POLITECNICO DI TORINO

Master's degree in Civil Engineering

Master of Science
in Civil Engineering Thesis

STRUCTURAL, FUNCTIONAL, AND MEP MODELLING OF CIVIL WORKS WITHIN AN INFRASTRUCTURE PROJECT TO AN EXECUTIVE LEVEL OF DESIGN

Case study: **Cascine Vica metro station & PC3 and PC4 vent shafts**

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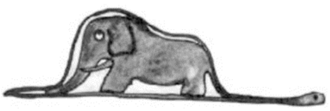
I l'hai pensaje pr'un péss a j'aventure dla giungla e peui, 'dcò mi, i son rivà a fé, con un crajon, mè prim dissegn. Mè dissegn nùmer 1. A l'era parèj:

Alora i l'hai dissegnà 'l serpent bòa an manera ch'as vëddèissa da drinta, përchè coj grand a podèisso capì. Loràutri a l'han sempe da manca dë spiegassion. Mè dissegn nùmer 2 a l'era parèj:



ANTOINE DE SAINT-EXUPÉRY, Ël Cit Prinsi

Abstract

The slow transition from the static components of drawing to a way of designing grounded on parametric components started in the last decade of the previous century and is encountering severe development over these years.

The BIM (Building Information Modeling) methodology is a very wide term, which includes various contents, topics, procedures, descriptions of activities, software applications, and well-structured and oriented information applied within vertically integrated applications, inside a circular work-process. It allows having control of all the information related to a project, under the form of a shared digital representation, founded on open standards for interoperability.

This master thesis is the perfect exemplification of the BIM genesis, which arises from the ashes of the 2D Paper-based process, to evolve into a 3D Digital Model-based process: the technical drawings provided as CAD files (Computer Aided Drafting) are used as starting information from which to build up an accurate virtual model, created digitally through the Revit software. Specifically, the thesis is developed throughout two practical strands of application: on one side, the development of the structural models of the entire future Cascine Vica subway station of the Metropolitan City of Turin and of the two ventilation shafts, belonging to the same line 1 metro station itself; on the other side, the functional and MEP models of the two mentioned ventilation wells (the Mechanical, Electrical and Plumbing systems are integrated and linked to their corresponding basic structural and functional building projects).

From a practical viewpoint, there were employed tools for the modeling of structural, functional and MEP elements, tools for linking different models together, and tools for the georeferencing the Revit model with respect to the global and project local's coordinate systems.

The BIM model is fundamental in every single step of the process, all over the whole life of the opera, from the design to the maintenance: design, planning, construction, documentation, decision making, cost-estimation, future interventions and managing of resulting facilities are the main areas directly touched and largely improved by this methodology.

Transferring all the data of brand new or existing constructions on a digital base is becoming a common tendency in this historical period of technological transformation of the construction industry.

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1. BIM engineering

Representation languages have always been a key element to communicate and share a design idea among the actors involved in the construction process. In this regard, the building industry has developed over time various tools and methods that can optimize this information transfer to allow professionals to manage the complexity of the construction process. [20]

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. BIM allows professionals to optimize their work by developing 3D parametric models that contain a large amount of data useful for the whole building life cycle. [1, 2]

As a methodology, BIM consists of a set of activities that allows the actors of the AECO ("Architecture, Engineering, Construction and Operation") industry to fill in, extract, and share data of the model through interoperability. It results in a very efficient process that passes through an improvement of the data transfer and of updating, via the development of a parametric model that collects all the information needed for a project and that is frequently updated. The final informative model is a digital representation of reality that came from a set of activities to create, manage, derive, and communicate information among stakeholders. Thus, this digitalization process is based not only on technology but also on skilled people that need the training to understand the strengths and challenges of BIM methodology. [1, 3]

The chapter is divided into several sections, each of which deals with specific BIM process aspects and themes, highlighting the corresponding characteristics and areas of interest.

1.1. Interoperability

As a very general definition, *Interoperability* is defined as "a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, in either implementation or access, without any restrictions". [44]

Specifically, with respect to software, the term is used to describe "the capability of different programs to exchange data via a common set of exchange formats, to read and write the same file formats, and to use the same protocols". [44]

So, it is clear how interoperability allows the customer freedom to switch from one product to another while keeping the data intact after the transfer. This is especially important in the construction industry where one-off projects teams are assembled across different organizations, disciplines, and phases for a long time. Here, the auspice is that the different discipline tools can share information with each other, and data generated in one phase are usable without re-entry for the next phase.

For having a true openBIM workflow, it is therefore fundamental to have interoperable software: this condition gives freedom to work with the bests in any discipline and for them to use the tools they are most comfortable and productive with. [44]

About this topic, two subsample definitions of interoperability could be defined:

- to communicate with each other, systems need to use common data formats (for example XML, JSON, SQL, ASCII, and Unicode) and communication protocols (as HTTP, TCP, FTP, and IMAP). When systems are able to communicate with each other using these standards they exhibit *Syntactic Interoperability*;

- for BIM tools to work together, we need the ability to transfer meaning, more than just the ability to transfer information (what is sent must be the same as what is understood). To achieve this, both sides must refer to a common information exchange reference model, for which we need *Semantic Interoperability*. [44]

In the project delivering process, many actors are involved and 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 with specific requirements in the appointments.

The information is formed by containers (that are basically all the files generated by the project team, which can have several extensions depending on its nature) and the set of containers form the information model.

Software is a specific tool, aimed to follow a particular purpose. It is clear how the information creation process embodies the usage of different software of different firms which use different formats and languages. This is where the term interoperability comes up. [1]

The BIM engine efficiency is limited due to the interoperable process that is not yet error-free: increase interoperability means gaining flexibility throughout the BIM project lifecycle.

In a 4D environment, the 3D resources (human resources, materials, equipment, and spaces) are connected to the planned activities, making the best to facilitate the construction sequences, manage potential variations more efficiently, and make easier comparisons among alternative scenarios. The configuration can then be updated, even during construction, and activities planning can be managed through the model and vice-versa. [1]

The overall result is a more efficient, more reliable, and safer construction process, capable of saving time and money.

1.2. Common Data Environment

The CDE (Common Data Environment) is the digital environment for the collection and management of data and files. This central repository houses the construction project information and is useful also for their processing, sharing, and disclosure to third parties. The contents of the CDE, which will therefore include documentation, graphical model, and non-graphical assets, do not let arguments about which version of information should be being referenced.

The Shared information should result in coordinated data which will, in turn, reduce both time and cost on the project. Project team members can all use the CDE to generate the documents and views they need, confident that they are using the latest assets. In other terms, without the data sharing environment, the BIM process could not even take shape.

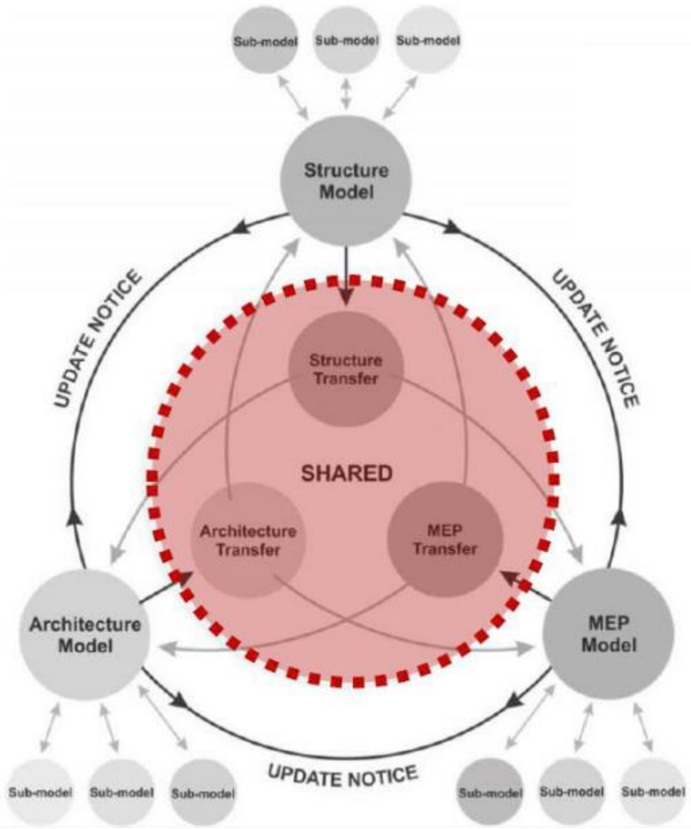


Figure 1: CDE scheme.

Many BIM protocols propose the use of a Common Data Environment since a single source of information should enhance the collaboration between project members, reducing mistakes and avoiding duplications. After all, this idea of collaboration for improving results and efficiencies is at the heart of implementing a building information model.

In Italy, the data-sharing environment is called ACDat (Ambiente di Condivisione Dati) and is defined by art.2 of DM 560/2017 as follows: "A digital environment for the organized collection and sharing of data relating to a work and structured in information relating to digital models and documents mainly attributable to them, based on an IT infrastructure whose sharing is governed by precise security systems for access, of traceability and historical succession of the changes made to the information contents, of conservation over time and relative accessibility of the information assets contained, of the definition of responsibilities in the elaboration and protection of intellectual property." [43]

In the Italian standard UNI 11337, it is not expressly specified how the ACDat should work and how it is organized, but it should be only reported the requirements it has to meet. Therefore, in the first information specifications this environment is described as divided into at least four areas: “Area in lavorazione”, “Area in condivisione”, “Area in pubblicazione”, and “Area in archiviazione”.

Table 1: CDE areas access criteria in accordance with UNI 11337. [43]

Area in lavorazione	Environment not accessible to third parties with respect to the specific work team, but with the possibility of acquiring information from external sources (external ACDat, other areas of the ACDat, etc.)
Area in condivisione	Area open to data exchange, visibility and operations, regulated in a differentiated manner towards accredited third parties
Area in pubblicazione	Area open to data exchange and visibility to accredited third parties
Area in archiviazione	Environment not accessible to third parties

Moreover, it is reported the requirements that ACDat will have to meet:

- accessibility by all actors involved in the process, in accordance with pre- established rules;
- traceability and historical sequence of updates and revisions;
- support of a wide range of types and formats and their processing;
- high query flow and ease of access, storage, and extrapolation of data (open data exchange protocols);
- conservation and updating over time;
- assurance of confidentiality and of security.

In addition, this standard defines the requirements of four professional profiles:

- Data Sharing Environment Manager;
- Digitized Processes BIM Manager;
- Information Flow BIM Coordinator;
- Advanced Information Management and Modeling Operator BIM Specialist. [43]

CDEs on the market represent more a file-sharing environment, rather than single data management, albeit as an evolution for the AEC sector compared to generic document management software, FTP, or the most recent cloud storage and exchange systems (Dropbox, Google Drive, OneDrive, etc.).

1.3. Data entry for BIM software

The construction of the basic structural model passes through the 2D data entry for Revit software, represented by the CAD file import. It allows to highlight some critical issues and provide advice, useful for easy and fast construction of three-dimensional models.

Generally, before connecting or import the DWG file into Revit, it must be checked as it is current with reality through a state of fact raised in situ. In the event that inconsistencies are identified, changes must be made to the .dwg files and then the Revit must be imported. Furthermore, to facilitate the elaboration of the BIM model it is fundamental to reorganize the 2D structural and architectural models in many individual drawings like plans and cross-sections. Finally, it is important to control the scale by measuring some elements of the design, testing the DWG drawing units and setting the units of measure in Revit when importing or connecting the drawing.

