20.26	Wiring Device Schedule
		26 06 30	Schedules for Facility Electrical Power Generating and Storing Equipment
		26 06 40	Schedules for Electrical Protection Systems
		26 06 50	Schedules for Lighting
		26 06 50.13	Lighting Panelboard Schedule
		26 06 50.16	Lighting Fixture Schedule
		26 08 00	Commissioning of Electrical Systems
		26 09 00	Instrumentation and Control for Electrical Systems
		26 09 13	Electrical Power Monitoring
		26 09 15	Peak Load Controllers
		26 09 16	Electrical Controls and Relays
		26 09 17	Programmable Controllers
		26 09 19	Enclosed Contactors
		26 09 23	Lighting Control Devices
		26 09 26	Lighting Control Panelboards

Table 4. MasterFormat 2016 edition [3]

This coding similar to UNI 8290 standard, however in this case it contains two parameters with 4 level coding, each level has two number separated with a dot. First level indicates the general division like facility construction, services, infrastructure and equipment etc, each division is subdivided into a number of sections. If there is no required title in the list of any discipline, it is possible to use general code and title for example 26.00.00 Electrical. By increasing the level of code, more specific and detail component or activity of project specifies. For example the 26.05.00 common work for electrical and 26.05.33 is work with electrical supply, however 26.05.33.16 indicates Boxes for electrical system. In the following table some example of masterformat coding from the project are provided.

MasterFormat	
MasterFormat Code	MasterFormat Title
26.05.33.16	Boxes for electrical systems
26 05 36	Cable Trays for Electrical Systems
26 27 16	Electrical Cabinets and Enclosures
26 05 26	Grounding and Bonding for Electrical Systems
28 46 10	Detection and Initiation

Table 5. MasterFormat

- **Identifier** (Identificativo)

Identifier is a unique characterization of each individual instance present within the model. This code consists from the name of Family code, Type code, Level and Progressive numbering written only uppercase letters divided with bottom line. The level parameter consist of floor, building code and the level where this element is located. For each type of element progressive numbering starts from beginning with 5-digits where first 4 digits are zeros. Important to use this coding only with system families, while loadable families must be filled as “NA” in this field, since the meaning of the family code appears in the family name itself. The following criteria for compilation and a table with some examples of Identifier parameter used in project.

Criteria for naming: FamilyCode_TypeCode_Level_ProgressiveNumber

Type of family	Family Code	Type code	Level	Identifier
System	NA	AC FL	LI03 IP 009.82	TRP_IP_ELE_NA_AC_FL_LI03_IP_009.82_00001
Loadable	TRP_IP_ELE_RP	TE GE	LI03 IP 009.82	NA

Table 6. Identifier

In the first example the element is a system family so family code is not applicable due to fact that it is cannot rename a system family of the Revit software. In order not confuse with same type code families, prefix TRP_IP_ELE_ add to family code. On the other hand second element is loadable family and contain family code so the identifier parameter not applicable for it.

- **Existing Code** (Codice Esistente)

Code detected from existing documentation for information maintenance in the CAD / BIM passage. This parameter used only for mechanical equipments which was already exist in design drawings or tables provided by supplier or vendor of equipments. This code provides a link between two-dimensional representation and three-dimensional modelling of an object. It allows tracking any components of mechanical equipment specification and characteristics indicated in manufacturer's catalog and replace it if necessary. In the design drawings for electrical system were not specified any Existing Code of equipment, as a result the parameter field filled as "NA" (Not Applicable).

- **Reliability** (Affidabilità)

The Reliability code indicates class of validity of information related to any instance connected to the model. This parameter accepts values from 1 to 3, where 1 means the measurements where made in the site and 2 if the measurements obtained from design drawings. However if there is no any information about an instance, number 3 must be taken meaning that the measures are hypothesized. Interesting fact to mention is that Reliability code is dynamic parameter and can be level upped by time when an additional information will be available for any instance in question. During modelling the electrical system, all measurements if they present where were taken from design drawings. As results reliability codes for instance are 3 or 2 respectively.

- **Electrical Father Code** (Codice Padre Elettrico)

Father code is the parameter which characterize the reference source to instance, in the hierarchical order for disciplines. Father code can be an electrical, mechanical or plumbing etc., all systems which have a circuit for connecting elements together. The idea is to maintain the hierarchy and sequence of the systems to define the source element for each system at each level. The compilation structure is similar to Identifier parameter, however there are some differences. Father code may or may not refer to an selected instance, due to fact that it may represented higher source element in the hierarchal level of the system.

These two parameters filled for each object of the system, allowing to reconstruct whole system from last instance in the system to the source element. In the maintenance phase this tools is very important, for example there is a need to replace any element of the system, it is easy follow component circuit path till the source element. The electrical system of underground parking at level minus three floor is shown as an example in the following figure 33

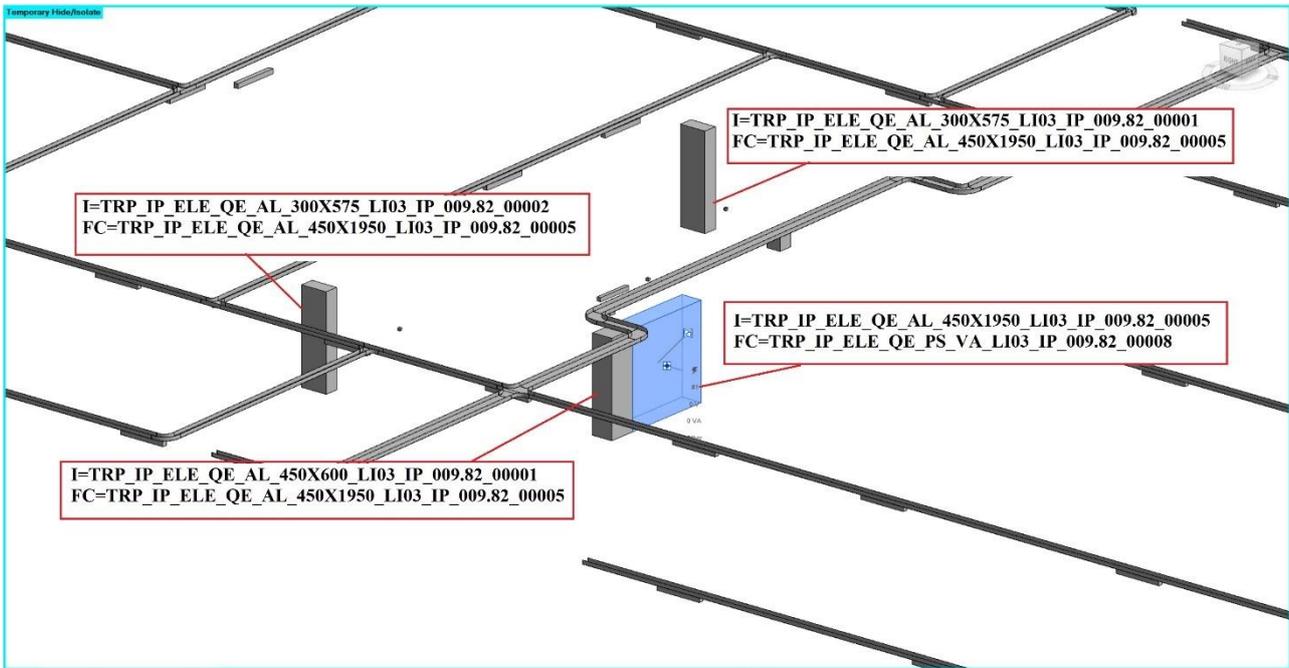


Figure 33. Father code

Where: I = Identifier

FC = Father Code

In the picture electrical box of the floor is used as "source-terminal" for other three electrical distribution panels. As a result, it is possible to evaluate the whole system by selecting any object in the system.

Creation CPR schedules

The Revit software allows to create different types of schedules like quantities, graphical column, material takeoff etc. In section view selection by schedules, quantities the new schedule panel must be chosen electrical schedules interested type from the list.

The electrical system model requires to create following schedules:

- Electrical devices
- Electrical equipment
- Lighting fixtures
- Lighting devices
- Cable trays
- Cable trays fittings

Due to the fact that schedule creations and filling procedures are the same for all types of schedules, a lighting fixtures schedule was chosen. Next step is to select all 15 parameters described above with a predetermined sequence as shown in the figure 34 below.

