

# **POLITECNICO DI TORINO**



**Master of Science in Civil Engineering Thesis**

## **MEP modelling of a subway station to an executive level of design with clash detection verification**

**Case study: Collegno Centro Station**

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“Ai miei nipotini,  
fonte infinita di gioia e spensieratezza.”

# *Abstract*

*In this historical period construction industry is experiencing an important change as a result of the technological transformation of the field.*

*Indeed, transferring all the data of brand new or existing constructions on a digital base is becoming a common tendency. BIM (Building Information Modelling) methodology plays a fundamental role in this objective and provides the control of all the information related to a project.*

*An important aspect of BIM can be found in the MEP modelling, which studies the three systems (Mechanical Electrical and Plumbing) linked to every building project and constitute an integral part of it.*

*MEP design is important for planning, decision making, accurate documentation, performance and cost-estimation, construction, and operating/maintaining the resulting facilities.*

*This thesis contains the modelling of some of the MEP systems made with Revit software of a future subway station of the metropolitan city of Turin, the Collegno Centro station.*

*Once models of various disciplines were obtained, the focus turned to macro and micro clash detections thanks to the use of different software. This last operation has been done both between single disciplines and structural and functional models of the subway station and between MEP disciplines themselves.*

*In addition, it has been analysed a more theoretical part of the MEP which regards drafting of the coding of the modelled single parts of plant engineering.*

# Contents

1 BIM Engineering .....	1
1.1 Interoperability .....	1
1.2 Common Data Environment.....	3
1.2.1 BIM 360 .....	6
1.3 MEP Engineering .....	9
1.4 LOD .....	11
2 Reference standards.....	15
2.1 UNI EN ISO 19650.....	15
2.2 Legislative Decree 50/2016 .....	15
2.3 Decree 560/2017 .....	16
2.4 UNI 11337 .....	17
3 Case study .....	18
3.1 System design.....	20
3.2 Ventilation, air conditioning and fire system .....	20
4 Methodology .....	21
5 Information production .....	23
5.1 MEP modelling within Revit.....	26
5.2 Templates.....	29
5.3 Levels .....	29
5.4 Linking files .....	30
5.4.1 Linking Revit .....	31
5.4.2 Linking CAD .....	32
5.5 Object creation.....	33
5.5.1 Family Editor .....	35

5.5.2 Duct accessories .....	36
5.6 LOI and LOG .....	40
6 Results.....	46
6.1 Ventilation and air conditioning system .....	46
6.2 Fire system.....	48
7 Clash detection .....	51
7.1 Revit.....	52
7.2 Navisworks.....	55
7.3 BIM 360 Coordinate .....	61
7.4 BIM 360 Coordinate and Navisworks interoperability .....	67
8 Conclusions .....	71
8.1 Future development.....	72
Bibliography .....	73

# Index of figure

Figure 1: Interfaces between parties and teams for the purpose of information management [ <a href="https://bim.acca.it/uni-en-iso-19650-2019-pubblicate-in-italiano-le-norme-internazionali-sul-bim/">https://bim.acca.it/uni-en-iso-19650-2019-pubblicate-in-italiano-le-norme-internazionali-sul-bim/</a> ] .....	1
Figure 2: Interoperability. [ <a href="https://biblus.accasoftware.com/en/ifc-whats-it-for-whats-its-connection-with-bim/">https://biblus.accasoftware.com/en/ifc-whats-it-for-whats-its-connection-with-bim/</a> ] .....	2
Figure 3: Common Data Environment scheme. ....	4
Figure 4: Different kind of section of BIM 360 as CDE. [ <a href="https://www.linkedin.com/pulse/future-bim-common-data-environment-autodesk-360-mileta-pejovic/">https://www.linkedin.com/pulse/future-bim-common-data-environment-autodesk-360-mileta-pejovic/</a> ] .....	6
Figure 5: Workflow for BIM 360 Clouds. [ <a href="https://www.autodesk.com/bim-360/bim-collaboration-software/design-collaboration/revit-cloud-worksharing/">https://www.autodesk.com/bim-360/bim-collaboration-software/design-collaboration/revit-cloud-worksharing/</a> ] .....	8
Figure 6: Example of MEP model in Revit. [ <a href="https://it.geofumadas.com/bim-curso-de-revit-mep-mecanica-electricidad-y-plomeria/">https://it.geofumadas.com/bim-curso-de-revit-mep-mecanica-electricidad-y-plomeria/</a> ]. ....	10
Figure 7: LOD, AIA. [ <a href="https://evolve-consultancy.com/lod-lod-loi/">https://evolve-consultancy.com/lod-lod-loi/</a> ] .....	12
Figure 8: Diagram of information links between entities of work digital objects and their level of development (LOD). [UNI 11337] .....	13
Figure 9: Map of the Turin subway. ....	19
Figure 10: Collegno Centro station. ....	20
Figure 11: Revit System tab. ....	26
Figure 12: Routing Preferences for IIA system. ....	28
Figure 13: Levels related to the system models. ....	30
Figure 14: Revit linking possibilities. ....	31
Figure 15: Difference between reference type. [ <a href="https://revitiq.com/attachment-vs-overlay-revit/">https://revitiq.com/attachment-vs-overlay-revit/</a> ] .....	31
Figure 16: New floor plan. ....	32
Figure 17: Hierarchical structure of Revit objects. [ <a href="https://revitpure.com/blog/33-weird-revit-terms-explained">https://revitpure.com/blog/33-weird-revit-terms-explained</a> ] .....	34
Figure 18: Project browser, Revit. ....	37
Figure 19: Type properties, Revit. ....	38
Figure 20: Different families used into the IVC model. ....	39

Figure 21: Junction with connection, Revit.....	39
Figure 22: Edit window for shared parameters.....	41
Figure 23: Parameter property, Revit.....	42
Figure 24: Detail of the modelled fire system.....	44
Figure 25: Detail of the air ventilation and conditioning system.....	44
Figure 26: 3D view of IVC model.....	46
Figure 27: 3D view of IVC, STR and FUN models.....	46
Figure 28: Lateral view of the model, Revit.....	47
Figure 29: Front view of the model, Revit.....	47
Figure 30: Top view of the model, Revit.....	47
Figure 31: 3D view of IIA, STR and FUN models.....	48
Figure 32: 3D view of IIA model.....	48
Figure 33: Top view of the model, Revit.....	49
Figure 34: Lateral view of the model, Revit.....	49
Figure 35: Front view of the model, Revit.....	49
Figure 36: Manage Links, Revit.....	52
Figure 37: Interference Check, Revit.....	53
Figure 38: Interference Report, Revit.....	54
Figure 39: Revit external tool.....	55
Figure 40: First step to add a test within Navisworks.....	55
Figure 41: Test settings.....	56
Figure 42: Add other models to make clash detection verification.....	57
Figure 43: IIA clash detection test.....	57
Figure 44: Clashes between IIA and IVC models.....	58
Figure 45: Solution found to the intersection.....	58
Figure 46: Case of pipe intersecting a duct.....	58
Figure 47: Intersection between IVC and FUN models.....	59
Figure 48: Intersection between IIA and FUN models.....	59
Figure 49: Intersection between IIA and STR models.....	60
Figure 50: Export Report and Reports Result. [ <a href="https://www.bim-hex.com/single-post/2018/04/09/Best-practice-for-Clash-Detection">https://www.bim-hex.com/single-post/2018/04/09/Best-practice-for-Clash-Detection</a> ].....	60
Figure 51: Model coordination set within BIM 360.....	61



Figure 52: Table present into the clashes section.....	62
Figure 53: Characteristics that is possible to set into a clash. ....	63
Figure 54: 3D view of a clash between IIA and FUN models. ....	63
Figure 55: List of assigned issues. ....	64
Figure 56: Different kind of issues. ....	64
Figure 57: Attachment set of the Issue. ....	64
Figure 58: Insight section of BIM360. [ <a href="https://knowledge.autodesk.com/support/bim-360/learn-explore/caas/simplecontent/content/automating-bim-360-model-coordination-clash-reports.html">https://knowledge.autodesk.com/support/bim-360/learn-explore/caas/simplecontent/content/automating-bim-360-model-coordination-clash-reports.html</a> ].....	65
Figure 59: Setting options within Report. [ <a href="https://knowledge.autodesk.com/support/bim-360/learn-explore/caas/simplecontent/content/automating-bim-360-model-coordination-clash-reports.html">https://knowledge.autodesk.com/support/bim-360/learn-explore/caas/simplecontent/content/automating-bim-360-model-coordination-clash-reports.html</a> ].....	66
Figure 60: Insight output of BIM360. [ <a href="https://get.construction.autodesk.com/bim360mc-navisworks-integration-webinar-ungated/?_ga=2.159291325.647887994.1606296178-362227237.1569592853">https://get.construction.autodesk.com/bim360mc-navisworks-integration-webinar-ungated/?_ga=2.159291325.647887994.1606296178-362227237.1569592853</a> ] .....	66
Figure 61: Interoperability between BIM 360 and Navisworks. ....	67
Figure 62: Model opening in Navisworks.....	68
Figure 63: Manage issue tab. ....	68
Figure 64: List of issues displayed.....	69

## Index of table

Table 1: Documents code table. ....	23
Table 2: Code for ventilation elements. ....	24
Table 3: : Code for single elements within IVC and IIA models.....	24
Table 4: Table of shared parameter used for IVC model.....	43

# 1 BIM Engineering

In the last years, the use of Building Information Modeling (BIM) has grown significantly as an optimizing factor of the whole building sector, supported by innovation technology. As a methodology, BIM allows the actors of AECO (Architecture, Engineering, Construction and Operation) 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. [1]

This thesis follows one of the main steps of BIM workflow, that is considered the engine of the VDC (Virtual Design and Construction) process. The procedure is represented by a scheme mainly composed of three sections:

- Inputs data, composed by a set of processes ecosystems and stored data;
- BIM Engine, a machine where 3D parametric model is generated with geometrical and alphanumerical detail;
- Outputs data, the products generated by the BIM engine in a form of exchange formats, oriented to target applications used by the project team.

Therefore, the use of innovative methods such as Building Information Modelling (BIM) allows professionals to optimize their work through developing 3D parametric models that contain large amount of data useful for the whole building life cycle. The meaning of BIM consists of a set of activities to create, manage, derive and communicate information among stakeholders based on an informative model that is a digital representation of reality.

The new concept of building industry should be based on efficient process where the involved actors usually fill-in and extract data from 3D parametric models that are frequently updated. Thus, digitalization is based not only on processes and technology, but also on people that need training to understand strengths and challenges of BIM methodology. [2,3,4,5]

## 1.1 Interoperability

In the project delivering process, many actors are involved. These actors are usually grouped by parties, which are at the same time assembled into teams when they have to perform a specific task. Parties exchange information in the appointments. The appointed party is who provides the information to the appointing party. This information must follow some requirements in order to be exchanged. The information is formed by containers and the set of containers form the information model. These information containers are practically all the files generated by the project team, which can have several extensions depending on its nature.

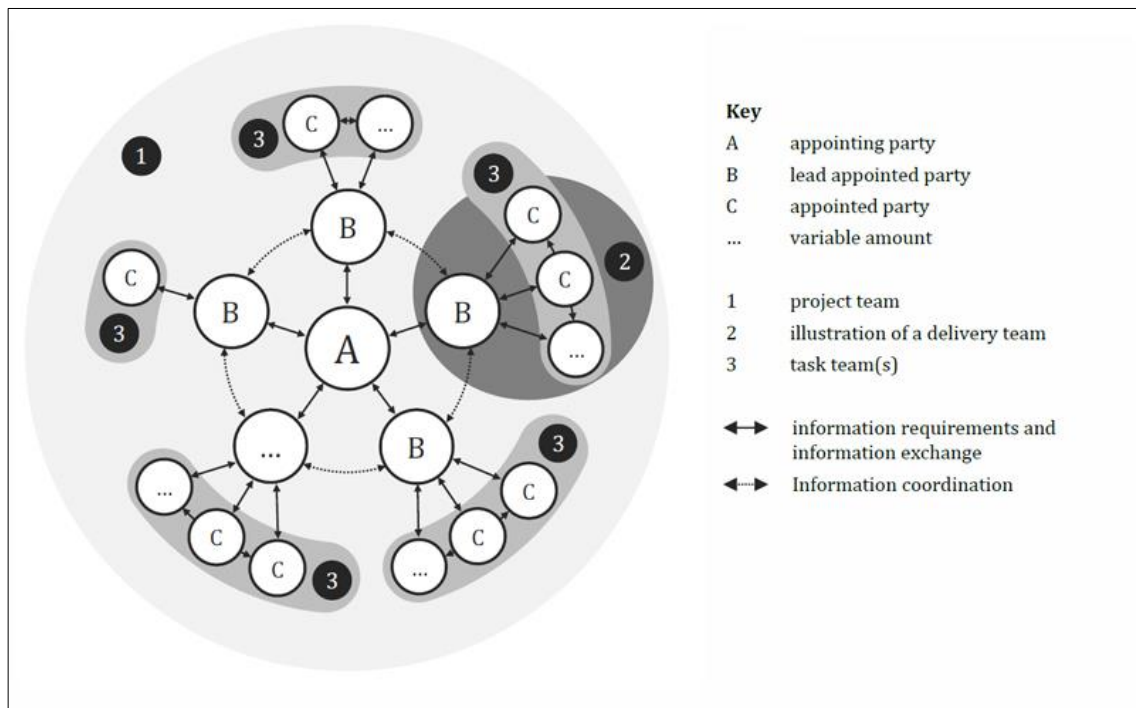


Figure 1: Interfaces between parties and teams for the purpose of information management  
[\[https://bim.acca.it/uni-en-iso-19650-2019-pubblicate-in-italiano-le-norme-internazionali-sul-bim/\]](https://bim.acca.it/uni-en-iso-19650-2019-pubblicate-in-italiano-le-norme-internazionali-sul-bim/)

It is important to mention that there is not only one unique software encompassing all the activity spectrum. A software is a tool created for a particular purpose. During the information creation process, designers may need different software of different firms, which use different formats and languages. This is where the term interoperability comes up.

In order to reach an objective, all actors must unify the way information is exchanged.

The idea of creating standards is born following the same principle. Actors that follow the same standards speak the same language. Unfortunately, there are lots of different standards even in the same country, like the case of USA. They were created in order to fulfil different requirements. The use of British standards for managing information became very popular on BIM environment, so nowadays the creation of an international standard based on those standards is in progress. The term that defines how well is information exchanged between two different software, is called interoperability. Usually during the process of importing and exporting files from a software to another one, some data are lost. These data can be graphical or even alphanumerical. The best is having a model interchange without distortions. The less information is lost, the better interoperability between two different software is.

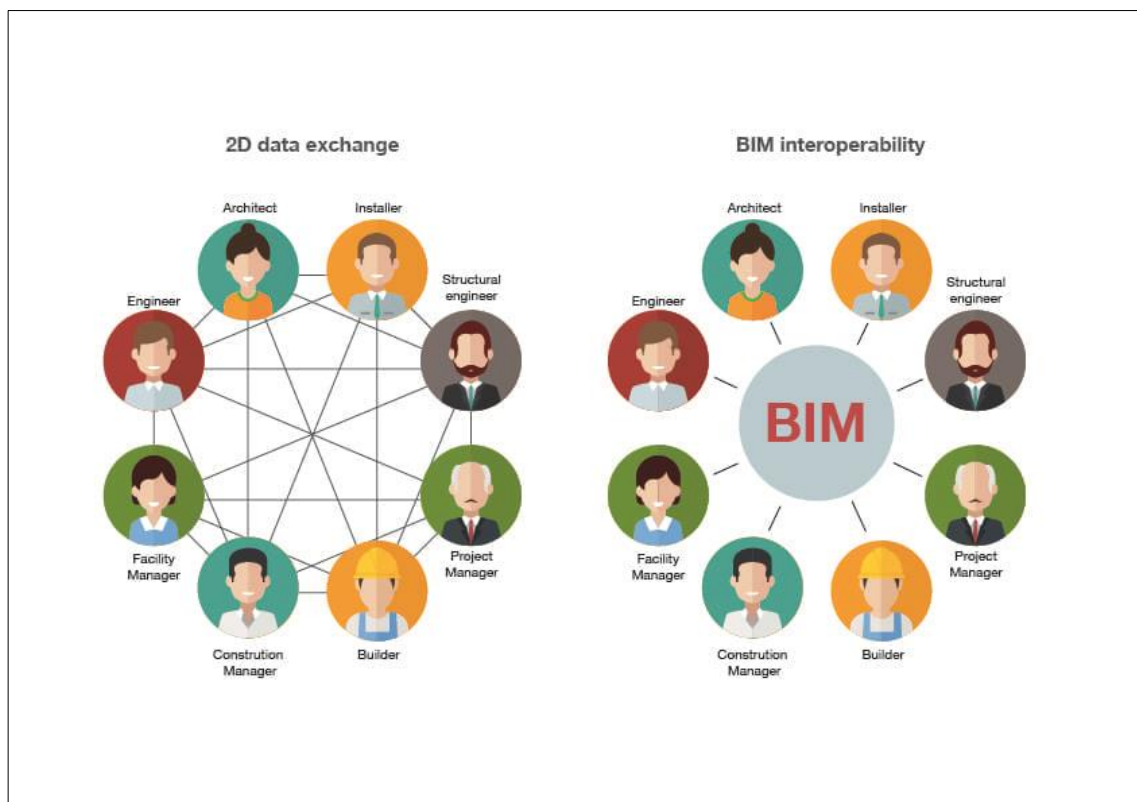


Figure 2: Interoperability. [<https://biblus.accasoftware.com/en/ifc-whats-it-for-whats-its-connection-with-bim/>]

## 1.2 Common Data Environment

The Common Data Environment (CDE) is a central repository where construction project information is housed. The contents of the CDE are not limited to assets created in a 'BIM environment' and it will therefore include documentation, graphical model and non-graphical assets. In using a single source of information collaboration between project members should be enhanced, mistakes reduced and duplication avoided.

Many BIM protocols, in particular the CIC BIM Protocol, propose the use of a common data environment. The ultimate aim being to improve the creation, sharing and issuing of information that underpins the delivery of your project. The idea of collaboration to drive improved results and efficiencies is at the heart of implementing a Building Information Modelling (BIM) approach on construction projects.

As a single source of information there's no arguments about which version of information should be being referenced. The CDE should serve as the ultimate source of 'truth' and bring a number of advantages for all involved:

- Shared information should result in coordinated data which will, in turn, reduce both time and cost on your project.
- Project team members can all use the CDE to generate the documents/views they need using different combinations of the central assets, confident that they are using the latest assets (as are others).
- Spatial co-ordination is inherent in the idea of using a centralized model.
- Production information should be right first time assuming that contributors adhere to processes for sharing information.

In Italy, the data sharing environment is called ACDat and is thus defined by art.2 of DM 560/2017: The data sharing environment is defined as a digital, organized and shared data collection environment for a work, and structured into information on, and primarily traceable to, digital models and processes, based on an IT infrastructure whose sharing is regulated by precise security access

systems, traceability and historical sequence of changes made to information content, conservation over time and relative accessibility of information heritage content, definition of responsibilities in the development and protection of intellectual property. [20]

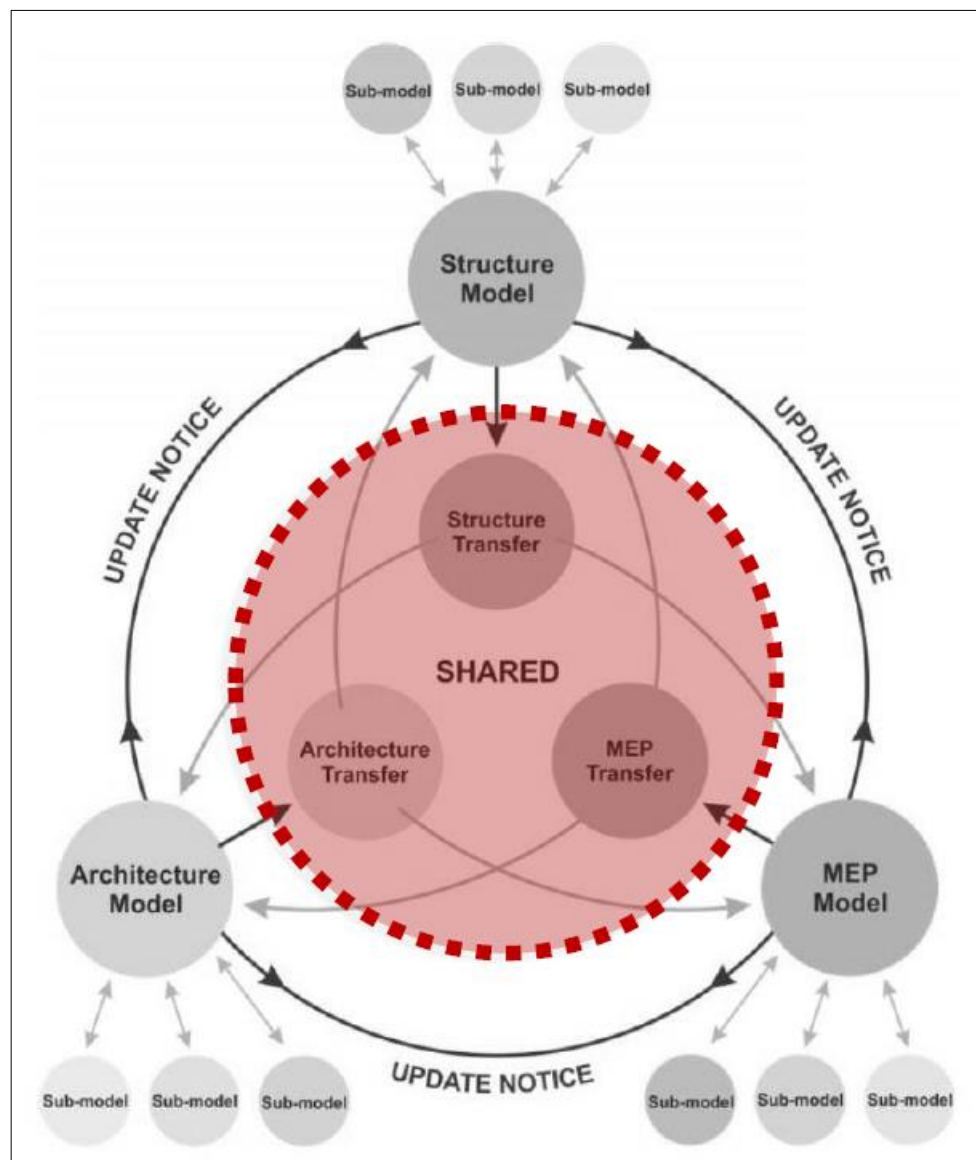


Figure 3: Common Data Environment scheme.

In the UK technical standards the CDE is defined in an organic manner, while the Italian standard, UNI 11337, does not specify how the ACData will work and how it will be organised, but only the requirements it will have to meet [16]:

- accessibility, according to certain rules, by all actors involved in the process;
- traceability and historical sequence of updates of the data contained;
- ease of access, storage and extrapolation of data (open data exchange protocols);
- conservation and updating over time;
- assurance of confidentiality and security.

In addition, UNI 11337-7 defines the requirements of four professional profiles:

- CDE Manager Data Sharing Environment Manager ;
- Manager of Digitized Processes BIM Manager ;
- BIM Coordinator Information Flow Coordinator ;
- Advanced Information Management and Modeling Operator BIM Specialist.