In some other very specific cases, the Revit entry data are represented by point clouds, mainly obtainable through laser scanning operations and photogrammetry-based techniques. Those are spatial data composed of points located in space, each of which contains coordinates, in accordance with a local or global reference system, and eventually also correspondent RGB color values. The point cloud can be integrated through a Global Navigation Satellite System (GNSS) survey in order to geo-reference it. [1]

1.4. 3D parametric model development

The structural framework followed for the realization of a tridimensional parametric model passes through the employment of a BIM authoring software, with its own conceptual structure and its property format. In particular, among the different software available on the market, the focus is maintained on Autodesk Revit.

1.4.1. Category

Each object that could be created within a Revit model (.rvt file extension) is classified in a specific *Category*, which is a group of elements that are used to model or document a building design. These ones are defined inside the modeling software, and it is possible to associate to them a whole series of operations mainly concerning the association of parameters, the realization of schedules, and the customization of visibility. [1]

1.4.2. Family

Each category consists of there are different kinds of *Families*, which are classes of elements with a common set of parameters (named “Properties”), identical use, and similar graphical representation. Different elements in a family could have different values for some or all properties but the set of them (such as their name, meaning, thickness, width, height, material setting, graphical features, and geometrical and alphanumerical customizations) is the same. [1]

Specifically, in Autodesk Revit there are three main family typologies:

- *System Families*, which are predefined inside the modeling software, are generally used to create the main basic elements of a building. To this kind of family belongs system settings that affect the project environment and include Types for levels, grids, drawing sheets, and viewpoints;

- *Loadable Families* are generally used to create building components that are usually purchased, delivered, and installed around a building such as windows, doors, casework, fixtures, furniture, planting, or system components with the same characteristic. These families are created outside the BIM model in specific external .rfa files and imported inside the single .rvt file. Autodesk Revit has a proper library of content in which is possible to select, save and upload loadable families in a BIM model. If the library does not contain desired families, the creation of these ones generally starts with templates supplied in the software itself. In relation to their highly customizable nature, these families are usually the most commonly used and modified during modeling activities;

- *In-Place Families* are unique elements that could be used when it is necessary to create an exclusive component related to the project. They are built using the same tools as loadable families and are used when it is not expected to repurpose them in another .rvt file, or when they contain geometry that must maintain one or more relationships to other project geometry. Unlike system families and loadable ones, it is not possible to duplicate in-place family types in order to create multiple types.

1.4.3. Type

Defined the concept of Family, it is important to highlight that the different assigned value of each parameter allows the creation of several variants called *Types*. These ones could be defined as a specific size of a family. The number of types that could be created is unlimited for each kind of System Families and Loadable Families while In-Place Families are characterized by the type's uniqueness. [1]

1.4.4. Instance

When an actor of the project selects a Type and create an object inside the BIM model, this one is called *Instance*. They are the items that are placed in the project and have specific locations in the building (model instances) or on a drawing sheet (annotation instances). It is possible to create several instances inside the same project file that belong to the same type. [1]

1.4.5. Parameters

Each object collects different kinds of parameters, that could belong to two different kinds: *Type Parameters*, which change the characteristic directly inside the type and in all instances that are related to it, and *Instance Parameters*, for which its variation occurs only within the specific modified object.

To better understand this difference, it is necessary to know the structure of the family and the windows where they are visible, looking at the BIM model DataBase, inside each Category Schedule. This aspect is related to how the parameter is created, and three kinds of them are available in a BIM model:

- the *Global Parameters* are specific parameters used to define values of other parameters. In detail, they can be used to report or drive the value of one parameter to another one;
- the *Shared Parameters* could be used in multiple families and projects and so added to different family files, templates, and models. In detail, they could be used to add specific data that are not already defined. The visibility inside tags is guaranteed and be shared by multiple projects and families and exported outside;
- the *Project Parameters* are specific parameters that could be added to categories of elements in a project and used in schedules, but it is not possible to share them with other projects or families. [1]

1.5. Structural and Architectural modelling

The structural and architectural models can be separately created starting from correspondent Template files to receive predefined settings.

The *structural* one is the first created, using the entry data available, and its components are basically represented by columns, beams, floors, stairs, connections, and foundations.

The analytical model consists of those structural components, geometry, material properties, and loads, that together form an engineering system. Analytical parameters of a structural element are instance properties that are unique and appliable only to one instance of a structural member. The analytical model is created automatically when it is created the physical model and can be exported to analysis and design applications. [1]

In Revit, the physical model, considered as a set of production drawings, is created within views that represent the physical structure.

Regarding the *architectural* model, the main objects consist of basic design elements such as floors, walls, stairs, which are System Families, and from components like fixtures and furniture, which can be loaded from existing object libraries or can be customized by creating new families.

Various properties and parameters can be set and modified. Especially, materials can be applied to all types of families to give objects a realistic appearance, real behaviour, and eventually further descriptive information about the manufacturer and physical-thermal and structural properties. They can be searched in the Autodesk Materials and AEC Materials default libraries and loaded into the current document. [1]

1.6. MEP modelling

This chapter is focused on *Mechanical*, *Electrical*, and *Plumbing* (MEP) modeling within Revit, for designing building or infrastructure systems:

- among the various types of *Mechanical systems* used in residential, commercial, and industrial buildings, three types account for most of the mechanical design work: Heating, Ventilation, and Air conditioning (HVAC) systems. Nevertheless, it is possible to mention also lifts, escalators, or transposing system, which interact to keep temperature and humidity within a range that provides comfort and health. The mechanical ventilation ensures that enough fresh air is supplied to keep pollutant concentrations at low and safe levels;
- regarding the *Electrical system*, it is possible to remark telecommunications, control, security, detection, and lighting systems;
- *Plumbing systems* are associated with fluid movement and can be used for many different purposes, like water supply, recovery and treatment systems, water drainage, waste removal, and more. [1]

Those three disciplines encompass the systems that make building interiors suitable for human occupancy and are normally addressed together because of the high degree of interaction between them, which could lead to conflicts in equipment location. Implementation of the design in a realistic way through a 3D overview of the building-plan system allows designing the system in a well-integrated way with the architecture and structure of the building. The methodology should also be useful for determining feasibility, verifying quantities, and defining construction sequences. [41]

The Revit software is practically organised so that in the Systems tab, MEP families are divided by the three main sub-disciplines mentioned: *Heating Ventilation and Air Conditioning* (HVAC), *Mechanical*, *Plumbing & Piping* and *Electrical*. This interface allows to easily identify the MEP objects to upload in the model, that can be Loadable families such as Air terminal and Plumbing fixture, or System families such as Duct and Pipes. The MEP model can also be created starting from a specific Template file with predefined settings based on the sub-discipline.

In order to start the MEP modelling, it is fundamental to customize the Mechanical and Electrical Settings. It is possible to set some proprieties 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 customizing specific settings of the project.

1.7. LOD

The concept of *LOD* (which is the acronym of "*Level of Details*") comes up to answer the question "What should be built into the Model?".

It essentially indicates how much detail is included in the model element in relation to the reference phase of the project. In fact, project management is divided into several steps, each of which requires a different level of information.

Creating a successful building information model is knowing what to build into the model and what to leave out of the model.

LOD of the data is defined by the project team and is contained in the *Model Production* and in the *Delivery Table* (MPDP). [37]

Exists different kinds of international standards that propose different LOD scales. It is reported a table below resuming the major standards, deeply explained in the following paragraphs.

Table 2: Reference standards. [1]

bsi.	*LOD as Level of model Definition for building and infrastructure projects: LOD as the description of graphical contents and LOI as the description of non-graphical content*
AIA	*LOD as Level of Detail and Level of Development of each element of the project*
UNI	*LOD as Level of Development of digital object: LOG related to the geometrical attribute of the element and LOI related to the alphanumerical attribute of the element*
ISO	*Level of Information Need as the minimum amount of information needed to answer each relevant requirement. Geometric and alphanumeric information has the same importance.*

1.7.1. BS-PAS 1192

Important historical normative that can be mentioned are the BS 1192 and Pas 1992, which represent an important reference to the application of the BIM methodology, covering all the life stages of a building artifact. LOD is conceived as *Level of model Definition* for building and infrastructure projects, and in particular, as *Level of model Detail* as the description of graphical content, and as *Level of model Information* as of the definition of non-graphical content. [40]

Stage number Model name	1 Brief	2 Concept	3 Definition	4 Design	5 Build and commission	6 Handover and closeout	7 Operation
Systems to be covered	N/A	All	All	All	All	All	All
Graphical illustration (building project)							
Graphical illustration (infrastructure project)							
What the model can be relied upon for	Model information communicating the brief, performance requirements, performance benchmarks and site constraints	Models which communicate the initial response to the brief, aesthetic intent and outline performance requirements. The model can be used for early design development, analysis and co-ordination. Model content is not fixed and may be subject to further design development. The model can be used for co-ordination, sequencing and estimating purposes	A dimensionally correct and co-ordinated model which communicates the response to the brief, aesthetic intent and some performance information that can be used for analysis, design development and early contractor engagement. The model can be used for co-ordination, sequencing and estimating purposes including the agreement of a first stage target price	A dimensionally correct and co-ordinated model that can be used to verify compliance with regulatory requirements. The model can be used as the start point for the incorporation of specialist contractor design models and can include information that can be used for fabrication, co-ordination, sequencing and estimating purposes, including the agreement of a target price/ guaranteed maximum price	An accurate model of the asset before and during construction incorporating co-ordinated specialist sub-contract design models and associated model attributes. The model can be used for sequencing of installation and capture of as-installed information	An accurate record of the asset as a constructed at handover, including all information required for operation and maintenance	An updated record of the asset at a fixed point in time incorporating any major changes made since handover, including performance and condition data and all information required for operation and maintenance The full content will be available in the yet to be published PAS 1192-3

Figure 2: Levels of model Definition for building and infrastructure projects. [1]

1.7.2. BIM FORUM of AIA

AIA (American Institute of Architects) defines the LOD as a Level Of Development, a reference that enables practitioners to specify and articulate with a high level of clarity the content and reliability of Building Information Models. This specification defines and illustrates characteristics of model elements, allowing model authors to define what their models can be relied on for, and allowing downstream users to clearly understand the usability and the limitations of models they are receiving. More precisely, AIA defines five levels of development:

- LOD 100: the element is represented generically with a symbol but does not meet the requirements for LOD 200. Further information about 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. It correctly interfaces with the other elements of the model;

- LOD 400: the element is shown with the correct size, position, and orientation. It correctly interfaces with the other elements of the model, and reports details relating to manufacturing, assembly, and installation;

- LOD 500: the element faithfully reflects reality. It is a representation verified on-site in terms of size, shape, position, quantity, and orientation.