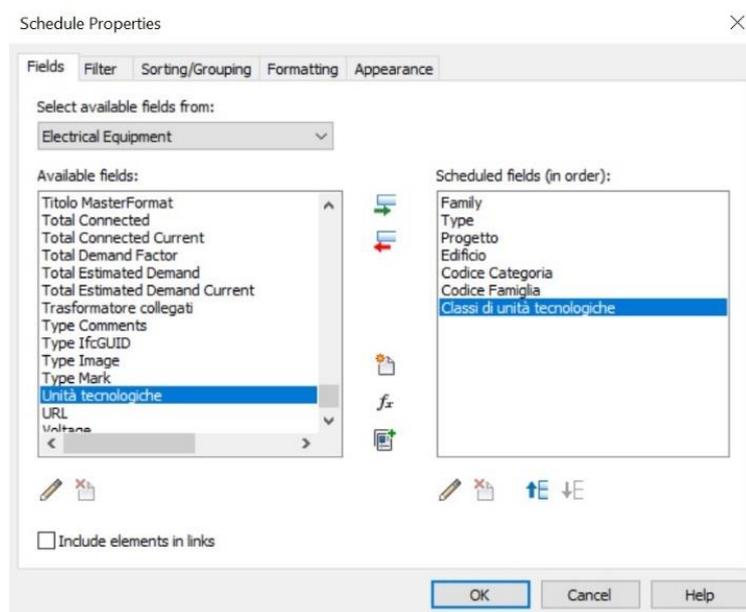


Figure 34. Schedule properties

The system will create a schedule for all instances with lighting fixtures which is more than one thousand elements in one schedule. It is possible to use the Dynamo software to fill schedules automatically, however it was decided to fill it manually, in order to understand all process and avoid big errors. Filling more than three thousand rows and fifteen columns means about forty-five

thousands of cells, could be time consuming activity. To help speed-up the process, BimOne software was chosen which is an extension to Revit software. BimOne allows to import and export schedules from a model to Excel file and manage them out of the Revit software.

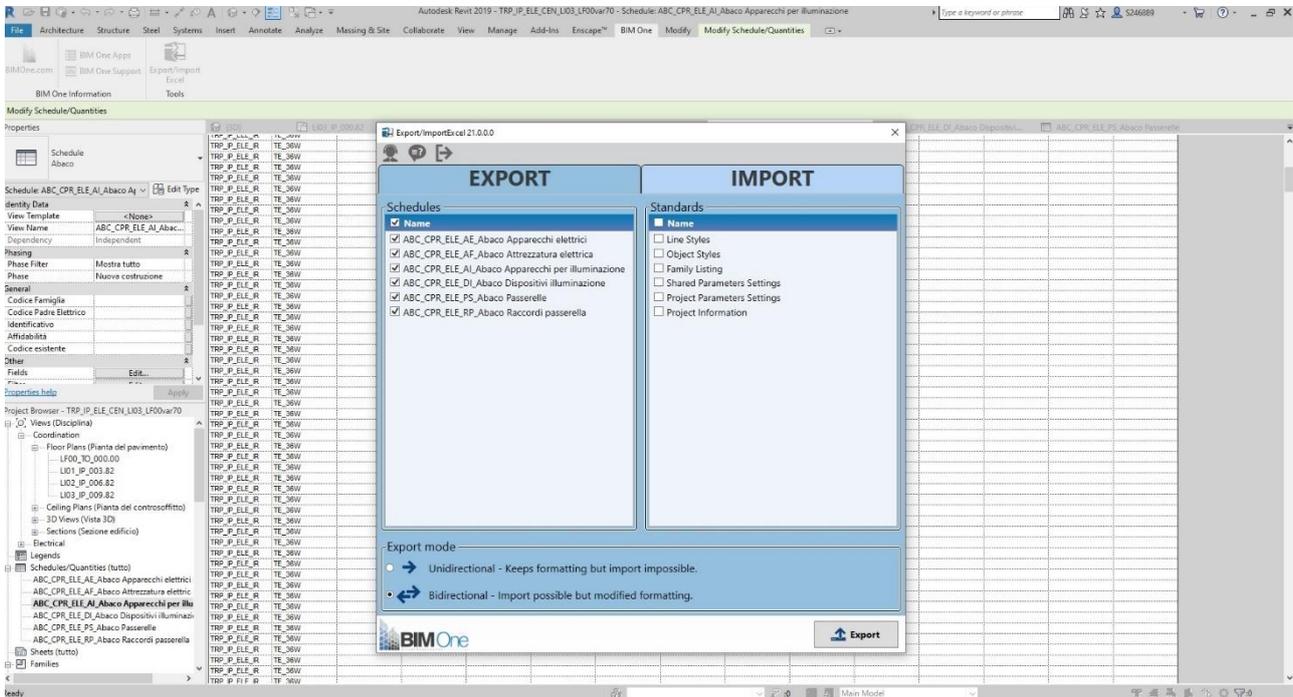


Figure 35. OneBIM

In Excel environment, it is still required to fill manually each column, but it is also possible create formulas for filling rows which most of the time repetitive as shown in the following figure 36

3	Family	Type	Progetto	Edificio	Codice Categoria	Codice Famiglia	Classi di unità tecnologiche	Unità tecnologiche	Classi di elementi tecnici	Codice MasterFormat	Titolo MasterFormat	Identificativo	Codice esistente	Affidabilità
4	ElementId	ElementId	Text	Text	Text	Text	Text	Text	Text	Text	Text	Text	Text	Text
1029	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00881	NA	2
1030	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00882	NA	2
1031	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00883	NA	2
1032	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00884	NA	2
1033	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00885	NA	2
1034	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00886	NA	2
1035	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00887	NA	2
1036	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00888	NA	2
1037	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00889	NA	2
1038	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00890	NA	2
1039	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00891	NA	2
1040	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00892	NA	2
1041	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00893	NA	2
1042	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00894	NA	2
1043	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00895	NA	2
1044	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00896	NA	2
1045	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00897	NA	2
1046	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00898	NA	2
1047	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00899	NA	2
1048	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00900	NA	2
1049	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00901	NA	2
1050	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00902	NA	2
1051	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00903	NA	2
1052	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00904	NA	2
1053	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00905	NA	2
1054	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00906	NA	2
1055	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00907	NA	2
1056	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00908	NA	2
1057	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00909	NA	2
1058	TRP_IP_ELE_IR	TE_80W	TRP	IP	AI	IR	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IR_TE_80W_LI03_IP_009.82_00910	NA	2
1059	TRP_IP_ELE_IS	TE_60W	TRP	IP	AI	IS	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IS_TE_60W_LI03_IP_009.82_00911	NA	2
1060	TRP_IP_ELE_IS	TE_60W	TRP	IP	AI	IS	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IS_TE_60W_LI03_IP_009.82_00912	NA	2
1061	TRP_IP_ELE_IS	TE_60W	TRP	IP	AI	IS	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IS_TE_60W_LI03_IP_009.82_00913	NA	2
1062	TRP_IP_ELE_IS	TE_60W	TRP	IP	AI	IS	5	5.7	5.7.4	28 46 10	Detection and Initiation	TRP_IP_ELE_IS_TE_60W_LI03_IP_009.82_00914	NA	2

Figure 36. OneBIM Import to Excel

After filling all schedules, it is possible just save excel file and import it again to the Revit schedules. The last step is the renaming of the CPR schedules according to the TRP LineaGuide.

The name of the CPR schedules is made up of 5 fields separated by the character "_", according to the following coding:

Field 1: is the Abacus Constant Code, formed by "ABC"

Field 2: is the Constant Code, made up of "CPR"

Field 3: this is the Discipline, Electrical "ELE"

Field 4: is the Category Code,

- Apparecchi Elettrici "AE" (Electrical devices)
- Attrezzatura elettrica "AF" (Electrical equipment)
- Apparecchi per illuminazione "AI" (Lighting fixtures)
- Dispositivi illuminazione "DI" (Lighting devices)
- Passerelle "PS" (Cable trays)
- Raccordi passerella "RP" (Cable trays fittings)

Field 5: is the default Schedule Name

The following figure illustrates the names of schedules created in the Revit software.