### 1.2.1 BIM 360

Developing this thesis BIM 360 Docs has been used as Common Data Environment platform, but depending on a construction stages, these are various Autodesk BIM 360 solutions to be progressively included in the process:

- BIM 360 Teams and C4R (collaboration for Revit)
- BIM 360 Glue
- BIM 360 Docs
- BIM 360 Layout
- BIM 360 Plan and BIM 360 Field
- BIM 360 Ops

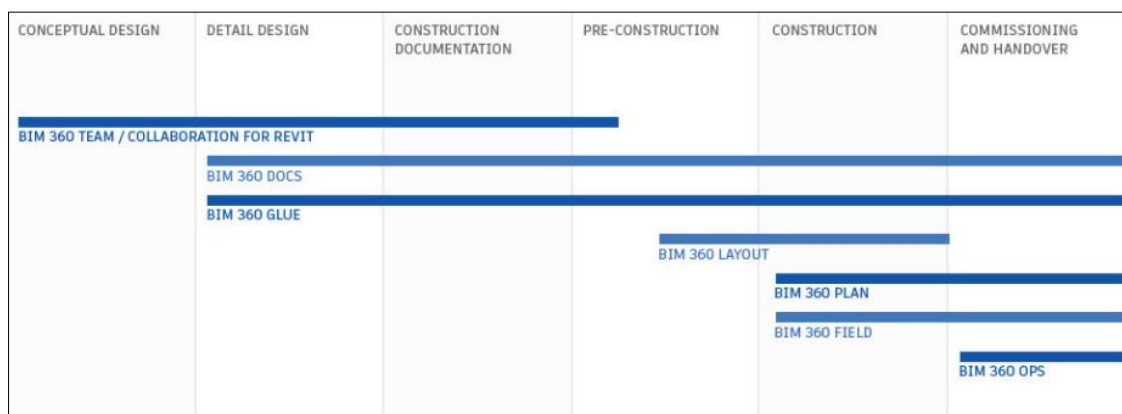


Figure 4: Different kind of section of BIM 360 as CDE. [<https://www.linkedin.com/pulse/future-bim-common-data-environment-autodesk-360-mileta-pejovic/>]

BIM 360 Docs is a unique, "all in one place" common data environment for all types of documents. As an addition to common document type file formats such as pdf, xls, docx, it also supports all Autodesk file formats and documents within them.

It allows to create new folder within different access permission. It is possible to add people to this folder and make sure that the right people have the access to the right information. In fact, when someone is added to the folder it is asked to select a permission level that include:

- View only: User/role/company may view documents, add private markups, and create issues.



- View + Download: User/role/company may view documents, add private markups, create issues.
- Upload only: User/role/company may upload documents but not see the folder contents.
- View + Download + Upload: User/role/company may share their own documents with team members and view any other documents in that folder.
- View + Download + Upload + Edit: User/role/company may share their own documents with team members, view and edit any other documents in that folder, and publish markups.
- Folder Control: User/role/company may share their own documents with team members and view and edit any other documents in that folder. With folder control permission they can also carry out tasks within that folder that are usually restricted to the project administrator. This includes creating title blocks, adding project members, managing permissions, and editing set assignment. This permission level offers the greatest access to folders. [28]

The approval workflow feature enables document managers to facilitate, control, and automate the distribution of documents to project members.

Members designated as reviewers can then review and comment on the documents, and members designated as approvers can give final approval for the documents to be used.

The Review and Approval Process is now available to both the BIM 360 Plans and Project folder workflows. [29]

Teams use issues to identify and communicate areas of concern or improvement with project documents. Within the Project Admin module, project administrators can create issue types, sub-types, and custom attributes. They also control permissions for issues across all modules in BIM 360.

In Document Management and Design Collaboration, issues are associated with documents. In Field Management, issues can be associated with documents or with an on-site quality, safety, or other problem.

The Issues workflow is controlled by two status sets, each with specific options in the Status drop-down menu on the Issue dialog:

- Basic (for Document Management and Design Collaboration issues): Draft, Open, Answered, Closed;
- Field (for Field Management issues): Draft, Open, Work complete, Ready to inspect, Not approved, In dispute, Closed, Void. [29]

Revit Cloud Worksharing with BIM 360 brings powerful, collaborative Revit workflows to the cloud. Enable your teams to co-author Revit models in real-time, staying up-to-date with the latest approved work. Use the best talent for the job, no matter where they are located. [30]

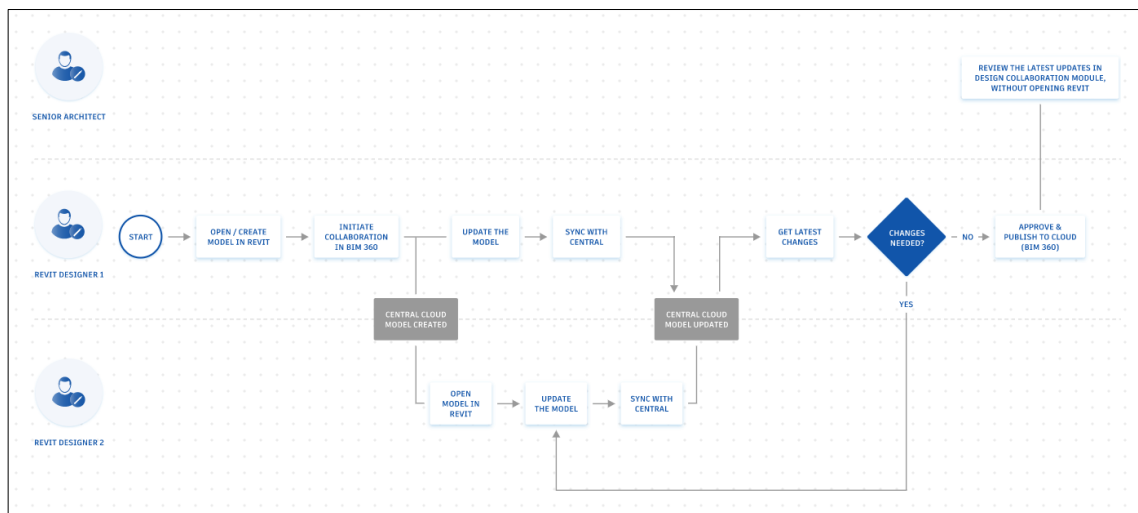


Figure 5: Workflow for BIM 360 Clouds. [<https://www.autodesk.com/bim-360/bim-collaboration-software/design-collaboration/revit-cloud-worksharing/>]

### 1.3 MEP Engineering

The author of this thesis was commissioned to model two MEP plants characterizing the metro station of Collegno Centro.

MEP is an acronym that stands for mechanical, electrical and plumbing engineering. These three technical disciplines encompass the systems that make building interiors suitable for human occupancy. MEP installations are addressed together due to the high degree of interaction between them, and also to avoid conflicts in equipment locations - a common problem when electrical, mechanical and plumbing systems are designed in isolation. (ny-engineers.com).

Various types of mechanical systems are used in residential, commercial and industrial buildings. However, three types account for most of the mechanical design work in multifamily and commercial constructions: Heating, Ventilation and Air conditioning (HVAC) systems. Nevertheless, some other systems can also be included like lifts, escalators, or other transposing system. These systems interact to keep temperature and humidity within a range that provides comfort and health. Mechanical ventilation also ensures that enough fresh air is supplied to keep pollutant concentrations at low and safe levels.

Not only power supply but also other systems conform the electrical system. Among them it can be mentioned telecommunications, control, security, detection and lightning systems.

Plumbing systems are associated with fluid movement. They can be used for many different purposes, like water supply, recovery and treatment systems, water drainage, waste removal, among others.

MEP engineers help in the design stage by providing information about the space to be occupied by the equipment, since location conflicts are very common. The use of BIM is strongly recommended during these phases since a good collaboration with the other teams will result in time reducing and consequently efficiency improvement. Another added value for MEP design is the use of models for energy, lightning or mechanical analysis, which allows to optimize the system design using specialized software, using the less resources possible.

MEP models may also be useful for operational phases, being conserved as reference for maintenance activities. [7,8]



Figure 6: Example of MEP model in Revit. [<https://it.geofumadas.com/bim-curso-de-revit-mep-mecanica-electricidad-y-plomeria/>].

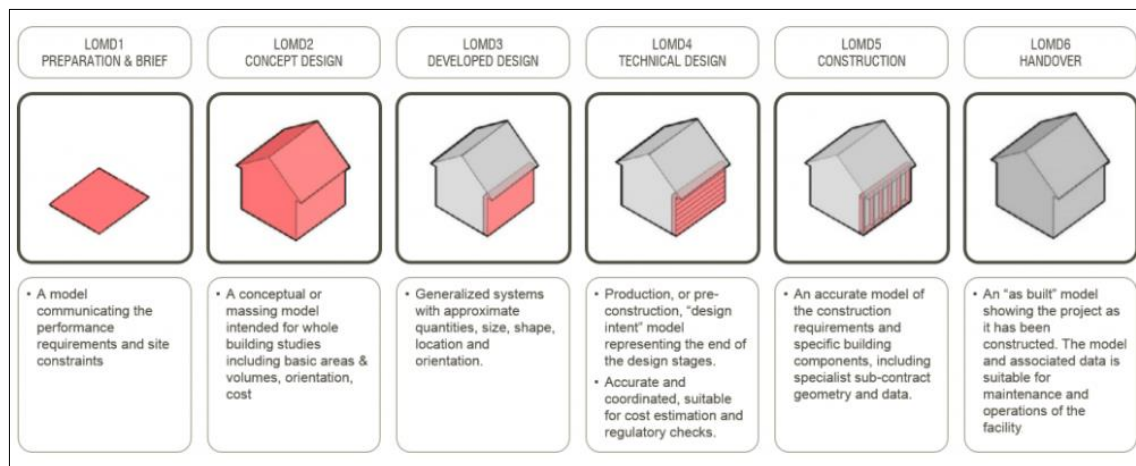
## 1.4 LOD

In recent years, attention to information management in the construction sector has visibly increased, also thanks to the continuous development of BIM applications.

Project management is divided into several phases, ranging from design to maintenance, and each phase requires a different level of information [10]. LODs, however, are not defined by the design phases, rather, they can be completion [11]. The Level of Development, or level of development, or even Level of Detail (LOD) of the data is defined by the project team and is contained in the Model Production and Delivery Table (MPDT). The LODs allow to precisely define the degree of depth of the information contained in the model. International standards propose different LOD scales. The AIA, American Institute of Architects, defines LODs as a level of development, because an element that can appear visually detailed could be generic in reality. In addition, it defines 5 levels of development:

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

## BIM Engineering



*Figure 7: LOD, AIA. [<https://evolve-consultancy.com/lod-lod-loi/>]*

In Italy the legislation that refers to LODs is UNI 11337-4 of 2017, which classifies them in LOG (level of development of geometric objects attributes) and LOI (level of development of informative objects attributes).

The Italian law allows the use of any of the existing LOD scales, according to the specific needs of the contract and provided that specific references, logic, objectives and structure are defined in advance for the purposes of maximum transparency for the subjects interested. The LODs represent the amount of information useful to meet the expectations of the BIM operator in a given design phase [12]. The UNI 11337-4 standard states that the level of development of a digital object is measured by the nature, quantity, quality and stability of the data and information making up the object as defined by the stable and structured connection of its geometric and not geometric.

Continuing the standard states that these data and information, geometric and non-geometric attributes, are expressed:

- in graphic form, for three-dimensional virtualization (3D object), possibly accompanied by specific two-dimensional representations (2D drawing);
- in written and multimedia form, also through the use of specific product and process information sheets.

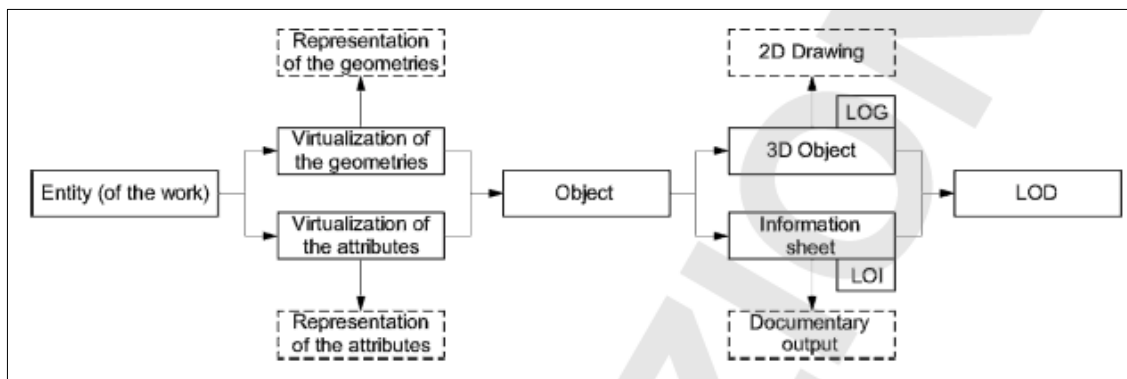


Figure 8: Diagram of information links between entities of work digital objects and their level of development (LOD). [UNI 11337]

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

- LOD A: the entities are represented graphically through a symbolic geometric system or a representation of genre taken as a reference without constraint of geometry. The quantitative and qualitative characteristics are indicative;
- LOD B: the entities are virtualized graphically as a generic geometric system or an outline geometry. Qualitative and quantitative characteristics are approximate;
- LOD C: Entities are virtualized graphically as a defined geometric system. The qualitative and quantitative characteristics are defined generically in compliance with the limits of current legislation and the reference technical standards and referable to a plurality of similar entities;
- LOD D: the entities are virtualized graphically as a detailed geometric system. The qualitative and quantitative characteristics are specific to a defined plurality of similar products. The interface with other specific construction systems is defined, including the approximate dimensions for operation and maintenance;
- LOD E: entities are virtualized graphically as a specific specific geometric system. The quantitative and qualitative characteristics are specific to a single production system linked to the defined product. The level of detail relating to manufacturing, assembly and installation is defined, including the specific dimensions for maneuvering and maintenance;
- LOD F: the objects express the virtualization verified on the site of the specific production system performed / built. The quantitative and qualitative

characteristics are those specific to the single production system of the product laid and installed. The management, maintenance and / or repair and replacement interventions to be carried out throughout the life cycle of the work are defined for each individual product;

- LOD G: objects express the updated virtualization of the actual state of an entity in a defined time. The management, maintenance and / or repair and replacement interventions to be carried out throughout the life cycle of the work are defined for each product [8].

The information models do not only contain geometric data but are also a series of attributes (type of elements, materials, characteristics, performances, etc.), consequently, the model can be characterized by levels of graphic and informative detail different. In addition, there is also the lack of homogeneity in the definition and content of the LODs, which varies according to the countries and the standard used. These considerations led to the introduction of a new definition "Level of Information Need" or LOIN in the ISO 19650 standard, using a terminology that underlines and reiterates, on the one hand, the importance of information contents whatever their nature, from Another requirement is that the number and type of information contained in the model be limited to what is actually necessary.

In this thesis the author was asked to model the plants with a LOD C, referring to the UNI11337.



## 2 Reference standards

To develop this thesis, both modeling and coding, regulatory standards were followed. In particular, reference was made to UNI EN ISO 19650 and UNI 11337 which are complementary to each other.

### 2.1 UNI EN ISO 19650

UNI EN ISO 19650-1: 2019 and UNI EN ISO 19650-2: 2019 are the Italian implementation of ISO, the international standards to refer to in the context of BIM design. Part 1 provides information and describes the principles for information management, according to ISO 19650. It also provides a series of recommendations always related to information management, which include exchange, registration, updating and organization for the actors involved in the process. planning. The standard is applicable to the entire life cycle of the work, including strategic planning, initial design, engineering, development, preparation of documentation for assignments and construction, daily operational operation, maintenance, refurbishment, repair and end of life. The standard can also be adapted to constructions of any size and complexity. Part two specifies the requirements for the management and exchange of information during the delivery phase of the work. This part can also be applied to all types of construction and to all types and sizes of organization, regardless of the choice of procurement strategy. These international standards apply jointly to UNI 11337, which is a complementary standard.

### 2.2 Legislative Decree 50/2016

Legislative Decree 50 of 2016, implementation of directives 2014/23 / EU, 2014/24 / EU and 2014/25 / EU, establishes the beginning of the processes for the development of new standards, aimed at innovating and integrating previous provisions in area of digitization. Article 23 paragraph 13 states: "The contracting authorities may request the use of electronic methods and tools for new works as well as for recovery, redevelopment or variants, especially for complex works.

These tools use interoperable platforms by means of non-proprietary open formats, in order not to limit competition between technology suppliers and the involvement of specific projects among designers.

The procedures and times for progressive introduction are defined by decree of the Ministry of Infrastructures and Transport of the mandatory nature of the aforementioned methods at contracting authorities, granting administrations and economic operators ".

### 2.3 Decree 560/2017

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

- For complex works relating to works with a tender amount equal to or greater than 100 million euros, starting from 01.01.2019;
- For complex works relating to works with a tender amount equal to or greater than 50 million euros, starting from 01.01.2020;
- For complex works relating to works with a tender amount equal to or greater than 15 million euros, starting from 01.01.2021;
- For works with a tender-based amount equal to or greater than the threshold referred to in Article 35 of the Public Contracts Code, starting from 01.01.2022;
- For works with a tender amount equal to or greater than 1 million euro, starting from 01.01.2023;
- For works with a tender amount of less than 1 million euro, starting from 01.01.2025;

In addition to the ministerial decree which represents a regulatory reference in the BIM field, what defines the timing of its introduction is accompanied by the voluntary (non-mandatory) technical standard, which defines the guidelines to

follow in the adoption of this methodology.

## 2.4 UNI 11337

The UNI 11337 standard is a document divided into ten parts that deals with the digital management of information processes in constructions and, specifically, deals with models, documents and information objects for products and processes, evolution and information development of models, respectively, documents and objects, information flows in digitized processes. The information is divided as follows:

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

Among the results of the thesis work, there is an object library; it is important to report the definition of objects, contained within part 1: objects are the virtual components, more or less complex, of an information model [9]. In addition, the objects and / or object libraries are the result of the digitization process of the report which involves the creation of an information model.

### 3 Case study

The Turin Metro (Italian: Metropolitana di Torino) is the modern VAL rapid transit system serving Turin. It is operated by Gruppo Torinese Trasporti (GTT), a public company controlled by the municipality of Turin. The system comprises one 13.2-kilometre (8.2 mi) line with 21 stations connecting Fermi station in Collegno with the Lingotto multifunctional centre in Turin.

Two additional stations, reaching the Southern boundary of the city, are currently under construction. These stations will be known as Italia '61, serving the new Piedmont Region Headquarters, and Bengasi, named for the piazza under which it will be located. Recent estimates suggest this southern extension will be completed not before February 2021.

A further Western extension is planned to reach the boundaries of Collegno and the city of Rivoli. In December 2017, the city approved the first stage of the project, valued at €123.7 million, to construct two already named stations: Certosa, which will interchange with the central railway station of the city of Collegno, and Collegno Centro, serving its central market area. An additional two stations, including one in the Leumann Village neighbourhood and another in the Cascine Vica district of Rivoli, were allocated €148 million.[13] The Ministry of Infrastructure and Transport expects the extension to Cascine Vica to be completed by Summer 2023. [24]

The first functional lot Fermi-Collegno Centro of the West extension of the Line 1 of the driverless metro of Turin represents a first part of the natural extension of the section Collegno – Porta Nuova – Lingotto – Bengasi, with a design that develops entirely underground. It extends in total for about 1,75 km. The station design was carried out taking into consideration the intention to standardize the station typology by implementing criteria that have guided from the beginning the development of Line 1. The project has been fully developed in BIM field, allowing the coordination of the different interfaces that contribute to the geometries definition to guarantee uniformity, control and coherence of the

functional design with other design disciplines (architectural finishes, structures and facilities). Stations design transposes assumed and adopted guidelines both for the operational section and for the one under construction in a way that guarantee an aesthetic coherence and a homogeneity from the point of views of volumes, transparency and architectural. In this sense, the main adopted criterion into the executive design is to use characteristics and kind of details already used for other stations of the Line 1 in order to maintain a sense of continuity and unitarity into the spaces definition, the interior architecture, the lighting and materials choices. [9]

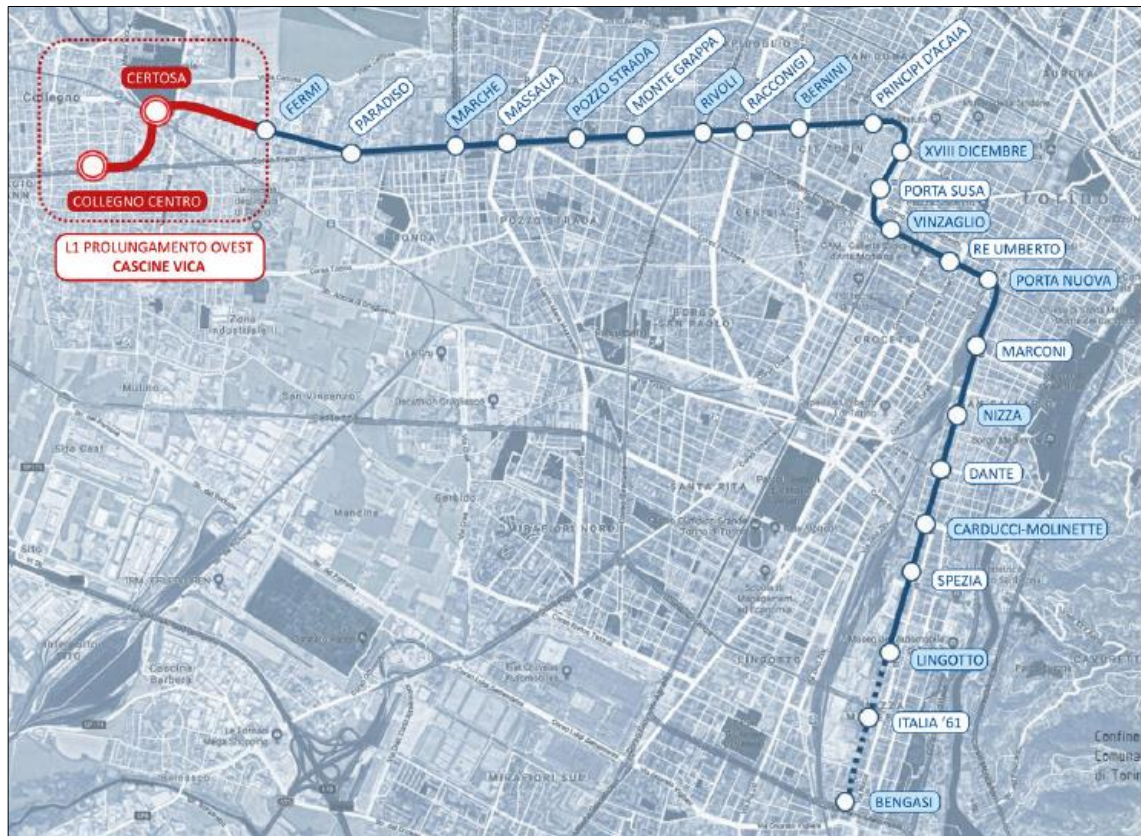
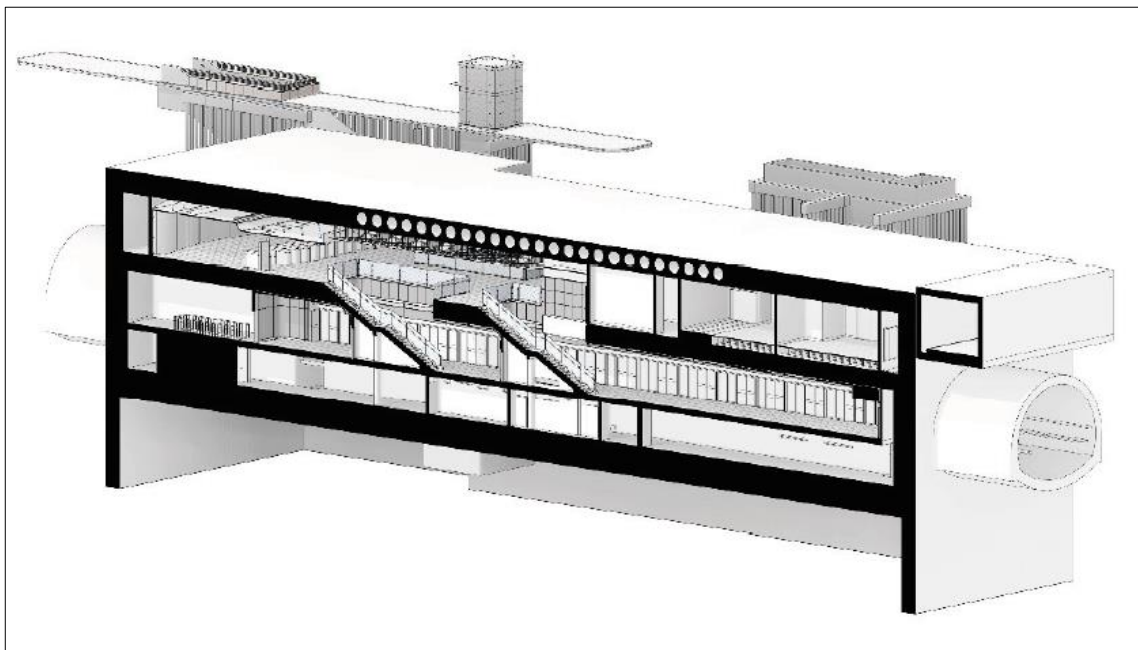


Figure 9: Map of the Turin subway.