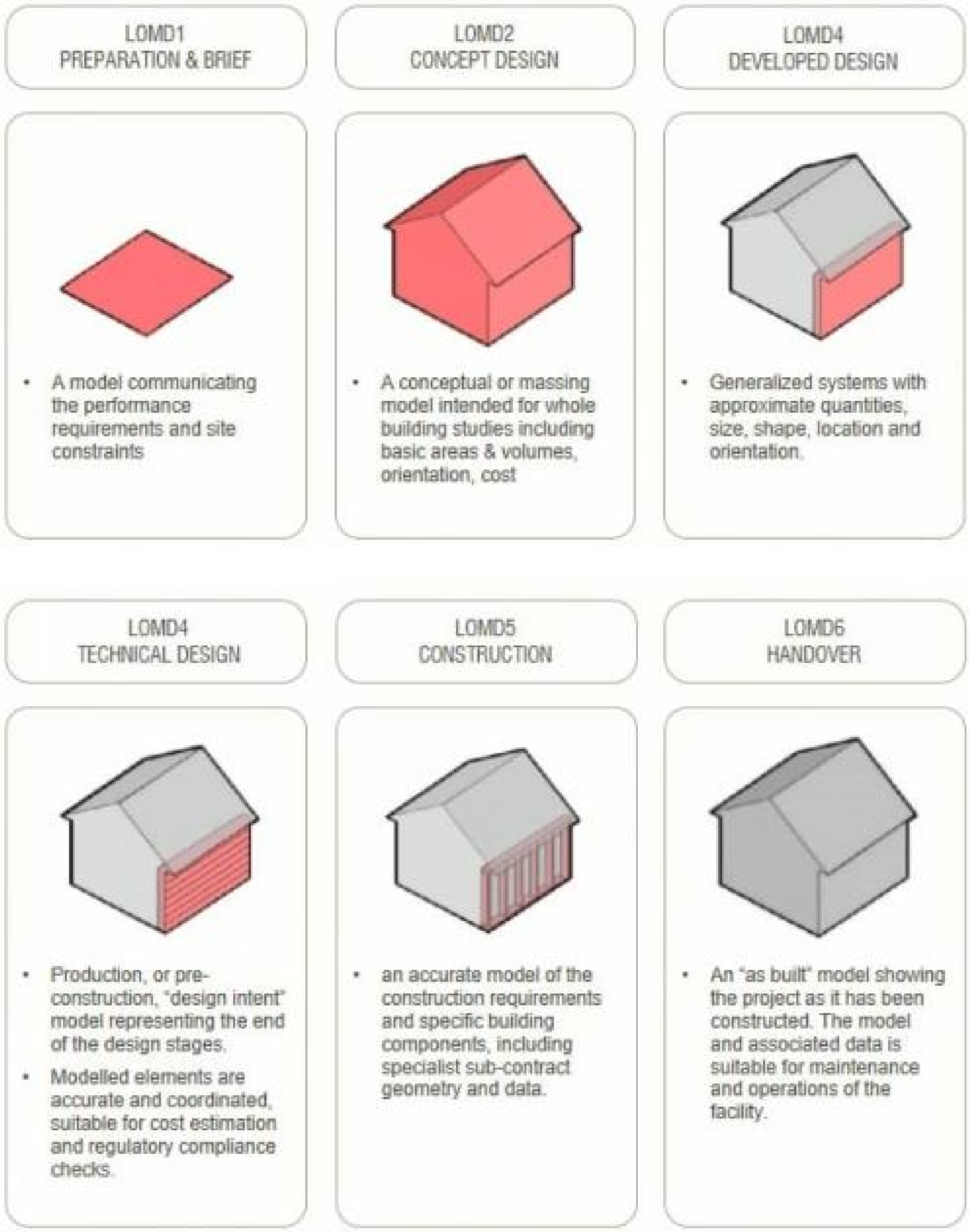


Figure 3: LOD AIA-classification. [38]

1.7.3. UNI 11337

UNI 11337-4 of 2017 is used as a reference by the Italian legislation and 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. Moreover, 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.

The classification is based on LOG (Level of development of Geometric object attributes) and LOI (Level of development of Informative objects attributes). UNI 11337 identifies the LODs throughout 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 any 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: the 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 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. [1]

The information models do not only contain geometric data but are also a series of attributes (type of elements, materials, characteristics, performances, and more). 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 both the importance of information contents whatever their nature and the requirement 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. Anyway, Italian law permits 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. [12]

1.7.4. EN ISO 19650

The release of ISO 19650 introduced the new concept of *Level of Information Need*, which should replace the concept of Level of Definition, in the panorama of BIM.
The standard is applicable to the entire life cycle of an immovable asset and describes the concepts, principles, and recommendations for information management, which includes exchange, registration, updating, and organization for all actors. [39]
The level of information need for each information deliverable should be determined according to its purpose. This should include the appropriate determination of quality, quantity, and granularity of information.
A range of metrics exists to determine levels of information need, which should be determined by the minimum amount of information needed to answer each relevant requirement. Anything beyond this minimum is considered waste.
The relevance of an information deliverable is not always correlated to its granularity. The level of information need is, however, closely linked to the federation strategy. The granularity of alphanumerical information should be considered to be at least as important as that of geometrical information. [1]
This international standard applies jointly to the UNI 11337 series, which is a complementary standard.

1.8. Georeferencing

An important element of metadata for any building information modelling model is its location and orientation on the Earth.
The process of spatially adjusting a Revit drawing without changing the original source data is called Georeferencing. It may be applied to any kind of object or structure that can be related to a geographical location, such as points of interest, roads, places, bridges, or buildings.

In Revit, project base point, survey point, Startup Location, and Control Points are used: the *Project Base Point* defines the origin of the project coordinate system and is used to position the structure on the site and to locate the design elements of a building during the construction phase (the spot coordinates and spot elevations in the Revit file that reference the project coordinate system are displayed relative to this point); the *Survey Point* represents the known point in geographic space and is used to correctly orient the building geometry in another coordinate system; the *Startup Location* provides the basis for positioning all elements in the model, establishing the project coordinate system and the survey coordinate system; the Control Points define the displacement paths known as links and form the basis of georeferencing. [35]

2. Reference standards

In Italy, the adoption of the BIM methodology was initially a totally private initiative, mainly limited to projects under international influences. Recently, it has taken hold in a systematic way, throughout the introduction of some main regulatory standards, complementary to each other, and followed as reference for both the modelling and the coding: UNI EN ISO 19650, DM 560/2017, and UNI 11337.

2.1. UNI EN ISO 19650

ISO 19650-1 and ISO 19650-2 are the Italian implementation of the international standards to refer to in the context of BIM design:

- "*ISO 19650 – Organization of information about construction works – Information management using building information modelling – Part 1: Concepts and Principles"* provides information, describes the principles for information management, and provides a series of recommendations also including planning, exchange, registration, updating, and organization for the actors involved in the process. The standard is applicable to the entire life cycle of the work and can be adapted to constructions of any size and complexity;
- "*ISO 19650 – Organization of information about construction works – Information management using building information modelling – Part 2: Delivery phase of the assets"* specifies the requirements for the management and exchange of information during the delivery phase of the work. This part of the standard can also be applied to all types of construction and to all types and sizes of organization, regardless of the choice of procurement strategy. [47]

2.2. Decreto Ministeriale 560/2017

The Italian Decree 560/2017, also known as 'BIM Decree', implementing article 23 paragraph 13 of Legislative Decree 50/2016, is the reference standard within the national territory. It defines the methods and times for the gradual introduction of electronic modeling methods and tools for building and infrastructures. [45]

Specifically, the timing for introducing the obligation of Building Information Modeling in public procurement indicated is reported below:

- for complex works relating to works with a tender amount equal to or greater than 100 million euros, starting from 1 January 2019;
- for complex works relating to works with a tender amount equal to or greater than 50 million euros, starting from 1 January 2020;
- for complex works relating to works with a tender amount equal to or greater than 15 million euros, starting from 1 January 2021;
- for works with a tender-based amount equal to or greater than the threshold referred to Article 35 of the Public Contracts Code, starting from 1 January 2022;
- for works with a tender amount equal to or greater than 1 million euro, starting from 1 January 2023;
- for works with a tender amount of less than 1 million euro, starting from 1 January 2025.

The provision also governs the preliminary obligations of the contracting authorities, which must adopt a training plan for their personnel, a plan for the acquisition or maintenance of hardware and software for the management of decision-making and information processes, and an organizational act that explains the control process, management process, data managers and conflict management.

Moreover, the use of interoperable platforms by means of non-proprietary open formats is envisaged by the contracting authorities and the use of the data and information produced and shared among all the participants in the project, in the construction and management of the intervention is defined. [45]

The introduction of the present ministerial decree, which undoubtedly represents the best-known regulatory reference, is accompanied by an intense voluntary (non-mandatory) standardization activity that performs an equally important function in defining the guidelines to be followed in the adoption of the BIM methodology. [45]

2.3. UNI 11337

The UNI 11337 standard is a document divided into ten parts that deal with the digital management of information processes in construction. Specifically, it handles models, their evolution and information development, documents, information objects for products and processes, and information flows in digitized processes. The information is divided as follows:

- *PART 1 | Models, Drawings, and Objects*: concepts of "data", "information" and "information content", methods of transmission and representation through documents and models, the meaning of digital objects and information structures of products and processes;
- *PART 2 | Denomination and Classification*: a system of classification and naming of works, objects, and activities;
- *PART 3 | (Information Sheets) LOI and LOG*: models for the collection, organization, and archiving of the technical information of the products to be built;
- *PART 4 | LOD and OBJECTS*: evolution and informative development of models, documents and objects;

- *PART 5 | Management of Models and Documents*: roles, requirements and flows necessary for the production, management and transmission of information, and their connection and interaction in digitized construction processes;
- *PART 6 | Example of Informative Specifications*: procedural indications for the drafting of the Information Specifications, general structure, and characteristics;
- *PART 7 | Qualification of Figures*: requirements for knowledge, skills, and competence of the figures involved in information management and modeling (BIM Manager, CDE Manager, BIM Coordinator, BIM Specialist);
- *PART 8 | PM/BIM-M*: processes of integration between activities and information figures and traditional activities and figures in the construction sector;
- *PART 9 | Building File*: information management during operation;
- *PART 10 | Administrative Verification*: guidelines for the digital information management of administrative practices. [46]

3. Case study

The infrastructures under examination are represented by an entire subway station (with its four accesses), and by two very similar vent shafts, belonging to the same section of the metro line. Here below, a description of the case studies is reported.

3.1 Cascine Vica subway station

This subway station belongs to a new section of the Metropolitana Automatica di Torino. It represents an extension of the existing line 1, towards the west direction, beyond the old Fermi terminus.

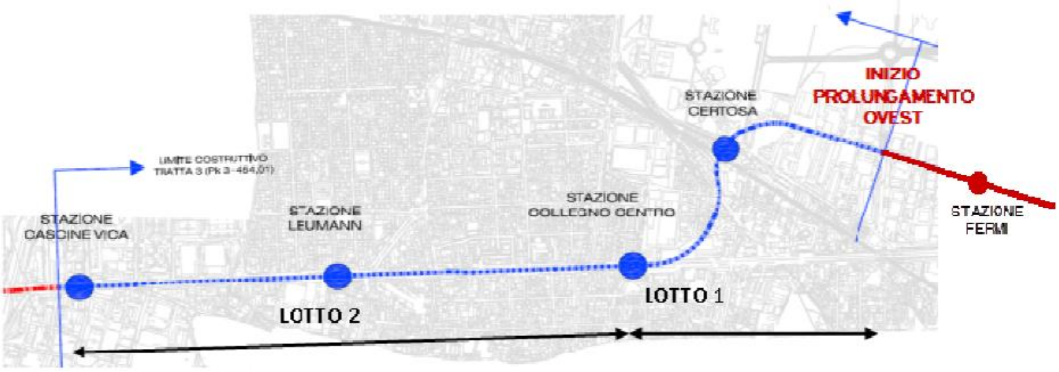


Figure 4: Chorography of the metro line west extension. [48]

This station is located on Corso Francia, in correspondence to P.zza Togliatti. It is one of the four stations (together with Certosa, Collegno Centro and Leumann) which are building along this 3,4 km route, that encounters in gallery the territories of the municipalities of Collegno and Rivoli. It belongs to the functional lot named “LOTTO 2, Collegno Centro – Cascine Vica”, which in its turn belongs to the “TRATTA 3” subway line section.