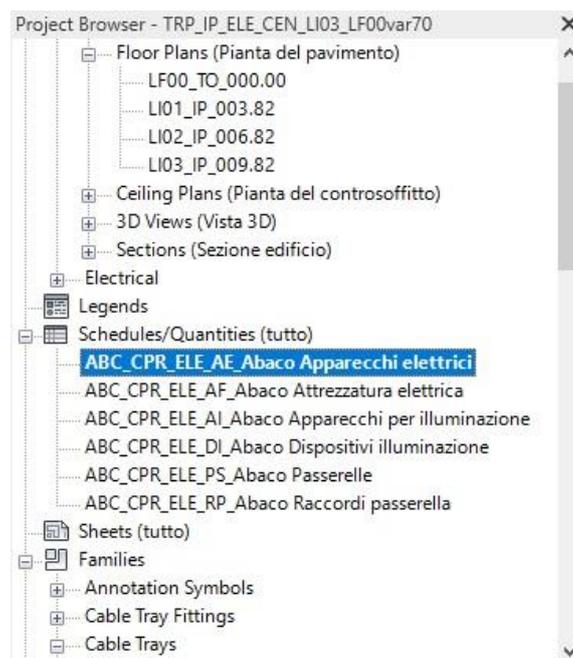


Figure 37. Project Browser

Function schedule

It is excel file schedule which separately from digital model in revit, this schedule included in the presentation tables of the work carried out and whose elimination would involve the modification of the tables themselves. The following function schedule was provide in excel file, all families and types in electrical discipline (ELE) were added.

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
Apparecchi Elettrici	AE	Cancabile/Sistema	Torre Regione Piemonte	TRP	Torre	TO	Elettrica	ELE	Scatole di giunzione - In PVC	SP	TRP_TO_ELE_SP	Accessorio	AC	Volt	230V	AC_230V
Apparecchi Elettrici	AE	Cancabile	Torre Regione Piemonte	TRP	ati Parch	IP	Elettrica	ELE	Punto alimentazione estrattore	AE	TRP_IP_ELE_AE	Alimentazione	AL	ND	ND	AL_ND
Apparecchi Elettrici	AE	Cancabile	Torre Regione Piemonte	TRP	ati Parch	IP	Elettrica	ELE	Gruppo di prese	GP	TRP_IP_ELE_GP	Alimentazione	AL	Ampere	16	AL_16A
Apparecchi Elettrici	AE	Cancabile	Torre Regione Piemonte	TRP	ati Parch	IP	Elettrica	ELE	collettore di terra	CT	TRP_IP_ELE_CT	Alimentazione	AL	ND	ND	AL_ND
Apparecchi Elettrici	AE	Cancabile	Torre Regione Piemonte	TRP	ati Parch	IP	Elettrica	ELE	Interruttore unipolare	IN	TRP_IP_ELE_IN	Accessorio	AC	Normale	N	AC_N
Apparecchi per illuminazione	AI	Cancabile/Sistema	Torre Regione Piemonte	TRP	Torre	TO	Elettrica	ELE	M_Apparecchio di illuminazione - Rettangolare	IR	TRP_TO_ELE_IR	Sorgente Luminosa	SL	Potenza	26W	SL_26W
Apparecchi per illuminazione	AI	Cancabile	Torre Regione Piemonte	TRP	ati Parch	IP	Elettrica	ELE	M_Apparecchio di illuminazione - Rettangolare	IR	TRP_IP_ELE_IR	Terminale	TE	Potenza	80W	TE_80W
Apparecchi per illuminazione	AI	Cancabile	Torre Regione Piemonte	TRP	ati Parch	IP	Elettrica	ELE	M_Apparecchio di illuminazione - Rettangolare	IR	TRP_IP_ELE_IR	Terminale	TE	Potenza	58W	TE_58W
Apparecchi per illuminazione	AI	Cancabile	Torre Regione Piemonte	TRP	ati Parch	IP	Elettrica	ELE	M_Apparecchio di illuminazione - Rettangolare	IR	TRP_IP_ELE_IR	Terminale	TE	Potenza	36W	TE_36W
Apparecchi per illuminazione	AI	Cancabile/Sistema	Torre Regione Piemonte	TRP	Torre	TO	Elettrica	ELE	M_Apparecchio di illuminazione - Rotondo - LOD	IS	TRP_TO_ELE_IS	Sorgente Luminosa	SL	Potenza	26W	SL_26W
Apparecchi per illuminazione	AI	Cancabile	Torre Regione Piemonte	TRP	ati Parch	IP	Elettrica	ELE	M_Apparecchio di illuminazione - Rotondo - LOD	IS	TRP_IP_ELE_IS	Terminale	TE	Potenza	60W	TE_60W
Apparecchi per illuminazione	AI	Cancabile/Sistema	Torre Regione Piemonte	TRP	Torre	TO	Elettrica	ELE	M_Apparecchio di illuminazione - Rotondo - LOD					Potenza	24W	SL_24W

Figure 38. Function schedule

To distinguish between existing elements in the schedule and added one, it was decided to colour it in yellow. All parameters required in the table already were described in previous chapter.

The name of the function schedules is similar to CRP schedules, only difference is:

Field 2: The Abacus Function Code, consisting of three letters: “QTO” Quantity Take Off

The following figure illustrates the function schedules

Name	Date modified	Type	Size
ABC_QTO_ELE_AE_Abaco Apparecchi elettrici	10/07/2021 12:50	Microsoft Excel W...	178 KB
ABC_QTO_ELE_AF_Abaco Attrezzatura elettrica	10/07/2021 12:50	Microsoft Excel W...	178 KB
ABC_QTO_ELE_AI_Abaco Apparecchi per illuminazione	10/07/2021 12:50	Microsoft Excel W...	178 KB
ABC_QTO_ELE_DI_Abaco Dispositivi illuminazione	10/07/2021 12:50	Microsoft Excel W...	178 KB
ABC_QTO_ELE_PS_Abaco Passerelle	10/07/2021 12:50	Microsoft Excel W...	178 KB
ABC_QTO_ELE_RP_Abaco Raccordi passerella	10/07/2021 12:50	Microsoft Excel W...	178 KB

Figure 39. Function schedule naming

4. Clash Detection

4.1. Clash types

In Building Information Modelling a term “Clash” means occupation of two components of different models the same space, while “Clash detection” is a technique to find clashes within project.

When clash detection is performing, 3 main types are looking for:

1. **Hard clash** it is when two or more objects are intersecting with each other. For example cable tray with concrete column.
2. **Soft clash** occurs when objects located too close to each other ignoring allowance rules. Example for such clashes could be not enough room for maintenance or installing HVAC system or locating electrical cables and firefighting pipes too close each other.
3. **Workflow Clash** occurs due to poor planning and scheduling of a construction process and could be any not logical sequence of work such as delivering a cement to start concrete works while there is no a concrete mixing unit in a site.

In this thesis focused on Hard clashes detection between electrical system and other disciplines of underground parking area.

Most of the cases the clash detection is performed between finished models of different disciplines, however it is possible use it while creating a model to avoid future clashes.

To perform Clash detection, Naviswork manage software was chosen as BIM integration tool.

Of course there is a way to check clash detection without BIM, by overlying 2D drawings of different disciplines. However this method difficult and time consuming due to fact that most projects are complex and big.

The clash detection has huge financial importance, due to fact that depending on importance and complexity of the project each clash costs around 20 000 euros to eliminated in construction phase considering also the project delays.

4.2. Model checking

After finish modelling phase of a discipline, it is possible to perform clash detection between other disciplines. At the time performing the test there were four 3d models of different disciplines were available:

- ARC STR* architectural and structural model
- HVAC heating, ventilation, and air conditioning system
- ELE electrical system
- ANT Firefighting system

*Architectural and structural models were decided to merge in one model due to fact that the underground parking is small.

Navisworks manage software allows to make test between only two disciplines in a time. The following figure 40 illustrates possible combination to perform it.