### 3.1 System design

Executive design of non-system installations, both for stations and line, takes into account the different related systems: ventilation and air conditioning systems, water and fire protection systems, electric systems, fire alarm systems and special systems (mobile ladders, elevators, automated ticketing and gate control, advertising). Respect to the definitive design has been adopted different technologic improvements taking into consideration standards updates following the approval of the design. [9]



*Figure 10: Collegno Centro station.*

### 3.2 Ventilation, air conditioning and fire system

The work done in this thesis revolves around the systems of ventilation and air conditioning (HVAC) and fire of the Collegno Centro station. The all work is been made under the supervision of the Geodata S.p.A. of Turin that has already build structural and functional models used to coordinate the MEP systems.

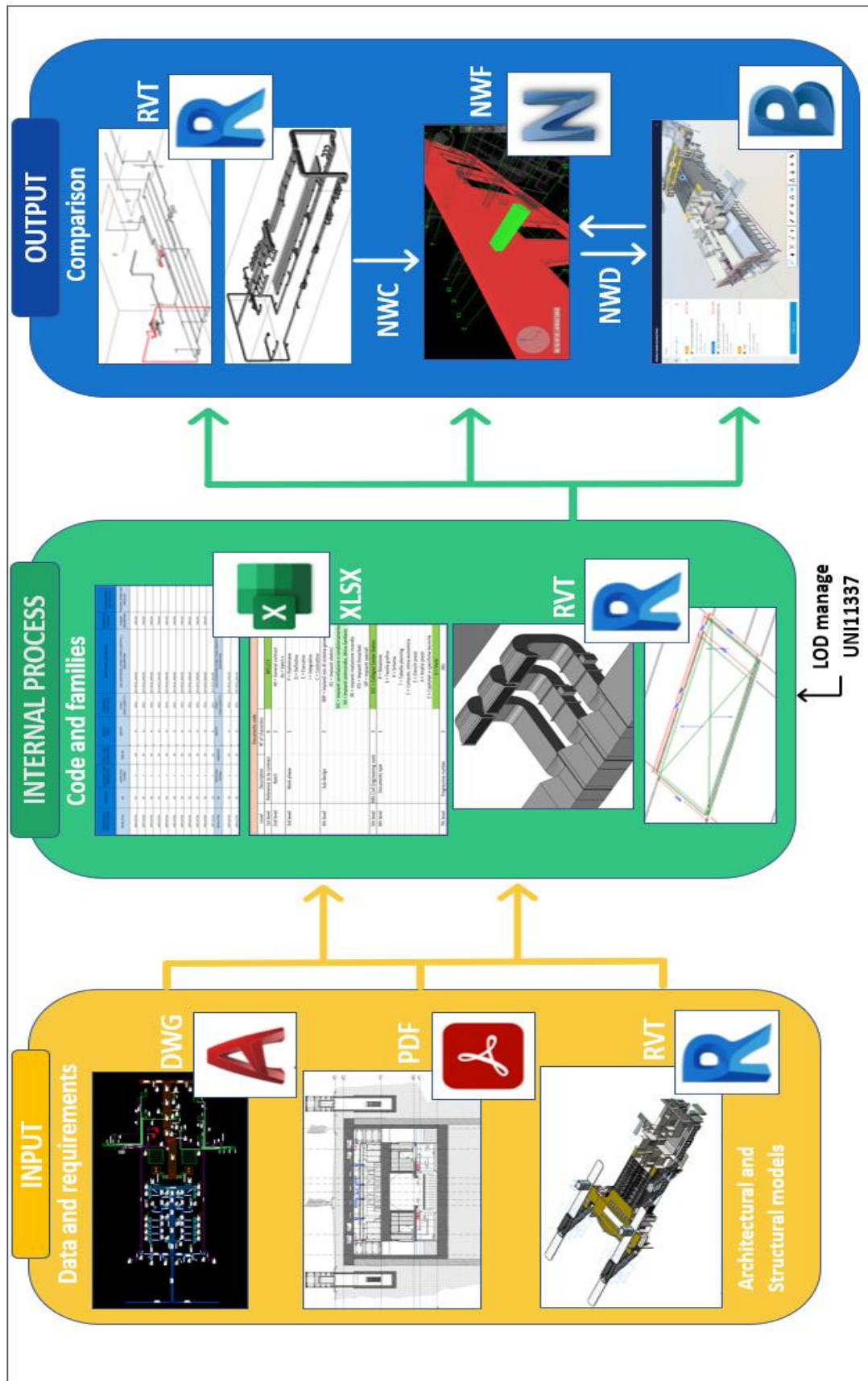


## 4 Methodology

In the following figure it is shown a sort of flowchart that explain the methodologic process used to complete this thesis. In particular as inputs have been used plans of structural, functional and systems in editable form (.dwg file) and not (.pdf file), and also .rvt file of structural and functional models.

The internal process involved the creation of a code made by .xlsx file in order to name both documents and MEP elements within models but also the building of the models themselves with the definition of families. As part of this phase there are also the modelling of the entire air ventilation and conditioning and fire systems.

As outputs it is been obtained the IVC, ventilation and air conditioning systems, and IIA ,fire systems, models within Revit and clash detection verifications comparisons between different sotware, in particular: Revit, Navisworks and BIM360 (Coordinate set).





## 5 Information production

The information production process in a BIM design consists in the creation of the Building Information Model. The task assigned to the author of this thesis was to create MEP models.

The information production process is generally ruled by a BIM Execution Plan (BEP) that is the response from the contractor company to the contracting one.

To make this thesis, one of the BEP aspect studied was the name coding of documents and single parameters used into the project as you can see into the following tables. The first coding constructed concerns the one related to the documents name:

*Table 1: Documents code table.*

Documents code			
Level	Description	N° of characters	
1st level	Reference to te contract	6	MTL1T3
2nd level	Batch	2	A0 = General contract
			Ax = batch x
3rd level	Work phase	1	P = Preliminary
			D = Definitive
			E = Executive
			I = Integrative
			C = Constructive
4th level	Sub-design	3	IMP = Non-general system installations
			IEL = Electrical systems
			IVC = Ventilation and air conditioning systems
			IIA = Fire and sanitation systems
			IRI = Fire detection systems
			IFD = Sound/data systems
			ISP = Special systems
5th level	VBS Civil Engineering work	3	SCC = Collegno Centro Station
6th level	Documents type	1	R = Report
			S = Graphic elaborates
			K = Scheme
			T = Planning table
			C = Stetament, economic assessment
			E = Price list
			A = Price analysis
			Z = Technical specifications
			V = Various
7th level	Progressive number	3	00n

## Information production

After having decided the general naming code for documents, another naming code was built for naming every single element within models.

Table 3: : Code for single elements within IVC and IIA models.

Code for single elements within the model			
Level	Description	N° of characters	
1 <sup>st</sup> level	Company	2	GD = GEODATA
2 <sup>nd</sup> level	Sub-discipline	1	V = VENTILATION P = PLUMBING
3 <sup>rd</sup> level	Object category	2	VD = VENTILATION DUCT GR = GRID CN = CONNECTION DP = DAMPER DF = DIFFUSER PP = PIPE
4 <sup>th</sup> level	Object characteristics	2	On = n° air flow SW = Sanitary Water

Table 2: Code for ventilation elements.

SYSTEM FAMILY / SİSTEM ELEMANI	TASARIMCI	DISCIPLINE CODE / DISİPLİN KODU	FAMILY CODE / ELEMAN KODU	IDENTITY / KİMLİK	TYPE MARK / ETİKET KODU	FAMILY NAME / ELEMAN İSMİ	DESCRIPTION NAÇIKLAMA	FINISHING WORKS UNIT PRICE LIST
VENTILATION	GD	VENTILATION SYSTEM:V	GRID:GR	IDENTITY	(FAMILY CODE )(IDENTITY)	(GD)(-)(DISCIPLINE)(-)(FAMILY CODE)(-)(IDENTITY)(L) (DESCRIPTION)	SUMMARY DESCRIPTION	FINISHING WORKS UNIT PRICE LIST
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_250x150	250x150	
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_300x100	300x100	
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_300x150	300x150	
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_350x200	350x200	
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_400x150	400x150	
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_400x200	400x200	
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_450x150	450x150	
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_500x150	500x150	
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_500x300	500x300	
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_600x200	600x200	
VENTILATION	GD	V	GR	01	GR.01	GD-V-GR.01_600x300	600x300	
VENTILATION	GD	VENTILATION SYSTEM:V	DAMPER:DP	IDENTITY	(FAMILY CODE )(IDENTITY)	(GD)(-)(DISCIPLINE)(-)(FAMILY CODE)(-)(IDENTITY)(L) (DESCRIPTION)	SUMMARY DESCRIPTION	FINISHING WORKS UNIT PRICE LIST
VENTILATION	GD	V	DP	01	DP.01	GD-V-DP.01_250x150	250x150	
VENTILATION	GD	V	DP	01	DP.01	GD-V-DP.01_300x150	300x150	
VENTILATION	GD	V	DP	01	DP.01	GD-V-DP.01_350x200	350x200	
VENTILATION	GD	V	DP	01	DP.01	GD-V-DP.01_400x200	400x200	
VENTILATION	GD	V	DP	01	DP.01	GD-V-DP.01_450x250	450x250	
VENTILATION	GD	V	DP	01	DP.01	GD-V-DP.01_650x350	650x350	
VENTILATION	GD	V	DP	01	DP.01	GD-V-DP.01_1100x700	1100x700	

## Information production

VENTILATION	GD	VENTILATION SYSTEM V	CONNECTION- CN	IDENTITY	(FAMILY CODE)(IDENTITY)	(GD)(-)(DISCIPLINE)(-)(FAMILY CODE)(IDENTITY)(-)	SUMMARY DESCRIPTION	FINISHING WORKS UNIT
VENTILATION	GD	V	CN	01	CN.01_01	GD-V-CN.01_01_500x300	500x300	
VENTILATION	GD	V	CN	01	CN.01_02	GD-V-CN.01_02_500x250	500x250	
VENTILATION	GD	V	CN	01	CN.01_02	GD-V-CN.01_02_550x300	550x300	
VENTILATION	GD	V	CN	01	CN.01_03	GD-V-CN.01_03_1150x600	1150x600	
VENTILATION	GD	V	CN	01	CN.01_04	GD-V-CN.01_04_500x300	500x300	
VENTILATION	GD	V	CN	01	CN.01_05	GD-V-CN.01_05_600x300	600x300	
VENTILATION	GD	V	CN	01	CN.01_06	GD-V-CN.01_06_650x350	650x350	
VENTILATION	GD	V	CN	01	CN.01_07	GD-V-CN.01_07_750x400	750x400	
VENTILATION	GD	V	CN	01	CN.01_08	GD-V-CN.01_08_800x400	800x400	
VENTILATION	GD	V	CN	01	CN.01_09	GD-V-CN.01_09_800x1000	800x1000	
VENTILATION	GD	V	CN	01	CN.01_10	GD-V-CN.01_10_850x450	850x450	
VENTILATION	GD	V	CN	01	CN.01_11	GD-V-CN.01_11_900x450	900x450	
VENTILATION	GD	V	CN	01	CN.01_12	GD-V-CN.01_12_950x500	950x500	
VENTILATION	GD	V	CN	01	CN.01_13	GD-V-CN.01_13_1000x500	1000x500	
VENTILATION	GD	V	CN	01	CN.01_14	GD-V-CN.01_14_1050x550	1050x550	
VENTILATION	GD	V	CN	01	CN.01_15	GD-V-CN.01_15_1100x550	1100x550	
VENTILATION	GD	V	CN	01	CN.01_16	GD-V-CN.01_16_1150x600	1150x600	
VENTILATION	GD	V	CN	01	CN.01_17	GD-V-CN.01_17_1200x600	1200x600	
VENTILATION	GD	V	CN	01	CN.01_18	GD-V-CN.01_18_1250x650	1250x650	
VENTILATION	GD	V	CN	01	CN.01_19	GD-V-CN.01_19_1750x900	1750x900	
VENTILATION	GD	V	CN	01	CN.01_20	GD-V-CN.01_20_1800x900	1800x900	
VENTILATION	GD	V	CN	01	CN.01_21	GD-V-CN.01_21_1850x900	1850x900	
VENTILATION	GD	V	CN	01	CN.01_22	GD-V-CN.01_22_1950x950	1950x950	
VENTILATION	GD	V	CN	01	CN.01_23	GD-V-CN.01_23_650x350	650x350	
VENTILATION	GD	V	CN	01	CN.01_24	GD-V-CN.01_24_600x300	600x300	
VENTILATION	GD	V	CN	01	CN.01_25	GD-V-CN.01_25_450x250	450x250	
VENTILATION	GD	V	CN	01	CN.01_26	GD-V-CN.01_26_1800x900	1800x900	
VENTILATION	GD	V	CN	01	CN.01_27	GD-V-CN.01_27_1800x900	1800x900	
VENTILATION	GD	V	CN	01	CN.01_28	GD-V-CN.01_28_1050x550	1050x550	
VENTILATION	GD	V	CN	01	CN.01_29	GD-V-CN.01_29_1150x600	1150x600	
VENTILATION	GD	V	CN	01	CN.01_30	GD-V-CN.01_30_1200x600	1200x600	
VENTILATION	GD	V	CN	01	CN.01_31	GD-V-CN.01_31_1300x650	1300x650	
VENTILATION	GD	V	CN	01	CN.01_32	GD-V-CN.01_32_1200x600	1200x600	
VENTILATION	GD	V	CN	01	CN.01_33	GD-V-CN.01_33_500x250	500x250	
VENTILATION	GD	VENTILATION SYSTEM V	DIFFUSER DF	IDENTITY	(FAMILY CODE)(IDENTITY)	(GD)(-)(DISCIPLINE)(-)(FAMILY CODE)(IDENTITY)(-)	SUMMARY DESCRIPTION	FINISHING WORKS UNIT
VENTILATION	GD	V	DF	01	DF.01	GD-V-DF.01_		

At this point it is obtained a code for each element built into the model.

## 5.1 MEP modelling within Revit

Revit is BIM software widely used by architects, engineers, and contractors to create a unified model that all disciplines and trades can use to complete their work. Autodesk Revit was created to support BIM and not to replace BIM. Revit hosts the information that forms the model from which drawings and documents are derived.

Some recommendations for creating the model were taken from the AEC BIM Protocol for Autodesk Revit. This is a unified standard for the AEC industry that also includes a checklist that helps the modeller make sure that the work was done as required in the standard.

In the System tab, MEP families are divided by main sub-disciplines: Heating Ventilation and Air Conditioning (HVAC), Mechanical, Plumbing & Piping and Electrical. This split of user interface allows to identify more easily the MEP objects to upload in the model. Under each sub-discipline, the MEP objects can be Loadable families such as Air terminal and Plumbing fixture, or System families such as Duct and Pipes. Moreover, the Systems tab includes P&ID Modeler, a panel for the advanced modelling.

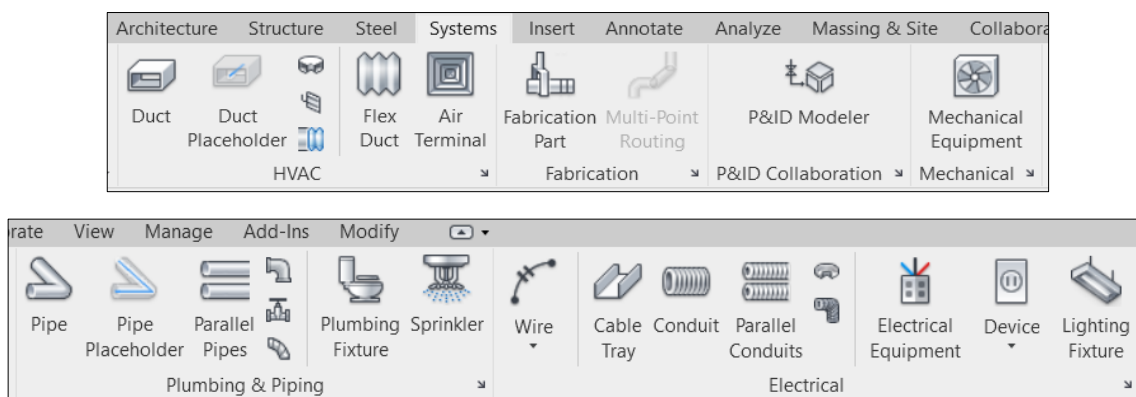


Figure 11: Revit System tab.

Like the Architectural model, the MEP model can also be created starting from a specific Template file with predefined settings based on the sub-discipline. Regardless of the template chosen, the software allows to model objects belonging to several disciplines within a single project file. Views can be organized based on

the “Disciplines” parameter within the Project Browser; when the Discipline property is set to Mechanical, Electrical, or Plumbing, the objects that do not belong to MEP categories are visualized halftone. In order to start the MEP modelling, it is fundamental to customize the Mechanical and Electrical settings. Opening the Mechanical Settings dialog starts from clicking the lower-right arrow of HVAC, Mechanical or Plumbing & Piping panel. Alternatively, click [Manage tab > Setting Panel > MEP Settings drop-down > Mechanical Settings]. In this tab, it is possible to set some properties of ducts and pipes, such as the fitting angle, the segments and sizes, the calculation methods, etc. It is fundamental to set these parameters before starting the modelling because it allows to customize specific settings of the project. The fundamental feature that makes MEP families different from other disciplines is the concept of Connector. In order to create a component belonging to system topology, the MEP object must get one or more connectors. The discipline assigned to a connector determines the systems types of belonging and how it will interact with other system components. Each family can have one or more connectors, belonging to the same or different disciplines, listed below: Electrical Connector, Duct Connector, Pipe Connector, Cable Tray Connector, Conduit Connector. A conduit connector can be an individual connector or a surface connector. The individual connector is used for connecting only one conduit. The surface connector is used for connecting more than one conduit to a surface.

The Loadable Families can be loaded from existing objects libraries or customized by creating new families. In order to create a new family of a component belonging to system topology, it is fundamental to start opening an adequate template. For this purpose, it is necessary to choose template system categories. When modelling is completed, adding a connector on an object surface is possible. Within a MEP model, System Families are used too, such as Ducts, Pipes and Conduits.

They link terminals and equipment, horizontally and vertically. In order to connect the system pipes with their fittings, it is necessary to specify the Routing Preferences for every type of duct. Once the element is selected it is necessary to

click [Edit type > Edit in the Routing Preferences row > Load Family of fittings useful in the project > Select correct fitting family in the drop-down tab in Pipe Segment > Select Pipe sizes to apply the fitting selected > Ok]. After this customization, the fitting between two pipes will be created automatically, as defined in the Routing Preference tab.

Modifying the attributes in Routing Preference tab, the pipe fittings do not change for existing pipes. The same procedure must be applied for ducts and conduits.

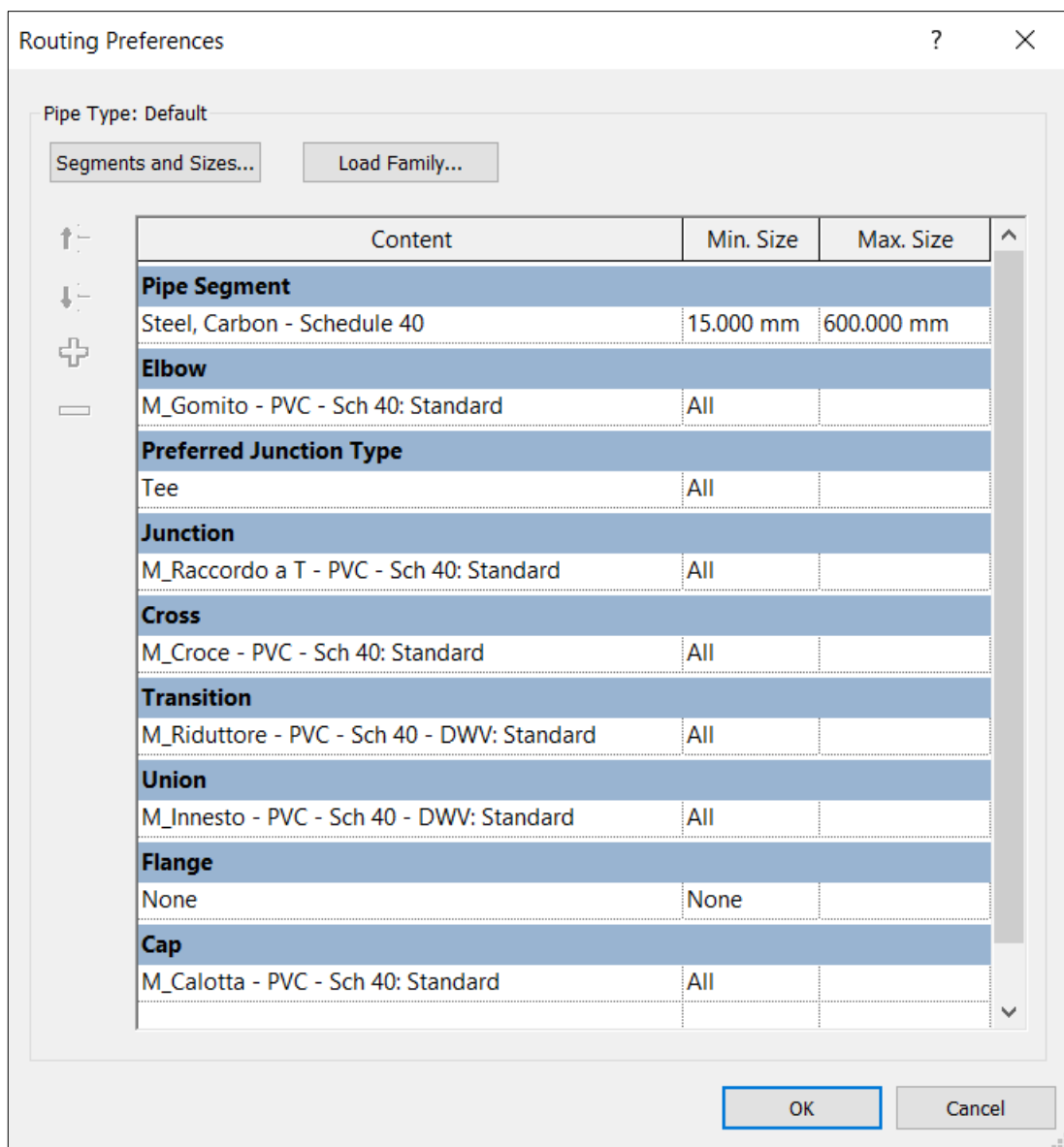


Figure 12: Routing Preferences for IIA system.

Every MEP component can be a part of a system. When a system component is selected, it is possible to choose a system of belonging, based on the types of connectors applied within the family.

Regarding the mechanical systems, it is possible to create a specific HVAC system, based on the System Type assigned to the Duct Connector in the component family: Supply Air,

Return Air, Exhaust Air. First, it is necessary to place air terminals and mechanical equipment in the model. By adding ducts to connect the components, they are automatically assigned to a system. Another way to create a mechanical system consists of selecting the components and manually adding them to a system. The same procedure is used to create

a Piping System. The system of belonging depends on the System Type set in the Pipe Connectors properties. Once fixtures are placed in the model, a system can be created by connecting automatically the components through pipes.

## 5.2 Templates

Before starting a new project, the Revit modeller asks for a project template file to be opened. The project template represents the starting point of the new project model. It includes view settings, load families and defined settings. They are saved in an RTE extension file. When IFC links were loaded they displayed in halftone mode, as it was preconfigured in the view of the System template. For the purpose of the thesis it is used the same template used in the already existing structural and functional models to be coherent with the whole design. [26]

## 5.3 Levels

Starting from the levels existing into the structural and functional models other three main levels have been added. They are called “Inferiore”, “Mezzanino” e “Superiore”. Gradually all elements are linked to the three levels.