3.1.1 Central core building

The underground structure is characterized by a regular plan, with the definition of three fundamental levels, which place below the roadway (such street-level comprises the accesses to the station and metallic grids for the ventilation wells and for the access of the material):

- PIANO ATRIO: it holds system and non-system technical rooms, besides the turnstiles for access to the train;

- PIANO BANCHINA: it is placed at an altitude of -4.80 meters with respect to the atrium floor, and can be reached throughout fixed elevators and stairs. It is a platform where passengers are waiting for trains;

- PIANO SOTTOBANCHINA: it is located at a depth of -3.05 meters with respect to the PIANO BANCHINA level, and constitutes a technical area entirely reserved for service personnel.

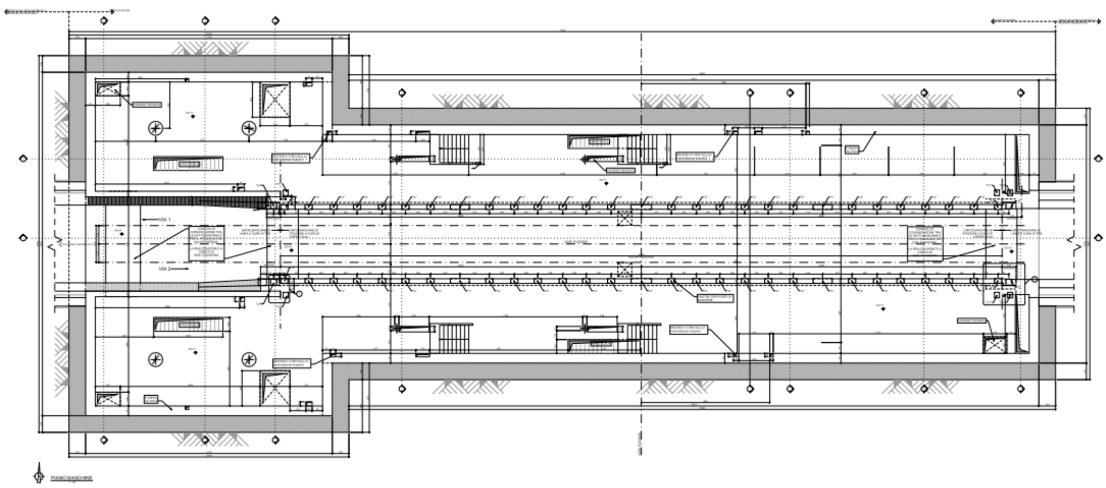


Figure 5: PIANO BANCHINE plan. [49]

About the geometry, it is evident from the plan the presence of one horizontal symmetry axis, which coincides with the rail alignment.

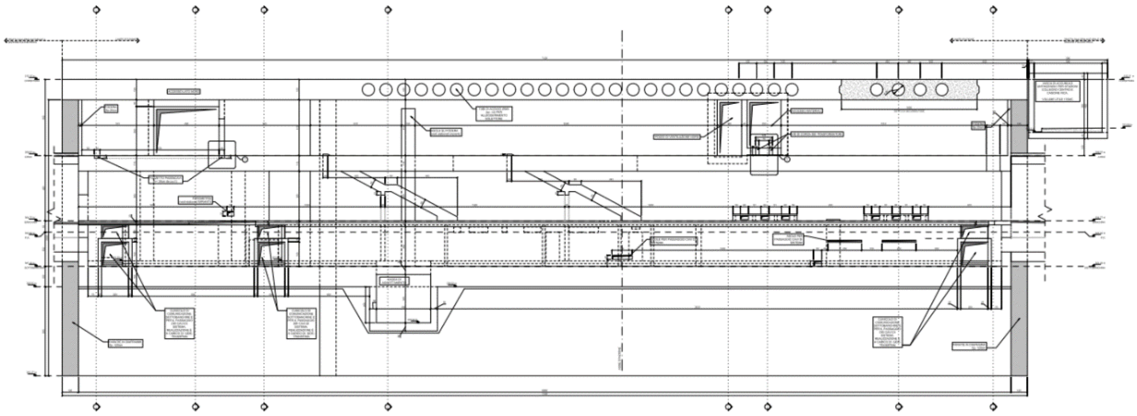


Figure 6: B-B longitudinal cross-section. [50]

It is also possible to notice the presence of a fire-fighting tank, located on the minor side of the structure, and of a water tank, placed immediately below the bottom slab of the SOTTOBANCHINA level.

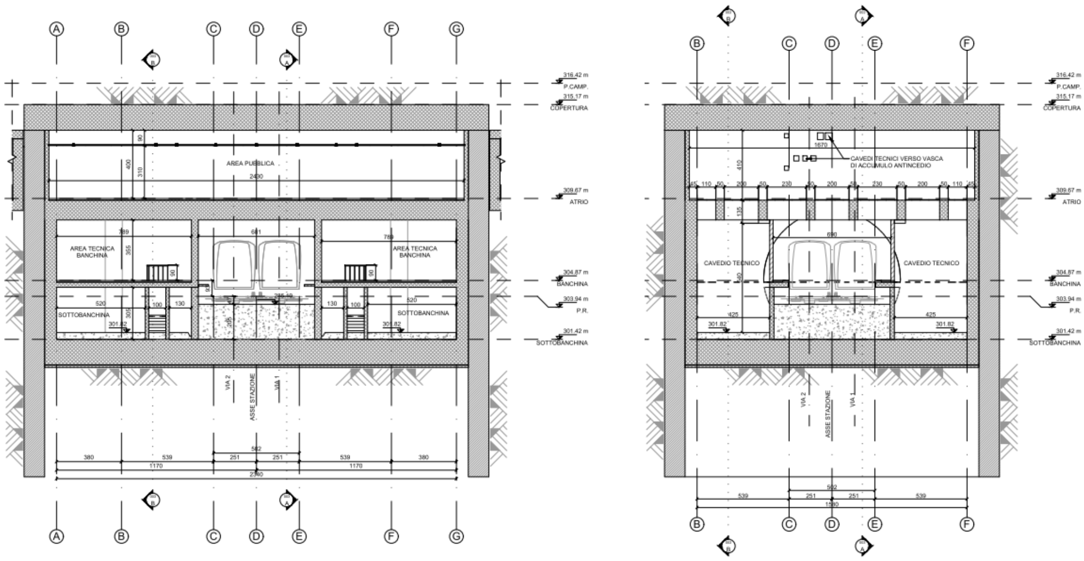


Figure 7: C-C and M-M cross-sections. [51]

Regarding the transversal sections, it is possible to study three different construction type sections: the first two cut the railway alignment at the level of the subway station (one nearby the gates and one nearby the shafts), whereas the third one refers to a section of the tunnel having a blind hole and polycentric geometry, which is outside the extremities of the subway station itself.

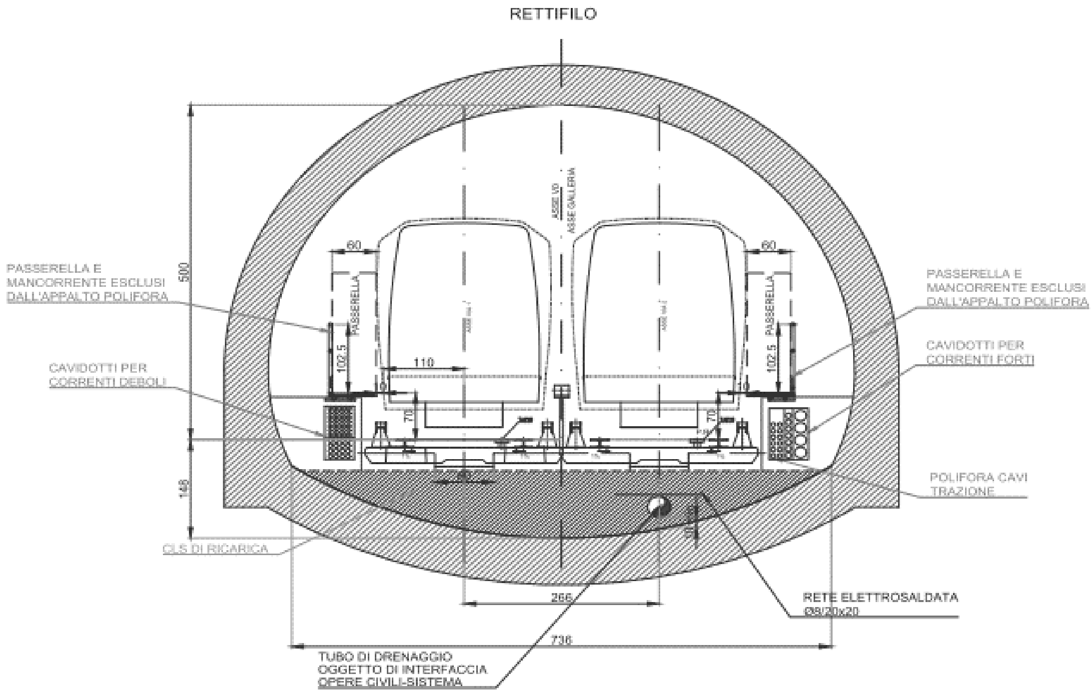


Figure 8: S cross-section, polycentric tunnel. [52]

From an executive point of view, the station is built with the cut & cover methodology, through the execution of bulkheads in continuous diaphragms. The executive sequences for the construction foresee the execution of the bulkheads with the aid of intermediate horizontal contrasts, the execution of the roof slab, the digging under the slab up to the depth of the excavation, and the construction of the definitive internal structures (linings and intermediate floors) rising from the bottom to the top.

3.1.2 Gates and shafts

Looking at the atrium functional plan, it is possible to identify the presence of four further facilities (two for each of the main sides of the building), directly connected to station.

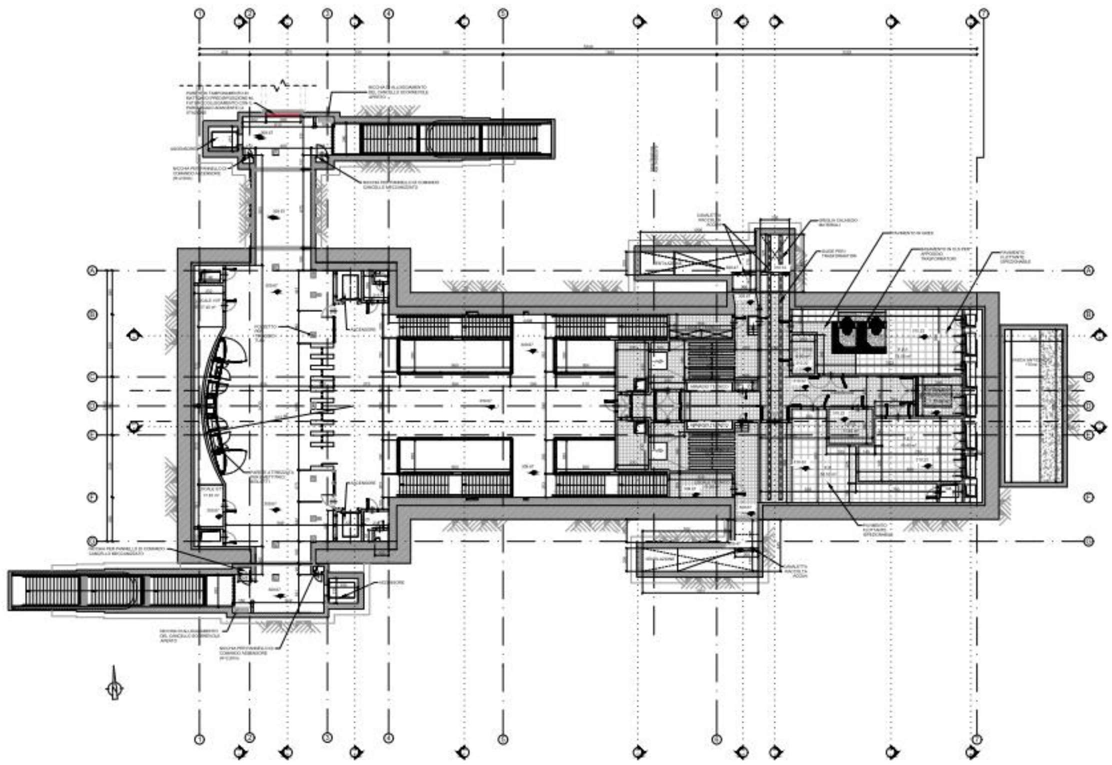


Figure 9: PIANO ATRIO plan. [53]

Precisely, it is two vent shafts (north ventilation well and south ventilation well) and two main entrances (north gate on P.zza Togliatti and south gate on the walk side in the west direction), which guarantee both access to the metro station and the underpass of the urban Corso Francia road.