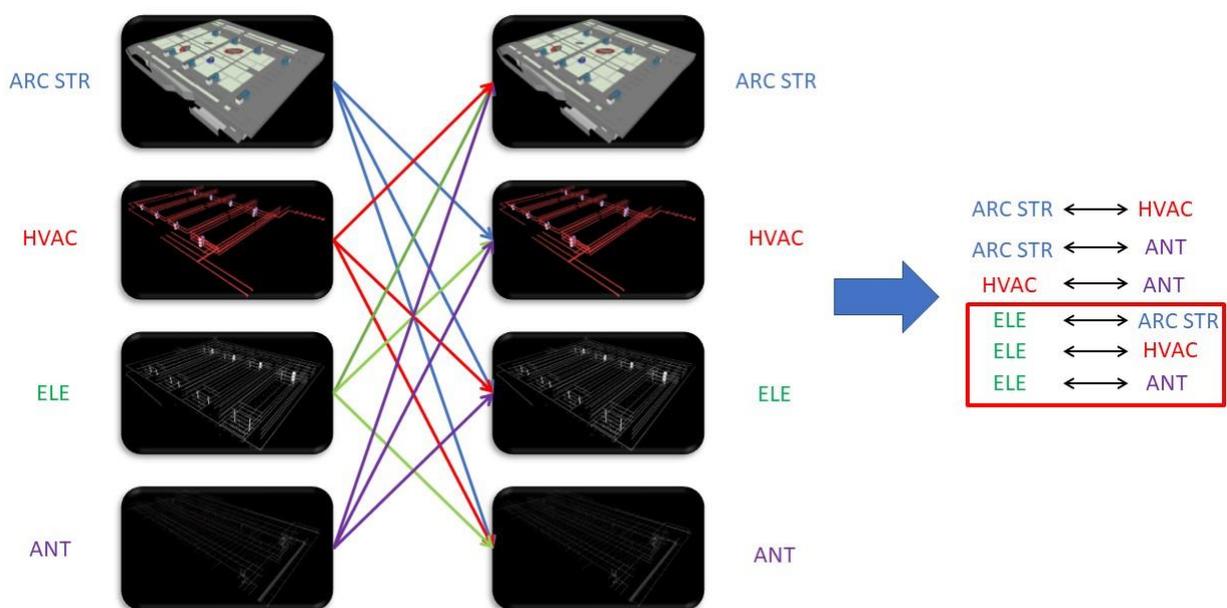


Figure 40. Model combinations

With 4 models it possible to perform the test in 12 ways, however for Navisworks manage software it does not matter which model is selected first to compare with another. So, there is only 6 possible combinations for 4 models provided. Due to fact that performing all possible combination with different tolerances and analysing the results are time consuming and complex task, so it was decided

make clash detection between electrical and other disciplines which means 3 tests will be done. Only the result between electrical and firefighting disciplines will be analysed.

4.3. Setting parameters

Performing clash test is not just selecting two 3d models and push “Run test” button, understating the models under test and adjustment of setting are required for more meaningful and accurate results. Otherwise, tons of useless, false positive results may be obtained which require waste of time for check. In case test between electrical system against architectural and structural combined models, we have to keep in main that some electrical components must be located partially or fully inside walls or ceilings. If such elements did not mention in the test parameter, Navisworks manage software detect them as errors (clashes). To avoid such unfavourable outcomes helps some parameter like **set**, **find items** and **selection inspector** which are located in **View** tab, **Windows** section as shown figure below.

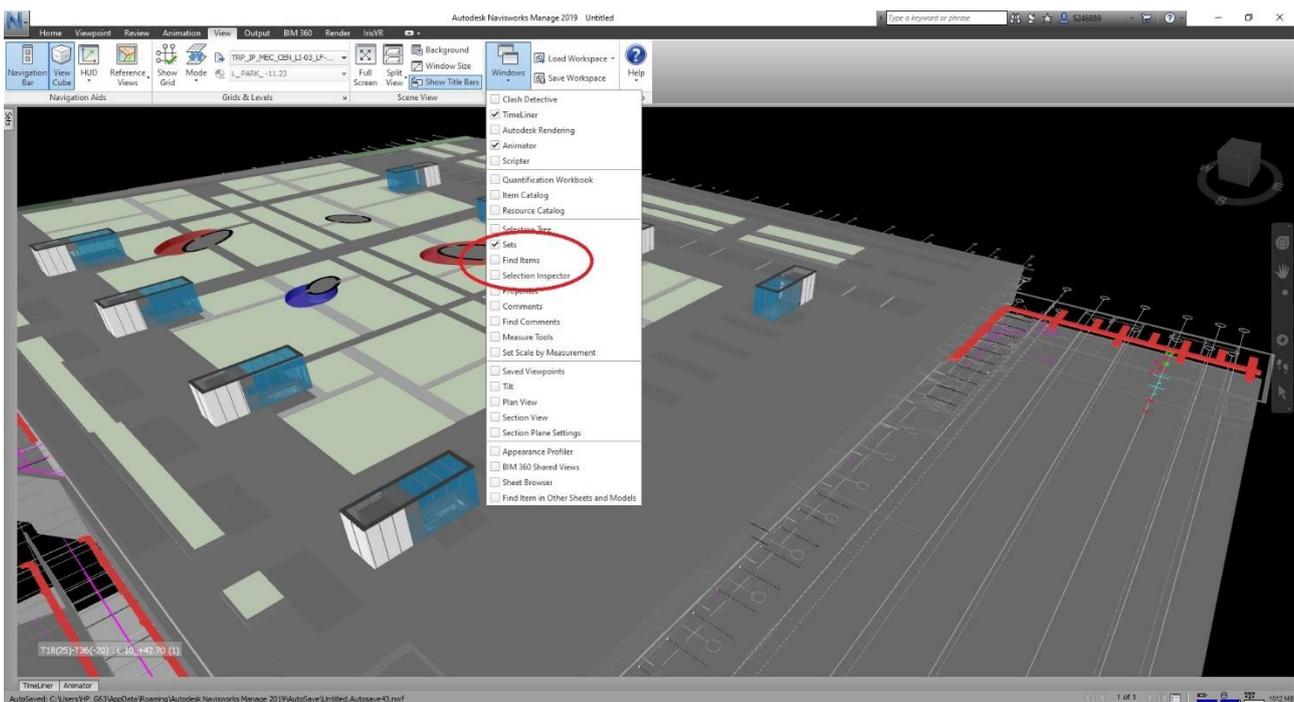


Figure 41. Setting parameters

Using these commands are easy and intuitive, first using **find items** it is possible select these electrical components which must be intersect with architectural and structural model. After selecting these elements, in the **selection inspector** windows create a selection set which will be seen in **Sets** window.

Second important parameters to enhance the results of the tests are **Type** and **Tolerance** of the each test

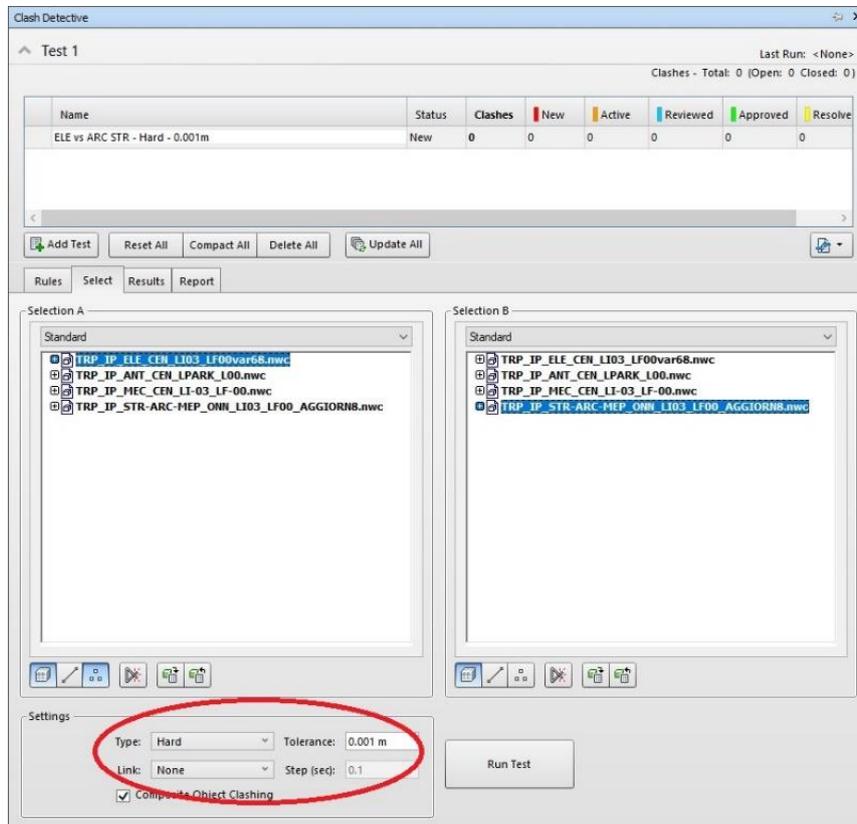


Figure 42. Clash detection window

To clarify the **tolerance definition** in case of two different clash types following examples from project were selected.