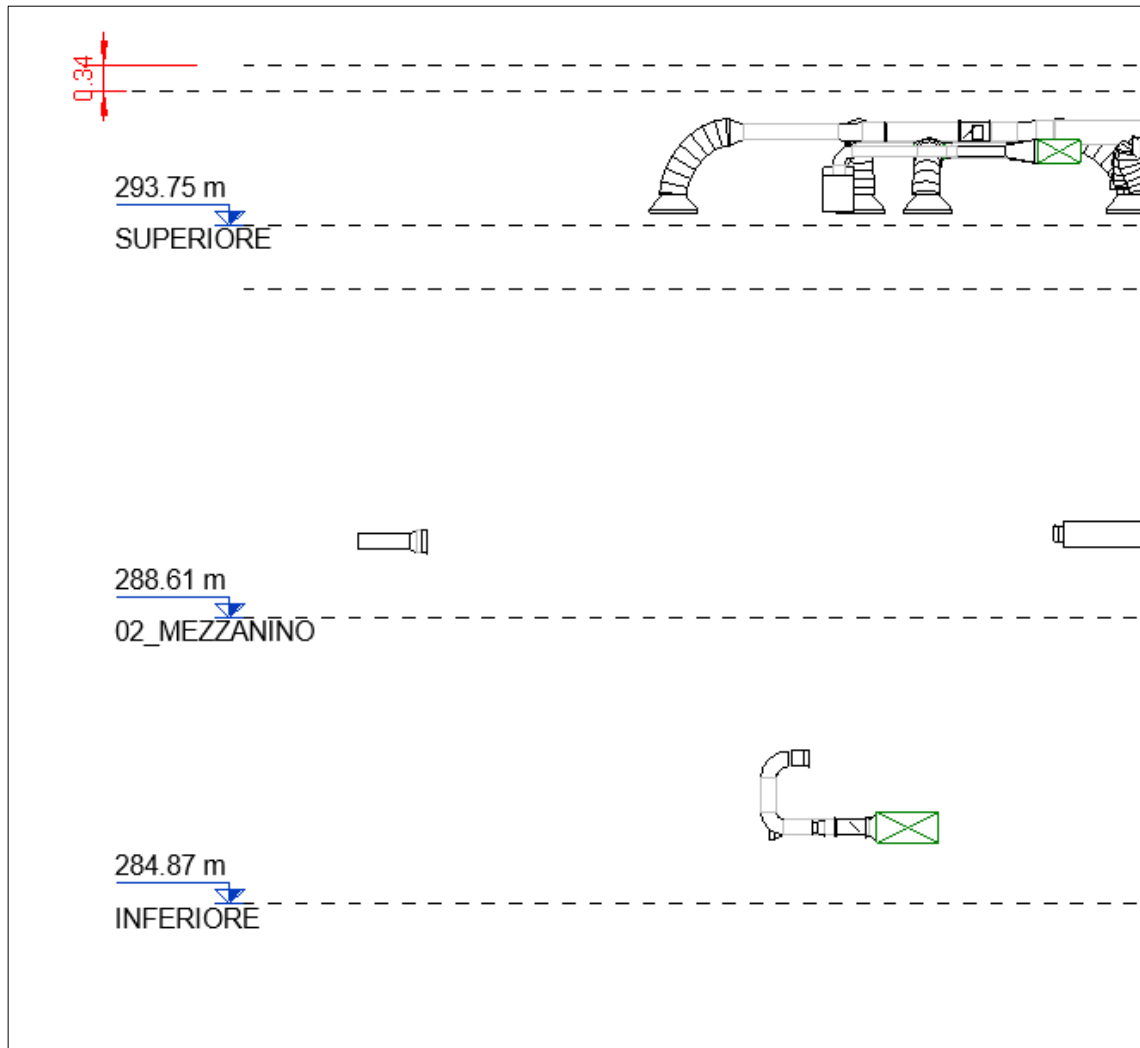


Figure 13: Levels related to the system models.

## 5.4 Linking files

In order to have all models together, it is sufficient to link the modelled ones into the current Revit project. To do it is possible to use the link tab into the insert panel. The same procedure it has been used to link Cad files of the design, necessary for the modelling phase. In this way it is maintained a connection between the file and the model, so the file it is used as un underlay or it is included in the construction documentation set.



### 5.4.1 Linking Revit

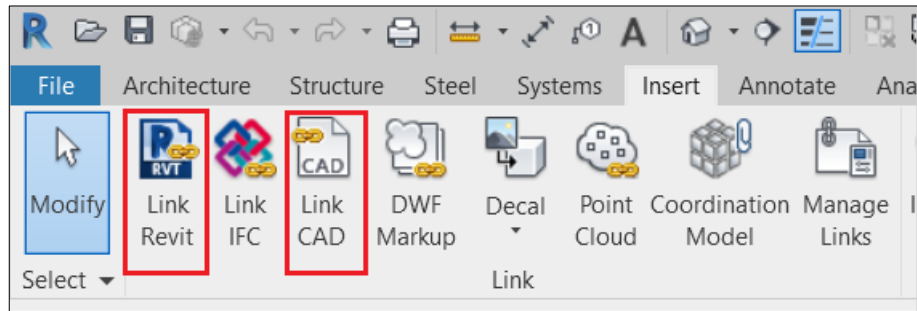


Figure 14: Revit linking possibilities.

To be coherent with the already existing models of the subway station it has been chosen to link Revit models with shared coordinates.

The reference type of linked files is very important because it will then determine how that link behaves in the new model.

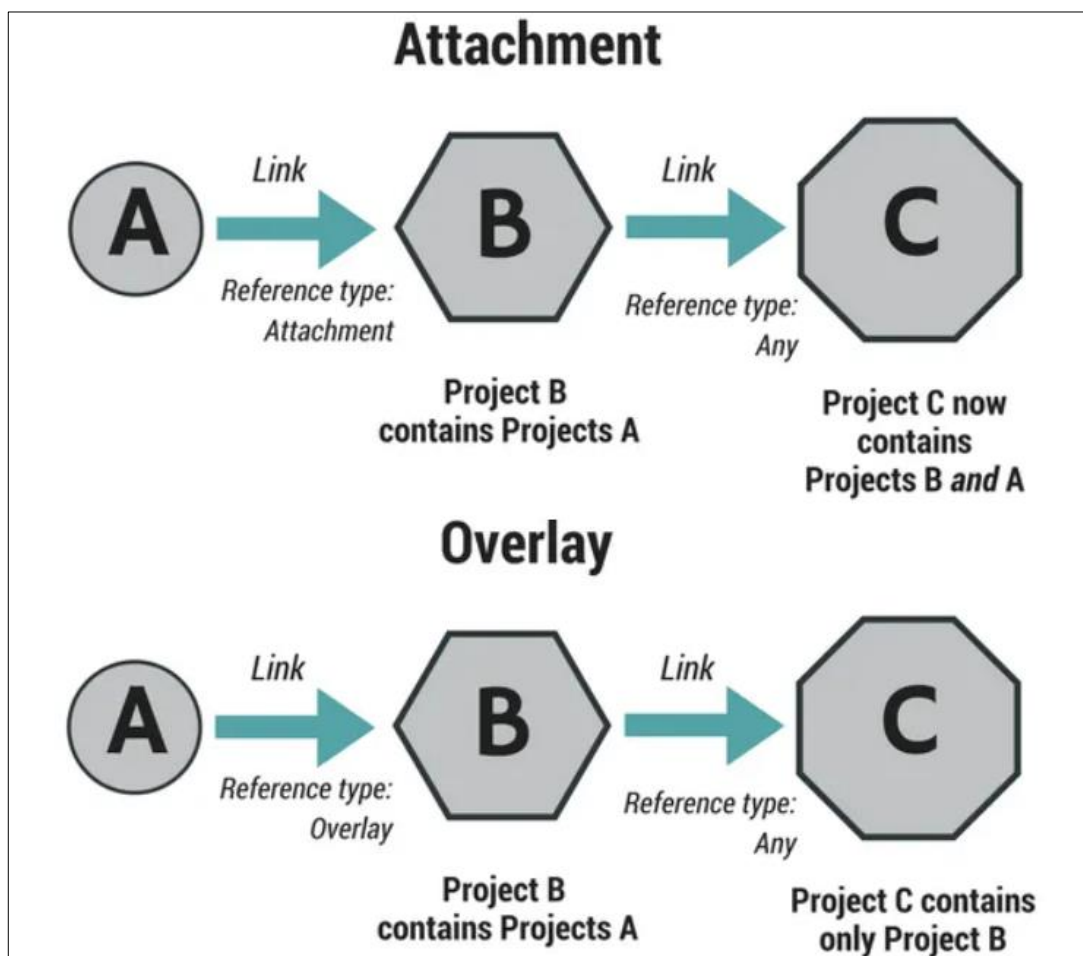


Figure 15: Difference between reference type. [<https://revitq.com/attachment-vs-overlay-revit/>]

In the Attachment case both project B and A will be visible into project C, for this reason this option is been chosen within the project.

### 5.4.2 Linking CAD

Project elaborations are provided among the input data. The next step was to connect the files in . dwg format to the template. First of all, plant views were created in Revit by clicking on View > Plant views > Floor Plan, so a window appear that permit to create a floor plan for each level.

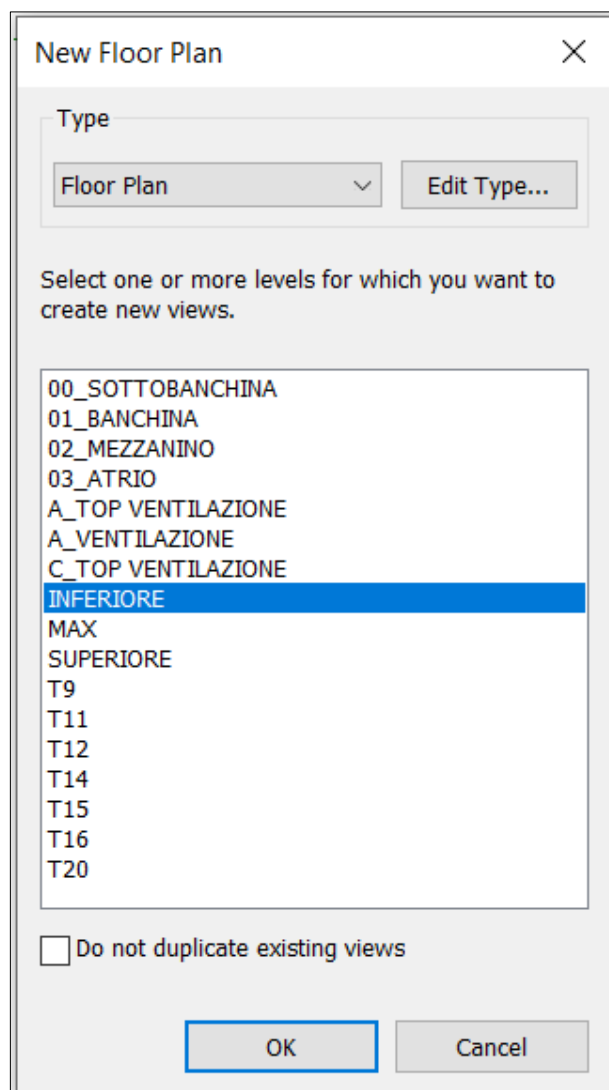


Figure 16: New floor plan.

Identified the plan view of the floor plan relative to the ventilation and air conditioning system, once created the relative floor plan view, it is passed to the linking of the CAD file. Revit allows, having chosen the file to be linked, to select the level to which to insert, the scale, to choose the positioning and to select or not some layers. For convenience, the Current View Only option was selected, so that the linked file is visible only in the plan view to which you want to link it and not in all the others. As well as importing a CAD file it is also possible to link it, the difference between importing and linking a file is that with the first option the inserted file is updated every time it is modified, even after being inserted in the project, while with the option imports if the CAD file undergoes changes after insertion, no automatic update happen. Linking or inserting a CAD file into the project is very useful and allows us to quickly position the elements of the model.

## 5.5 Object creation

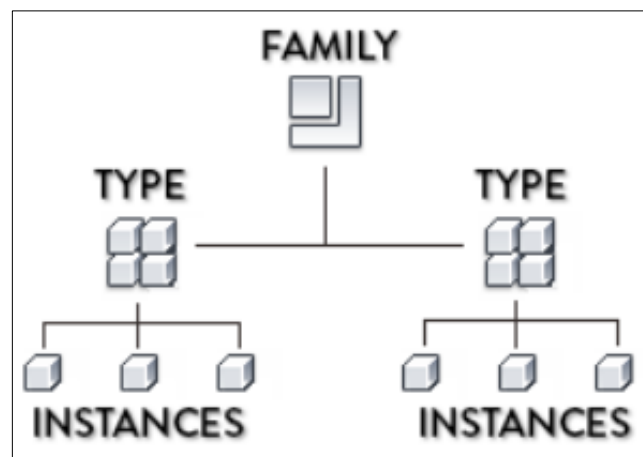
Once links are loaded, the next step is to start modelling. The right way for modelling MEP equipment is to first locate the terminal families in the right place. Then, pipes or duct layout is created. In the next paragraphs the methodology employed for creating the Revit models is explained. Firstly, it is important to introduce some new concepts. Every object created on Revit is technically called “instance”. Each instance corresponds to a hierarchical classification inside Revit that consists on: Categories, Families and Types. Categories represent the most general classification. Some examples of category are Pipe, Pipe Fitting or Mechanical Equipment. Depending on the category, a property set for each instance will be provided. Within Revit there are three types of families:

- **System Families:** They are always available in any project; it is impossible neither to remove them nor to load an own version. This is the case of pipes or air ducts into the project.
- **In-place Families:** Created in the Revit project directly, they cannot be saved as a separate file and they cannot have different types. For this project few families have been created in this way.

- **Loadable Families:** These are the most common ones. They can be found on the Revit libraries, on the internet or be designed from scratch at the Family Editor. They are saved with RFA extension as separated files, and they can be also loaded in other projects.

Families have their own “Families parameters”, which depends on the category they are part of. Some of them, nevertheless, are common to every category like “always vertical”, “shared” or “Identify Data parameters”.

Subdividing families into types is very useful when standardized objects with different dimension or properties are needed. What make the difference between family types are the “type parameters”, while at the same time, every type shares the same standard parameters of the family, such as Material, Model; Manufacturer and so on.



*Figure 17: Hierarchical structure of Revit objects.  
[<https://revitpure.com/blog/33-weird-revit-terms-explained>]*

Lastly, instances represent the single object placed in the project. They adopt the property set of the category they correspond to, as well as the family and type properties, but that is not all: They can also have instance project parameters. These parameters can be completed into the property panel, when a certain instance is selected.

### 5.5.1 Family Editor

The family editor is a tool inside Revit which has an easy access by double-clicking in a loadable family or by left clicking and selecting the “edit” option. It is desired to start sketching a new loadable family, the way to do it is by clicking on File > New > Family.

When a new family is created from scratch, similarly to new projects case, a window asking for the starting template is asked. There are many templates according to the host and family category. It is not recommended to use hosted families, most of the families were created starting from the generic template. However, it must be said that selecting the template is a point of no return: if it is desired to model a face-based family, it must be picked the face-based template. Else, the family would require to be modelled again.

The next step is to pick the category to which the family will take part. Failing in this step is not a problem since it is always possible to change it.

When starting to create the family, the modeller should pay attention to some standards and recommendations for the type desired. They are not strict rules but the result of years of experience of specialist modellers. Some of them are written below:

- Avoid using Speciality equipment Category;
- Use Lookup tables rather than creating separate families;
- File size: No more than 400KB for single objects and 800KB for more complex ones.

They have been taken from the Revit Model Content Style Guide from Autodesk and the European MEP Content Standard.

### **Altimetric position**

The rest of the information about MEP equipment received consisted on a CAD section of the platform, information taken from the general and evaluation report and the answers to some questions made by phone call to the company’s designer.

### 5.5.2 Duct accessories

The most numerous parts of the library of modelled objects consists of accessories for the ducts. All families have been created from a new model, except for the family of damper shutters and for the one of grids.

The family most present in the ventilation model is that of the joints; joints are connecting/joining elements between two channel segments.

To make the elements connect to the two duct sections, connectors have been inserted on both sides. Connectors are those elements that differentiate the MEP model from the architectural and structural one. In fact, each element belonging to an installation is equipped with at least one connector.

The couplings were created as a new family from a generic metric model, once inserted the connectors and classified as duct accessories, were loaded into the project.

Although the family has been created with parametric dimensions, which allow to adapt the joints to any duct, as the dimensions of the connectors have not been parameterized, a family has been created for each dimension.

This was an initial error due to the author's little experience with the software. Subsequently it was chosen to have a single family with a parametric size connector, so as to have more types of elements of a single family, as for the supports for ducts.

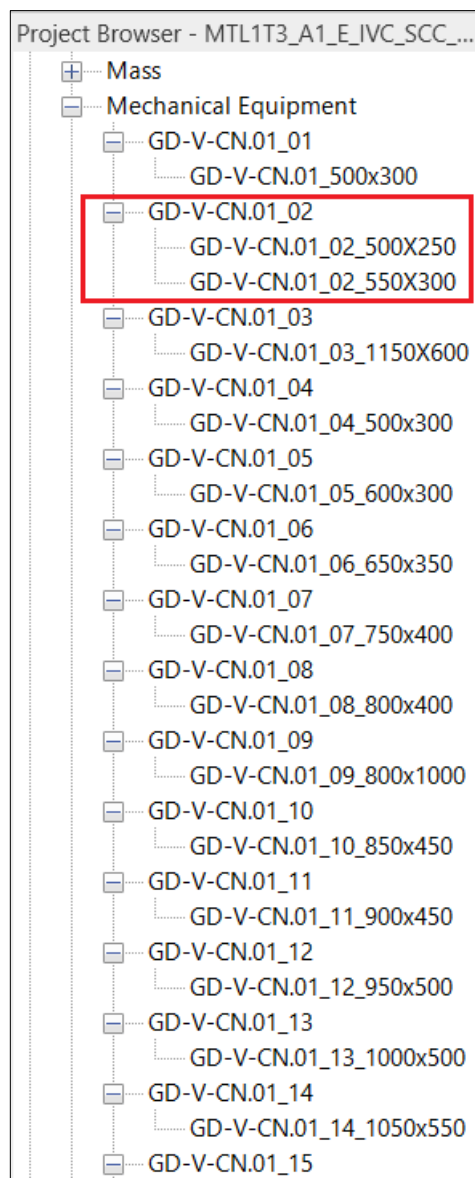


Figure 18: Project browser, Revit.

In the families section of the project browser, clicking on the "+" you can see all types associated with each family. To change the size of the element, once inserted, just click, selected the object, in the property panel on Edit Type and choose the size of the drop-down menu.

If the required type is not available, by clicking on the Duplicate button you can create it.

Type Properties

Family: GD-V-CN.01\_02 Load...

Type: GD-V-CN.01\_02\_550X300 Duplicate... Rename...

Type Parameters

Parameter	Value
<b>Constraints</b>	
Default Elevation	1.2192
<b>Dimensions</b>	
H	0.0100
L1	0.5500
L2	0.3000
L3	0.3500
L4	0.3000
L6	0.2000
<b>Mechanical</b>	
Classification	None
<b>Identity Data</b>	
Type Image	
Keynote	
Model	
Manufacturer	
Type Comments	

[What do these properties do?](#)

<< Preview OK Cancel Apply

Figure 19: Type properties, Revit.



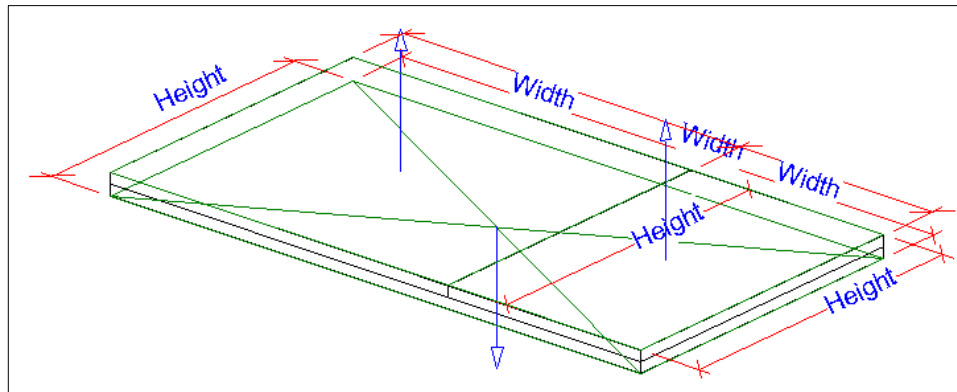


Figure 21: Junction with connection, Revit.

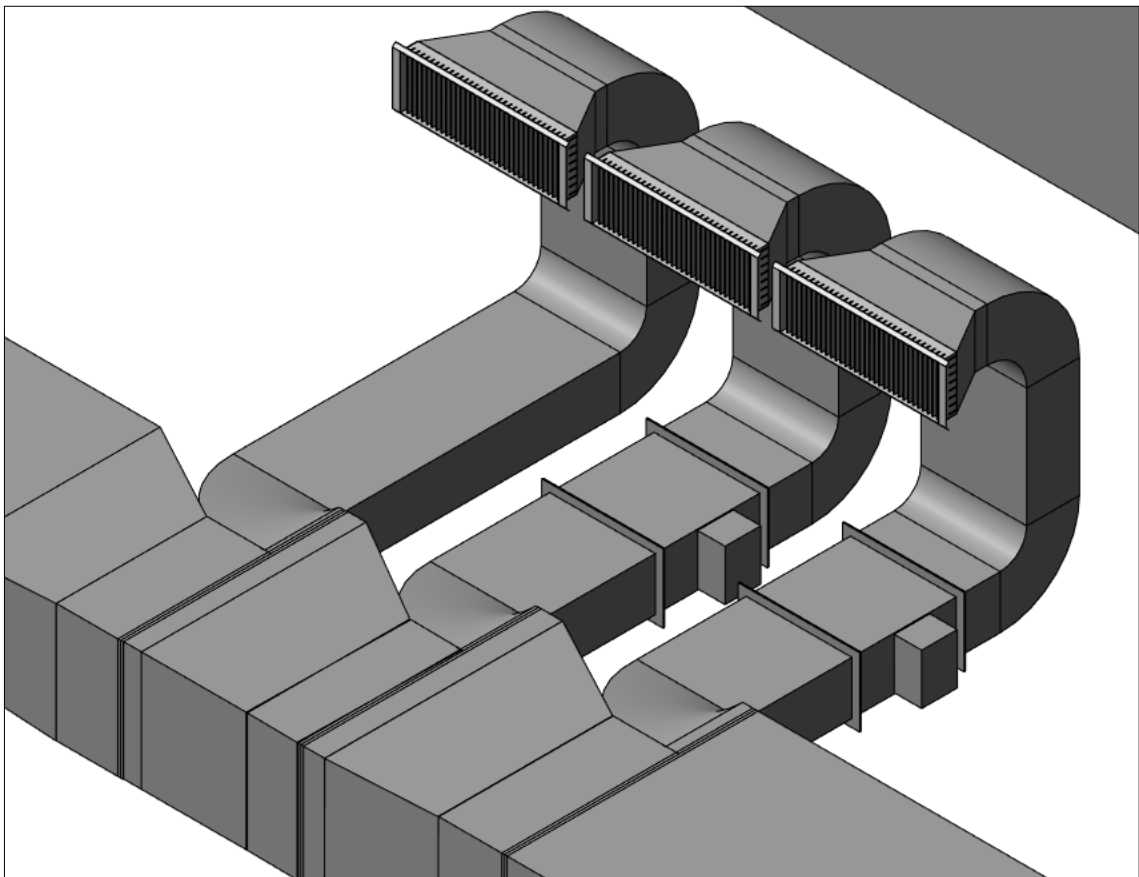


Figure 20: Different families used into the IVC model.

## 5.6 LOI and LOG

Information, as seen in the paragraph dedicated to LODs, plays an important role in a BIM project. The level of information more commonly indicated by the acronym LOI (Level Of Information), is used to indicate all the non-geometric information content of a family. A family with a high level of information may include, for example, manufacturer specific data sheets and instructions regarding maintenance. The parameters allow us to enter information within a project. In Revit, it is possible to create custom parameters for a project and for any category of elements or components within it. The parameters created are visible in the type properties dialog box or in the properties palette, depending on whether they are of type or instance, in the selected group. There are different types of parameters:

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

Global parameters are parameters specific to a single project, but are not associated with any category, they can be simple values, values obtained from equations or even parameters derived from the model by means of other global parameters.