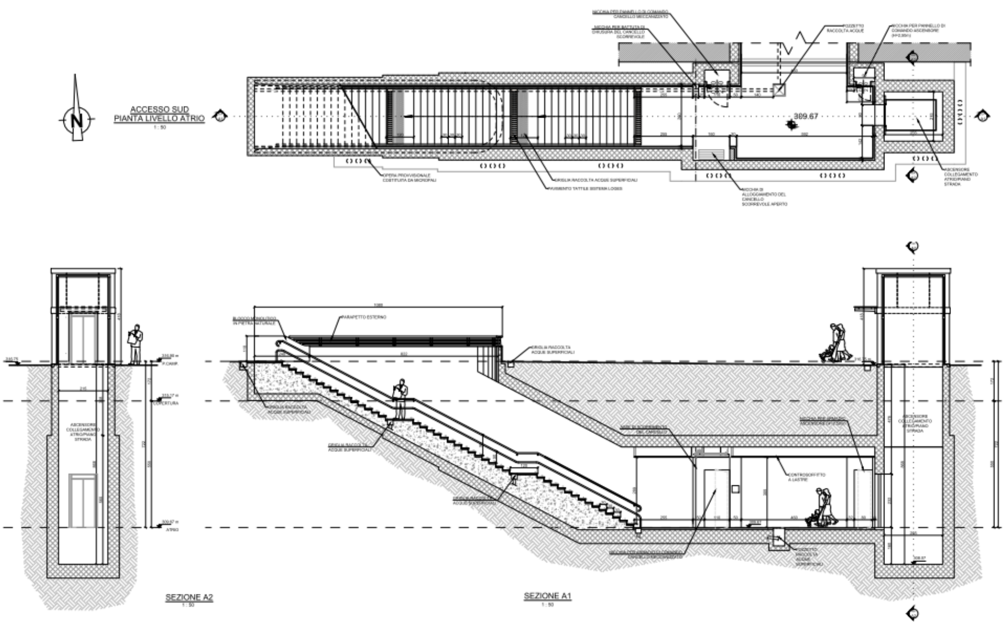


Figure 10: plan and section of north gate. [54]

The installation of an elevator for each entrance, together with the escalator, facilitates the accessibility to different types of users, besides the usage of the stations as safe underpasses of Corso Francia.

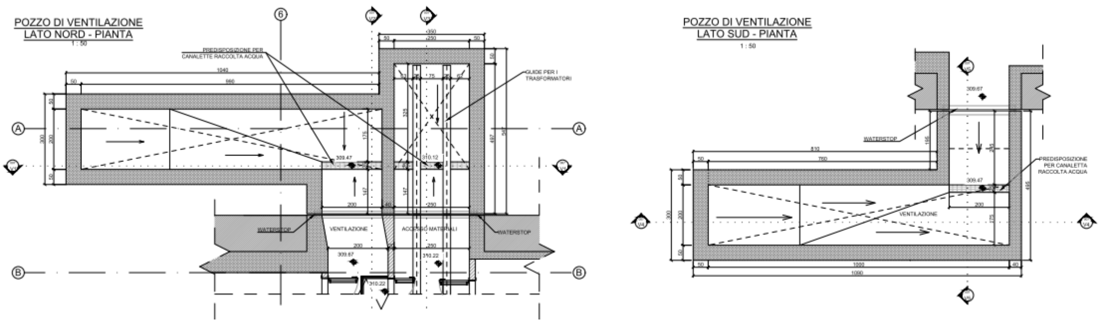


Figure 11: vent shafts plants. [55]

The excavation works for the realization of gates and wells entail using bulkheads, consisting of a single row of micropiles connected at the head by a continuous reinforced concrete curb.

3.2 Ventilation shafts

The inter-section wells are underground buildings performing the functions of operating ventilation, emergency ventilation, line access for the fire department and water catchment for the interstation sections. More specifically, they include a surface ventilation grid, a hatch for the lowering of materials, a hatch for access to the electrical panel room by the operator, a hatch for access by the fire brigade, the underground ventilation room containing fans with silencers and electrical panels, and the connection section between the well itself and the tunnel.

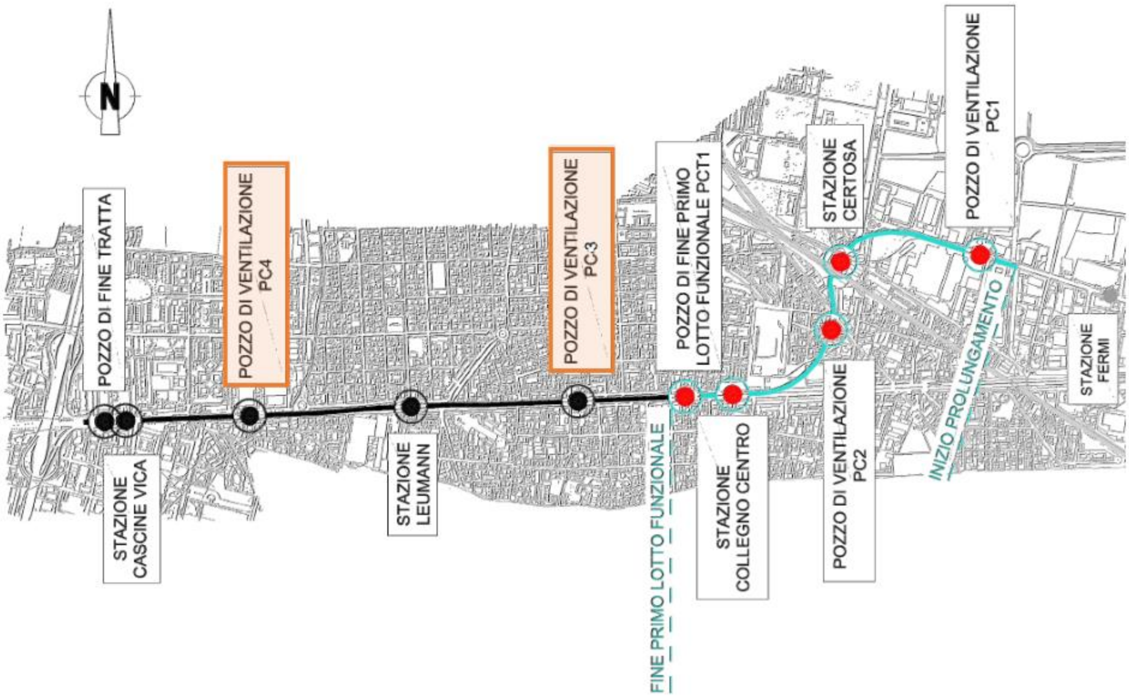


Figure 12: Chorography of the ventilation shafts. [56]

From the structural point of view, two portions can be distinguished:

- *CORPO 1*: three-story rectangular plan building, which includes three fundamental levels:
  - PIANO SOLETTONE TECNICO: it holds technical rooms, accessible throughout vertical ladders;
  - PIANO BANCHINA: it is placed at an altitude of -7.00 meters for PC3 and -6.50 meters for PC4 with respect to the technical floor. It is a platform (accessible with stairs only) represented by a metallic grid upheld by a system of IPE steel beams.
  - PIANO SOLETTONE DI FONDO: it is located at a depth of -2.20 meters (for both PC3 and PC4) with respect to the PIANO BANCHINA level. The access is guaranteed by two simple metallic vertical ladders.
- *CORPO 2*: single-story rectangular plan building with external lining in reinforced concrete, intended to hold the compartment for the lowering of materials and the compartment for the access of the fire brigade. The excavation is carried out after the construction of a temporary bulkhead of micropiles which has the purpose of allowing the descent to an excavation base and the execution of the internal structures in reinforced concrete.

The whole ventilation well represents a technical area reserved for service personnel.

3.2.1 PC3

The ventilation shaft named PC3 belongs to LOTTO 2 “Collegno Centro-Cascine Vica”, TRATTA 3. It is located in between Collegno Centro and Leumann stations.

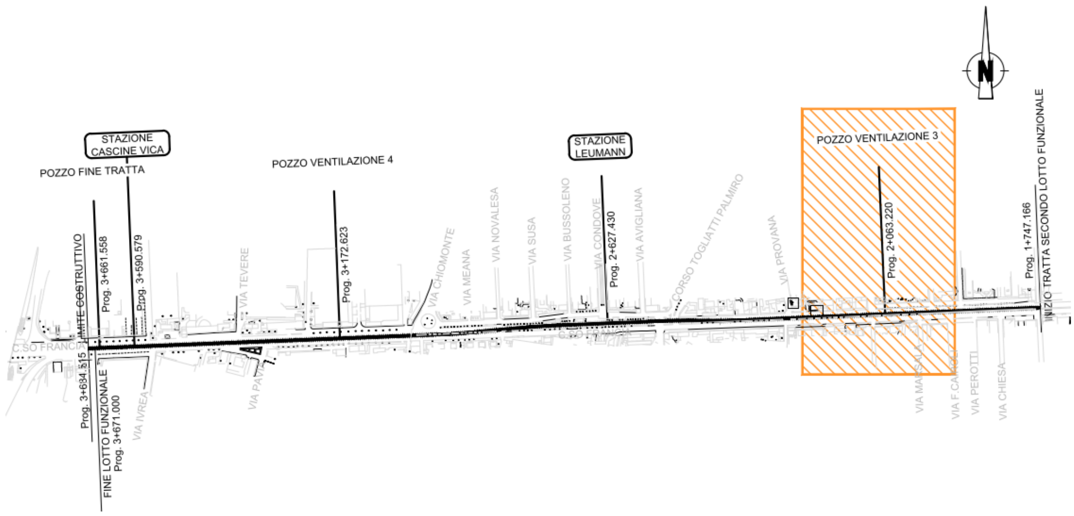


Figure 13: Chorography of the PC3 vent shaft. [57]

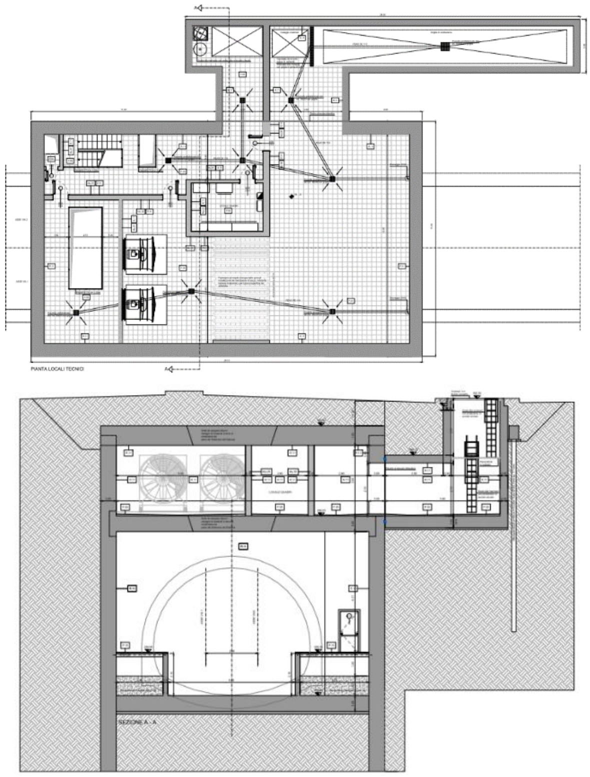


Figure 14: Atrium plan and A-A cross-section of the PC3 vent shaft. [58]

3.2.2 PC4

The ventilation shaft named PC4 belongs to LOTTO 2 "Collegno Centro-Cascine Vica", TRATTA 3. It is located in between Leumann and Cascine Vica stations.