Depending on which type of clash was used the meaning of **tolerance** change oppositely, in the following figure illustrated the **hard clash** between HVAC duct and electrical cable tray with tolerance 30 mm which means in order to be reported as a clash the intersection between two objects must be at least 31 mm or more. All other intersections less then 30 mm the software will not identify as hard clash in the result. So if we repeat the same hard clash test with 50 mm tolerance the system will not report the issue in the figure this time, due to fact that this intersection is just 38 mm.

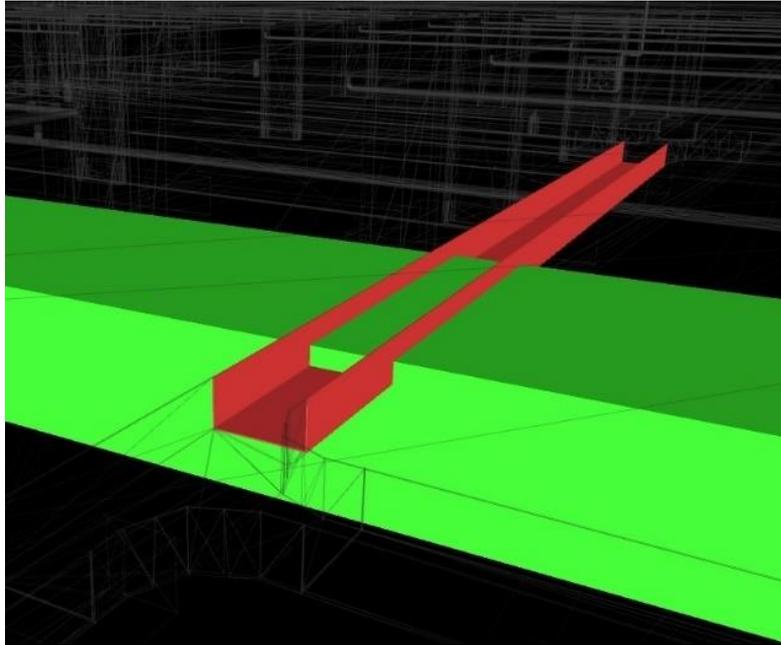


Figure 43. Example of hard clash

On the other hand, performing **clearance clash** (soft clash) test between Duct of HVAC system and electrical cable tray with **tolerance** 50 mm which means software will report all cases where two objects close each other to 50mm and less then 50mm as shown figure even if these two objects do not intersect.

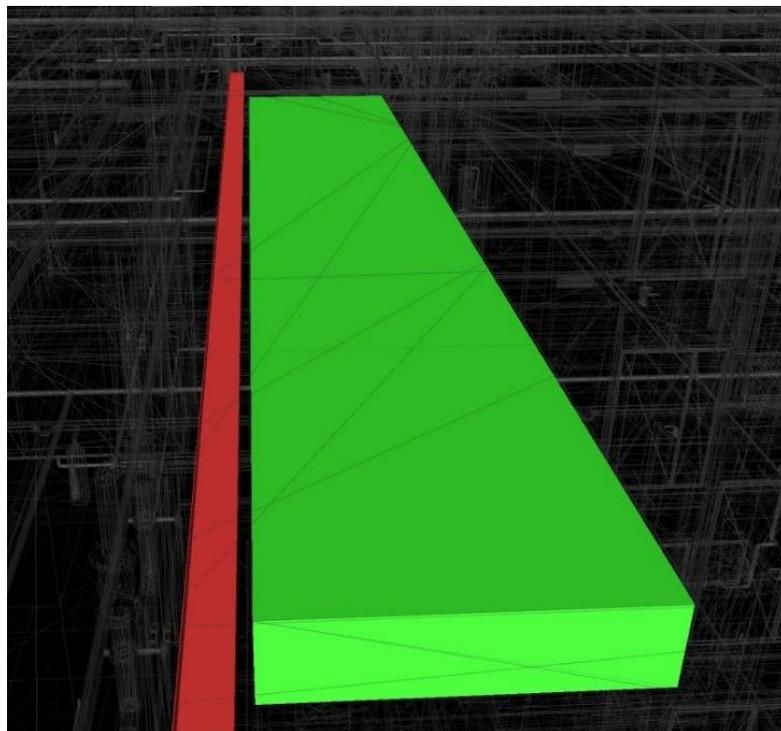


Figure 44. Example of Soft clash

There are no general rules for **tolerance** used for clashes, it always depends on:

- Type of clash
- Type of discipline testing
- Specific requirements for equipment or system (installation, operating or maintenance)

As dicribeed in previous chapter the electrical system has some components which must be recessed into or located in the surface of a floor, wall and ceiling. Due to this fact there is two option for performing the test. First is select all these elements in the model one by one and create selection set and second increase the tolerance for a hard clash

First option is more time consuming, so second option were selected by knowing the result will contain some false positive results.

As regards Clearance (soft) clash in this case not critical, for most of components of electrical system except couple equipment's like electrical panels which require free access.

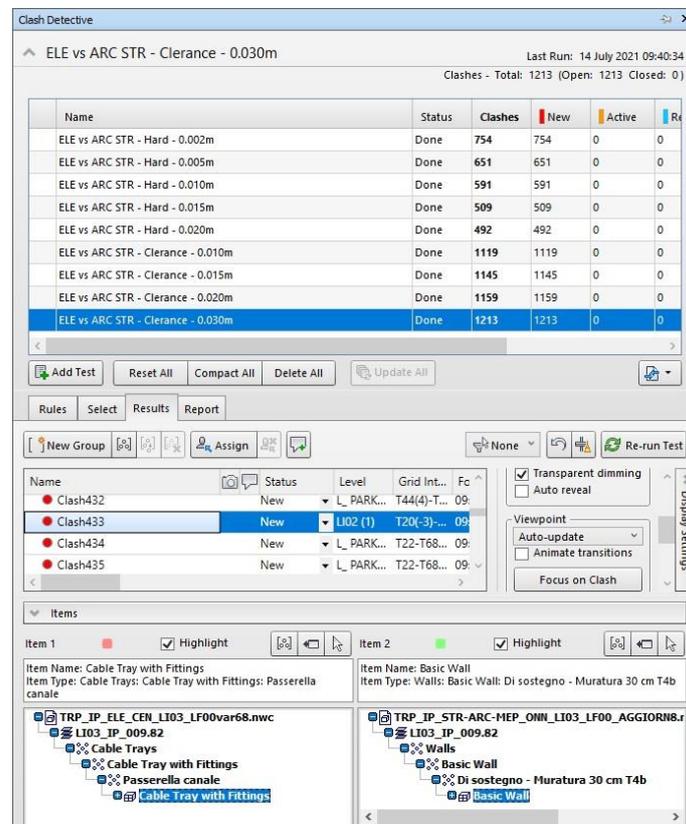


Figure 45. Electrical vs Architectural and structural models

In the figure we can observe as we increase tolerance in hard clash, number of clashed decreases however not dramatically and opposite trend can be seen for soft clash. The reason already was explained above and these results were expected.