Shared parameters are definitions of parameters that can be used within multiple families and projects. After inserting a new shared parameter, you can use it as a family or project parameter. The definition of a shared parameter is stored in a separate file and as a result, the shared parameter is protected from changes. For this very reason, shared parameters can be labelled and included in schedules. A schedule is a collection of information extracted from the properties of elements in a project and displayed in a table. Revit schedules are extremely useful tools and it is possible also to export them to other programs, such as a spreadsheet. You can create a schedule at any point in the process design. When changes are made to the project that affect the schedule, the latter is automatically updated.

The project parameters are also, like the global parameters, specific to a single

project. The information contained within this type of parameters cannot be shared with other projects but can be used for the creation of schedules, for their ordering and for the creation of filters.

Family parameters are family specific settings, they can be also used for the control of parameters of nested families, associating the parameter of the host family to the parameter of the nested family. For creation the same procedure was followed for each parameter:

- Create shared parameter: go to Manage and click on the shared parameters icon. Once the shared parameters editing tab is open, click on New and create the desired parameter, and finally insert it in the category of interest.

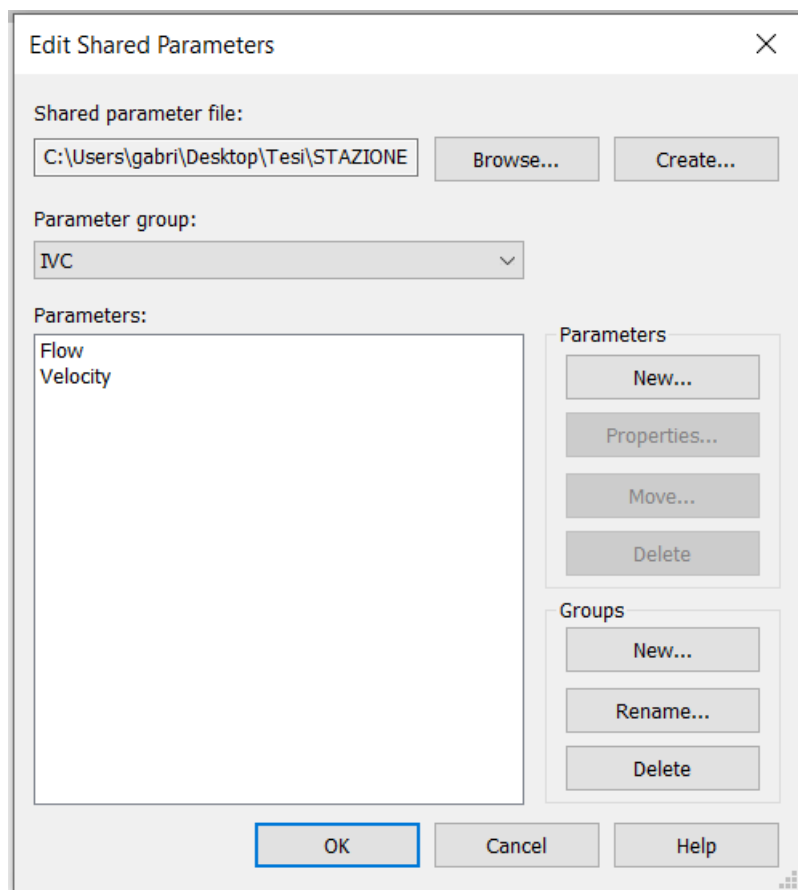


Figure 22: Edit window for shared parameters.

- Create project parameters: go to Manage and click on the project parameters icon. Clicking on Add opens the window shown in the figure below.

Figure 23: Parameter property, Revit.

Select the Shared parameter option and choose the shared parameter just created. Depending on the parameter, choose whether to attribute it to the type or to the instance and to which elements to assign it. If you select the Type option, the parameter is entered in the properties of the type and its value can be changed in the Edit type window, if you choose the Instance option, the parameter appears and can be changed in the Properties panel.

In order to avoid having different parameters names among the different model files, it is crucial to used “shared parameters”. Having different names or field types for parameters would generate important issues, like no being able to schedule them in the federated model. This concept improves information consistency.

Shared parameters can be used in multiple families and projects. These types of parameters are saved into a XLSX extension file in which it is been specified the Name of the parameter, the Parameter group, the Group, the Type and the Unit of measure. For the purpose of this thesis, a unique file was created where parameters were divided into groups.

*Table 4: Table of shared parameter used for IVC model.*

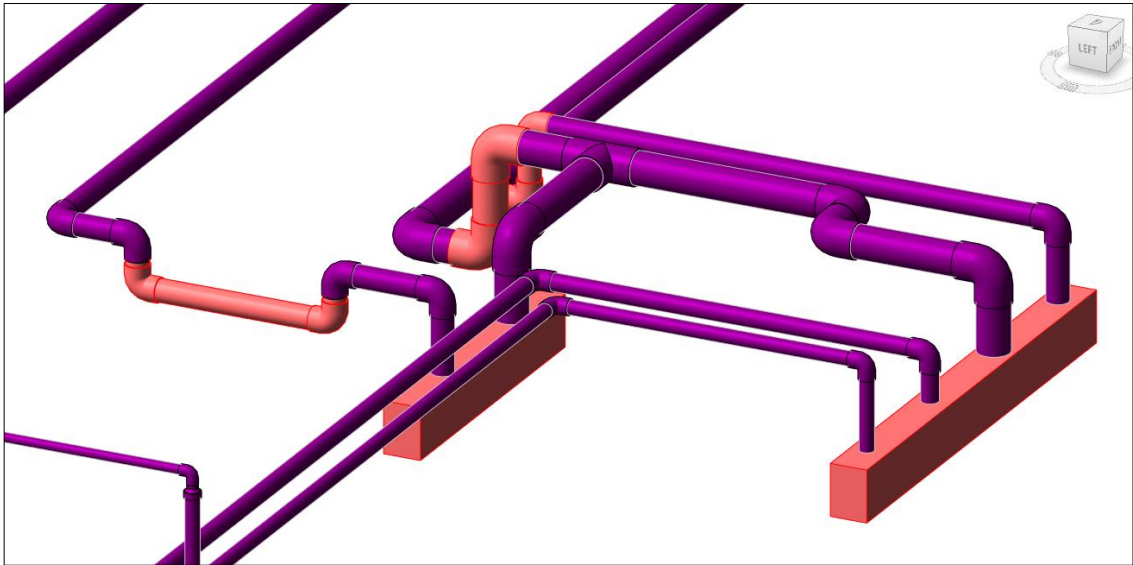
Name	Parameter group	Group	Type	Unit of measure
Flow	IVC	Mechanical	Instance	[m <sup>3</sup> /h]
Velocity	IVC	Mechanical	Instance	[m/s]

As regards, instead, the creation of family parameters, the path that has been followed is divided into two phases:

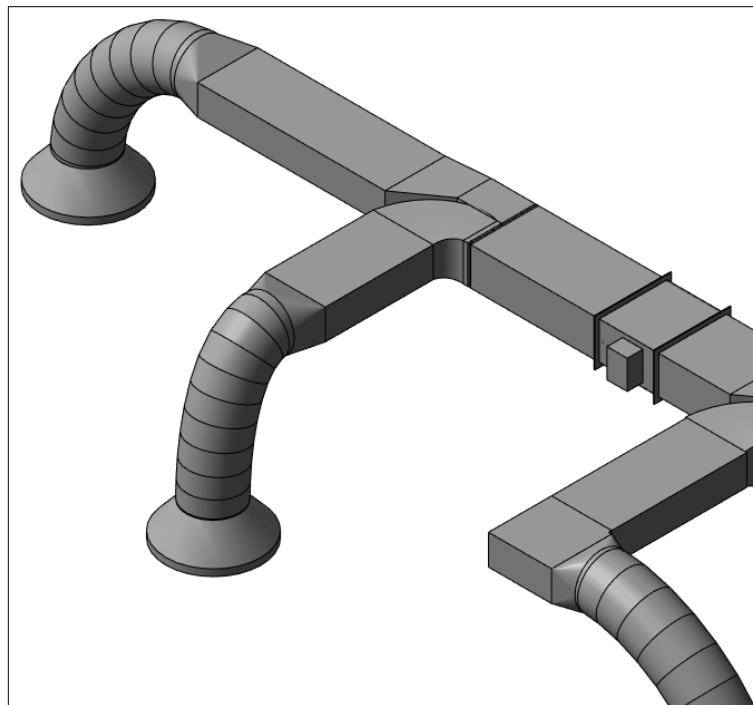
1. Create shared parameter (as for project parameters).
2. Create family parameter: open the family to which you want to associate the parameter, click on the Family Types icon and create the new parameter.

The outside, the visible part of the represented elements, is the Level of Geometry. It tells us something about the appearance of the element. The LOG in a BIM model expresses the geometric level of detail.

For the MEP models build with this thesis, the customer had requested a LOD C, but the final models realized was modelled with a higher LOD to understand the actual interference. In fact, looking at the UNI 11337, a LOD C for a MEP system includes from a geometrical point of view just a conceptual and generic representation of the spaces of the main overall dimensions of the pipes (technical tunnels) and has as characteristics just the definition of the main paths within the technical tunnels as it is possible to see into the table in the following page. While in the developed models the LOD results higher because, from the geometrical point of view, ducts and pipes have real dimensions, from the information point of view, they have specific parameters, like the ones in Table 4, that characterize them as reported in the design files.

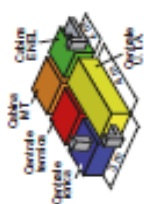
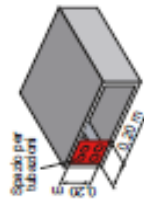






*Figure 24: Detail of the modelled fire system.*



*Figure 25: Detail of the air ventilation and conditioning system.*

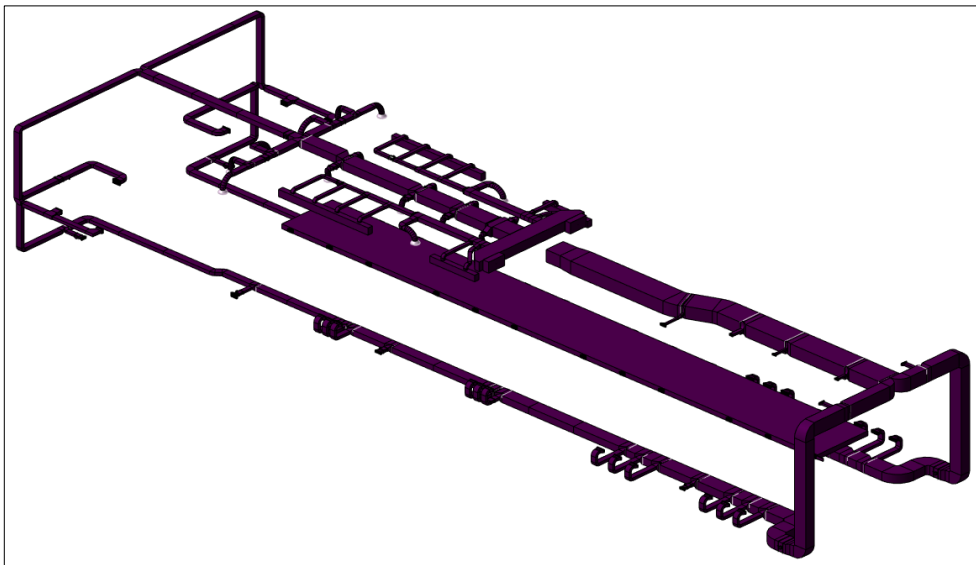
prospetto C.35 Esempio di LOD tubazione antincendio

LOD A	LOD B	LOD C	LOD D	LOD E	LOD F	LOD G
						
<b>Geometria</b>	Rappresentazione concettuale e gerarchia degli spazi degli ingombri principali di tutti gli impianti (cavedi e cunicoli tecnici).	<b>Geometria</b> Rappresentazione concettuale e gerarchia degli spazi degli ingombri complessivi principali delle tubazioni (cavedi e cunicoli tecnici).	<b>Geometria</b> Forma, dimensioni, posizione, ingombri, pendenze, valvole, pezzi speciali per montanti, dorsali e derivazioni effettivi. Margini ed ingombri effettivi per manutenzione, supporti, ancoraggi effettivi, per controllo vibrazioni e consolidamento antisismico utilizzati per montanti, dorsali, derivazioni. Forme e derivate orizzontali e verticali.	<b>Geometria</b> Componenti supplementari per la fabbricazione e l'installazione in cantiere.	<b>Geometria</b> Come LOD E (rilievo di quanto eseguito).	<b>Geometria</b> Nuovi interventi: Come LOD F (con aggiornamenti). Manutenzione e gestione su elementi esistenti Come LOD C o D (a partire da).
<b>Oggetto</b>	<b>Oggetto</b>	<b>Oggetto</b> Solido 3D	<b>Oggetto</b> Solido 3D	<b>Oggetto</b> Solido 3D	<b>Oggetto</b> Solido 3D	<b>Oggetto</b> Solido 3D
<b>Caratteristiche</b>	<b>Caratteristiche</b> Indicazione delle dimensioni complessive occupate dalle tubazioni	<b>Caratteristiche</b> Definizione dei percorsi principali all'interno dei cavedi e dei cunicoli tecnici	<b>Caratteristiche</b> Definizione effettiva di parametri di performance (diametro nominale, allacciamento, pressioni, portata, potenza, curva caratteristica, prevalenza, ecc.)	<b>Caratteristiche</b> Nome prodotto, nome prodotto Modalità di installazione	<b>Caratteristiche</b> Nome prodotto, nome produttore Modalità di installazione	<b>Caratteristiche</b> Data di manutenzione/sostituzione Soggetto manutenzione Storico delle manutenzioni

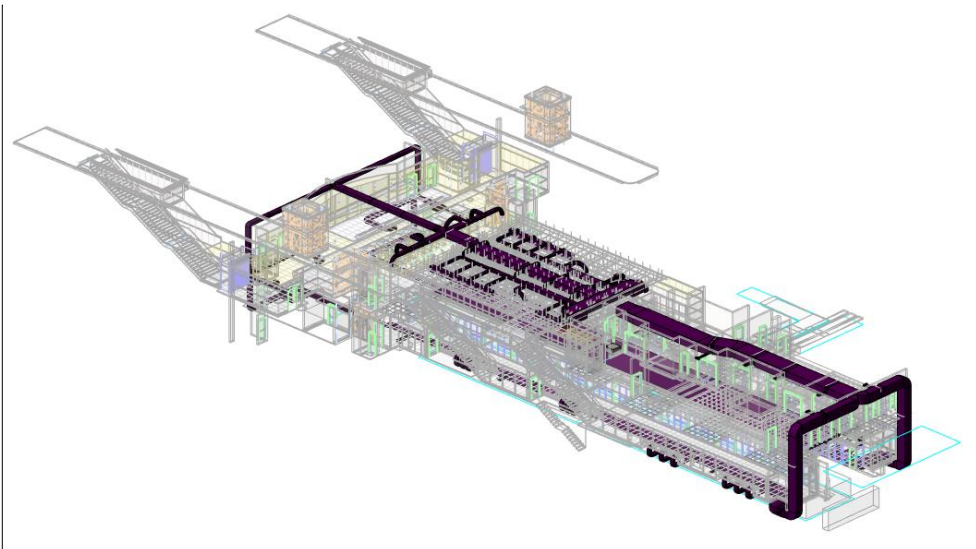
## 6 Results

### 6.1 Ventilation and air conditioning system

In conclusion, at the end of the modelling phase, an information and three-dimensional model of the HVAC system was obtained, based on a library of parametric objects, to which a certain amount of useful information was assigned.



*Figure 26: 3D view of IVC model.*

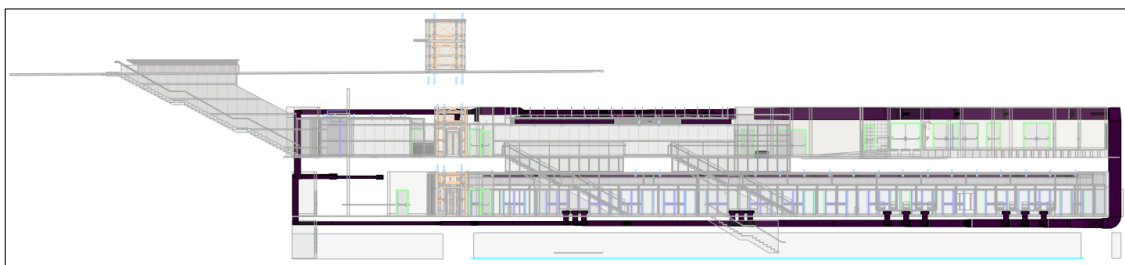


*Figure 27: 3D view of IVC, STR and FUN models.*



## Results

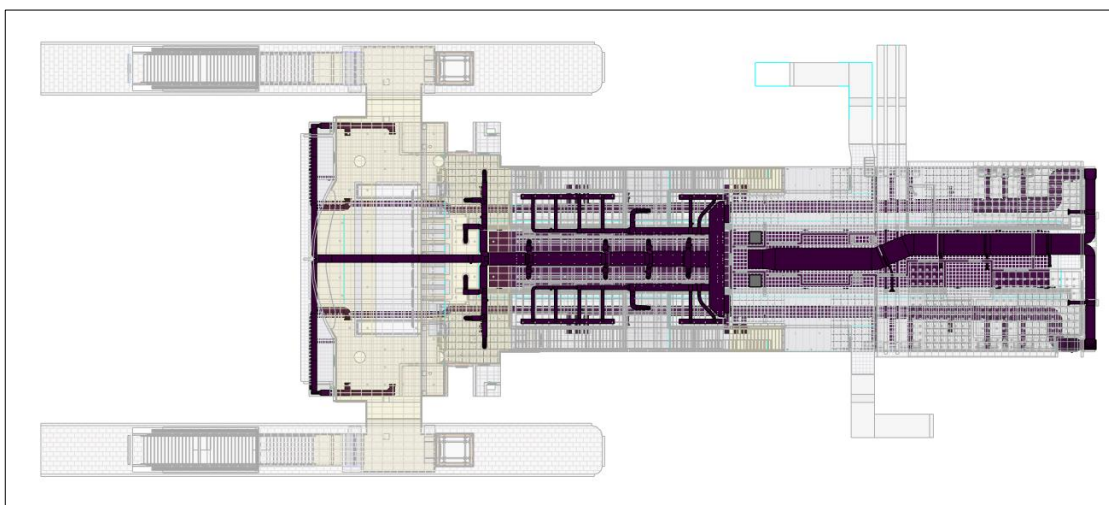
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*Figure 30: Lateral view of the model, Revit.*



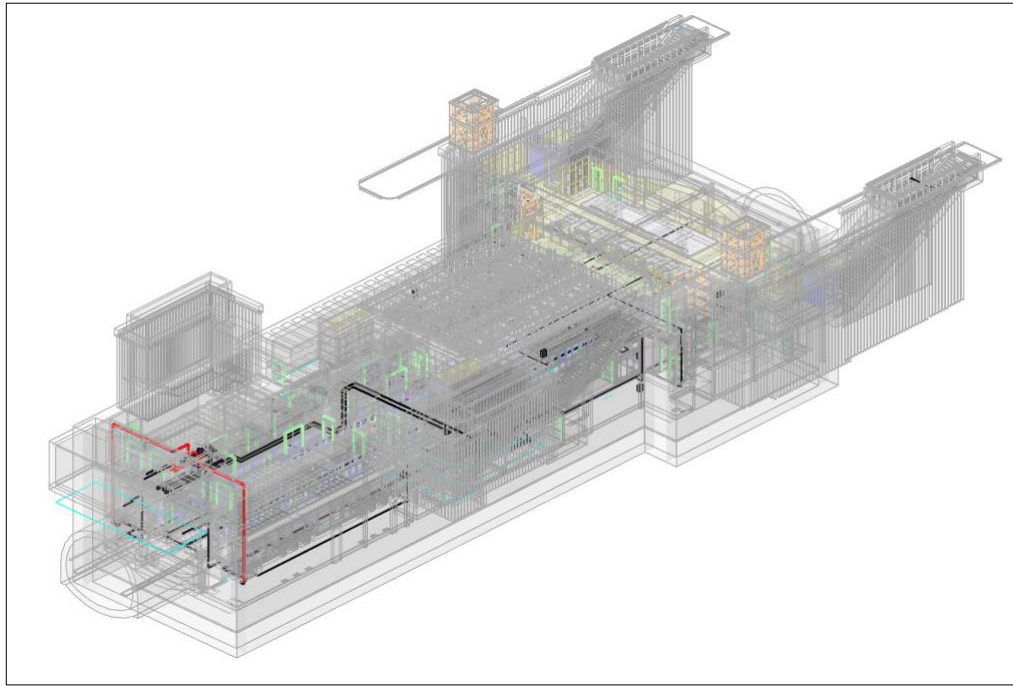
*Figure 29: Front view of the model, Revit.*



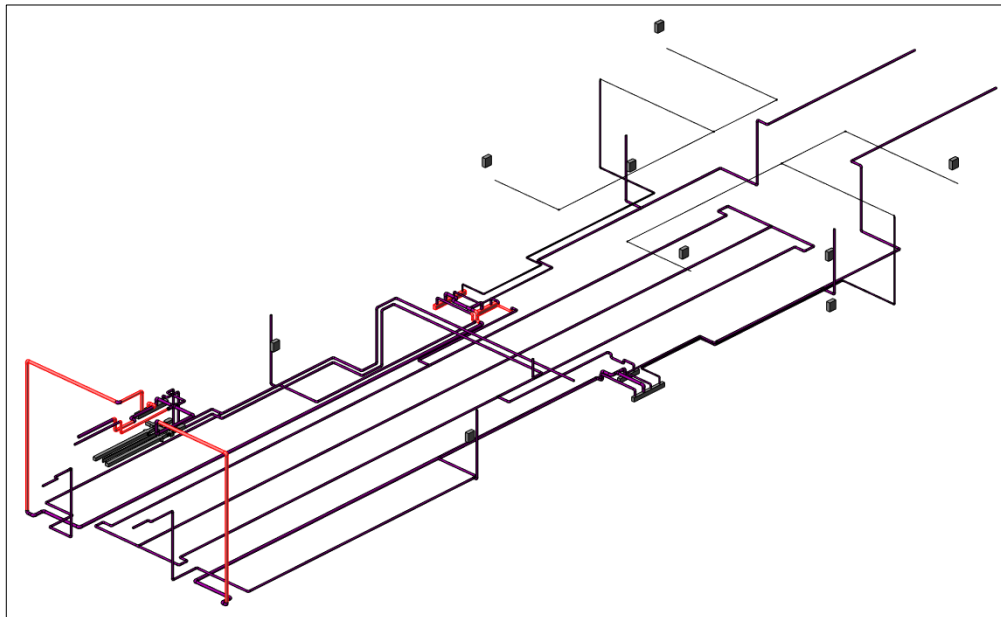
*Figure 28: Top view of the model, Revit.*

## 6.2 Fire system

Successively, at the end of the modelling phase, an information and three-dimensional model of the HVAC system was obtained, based on a library of parametric objects, to which a certain amount of useful information was assigned.