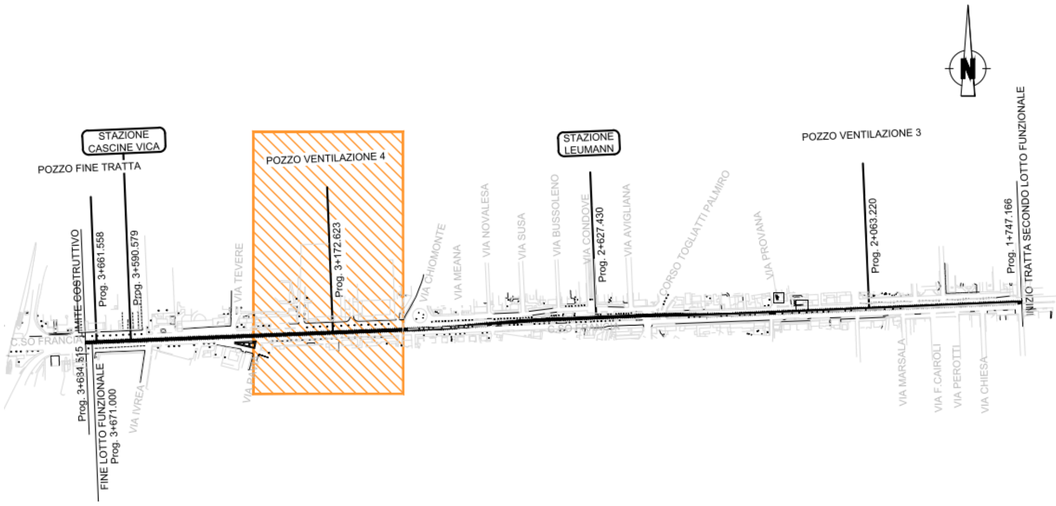


Figure 15: Chorography of the PC4 vent shaft. [59]

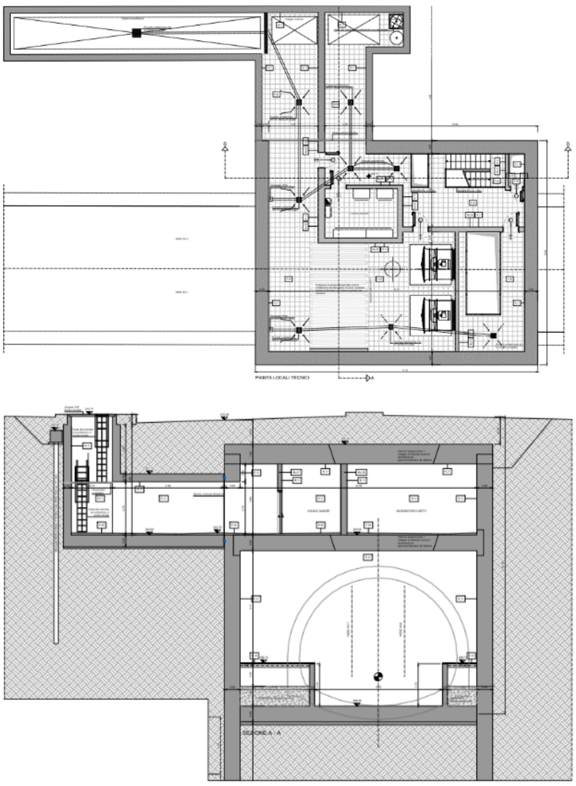


Figure 16: Atrium plan and A-A cross-section of the PC4 vent shaft. [60]

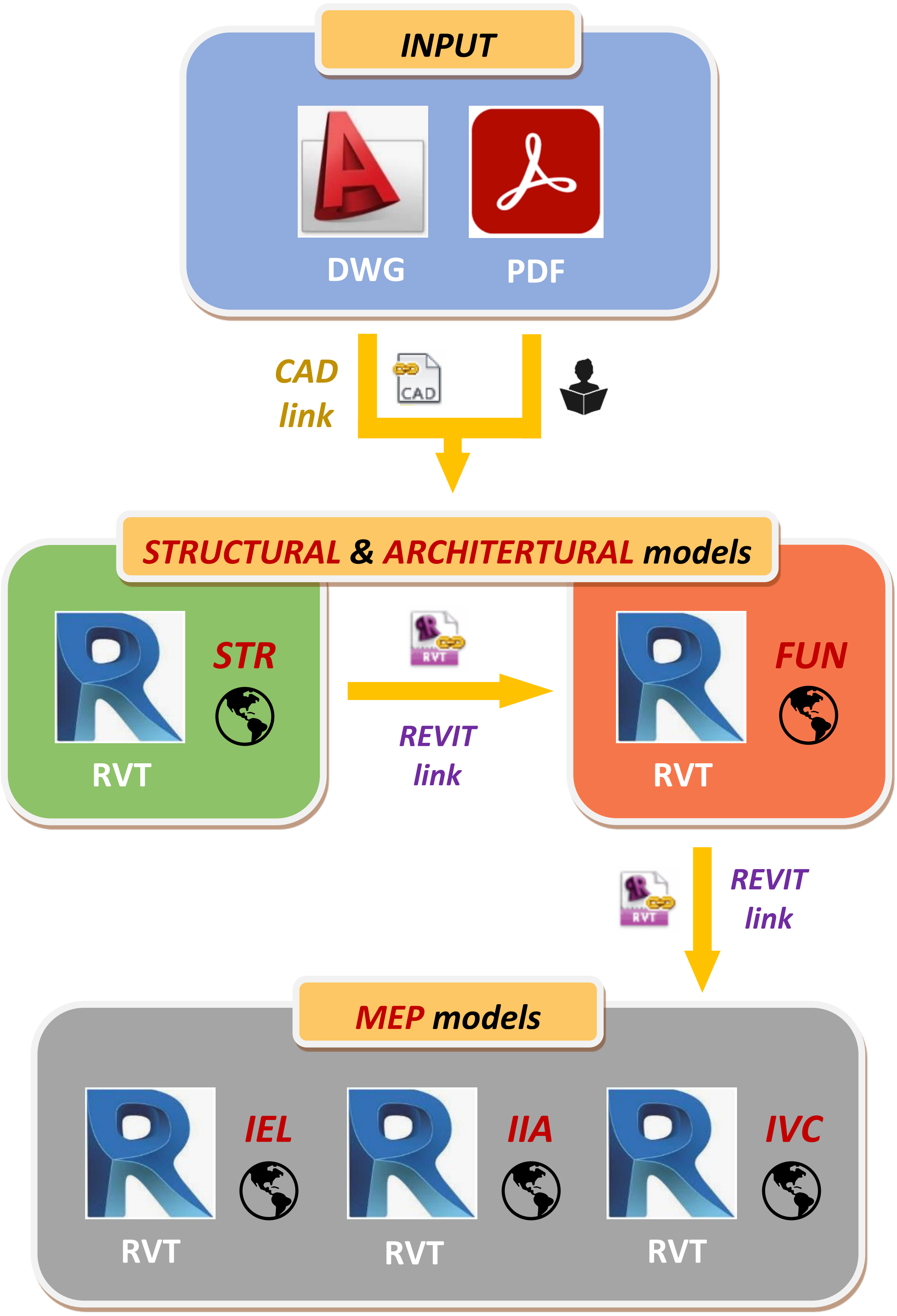
4. Methodology

The explanation of the methodology is briefly shown through the flowchart of the sequence of actions carried out, practically performed by using a series of Revit commands.

Indeed, the figure on the following page tries to explain the methodologic process followed all over the present thesis' work, and summarised throughout three main steps:

- collection of the data about the projects, in form of technical drawings and reports (provided as .dwg and .pdf files);
- creation of the geo-referenced *structural model* at first (as .rvt file), and afterward of the geo-referenced *functional model* (.rvt file again), directly linked to the structural one;
- creation of the three geo-referenced *MEP models* (all .rvt files), directly linked to the functional one.

Successively, it follows a chapter with a series of the most important and common practical tools that have been used for modeling the features under examination. So, for each of those ones, a specific paragraph is dedicated, in which the command is explained in detail (the purpose for which it is used, and the practical sequence of operations need to be performed).


INPUT
DWG
PDF
CAD link
CAD
STRUCTURAL & ARCHITERTURAL models
STR
RVT
RVT
REVIT link
FUN
RVT
RVT
REVIT link
MEP models
IEL
RVT
IIA
RVT
IVC
RVT

5. Information production

The information production process in a BIM design consists of the creation of the Building Information Model. Precisely, the task assigned to the author was to create structural, functional, and MEP models of the subway facilities largely described in chapter 3.

5.1. Name coding

The name coding of the documents and project parameters is a fundamental aspect which belong to the BIM Execution Plan (BEP) and which is necessary to be clearly defined since the beginning.

The first one considered is the base coding concerning the documents name. The description of the levels of the codification is explained in the table on the following page. [21]

Here below, an example is reported.

Table 3: Example of document coding.

Reference contract						Batch		Phase	Subproject			WBS			Type	Station		
M	T	L	1	T	3	A	2	E	F	U	N	S	C	V	M	0	0	1

The document named "MTL1T3_A1_E_FUN_SCV_M_001" is the first functional model of the Cascine Vica subway station, line 1 – batch 2 – section 3, related to the project executive phase.

Table 4: Document coding table.

Level	Description	Chars	Options
1st	Contract reference	6	MTL1T3 = Metro Torino, Linea 1, Tratta 3
2nd	Functional batch	2	A0 = General procurement An = Batch n
3rd	Work phase	1	P = Preliminary D = Definitive E = Executive I = Integrative C = Constructive
4th	Sub-project	3	ZOO = General ARC = Architectural FUN = Functional STR = Structural IMP = Non-general system installations IEL = Electrical systems IVC = Ventilation and air conditioning system IIA = Fire and sanification system IRI = Fire detection systems IFD = Sound7data systems ISP = Special systems
5th	WBS civil works	3	SCV = Cascine Vica subway station PC3 = 3rd ventilation well from Fermi PC4 = 4th ventilation well from Fermi
6th	Document type	1	R = Report M = Model S = Graph K = Scheme T = Planning table C = Statement, economic assessment E = Price list A = Price analysis Z = Technical specifications V = Various
7th	Progressive number	3	00n

The second kind of naming code to be considered is the one related to the nomenclature of the single model elements.
The families of the project are coded using five different levels, in accordance with what showed in the table on the following page.
It is necessary to highlight that when system families are used, the family name cannot be edited. So, the described conventional coding is used in relation to the family type. [21]

Here below, an example is reported.

Table 5: Example of model element coding.

Designer		Discipline	Family		Identity		Type
G	D	S	W	L	0	1	200mm

The family named "GD_S_WL.01_200mm" indicates the wall structural element modeled by Geodata S.p.A. staff, having a thickness of 200 mm and built up in concrete.

Table 6: Model elements coding table.