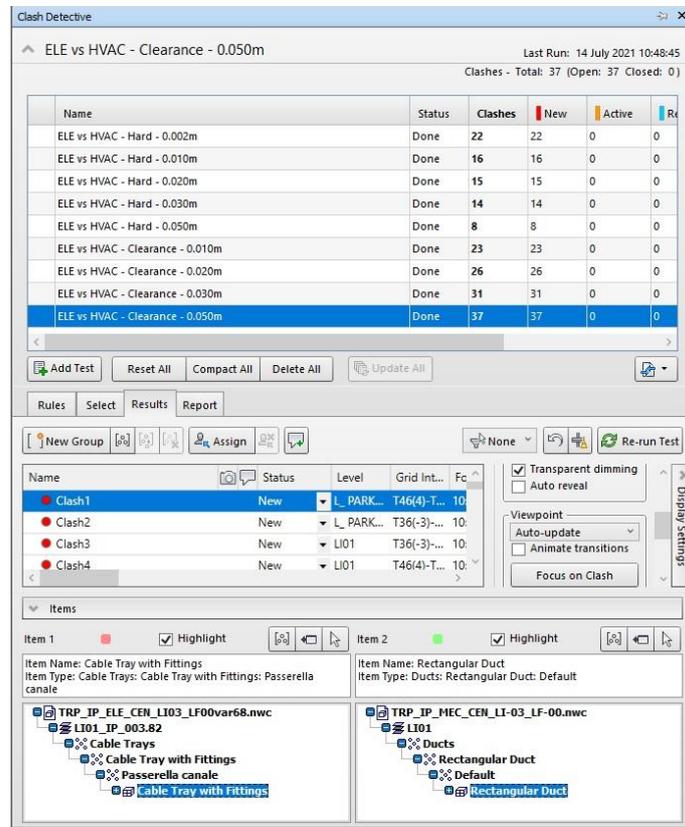


Figure 46. Electrical vs Heating, ventilation, and air conditioning system

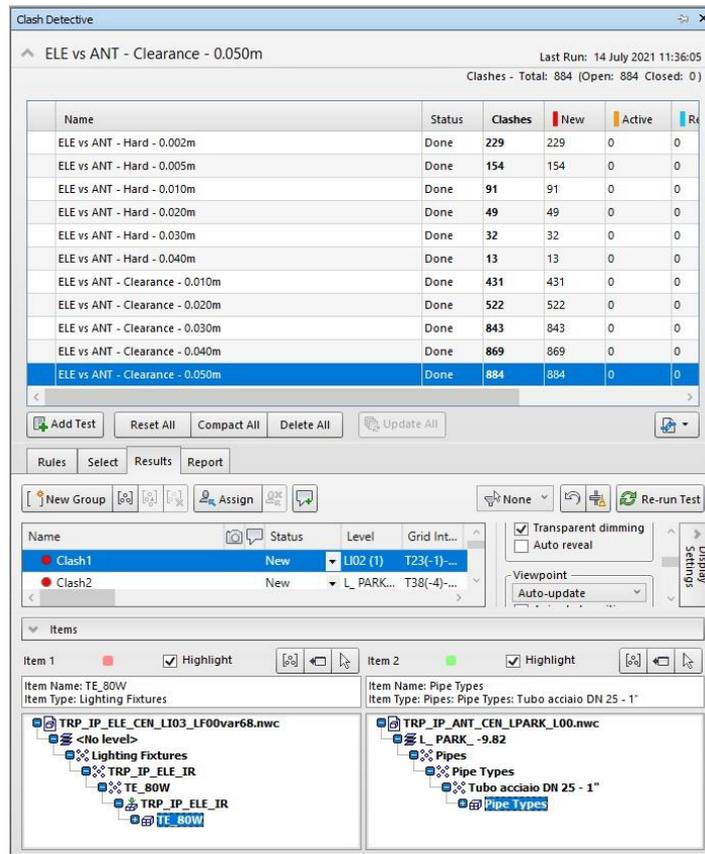


Figure 47. Figure Electrical vs Firefighting system

4.4. Clash detection results

The software Navisworks manages provides the results in table form for each clash with different tolerance shown as in figure 48. In total for 3 combinations between 4 disciplines with 2 types of clash and different tolerances, there were made 28 tests made which end up this about **12 000 clash results** which can be observed in the following table 7

HARD CLASH									
Tolerance	0.002m	0.005m	0.010m	0.015m	0.020m	0.030m	0.040m	0.050m	sub.Total
ELE vs ARCH STR	754	651	591	509	492	N/A	N/A	N/A	2997
ELE vs HVAC	22	N/A	16	N/A	15	14	N/A	8	75
ELE vs ANT	229	154	91	N/A	49	32	13	0	568
Total by tolerance	1005	805	698	509	556	46	13	8	3640

SOFT CLASH							
Tolerance	0.010m	0.015m	0.020m	0.030m	0.040m	0.050m	sub.Total
ELE vs ARCH STR	1119	1145	1159	1213	N/A	N/A	4636
ELE vs HVAC	23	N/A	26	31	N/A	37	117
ELE vs ANT	431	N/A	522	843	869	884	3549
Total by tolerance	1573	1145	1707	2087	869	921	8302

Total clashes	11942
----------------------	--------------

Table 7. Results

Of course, these results contain false positive clashes, however to each report, group similar clashes, eliminate false ones, checking each discipline element requirements and solve clashes will take too much time for analyse. These operations must be done by qualified specialist of each discipline with coordination of Chief designer engineer of the project.

Due to this fact, only ELE vs ANT hard clash report with tolerance 0.001m was selected for group the similar clashes and analyse it. From the results table can be observe that all intersection between electrical and firefighting are in the range of 2mm and 5cm tolerance. However, for electrical and Firefighting systems the intersections up to 1-2 cm are not critical, however all cases must be checked.

AUTODESK NAVISWORKS Clash Report

ELE vs ANT - Hard - 0.002m	Tolerance	Clashes	New	Active	Reviewed	Approved	Resolved	Type	Status
0.002m	229	229	0	0	0	0	0	Hard	Old