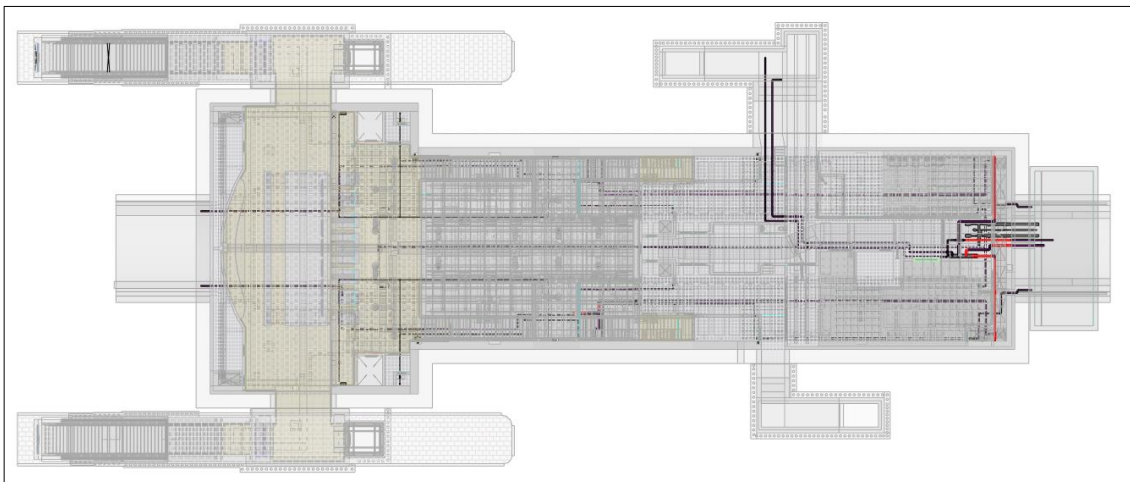
*Figure 32: 3D view of IIA, STR and FUN models.*



*Figure 31: 3D view of IIA model.*

## Results

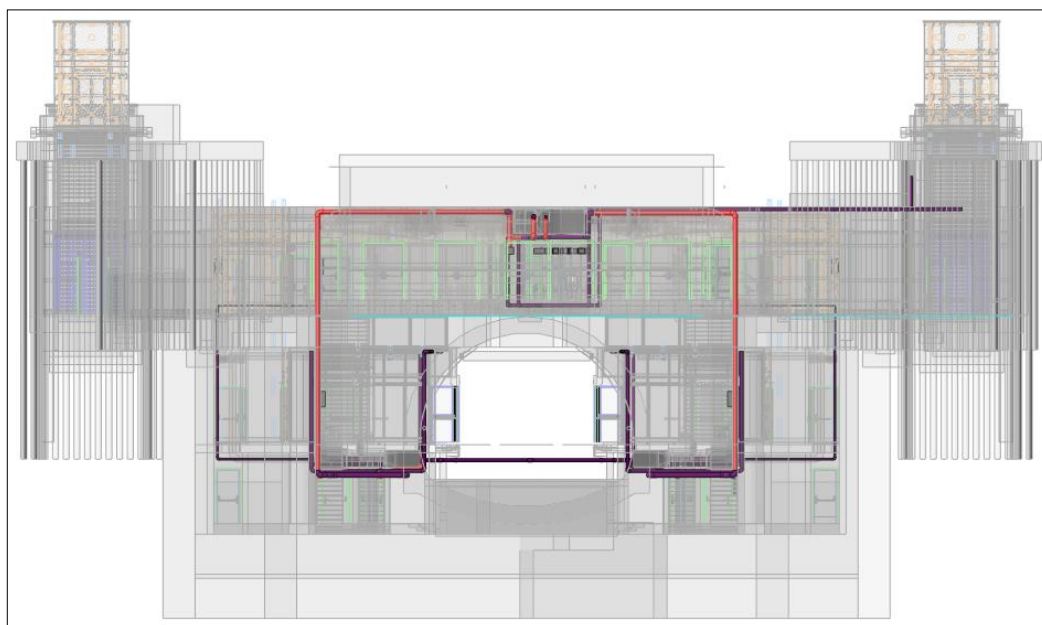
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*Figure 34: Top view of the model, Revit.*



*Figure 33: Lateral view of the model, Revit.*



*Figure 35: Front view of the model, Revit.*

As it is possible to notice in the previous figure, some pipes of the fire system have been highlighted in red. Indeed, during the build of the IIA model the author noticed that there were some clashes between the already build ventilation and air conditioning model and the fire one. So, it has been decided to highlight in a different colour all that pipes that differ from the original design position in order to avoid clashes between models.

## 7 Clash detection

Clash detection is one of the most fundamental part of the whole BIM modeling process. Once the designers have finished their work (according to several disciplines) it is necessary to proceed to the next step in the BIM process that is defined clash detection, which is the process of finding where the elements of the models intersect. The software can highlight when the elements of separate models occupy the same space and detect in general, the geometrical interference between elements that belongs to several disciplines. It is a decision of the user to set the different rules and tolerance according to a level of severity of the clash. Finding these inconsistencies is vital, as they would severely impact the construction process, causing delays, design changes, materials costs and a cascade of headaches and budget overruns. [15]

Only after the models were federated (models are over-lapped: typically, the models are architectural, structural and MEP models) performing the collision is evaluable. The report of the collision will be communicate by the BIM manager to the all BIM coordinator. After that the design team decide who has to change the model.

## 7.1 Revit

Performing a clash detection is recommended to used linked models (for instance, the architectural model could be used as “container” in which linked structural and MEP model).[14]

This can be done following the menu Insert and going through Manage Link. After the linking phase, the Interference Check can be performed with Revit. The Clash can be performed for the same elements (the detection of duplications or interference between levels of, such as walls) or between different discipline and categories (for instance, wall and ducts, walls and beams, beams and pipes).

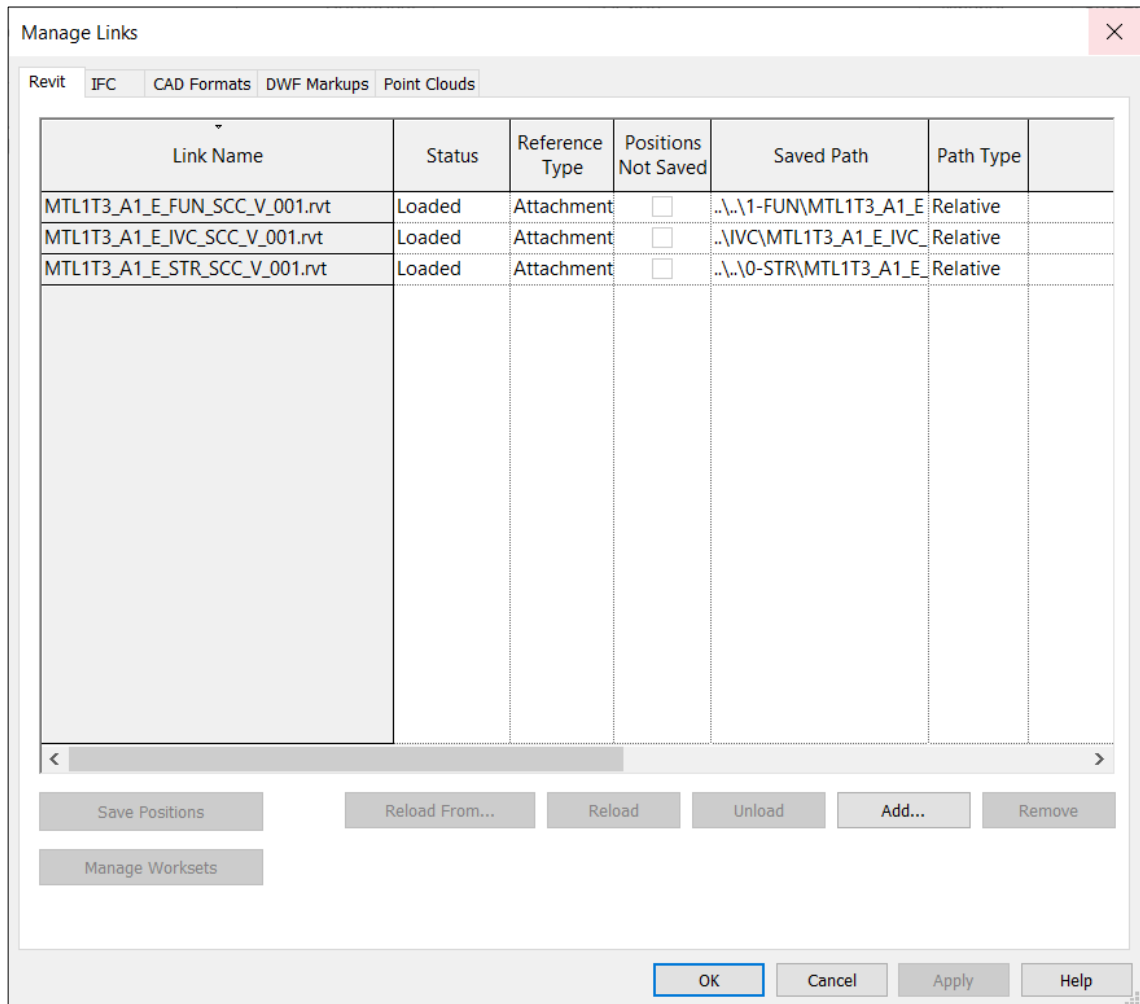


Figure 36: Manage Links, Revit.

## Clash detection

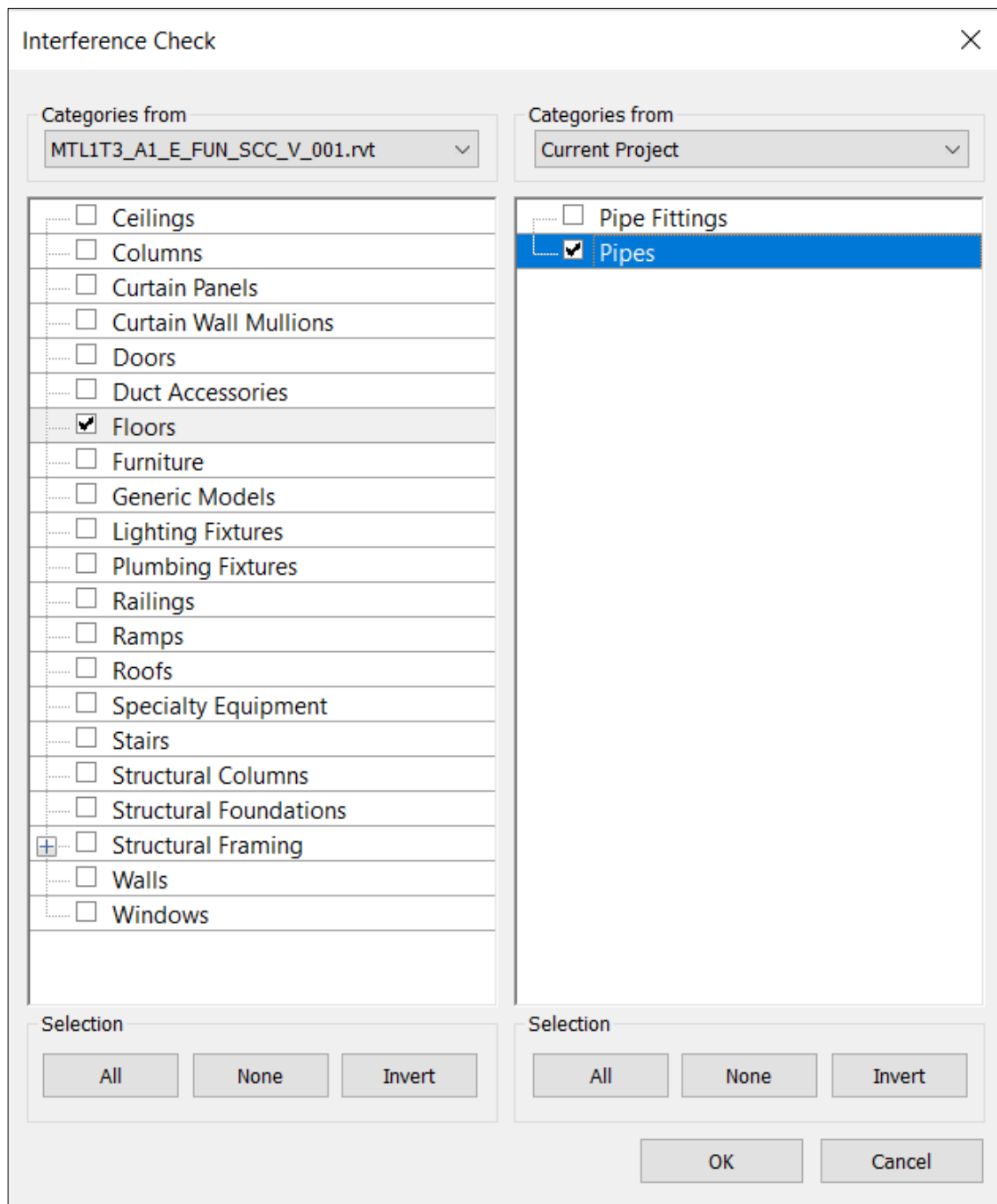
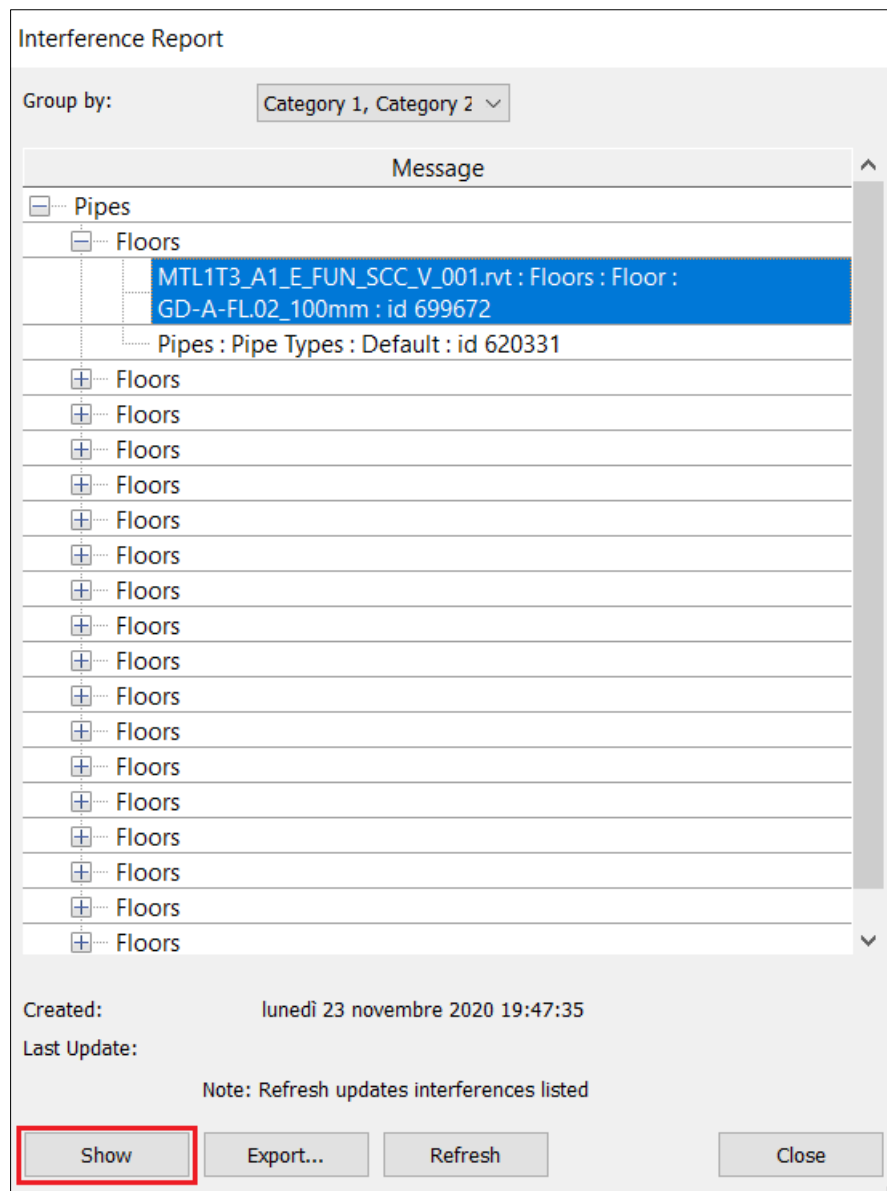


Figure 37: Interference Check, Revit.



*Figure 38: Interference Report, Revit.*

First limit: the clash detection can be performed into Revit only between two models each time. This could be overcome if the modelling phase will be done only in a unique model. But if the file size does not allow it (suggested 250 Mb each file), it is recommended to separate the models.

Second limit: is not possible to establish in Revit a tolerance for the clash detection. For instance, if two elements do not intersect but only associate by a side, Revit will detect a clash and it is not correct. When the clash is confirmed,



Revit report a list of clashes that can help to visualize the elements.

## 7.2 Navisworks

In this step a clash detection verification is made using Navisworks software. Navisworks allows users to open and combine 3D models; navigate around them in real-time; and review the model using a set of tools including comments, redlining, viewpoint, and measurements. A selection of plug-ins enhances the package adding interference detection, 4D time simulation, photorealistic rendering and PDF-like publishing.



To export the model from Revit it is necessary to use the external tools into the add-ins tab make sure to disable the analytical before exporting, then open Navisworks.

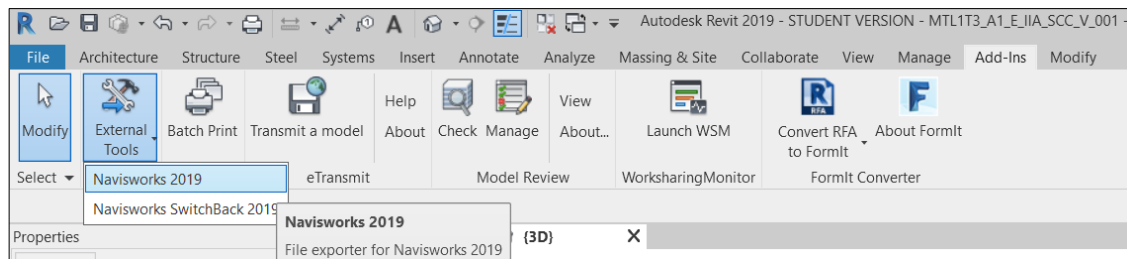


Figure 39: Revit external tool.

Once open the .nwc file within Navisworks a test is added with specific rules like the tolerance and the type of clash as it is possible to see in figures below.

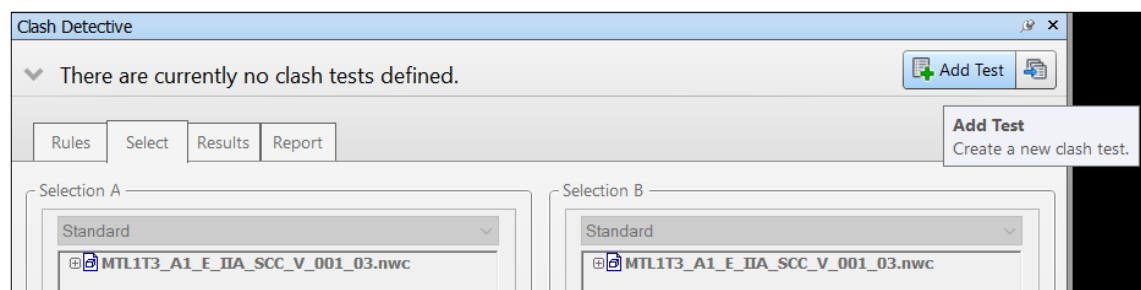


Figure 40: First step to add a test within Navisworks.

## Clash detection

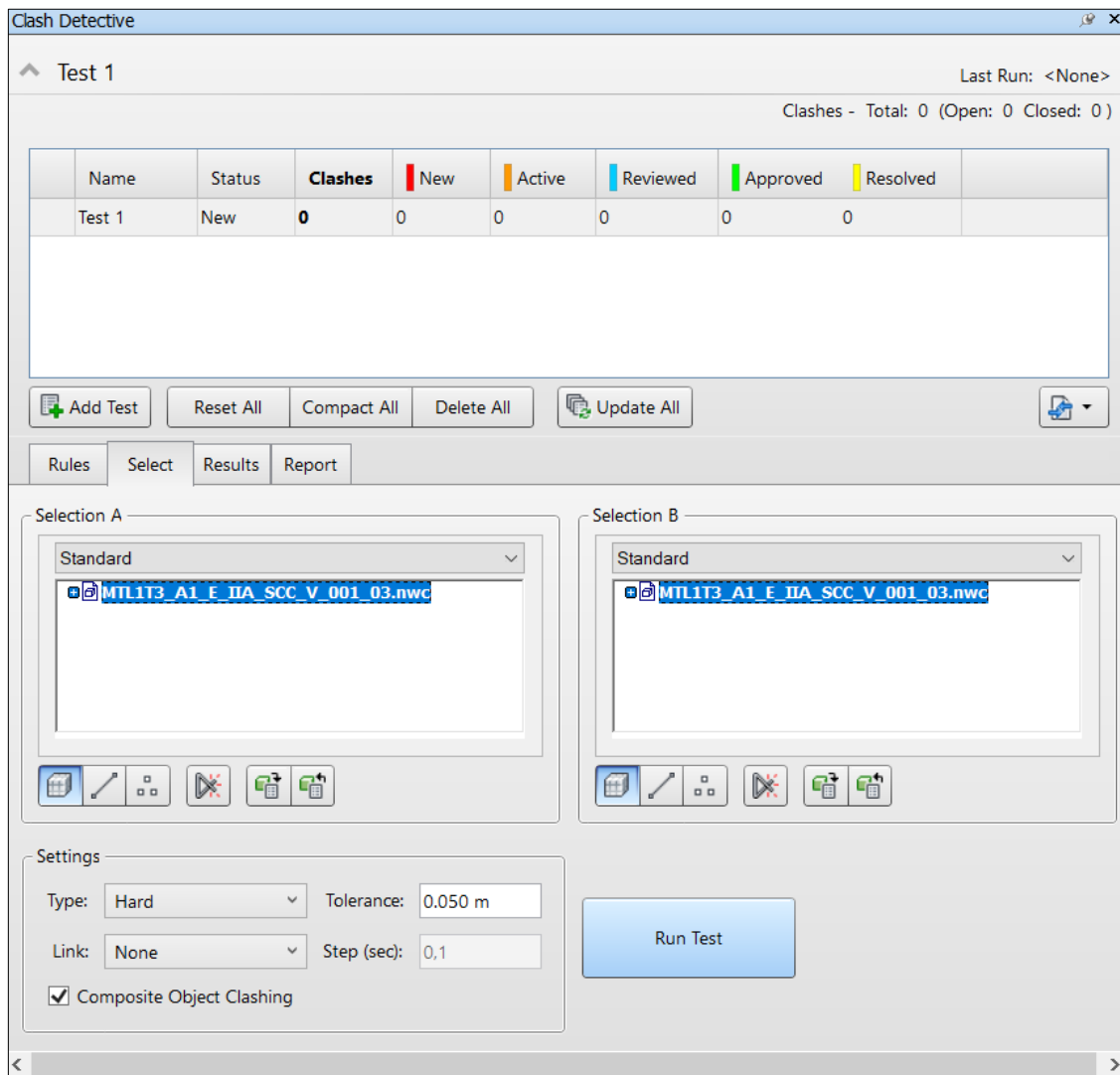


Figure 41: Test settings.

The clash detection can be performed also with elements belonging to the same models.

Automatically the software allows to visualize all the interference and produce several images to visualize the collision between elements.

After running the test, it is possible to check the results in Navisworks with details about the clash and auto focusing on the clashed elements if present. For what concern the fire system there are no clashes identified.

## Clash detection

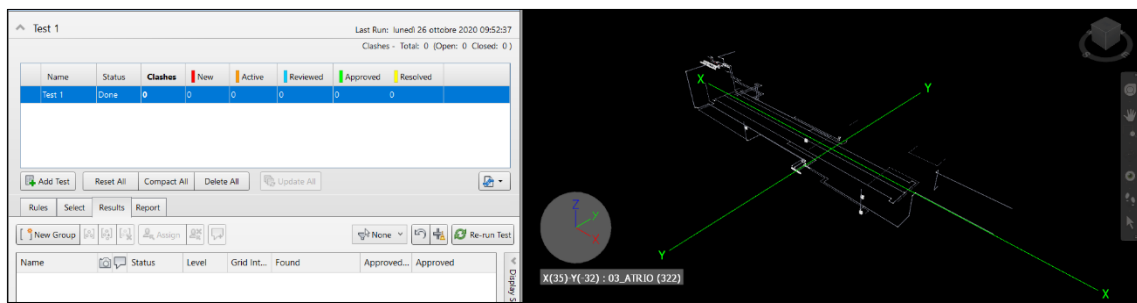


Figure 43: IIA clash detection test.

In order to check clash detection between different models, it is needed to add those models within Navisworks and make different tests.