Level	Description	Chars	Options
1st	Company	2	GD = Geodata Engineering S.p.A.
2nd	Sub-discipline	1	A = Architecture S = Structure V = Ventilation system F = Fire system E = Electric system I = Water and sanitation systems T = Tunnel G = Ground P = plumbing
3rd	Object category	2	FF/WF = Floor/Wall finish DR = Door WI = Windows RA/HR = Railing/Handrail EQ = Equipment BA = Baseboard WA/WL = Architectural/Structural wall CE = Ceiling FL = Structural floor CL = Column BM = Beam SS = Structural stair FO/WO = Floor/Wall opening DC = Duct GR = Grid DP = Dumper CN = Duct connection PP = Pipe
4th	Identity	2	0n = Material/Characteristic/Typology
5th	Family type name	-	Alphanumeric description

5.2. Modeling within Revit software

Autodesk Revit is a building information modelling software that allows building professionals to design and document a building by creating a parametric three-dimensional model that includes both geometry and non-geometric design and construction information.

Users create parametric components in a graphical "family editor" rather than a programming language, and the model captures all relationships between components, views, and annotations so that a change to any element automatically propagated to keep the model consistent. [22]

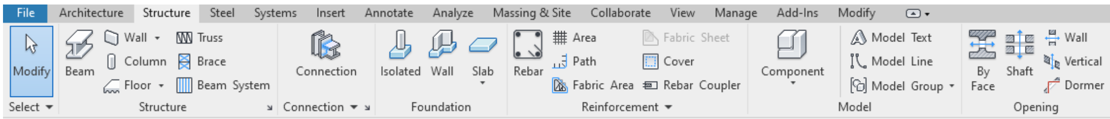


Figure 17: "Structure" Revit tab.

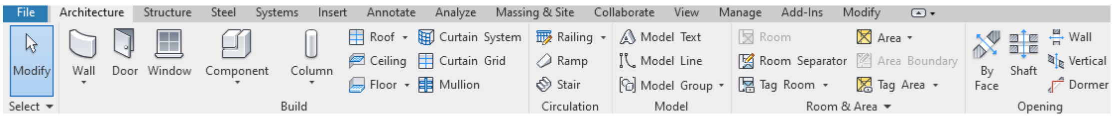


Figure 18: "Architecture" Revit tab.

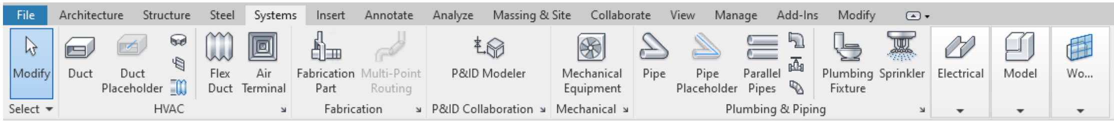


Figure 19: "System" Revit tab.

In the ribbon, it is possible to choose among different disciplines like Architecture, Structure, and Systems, by selecting the specific correspondent tab (like showed in the figures above).

In the System tab, MEP families are divided by main sub-disciplines: Heating Ventilation and Air Conditioning (HVAC), Mechanical, Plumbing & Piping, and Electrical.

5.3. Templates

Before starting a new project, the Revit modeler asks for a project template file to be opened. The project templates use the file extension RTE and represent the starting point for new models since include view templates, loaded families, and further defined settings (such as units, fill patterns, line styles, line weights, view scales, and more). [23]

It is possible to use default templates or create customized templates aimed to enforce the office standards and address specific needs. For the purpose of the thesis, to be coherent with the whole design, it is used the same customized templates already created for modeling the other facilities belonging to the same subway line project.

Architects and engineers of the agency already created five basic customized templates, each one related to a specific discipline: structural template ("2020_TEMP_PE_STRU.rte"), functional template ("2020_TEMP_PE_FIN.rte"), ventilation and air conditioning system template ("2020_TEMP_PE_IVC.rte"), fire protection & water-sanitation facilities system template ("2020_TEMP_PE_IIA.rte") and electrical system template ("2020_TEMP_PE_IEL.rte").

Nome	Tipo	Dimensione
2020_TEMP_PE_FIN	Autodesk Revit Template	10,308 KB
2020_TEMP_PE_IEL	Autodesk Revit Template	47,708 KB
2020_TEMP_PE_IIA	Autodesk Revit Template	19,024 KB
2020_TEMP_PE_IVC	Autodesk Revit Template	25,072 KB
2020_TEMP_PE_STRU	Autodesk Revit Template	2,832 KB

Figure 20: Geodata S.p.A. customized templates.

5.4. Levels

In Revit, levels are finite horizontal planes that serve as a reference for the elements housed in the levels themselves. [24]
It follows two tables in which the lists of main levels used are reported, for the three facilities under examination (Cascine Vica subway station and PC3 and PC4 ventilation wells).

Table 7: Levels of the Revit Cascine Vica model.

Level Name	Altitude [m]
T15	293.37
T14	299.92
00_SOTTOBANCHINA	301.42
P.R.	303.94
01_BANCHINA	304.77
02_ATRIO	309.57
T64	310.22
03_COPERTURA WIP	315.17

Table 8: Levels of the Revit PC3 and PC4 models.

Level Name	Altitude_PC3 [m]	Altitude_PC4 [m]
00_SOLETTONE DI FONDO	286.86	295.95
01_BANCHINA	289.01	298.10
Pianerottolo0	289.06	297.98
Pianerottolo1	291.30	299.89
Pianerottolo2	292.68	301.28
Pianerottolo3	294.41	303.02
02_SOLETTONE TECNICO INTERMEDIO	296.03	304.65
03_SOLETTONE COPERTURA	300.63	309.25

5.5. Views

It is possible to use a view template, which is a collection of view properties, such as view scale, discipline, detail level, and visibility settings. It can help to ensure adherence to office standards and achieve consistency across construction document sets. [26]

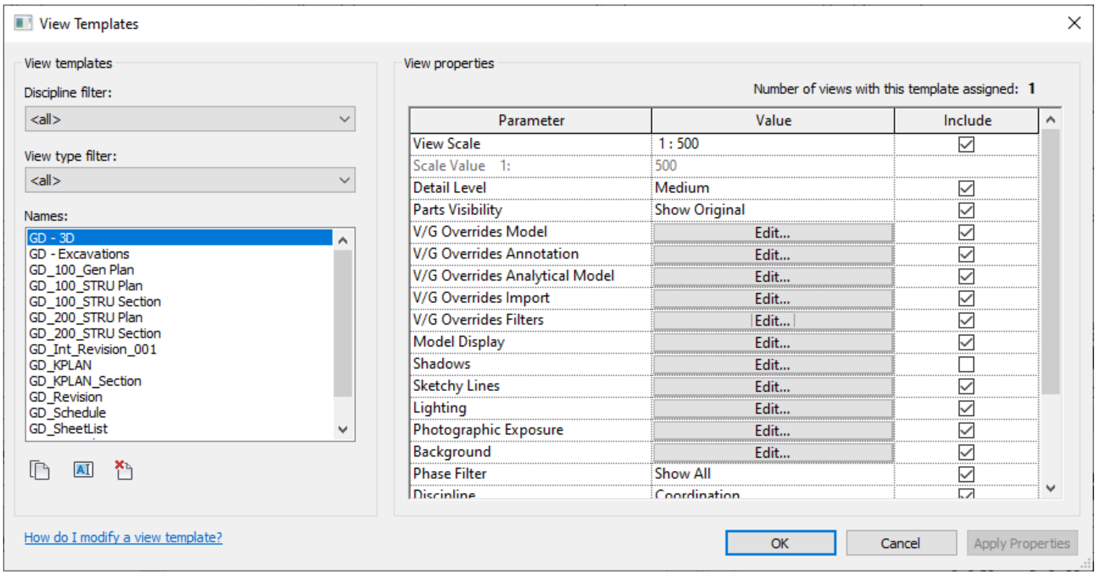


Figure 21: "View Templates" Revit dialog window.

Anyway, view templates can be specifically customized on the basis of the needs, as for example highlighting specific elements of the model. It is done acting on the visibility and the graphical display of the elements identified by the filter: it is possible to use a filter of selected elements or a rule-based filter (that identifies elements using parameter values) for changing colors, transparency, patterns, halftones, and more.

It follows an example about the creation of a filter that permits to identify all the cable trays and cable tray fittings elements having as comments the char "B", in the IIE model. This filter is successively used for coloring the selected elements in blue.

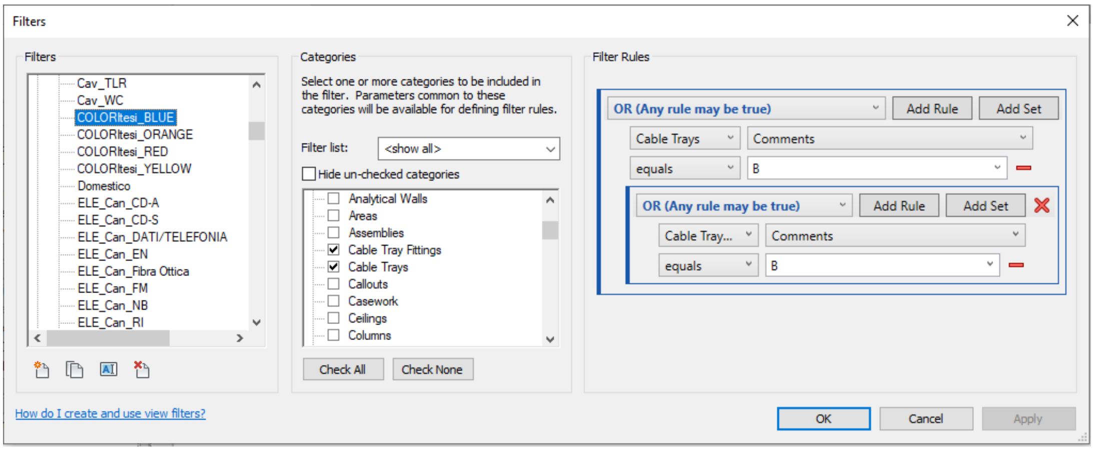


Figure 22: "Filters" Revit dialog window.

Moreover, exists several commands which allow us to differently manage the opened views in the project: each view has its own tab inside the drawing area, and so it is possible to put the views in a particular order, dock the view to a position in the drawing area, move the view to another monitor and see multiple views at once. [25]
Smart usage of those tools can result to be a big advantage for the Revit modeler, which will be quicker in its operations.

All these commands, and many others not mentioned because not directly used, are accessible throughout the View tab, present in the ribbon.

5.6. Linking files

For linking files into the Revit model, it is necessary to operate in the Insert tab, on the ribbon panel.

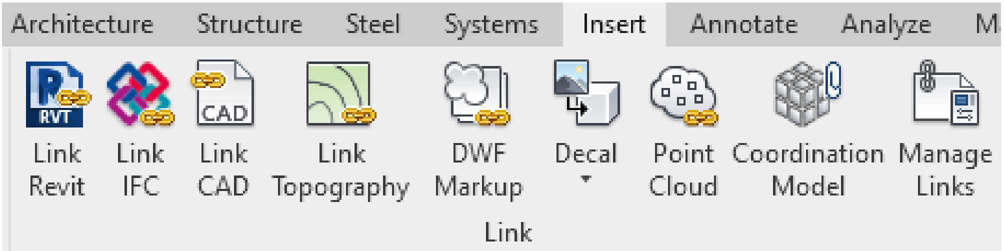


Figure 23: "Link" Revit panel.

5.6.1. Link a CAD File to the Revit model

This command is used for maintaining a connection between the file and the model so that it is possible to use the file as an underlay or include it in the construction document set. [27]
The command was used several times over all the modeling process, in order to link the AutoCAD files of the subway station plans and of the vent shafts plans. Also, the files of the sections of some particular structural elements like the stairs were used. In general, linking a CAD file into the project is very useful because allows you to quickly create and position the elements of the model.