Image	Clash Name	Status	Distance	Grid Location	Description	Date Found	Clash Point	Item 1				Item 2					
								Item ID	Layer	Path	Item Name	Item Type	Item ID	Layer	Path	Item Name	Item Type
	Clash1	New	-0.049	T23-T25 : L02	Hard	2021/7/14 09:28	x:-109.914, y:84.444, z:-7.073	Element ID: 914042	<No level>	File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures > TRP_IP_ELE_IR > TE_80W > TRP_IP_ELE_IR > TE_80W > Solid	TE_80W	Solid	Element ID: 862476	L_PARK_-9.82	File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-9.82 > Pipes > Pipe Types > Tubo acciaio DN 25 - 1" > Pipe Types > Acciaio, carbonio	Acciaio, carbonio	Line
	Clash2	New	-0.048	T38-T67 : L_PARK_-1.75	Hard	2021/7/14 09:28	x:-93.411, y:63.912, z:-1.345	Element ID: 939881	<No level>	File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures > TRP_IP_ELE_IR > TE_80W > TRP_IP_ELE_IR > TE_80W > Solid	TE_80W	Solid	Element ID: 702793	L_PARK_-3.82	File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-3.82 > Pipes > Pipe Types > Tubo acciaio DN 25 - 1" > Pipe Types > Acciaio, carbonio	Acciaio, carbonio	Line
	Clash3	New	-0.048	T22-T67 : L_PARK_-1.75	Hard	2021/7/14 09:28	x:-108.760, y:68.405, z:-1.152	Element ID: 939855	<No level>	File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures > TRP_IP_ELE_IR > TE_80W > TRP_IP_ELE_IR > TE_80W > Solid	TE_80W	Solid	Element ID: 701542	L_PARK_-3.82	File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-3.82 > Pipes > Pipe Types > Tubo acciaio DN 25 - 1" > Pipe Types > Acciaio, carbonio	Acciaio, carbonio	Line
	Clash4	New	-0.047	T22-T33 : L_PARK_-1.75	Hard	2021/7/14 09:28	x:-124.727, y:13.668, z:-1.144	Element ID: 939845	<No level>	File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures > TRP_IP_ELE_IR > TE_80W > TRP_IP_ELE_IR > TE_80W > Solid	TE_80W	Solid	Element ID: 700812	L_PARK_-3.82	File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-3.82 > Pipes > Pipe Types > Tubo acciaio DN 25 - 1" > Pipe Types > Acciaio, carbonio	Acciaio, carbonio	Line
	Clash5	New	-0.047	T33-T38 : L_PARK_-1.75	Hard	2021/7/14 09:28	x:-109.374, y:9.189, z:-1.336	Element ID: 939827	<No level>	File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures > TRP_IP_ELE_IR > TE_80W > TRP_IP_ELE_IR > TE_80W > Solid	TE_80W	Solid	Element ID: 702102	L_PARK_-3.82	File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-3.82 > Pipes > Pipe Types > Tubo acciaio DN 25 - 1" > Pipe Types > Acciaio, carbonio	Acciaio, carbonio	Line
	Clash6	New	-0.047	T22-T25 : L02	Hard	2021/7/14 09:28	x:-104.411, y:82.840, z:-7.152	Element ID: 913996	<No level>	File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures > TRP_IP_ELE_IR > TE_80W > TRP_IP_ELE_IR > TE_80W > Solid	TE_80W	Solid	Element ID: 862488	L_PARK_-9.82	File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-9.82 > Pipes > Pipe Types > Tubo acciaio DN 25 - 1" > Pipe Types > Acciaio, carbonio	Acciaio, carbonio	Line
	Clash7	New	-0.045	T20-T69 : L_PARK_-1.75	Hard	2021/7/14 09:28	x:-95.933, y:55.268, z:-1.337	Element ID: 939877	<No level>	File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures > TRP_IP_ELE_IR > TE_80W > TRP_IP_ELE_IR > TE_80W > Solid	TE_80W	Solid	Element ID: 702690	L_PARK_-3.82	File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-3.82 > Pipes > Pipe Types > Tubo acciaio DN 25 - 1" > Pipe Types > Acciaio, carbonio	Acciaio, carbonio	Line
	Clash8	New	-0.045	T22-T69 : L_PARK_-1.75	Hard	2021/7/14 09:28	x:-111.285, y:59.747, z:-1.144	Element ID: 939853	<No level>	File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures > TRP_IP_ELE_IR > TE_80W > TRP_IP_ELE_IR > TE_80W > Solid	TE_80W	Solid	Element ID: 701439	L_PARK_-3.82	File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-3.82 > Pipes > Pipe Types > Tubo acciaio DN 25 - 1" > Pipe Types > Acciaio, carbonio	Acciaio, carbonio	Line
	Clash9	New	-0.044	T33-T41 : L02	Hard	2021/7/14 09:28	x:-130.076, y:15.325, z:-7.069	Element ID: 914012	<No level>	File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures > TRP_IP_ELE_IR > TE_80W > TRP_IP_ELE_IR > TE_80W > Solid	TE_80W	Solid	Element ID: 861560	L_PARK_-9.82	File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-9.82 > Pipes > Pipe Types > Tubo acciaio DN 25 - 1" > Pipe Types > Acciaio, carbonio	Acciaio, carbonio	Line
	Clash10	New	-0.043	T23-T69 : L02	Hard	2021/7/14 09:28	x:-116.634, y:61.406, z:-7.066	Element ID: 914030	<No level>	File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures > TRP_IP_ELE_IR > TE_80W > TRP_IP_ELE_IR > TE_80W > Solid	TE_80W	Solid	Element ID: 862191	L_PARK_-9.82	File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-9.82 > Pipes > Pipe Types > Tubo acciaio DN 25 - 1" > Pipe Types > Acciaio, carbonio	Acciaio, carbonio	Line
				T22-T33 :		2021/7/14	x:-124.478,	Element ID:		File > File > TRP_IP_ELE_CEN_L03_LF00var68.nwc > <No level> > Lighting Fixtures >			Element ID:		File > File > TRP_IP_ANT_CEN_LPARK_L00.nwc > L_PARK_-9.82 > Pipes > Pipe Types > Tubo acciaio DN	Acciaio,	

Figure 48. Hard clash detection report between ELE vs ANT with tolerance 2mm

After analysing all 229 cases of hard clashes, it was possible for grouping the results into 6 main groups as depicted in the following figure 49.

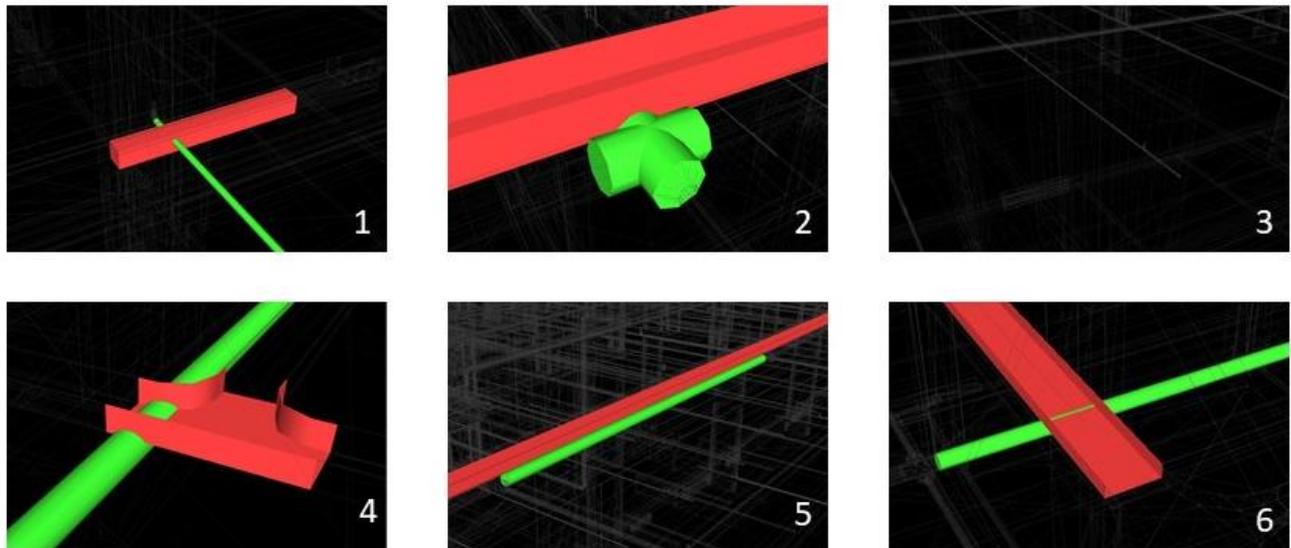


Figure 49. Grouping of results

Where:

- **Group 1.** Intersection between lighting fixture and firefighting pipe with sprinkler
- **Group 2.** Intersection between electrical cable tray and firefighting fitting pipe
- **Group 3.** False positive
- **Group 4.** Intersection between electrical cable tray fitting and firefighting fitting pipe
- **Group 5.** Very close parallel location of electrical cable tray and firefighting fitting pipe
- **Group 6.** Perpendicular intersection of electrical cable tray and firefighting fitting pipe

Groups number 3 and 5 can be eliminated as false positive results, even if in group 5 has 2mm intersection which is not critical at all. All other groups of clashes can be solved by changing one of the system elevations, however clashes in the groups number 1,2 and 4 are more severe and must be studied in more detail.

To check actual situation regarding these clashes and discuss possible solutions, the visit to contraction site was organized. During the site inspection with a head engineering of project were discovered that:

- It is not enough to change elevation of only one system, due to the fact that electrical cable tray passes the fire fighting pipeline above and below.
- All clashes related to electrical, firefighting and HVAC systems already were solved in the construction site.
- The model validation of Electrical system require taking measurements of whole systems.

In following figures it possible observe the comparison between 3D core model and picture of actual clash solution taken during the inspection.