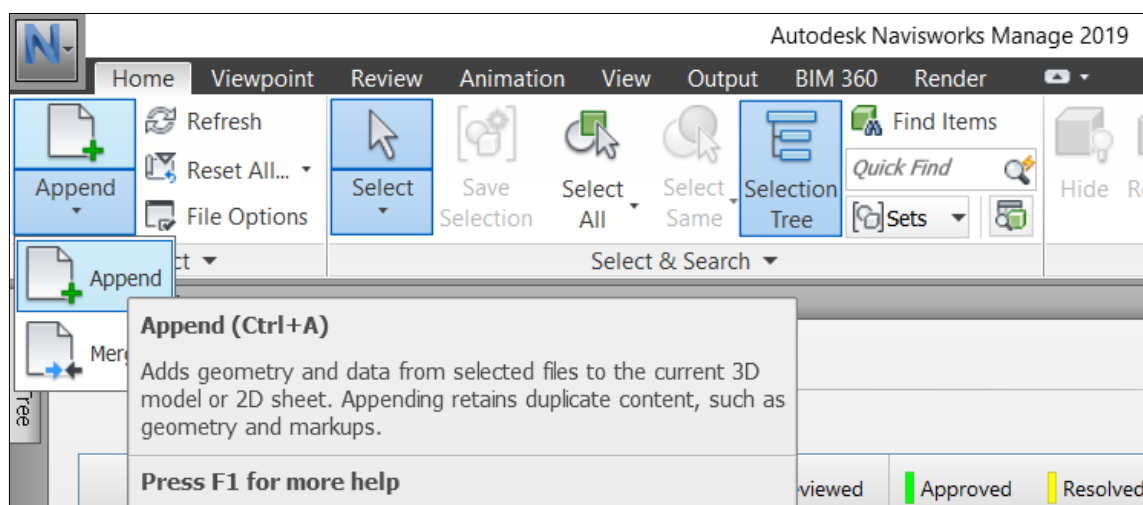


Figure 42: Add other models to make clash detection verification.

In this way clash detection verifications between single models themselves, IIA and IVC, IIA and functional model (FUN), IIA and structural model (STR), IVC and FUN, IVC and STR have been conducted. For what concern clashes between MEP systems solutions have been found like in the case show in the figure below where a pipe of the fire system intersects a duct of the ventilation system. In this specific case the solution adopted solve the intersection bringing the pipe under the duct considering the space needed between the two for maintenance issues.

## Clash detection

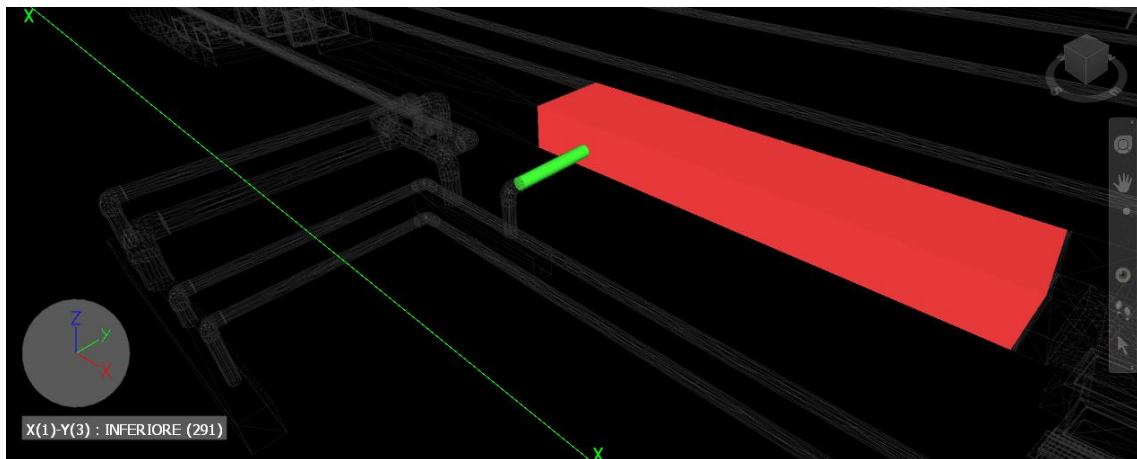


Figure 46: Case of pipe intersecting a duct.

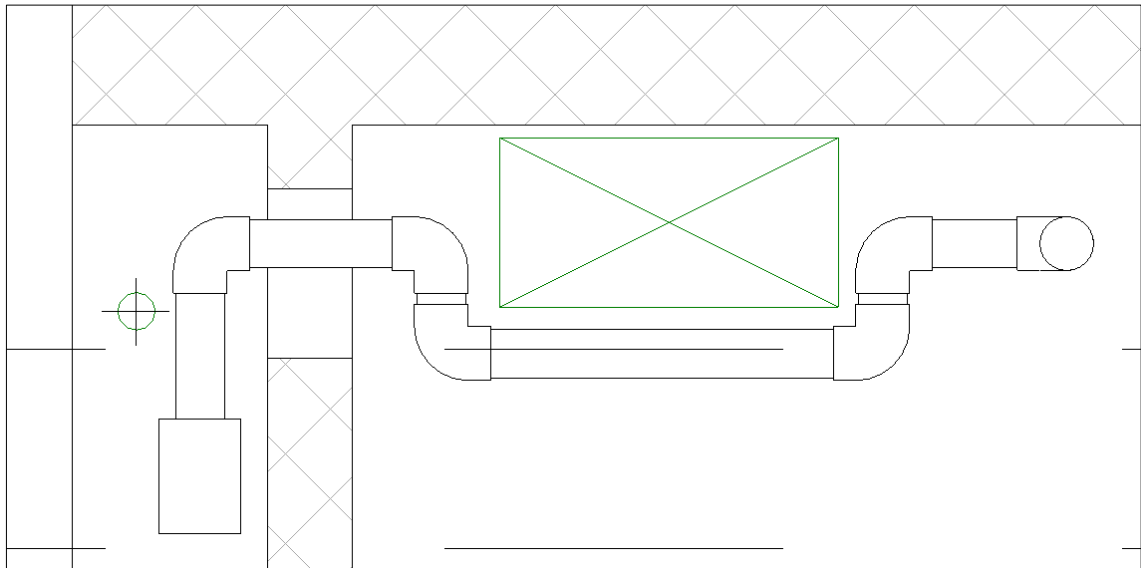


Figure 45: Solution found to the intersection.

After solving this issues Navisworks find zero clashes between IIA and IVC systems.

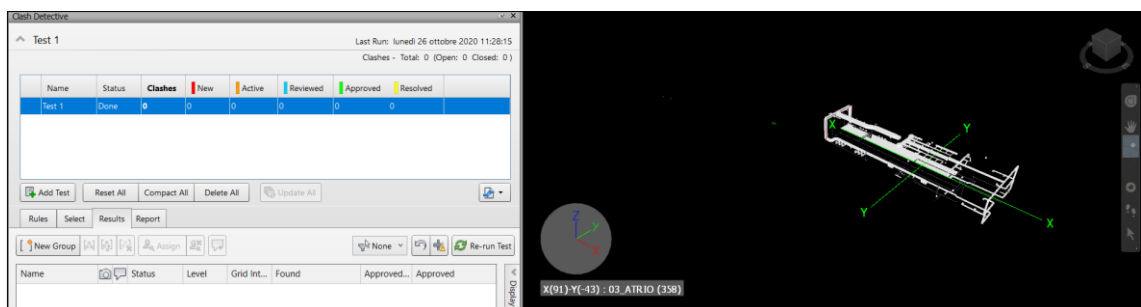


Figure 44: Clashes between IIA and IVC models.

There are many clashes between system models and structural and functional ones. In the majority of them is sufficient to create a hole in the wall giving the possibility to pipes and ducts to pass through the walls, but it is important to be careful in case of reinforced concrete elements because maybe in this cases it's better to find another path for the systems.

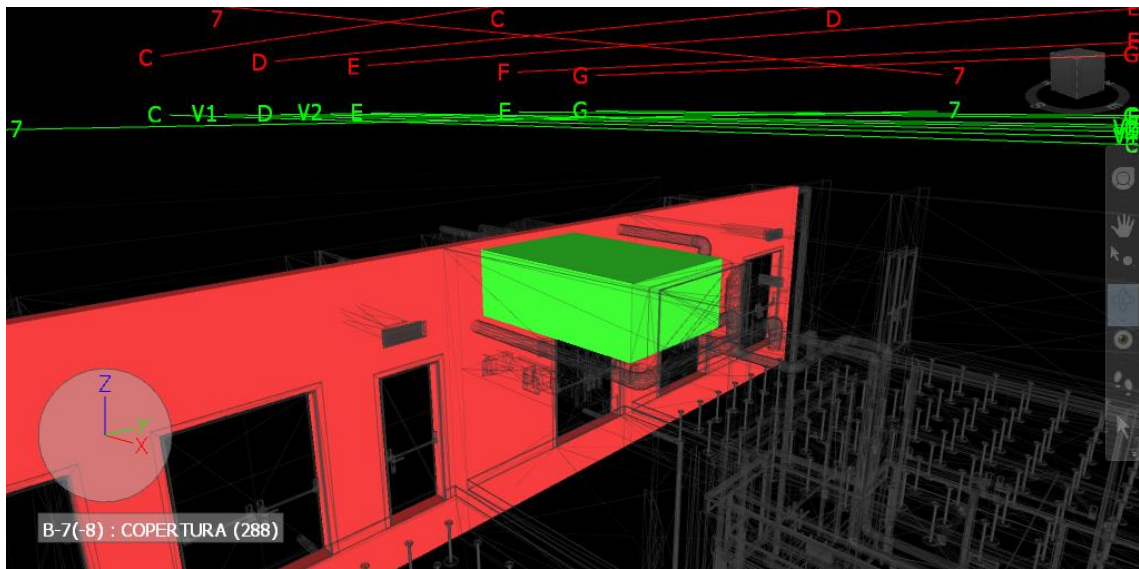


Figure 47: Intersection between IVC and FUN models.

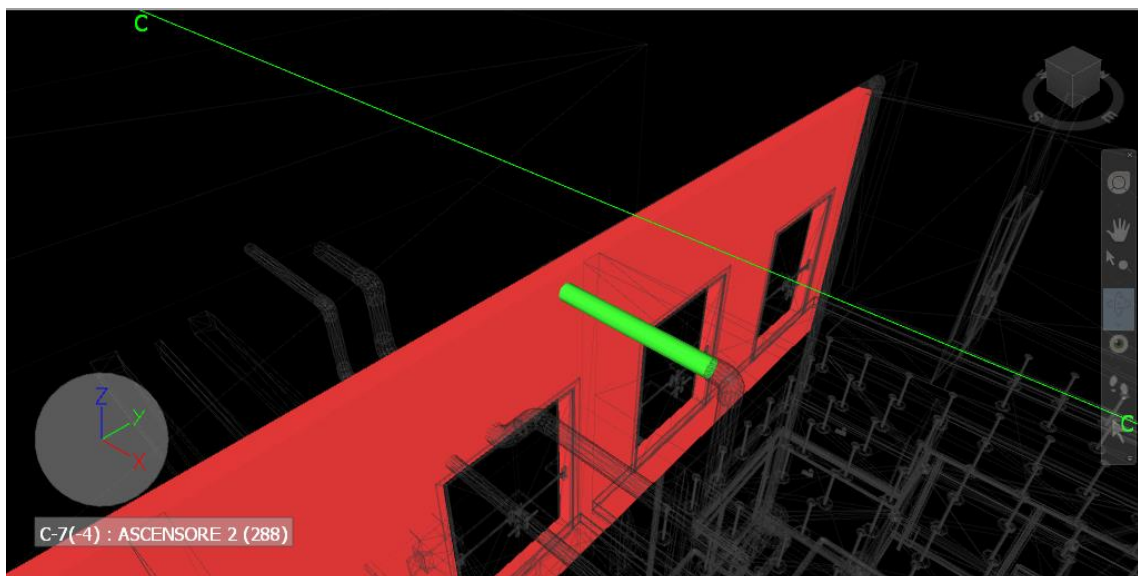


Figure 48: Intersection between IIA and FUN models.

## Clash detection

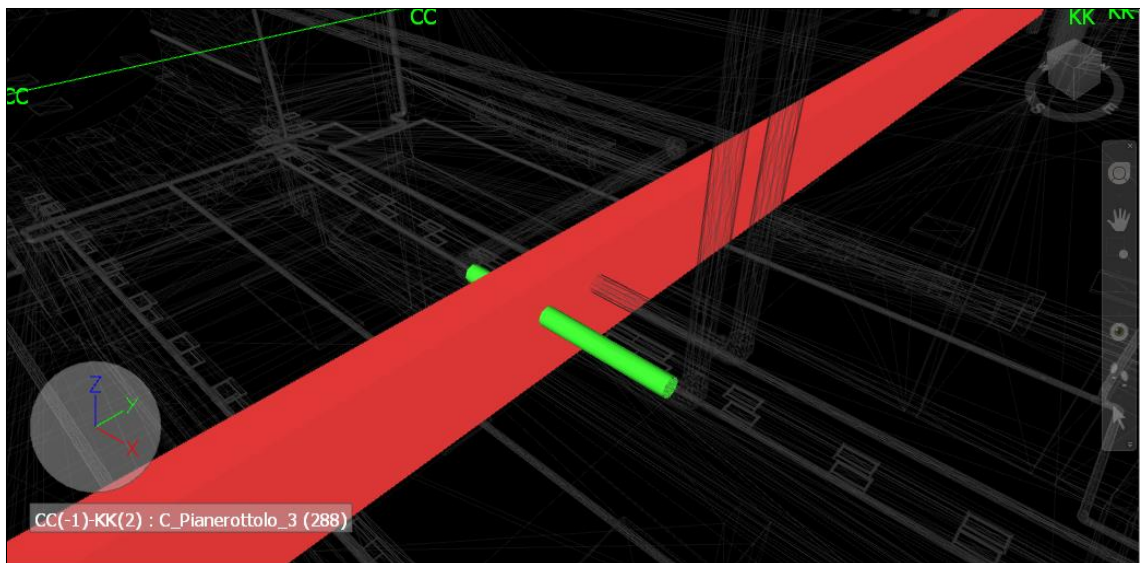


Figure 49: Intersection between IIA and STR models.

Using Navisworks, the clash detection has got an improvement compared to the clash detection performed previously in Revit, because it is possible to set the tolerance.

Sometimes is better to set the tolerance to some centimetre (2 - 5 cm ) because going down to this precision is not necessary, especially during the building process.

The final report could be visualized internally to Navisworks or externally via .html or other kinds of interoperable formats. [16]

Clash Point	Item ID	Path	Item ID	Path	Item ID
x: 3.300, y: 5.535, z: 25.791	(Element ID: 542643)	File > model2.mec > Level 2 > Walls > Basic Wall > Generic - 8" > Basic Wall > (Element ID: 542614)	(Element ID: 542614)	File > model2.mec > model2.int: 1, location effect (Shards) > 1 > (Default Floor)	
x: 3.300, y: 5.535, z: 25.791	(Element ID: 542614)	File > model2.mec > Level 2 > Walls > Basic Wall > Generic - 8" > Basic Wall > (Element ID: 542614)	(Element ID: 542614)	File > model2.mec > model2.int: 1, location effect (Shards) > 1 > (Default Floor)	
x: 3.300, y: 5.535, z: 25.791	(Element ID: 542614)	File > model2.mec > Level 2 > Walls > Basic Wall > Generic - 8" > Basic Wall > (Element ID: 542614)	(Element ID: 542614)	File > model2.mec > model2.int: 1, location effect (Shards) > 1 > (Default Floor)	
x: 3.300, y: 5.535, z: 25.791	(Element ID: 542614)	File > model2.mec > Level 2 > Walls > Basic Wall > Generic - 8" > Basic Wall > (Element ID: 542614)	(Element ID: 542614)	File > model2.mec > model2.int: 1, location effect (Shards) > 1 > (Default Floor)	
x: 3.300, y: 5.535, z: 25.791	(Element ID: 542614)	File > model2.mec > Level 2 > Walls > Basic Wall > Generic - 8" > Basic Wall > (Element ID: 542614)	(Element ID: 542614)	File > model2.mec > model2.int: 1, location effect (Shards) > 1 > (Default Floor)	
x: 3.300, y: 5.535, z: 25.791	(Element ID: 542614)	File > model2.mec > Level 2 > Walls > Basic Wall > Generic - 8" > Basic Wall > (Element ID: 542614)	(Element ID: 542614)	File > model2.mec > model2.int: 1, location effect (Shards) > 1 > (Default Floor)	
x: 3.300, y: 5.535, z: 25.791	(Element ID: 542614)	File > model2.mec > Level 2 > Walls > Basic Wall > Generic - 8" > Basic Wall > (Element ID: 542614)	(Element ID: 542614)	File > model2.mec > model2.int: 1, location effect (Shards) > 1 > (Default Floor)	
x: 3.300, y: 5.535, z: 25.791	(Element ID: 542614)	File > model2.mec > Level 2 > Walls > Basic Wall > Generic - 8" > Basic Wall > (Element ID: 542614)	(Element ID: 542614)	File > model2.mec > model2.int: 1, location effect (Shards) > 1 > (Default Floor)	
x: 3.300, y: 5.535, z: 25.791	(Element ID: 542614)	File > model2.mec > Level 2 > Walls > Basic Wall > Generic - 8" > Basic Wall > (Element ID: 542614)	(Element ID: 542614)	File > model2.mec > model2.int: 1, location effect (Shards) > 1 > (Default Floor)	
x: 3.300, y: 5.535, z: 25.791	(Element ID: 542614)	File > model2.mec > Level 2 > Walls > Basic Wall > Generic - 8" > Basic Wall > (Element ID: 542614)	(Element ID: 542614)	File > model2.mec > model2.int: 1, location effect (Shards) > 1 > (Default Floor)	

Figure 50: Export Report and Reports Result. [<https://www.bim-hex.com/single-post/2018/04/09/Best-practice-for-Crash-Detection>]



## 7.3 BIM 360 Coordinate

Once clash detections have been verified with Navisworks, it has been decided to make a comparison with another Autodesk family software: BIM360, in particular using the Coordinate set. Using BIM360 Coordinate it is possible to see all clashes between models inside it.

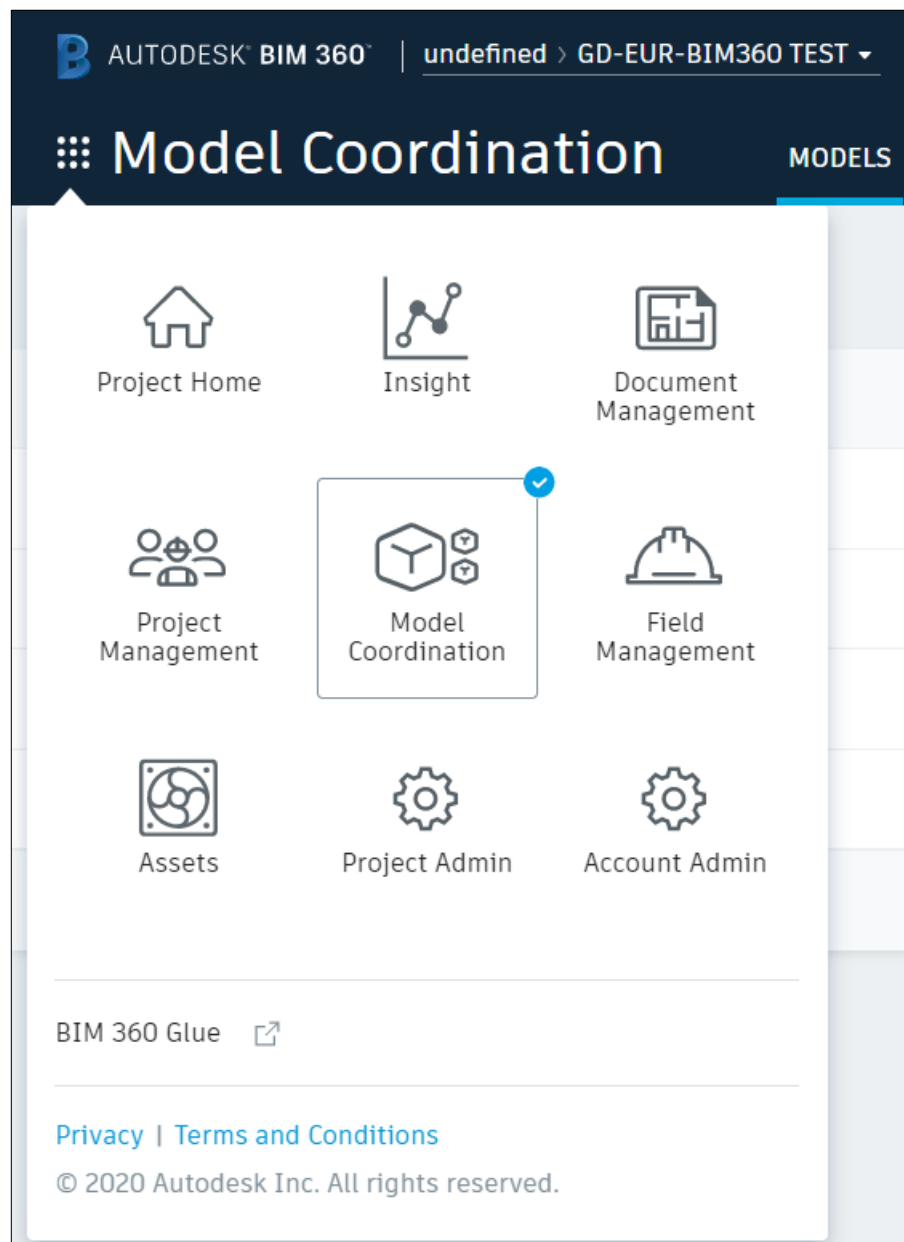
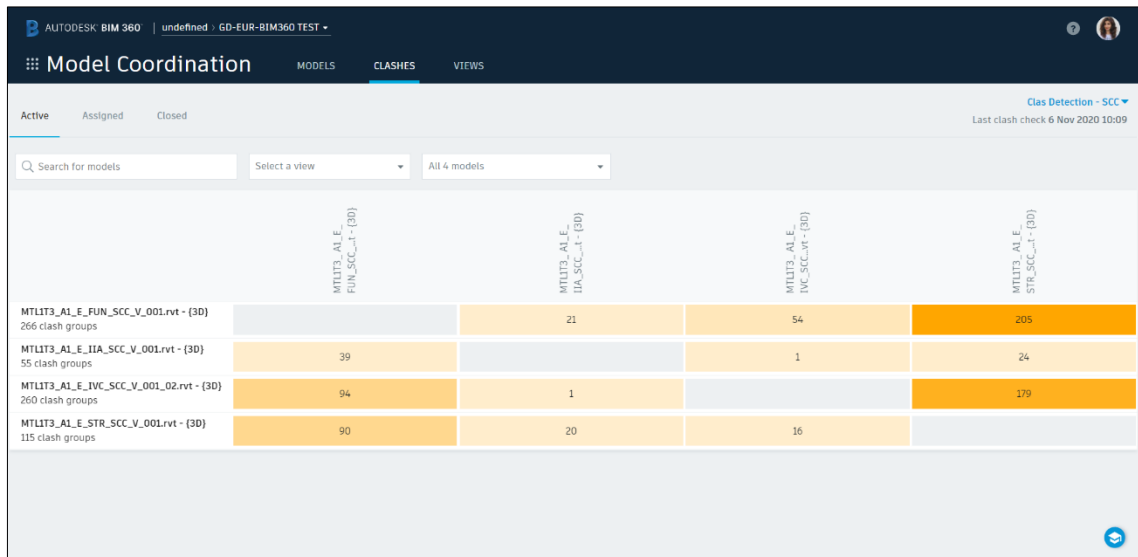


Figure 51: Model coordination set within BIM 360.

## Clash detection

Once entered into the Model Coordination there are three different sections: Models, in which it is possible to see all models uploaded in BIM360, Clashes, in which it is present a table that shows the number of clashes present between different models, and Views, where are saved the screens done through the models.



	MTL113_AI_E_FUN_SCC_V_001.rvt - (3D)	MTL113_AI_E_IIA_SCC_V_001.rvt - (3D)	MTL113_AI_E_IVC_SCC_V_001_02.rvt - (3D)	MTL113_AI_E_STR_SCC_V_001.rvt - (3D)
MTL113_AI_E_FUN_SCC_V_001.rvt - (3D) 266 clash groups		21	54	205
MTL113_AI_E_IIA_SCC_V_001.rvt - (3D) 55 clash groups	39		1	24
MTL113_AI_E_IVC_SCC_V_001_02.rvt - (3D) 260 clash groups	94	1		179
MTL113_AI_E_STR_SCC_V_001.rvt - (3D) 115 clash groups	90	20	16	

Figure 52: Table present into the clashes section.

Clicking on a specific combination of models present into the table it is visualized the 3D view of the models and the present clashes are highlighted. A very useful aspect of the Model Coordination tool is that it is possible to assign the solution of a specific clash to a person inside the project and it is done selecting the clash and then clicking on the “Issue” tab that is present at the bottom of the clashes window as it is possible to see into the following figure.