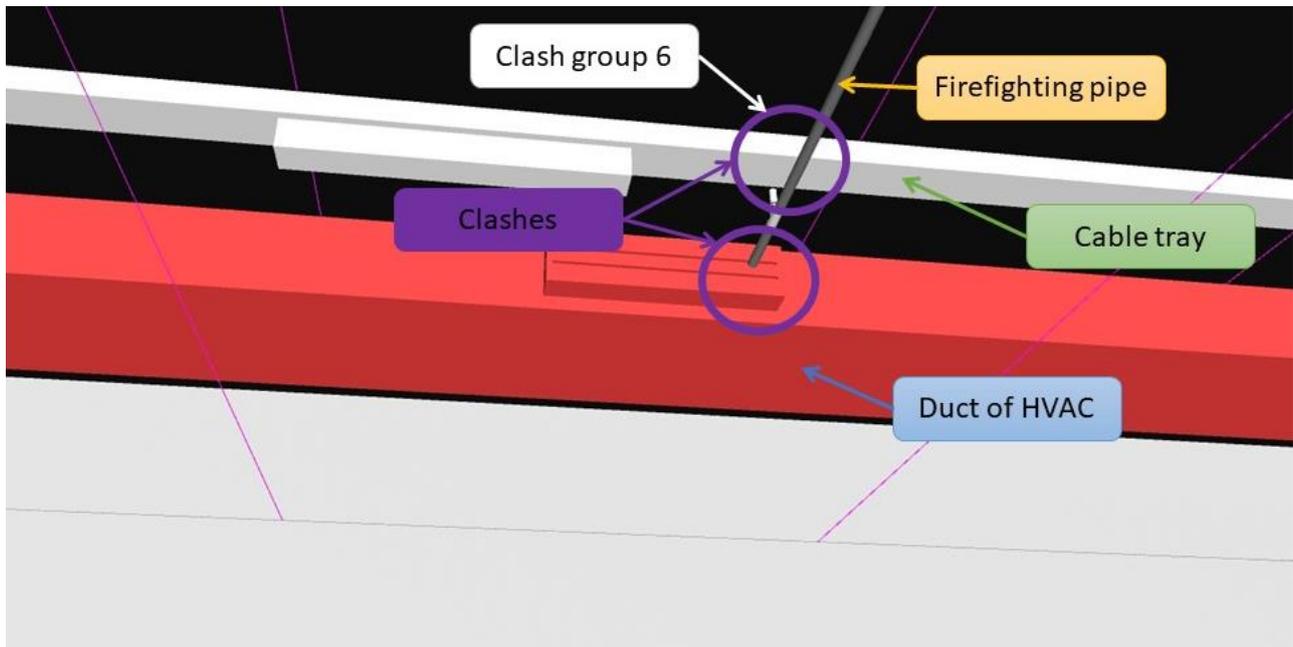


Figure 50. 3D core model

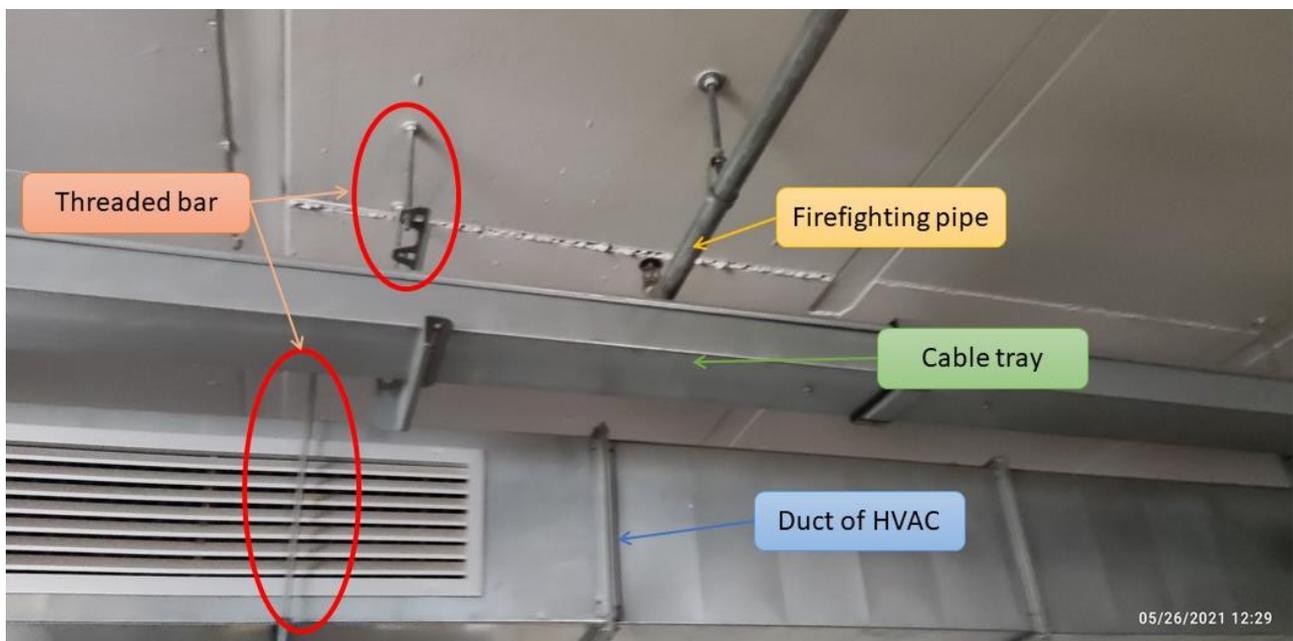


Figure 51. Actual clashes solution on the site
 [Source: photo made during the visit of the site 05/26/2021]

as we can observe the threaded bars were a solution for these two clashes. Due to fact that it was possible to manage the elevations of the electrical, fire fighting and HVAC systems during installation, there no severe issued occurred during the construction phase.

There are some other comparison between clash groups detected by Navisworks manage software and actual solutions made in the construction site.

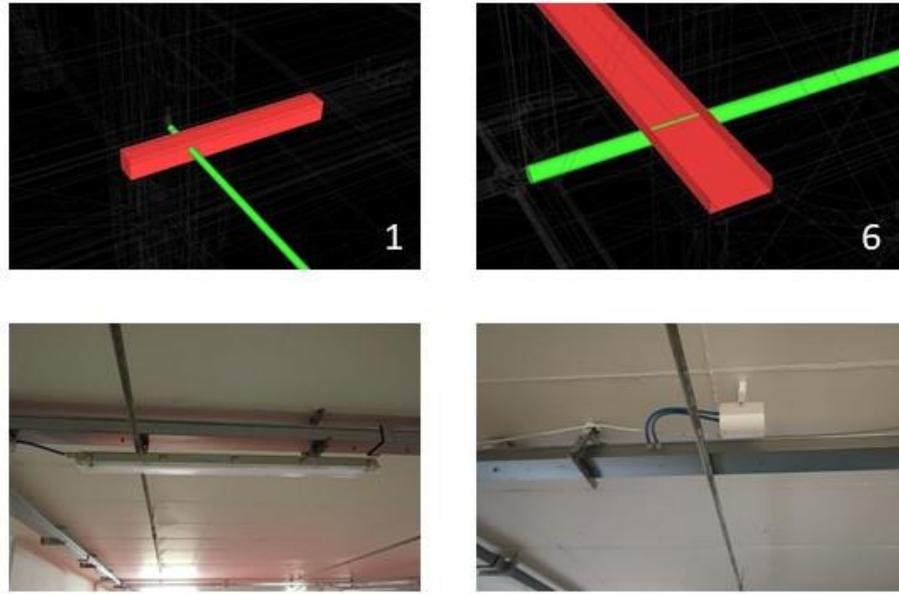


Figure 52. Additional actual clashes solution on the site

5. Conclusion

Conclusion

In general, I found working on this thesis as a crucial contribution in my development as a BIM engineer. During thesis work I was able to acquire knowledge about BIM and its direct use in practical case study of Skyscraper of the Piedmont Region for getting real life experience. Theoretical learning gives only knowledge about some subjects or concepts, while practical application teaches how to implement it in certain problems. The combination of these two allows a deeper understanding of a concept through performing a personal experience. I was able to develop my skills in BIM tools, I particularly found Revit BIM software to be useful in improving my skills in parametric modelling with different levels of detail on the basis of project regulations. However, BIM use with Navisworks manages for clash detection between different disciplines seems more important and a high demanded skill in the market.

As regards the results, most of severe clashes would possibly be detected and solved during the design phase if the project were designed with BIM methodology from the beginning. Due to the fact that the current project was made with traditional methodology with 2D CAD drawings, it was not possible to detect these clashes between electrical, firefighting and HVAC systems. Modelling of MEP based on 2D drawings with wrong elevations, as a result while creating each discipline it was not possible to detect elevation issues. These discrepancies were found only in the core model where all discipline models are merged together, to detect all of them Clash detection tests were performed.

I believe that if these discipline clashes were not possible to solve by just manipulation of their elevations, during the construction time they may end up with huge financial issues. However, this project has been in construction about 10 years maybe the reason for such delay are other clashes in the main building which is much more complex compared to the parking area.

While I had many useful experiences as a junior BIM engineer, I feel that Building Information Modelling is not complete and further development is required.

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Notes

Chapter 1. Case study

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Figure. Real 3D model of Piedmont Region Tower

Chapter 2. BIM

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Figure. BIM (Building Information Modeling)

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IFC definition and figure

Chapter 3. MEP modelling

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Table. UNI 8290 Building elements - classification and terminology

[3] *Table. MasterFormat 2016 edition*