## Clash detection

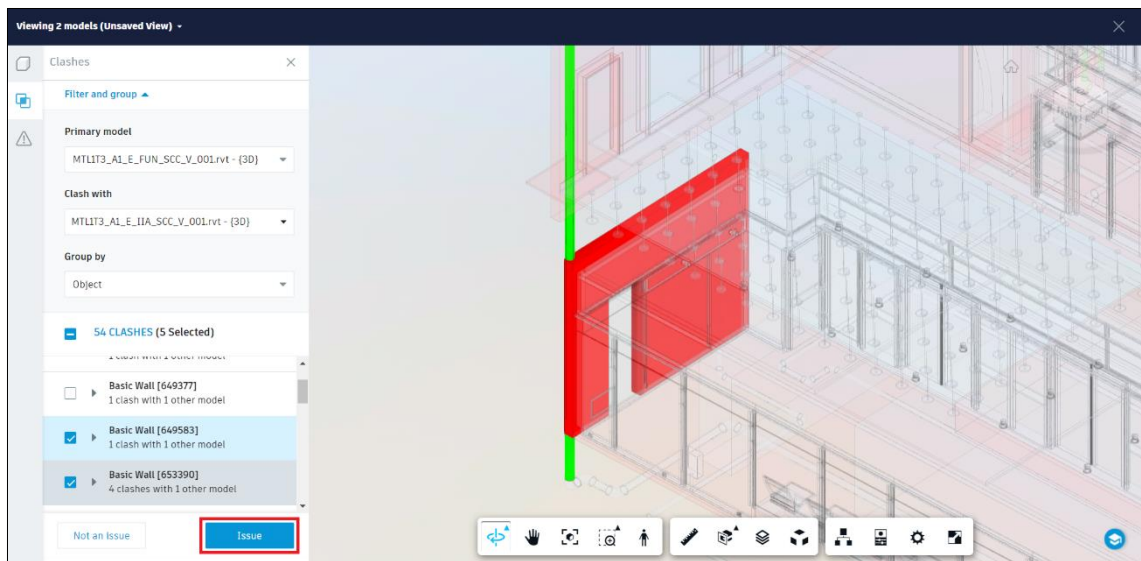


Figure 54: 3D view of a clash between IIA and FUN models.

In this section you can also define other characteristics of the clash as: type, status, title, due date and location. The responsible of the clash receive a mail with the issue notification.



Figure 53: Characteristics that is possible to set into a clash.

At this point it is the assigned clash is visible into the Attachment set of the Issue section and it is represented by a yellow point into the 3D view. If the person responsible of the issue answer to it, the status of the clash change and it appear with a blue point into the 3D view instead of yellow.

## Clash detection

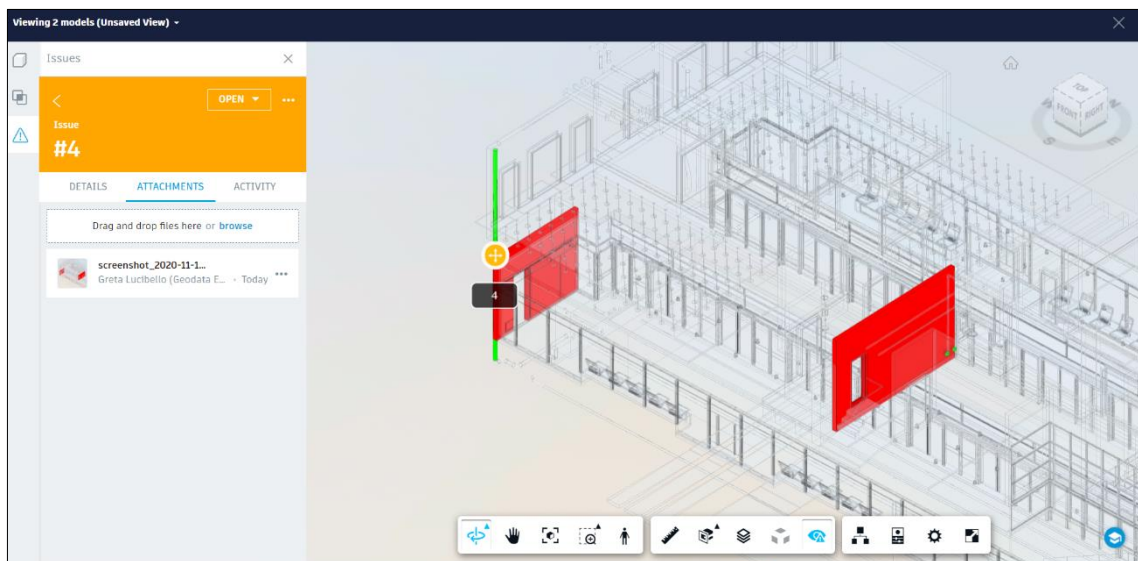


Figure 57: Attachment set of the Issue.



Figure 56: Different kind of issues.

Those assigned issue appear listed into the Assigned set under the Clashes section of the Model Coordination. [12]

AUTODESK BIM 360   undefined - GD-EUR-BIM360 TEST								
Model Coordination								
MODELS CLASHES VIEWS								
Active Assigned Closed								
Clash Detection - SCC								
Last clash check 6 Nov 2020 10:09								
ID	Title	Assigned to	Company	Due date	Linked document			
4	Pipe VS Wall	Gabriella Monticelli	Politecnico di Torino	-	MTLIT3_A1_E_FUN_SCC_V_001.rvt - (3D)	1	0	
2	Basic Wall [646377] and Rectangular Duct [627814]	Gabriella Monticelli	Politecnico di Torino	10 Nov 2020	MTLIT3_A1_E_FUN_SCC_V_001.rvt - (3D)	1	1	

Figure 55: List of assigned issues.

## Clash detection

Some useful outputs of BIM 360 are represented by the Insight section. To have them go to the BIM 360 Module Picker and select Insight (1). Along the top, to the far right of the tab options select Reports (2). Below that, switch from Recent to Saved (3). Finally, select the blue button on the right “Create Report”(4).

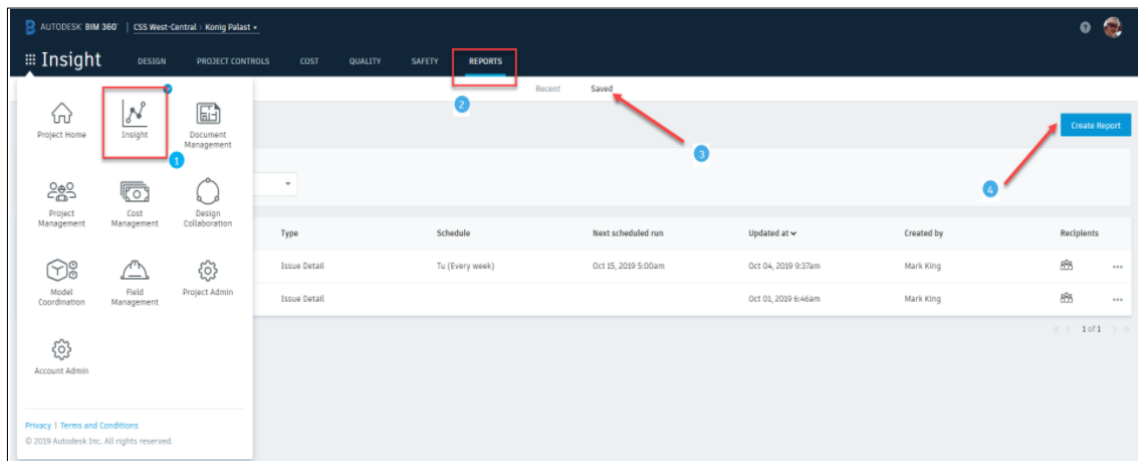


Figure 58: Insight section of BIM360. [<https://knowledge.autodesk.com/support/bim-360/learn-explore/caas/simplecontent/content/automating-bim-360-model-coordination-clash-reports.html>]

With “Data” selected on the left side of the screen, configure the sorting and filtering options to make your report specific to a company, and the coordination issues assigned to them.

Sort first by ID, then set the secondary sort option based on your needs (1). In the Type filter option, select “Coordination” (2).

Status can be left blank to report all options, or you can select all status’ that are not Closed if you want to exclude Closed issues from your report.

In the ‘Assigned To’ field select the Member, Role or Company that you want to filter on. This needs to coincide with the format you are assigning issues in Model Coordination. If you are assigning by company name, select the company name in the drop down associated with this report. If issues are assigned to individual members within a company, select that member in this field (3).

## Clash detection

The screenshot shows the 'Reports' tab in the Autodesk Insight interface. The report title is 'Electrical Engineer Clash Report'. On the left, there are tabs for 'Data' and 'Share and Schedule'. The 'Data' tab is active, showing a list of filters and sort options. The filters include 'Type' (set to 'Coordination'), 'Status' (set to 'Select a status'), 'Location' (set to 'Select a location'), 'Assigned to' (set to 'Electrical Engineer'), 'Due date' (set to 'Choose date'), 'Root cause' (set to 'Select a root cause'), 'Created by' (set to 'Select a user'), and 'Created on' (set to 'Choose date'). The sort options are 'Sort by' (set to 'ID') and 'Sort order' (set to 'Ascending').

Figure 59: Setting options within Report. [<https://knowledge.autodesk.com/support/bim-360/learn-explore/caas/simplecontent/content/automating-bim-360-model-coordination-clash-reports.html>]

Working on a construction project can involve hundreds of subcontractors, thousands of issues, and a daily changing environment. Insight is an ecosystem that delivers unified project-level data, analytics, and predictive insights. It can help get you up to speed with what's going on in a project, assess trends and patterns in project data, identify any gaps and problems, and use predictive risk data to improve project efficiency.

Navigate between the tabs to view different areas of Insight and then use the cards on each tab to review project data. [22]

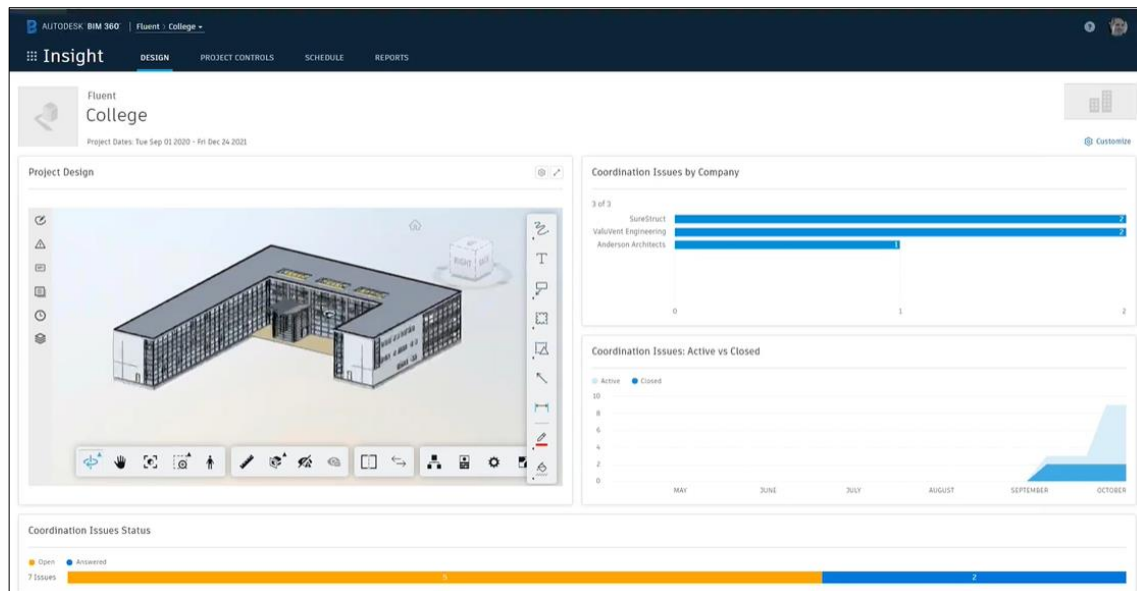


Figure 60: Insight output of BIM360. [[https://get.construction.autodesk.com/bim360mc-navisworks-integration-webinar-ungated/?\\_ga=2.159291325.647887994.1606296178-362227237.1569592853](https://get.construction.autodesk.com/bim360mc-navisworks-integration-webinar-ungated/?_ga=2.159291325.647887994.1606296178-362227237.1569592853)]

Insight aggregates all data across the different areas of the project, especially Issues. It is possible to create a dashboard like in the previous figure in which it is possible to manage the view. [18]

## 7.4 BIM 360 Coordinate and Navisworks interoperability

One of the most interesting aspects is that it is possible to make in communication BIM 360 and Navisworks. In order to do that it is important to upload a Navisworks file with .nwd extension on BIM 360 Coordinate and also it is fundamental to install on the computer a Desktop Connector for BIM 360 that will appear within the explorer folder.

Once models are uploaded on BIM 360, they can be opened from Navisworks following this procedure: Click on the Coordination tab > Coordination panel > Open Models > Select BIM 360 account from the drop-down list > Click on the project > Click Open.

Consequently, to see the issues added on BIM 360 it is necessary to: Click the Coordination tab > Issues panel > Manage issues to open the BIM 360 Issues panel. In this way Issues are displayed on the model as push pins and listed in the panel. Clicking Refresh in the panel changes are loaded to issue data and synchronized between BIM 360 and Navisworks. [17],[18],[19],[23]

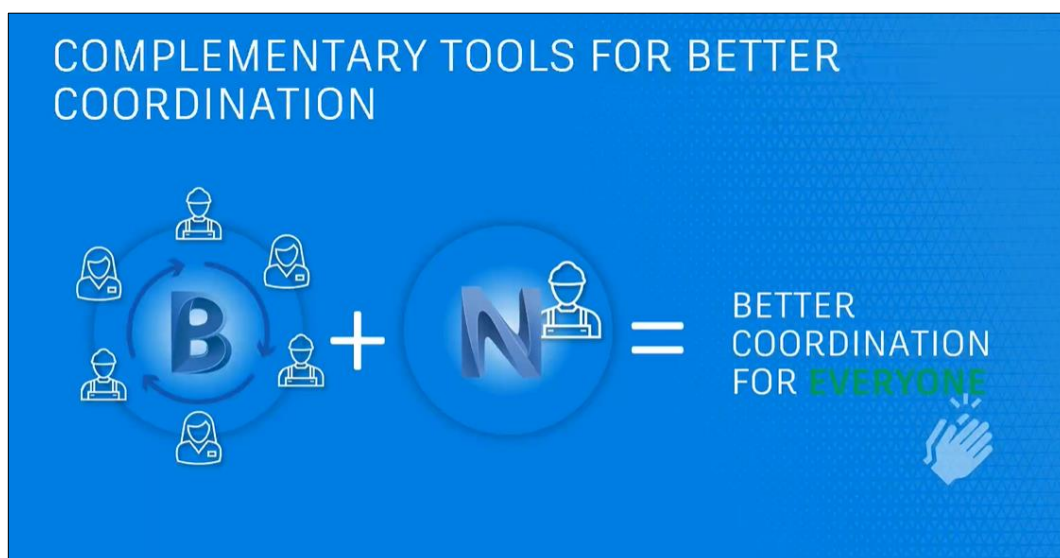


Figure 61: Interoperability between BIM 360 and Navisworks.

## Clash detection

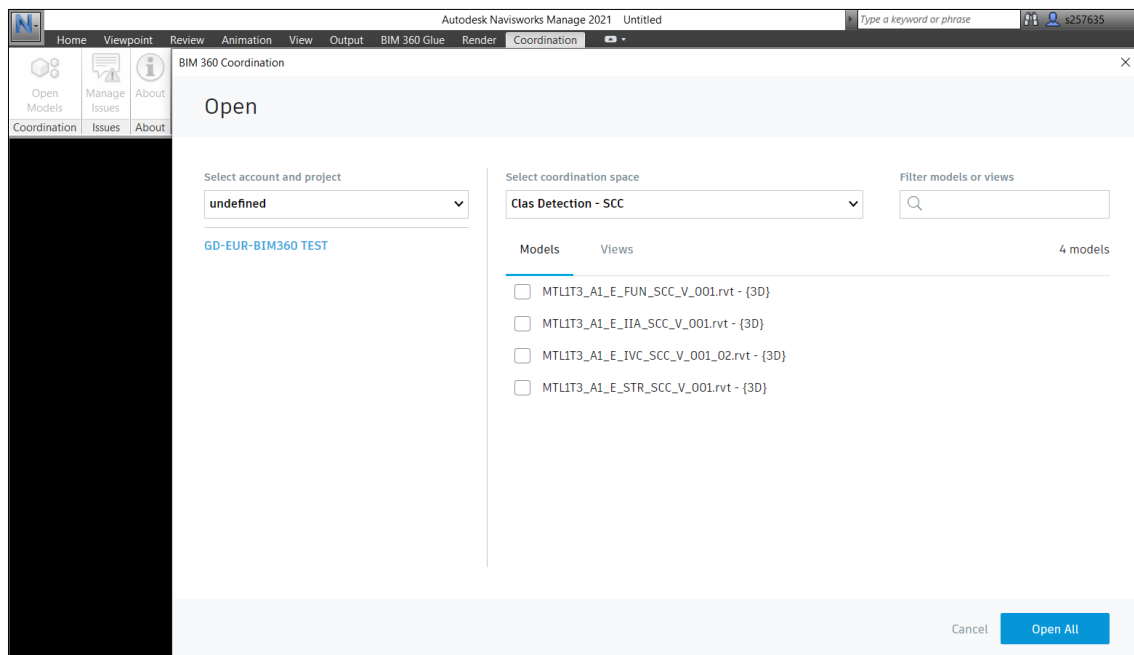


Figure 62: Model opening in Navisworks.

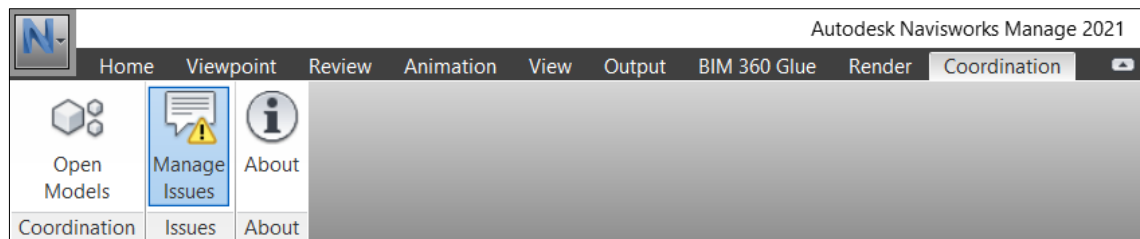


Figure 63: Manage issue tab.

## Clash detection

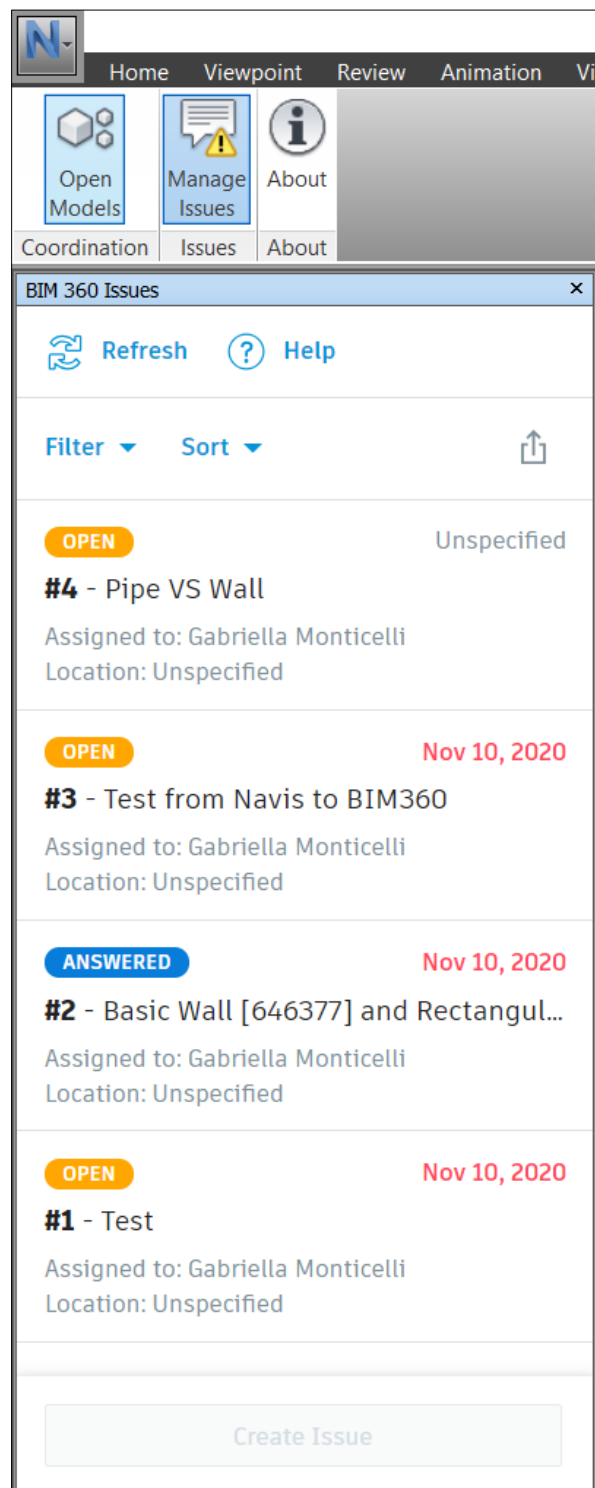


Figure 64: List of issues displayed.



The integration between BIM 360 and Navisworks allows project teams to save time with automated clash detection, increase the quality of the models, and create a single source of truth for issue management across the entire project team.

This approach ultimately enables the issue to be tracked by the VDC manager through to resolution all from within Navisworks and in empowering anyone to be involved in the coordination process, represents an entirely new way to manage the model coordination workflow.

With this tool project teams can:

- Create and assign issues directly from Navisworks
- Save hours with automated clash detection in BIM 360 Model Coordination
- Maintain a common data environment for the entire coordination process

With the integration, users can create and view issues in either Navisworks or BIM 360 Model Coordination. This allows for a complementary workflow that enhances existing Navisworks-based processes and empowers Model Coordination users to do more specific clash detection and analysis in Navisworks. And, with the Revit Issues Add-in (currently in open beta), users can open Revit and view BIM 360 issues, fully closing the workflow between design and construction teams. [31]



## 8 Conclusions

To conclude with this thesis, the author would like to sum up what he has learned during her experience with BIM methodology.

The modelling process is very tedious at first, for unexperienced users. Plenty of mistakes are made due to the lack of knowledge about the software and their tools. However, it is important to be alert to these mistakes in order not to repeat them, since working in a wrong way leads to inconsistency problems that make the model useless for being used for other scopes.

The creation of a BIM guide with specification on standards is strongly useful for the modeller to have an idea which are the limits of the model. Specifying the parameters that will be used help the designers to avoid information inconsistencies and consequently hard work changing parameter values. LOD specification not only improve communication between contractors but also helps the designer identify when something is worth to be modelled and when becomes a time waste.

In conclusion, the elaboration of thesis has faced several topics whose thread is the BIM methodology. The aim was to demonstrate how the use of these technologies can bring many benefits.

It must be remarked that working with BIM based software usually requires a high computational potential, so, companies that would want to introduce BIM methodology must think in making an investment not only in training personal but also in technology.

The final phase of this thesis focuses on the clash detection verifications and in particular to the comparison between the use of different software. To make those comparisons it has been necessary to download different external tool and plug-in and try different work paths to make the process work well. This phase is been particularly hard and takes a lot of time because of the use of different software that were unknown to the author.

It can be said that the work carried out represents a practical application, aimed at highlighting the benefits and some criticalities of BIM processes and tools.

### 8.1 Future development

Future developments certainly include the resolution of interferences between MEP models and structural and architectural models.

Other analyses that can be carried out for completeness concern the other dimensions of the BIM: a 4D analysis to perform a simulation of the expected times for the construction phase, a 5D analysis to have an estimation of the costs for construction and maintenance of the structure, a 6D analysis for the management of the same and finally a 7D analysis for the maintenance of the station.

In addition, a possible development could be represented by the navigability of the model by means of virtual reality.

Obviously, this would make more sense if developed for the entire metro line of the city of Turin.

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