As well as linking a CAD file, it is also possible to import it, with the difference that in the latter option, if the CAD file undergoes changes after insertion, no automatic update happens. With the link option, the inserted file is updated every time it is modified, even after being inserted in the project.

Practically, the command is reached by clicking on *Link CAD*, inside the *Link* panel in the ribbon. Successively, in the dialog, it is required to select the name and type of the desired file to link.

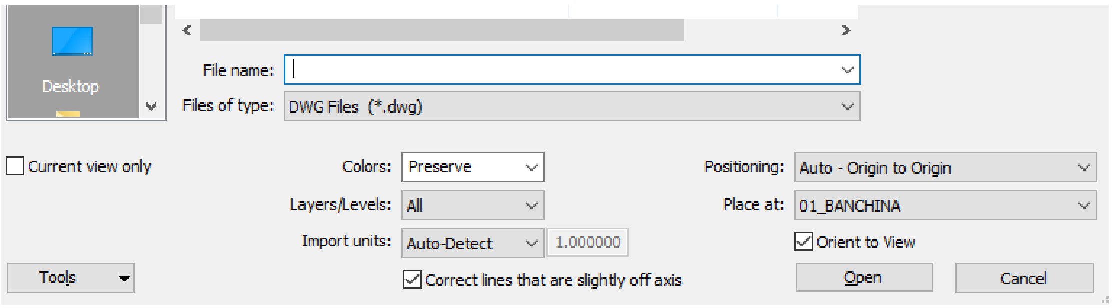


Figure 24: "Link CAD Formats" Revit dialog.

Hence, it is required to specify the values for all the available options, before clicking on Open, to place the linked file content in the drawing area.

- *Current view only*: tick it if you want the linked file to display in the current view only; otherwise, the linked file is displayed in all relevant 2D views, such as floor plans.
- *Colors*: choose one among the options "invert", "preserve", and "black and white".
- *Layers/Levels*: the available options are "All" (displays all linked file layers in the project, including hidden layers), "Visible" (displays visible layers of the linked file in the project), and "Specify…" (allows us to select the layers to display in the project from a list).
- *Import units*: select the correct unit of measure set in the AutoCAD file, or click on the "Auto-Detect" option.
- *Positioning*: specify the desired option among the available ones for placing the AutoCAD link in the Revit model.
- *Place at*: select the level of the model to which you want to attach the linked AutoCAD file.

5.6.2. Link one Revit model to another

To be coherent with the structural model, and to facilitate the modeling operations of the functional and MEP models, it has been chosen to link Revit models with shared coordinates.

In particular, a simple link with the structural model was done for creating the functional model; and a link with the functional model was performed for creating the three MEP models.

Once the Revit model is linked into the project, the Reference Type option can be changed from Overlay to Attachment, or vice versa.

The reference type of a link is very important because it determines how Revit will regard that link when the host model is linked into another model. So, it defines the visibility of nested models (models in their turn linked to the link) in the main model.

In the following diagram, the difference between the two options is explained.

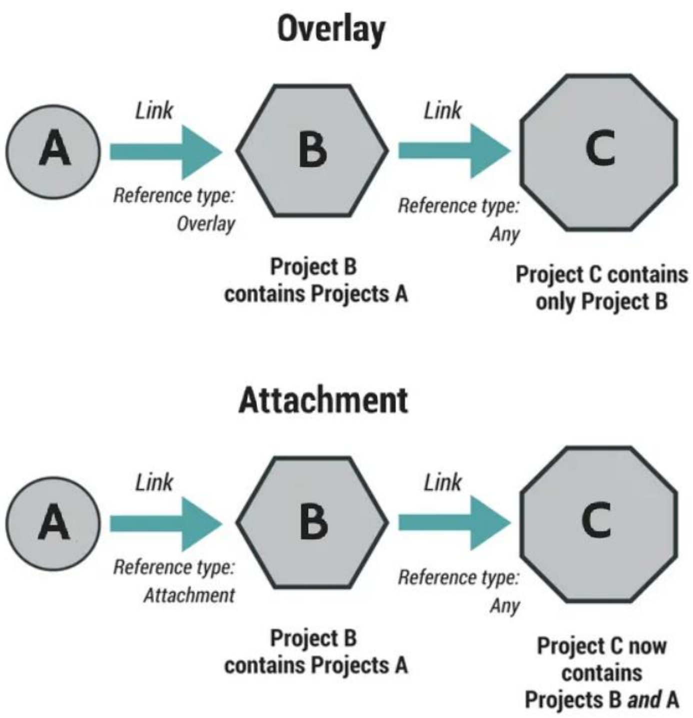


Figure 25: Diagram of the "Overlay" and "Attachment" reference types. [30]

Supposing to work in Project B, and link in Project A:

- if Project A's reference Type is set to *Attachment*, when Project B gets linked into Project C, Projects B and A both will be visible in C. Basically, Project A will get attached or nested into Project B;
- if Project A's reference Type is set to *Overlay*, when Project B gets linked into Project C, only Project B gets linked in and Project A gets ignored. [30]

Practically, the command is reached by clicking on *Link Revit*, inside the *Link* panel in the ribbon. In the dialog, it is required to select the name and type of the desired file to link and the desired option among the available ones related to the *positioning*.

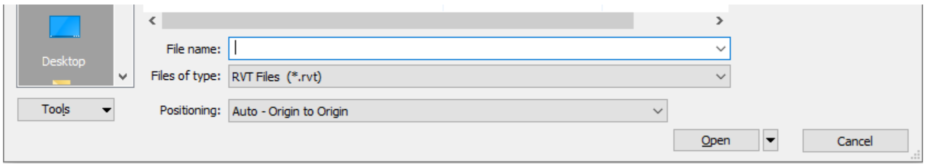


Figure 26: "Import/Link RVT" Revit dialog.

Once the Revit model is linked to the current project, it is possible to change the *Reference Type* option. To correctly manage this aspect, it is necessary to access the *Manage Links* button inside the *Manage Project* panel, in the *Manage* tab on the ribbon. In the proper column named *Reference Type,* at the *Revit* sheet, it is possible to alternatively select "Overlay" or "Attachment".

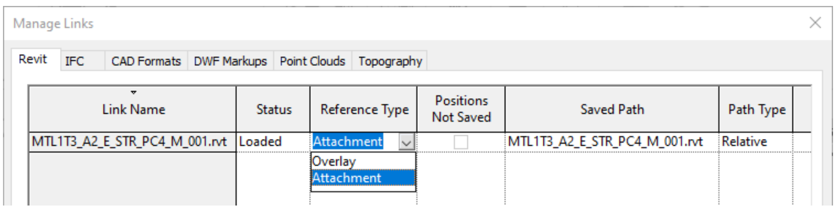


Figure 27: "Manage Links" Revit dialog.

For the cases under examination, all the functional models use links to the correspondent structural models which are overlayed links. In this way, the geometry of the structural elements can be visible also inside the MEP models.

5.7. Object creation

The modeling phase consists of the creation and allocation in the right place of all the objects of the model. These single elements placed in the project are called *Instances* and can be classified on three hierarchical levels inside the Revit software: *Categories*, *Families,* and *Types*. Instances adopt the property set of the category that corresponds to, as well as the family and type properties. Anyway, exists also the instance project parameters, which enables modification of the parameter value separately for every instance.

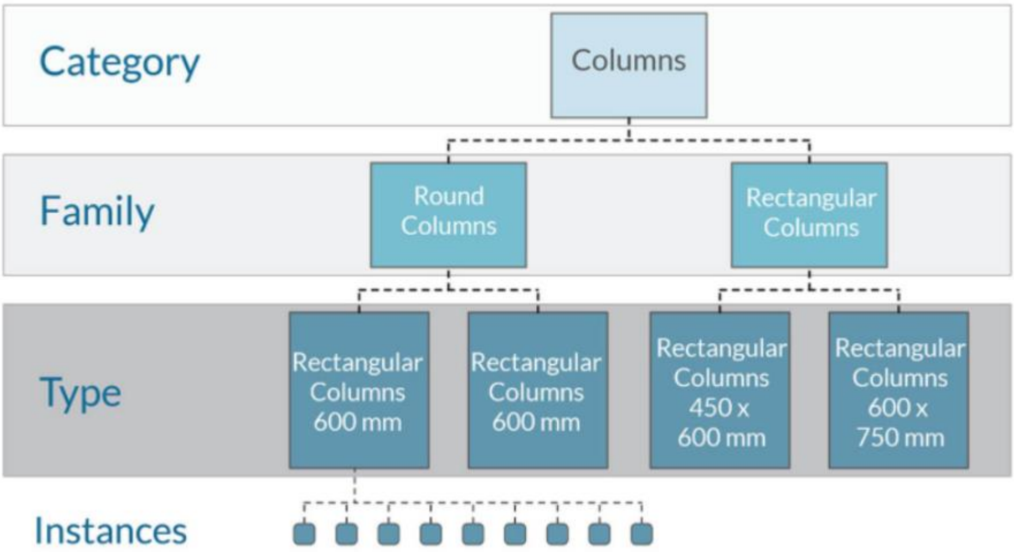


Figure 28: Revit hierarchy example. [29]

In particular, in Revit, exists three different kinds of families, of which the first two are the most largely used: *system families*, *loadable families*, and *in-place families*.
The following three paragraphs are dedicated to this topic.

5.7.1. System families

System families are always available in any project and contain family types used to create basic building elements related to different disciplines (such as walls, columns, floors, stairs, ceilings, beams, ducts, cables, trays, pipes, and more). They are predefined in Revit and saved in templates and projects, not loaded from external files.
System families also include project and system settings, which affect the project environment and include types for elements such as levels, grids, sheets, and viewports.

System families could be inserted in the project thorough *Architecture (example in the figure below)*, *Structure*, *Steel* and *Systems* tabs.

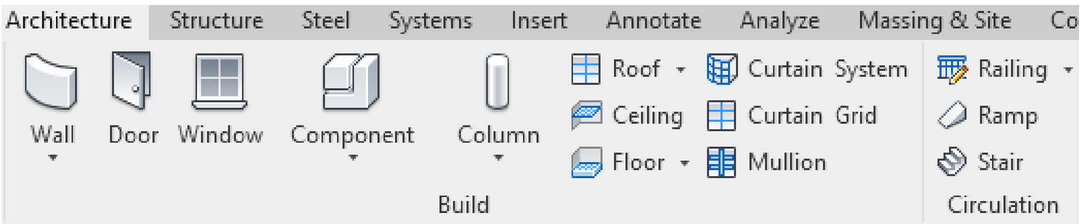


Figure 29: "Architecture" Revit tab.

It is not possible to create, copy, modify, or delete system families, but it is allowed to duplicate and modify the types within system families to create personally customized system family types. It is also possible to import a system family from one project to another, by using the *Transfer Project Standards* command available in the *Settings* panel of the *Manage* tab.

System families can also host other kinds of families, usually loadable families. [30]

5.7.2. Loadable families

Loadable families are common families, used to create:

- building components that would usually be purchased, delivered, and installed in and around a building, such as windows, doors, casework, fixtures, furniture, and planting;
- system components that would usually be purchased, delivered, and installed in and around a building, such as boilers, water heaters, air handlers, and plumbing fixtures;
- some annotation elements, that are routinely customized, such as symbols and title blocks.

Loadable families can be found on the Revit libraries, on the internet, or be designed from scratch at the Family Editor. They are saved as separated files with RFA extension and imported (loaded) in the project. [31]

In order to load a family: select *Place a Component* in *the Insert* tab > click on *Load Family* command inside the *Load from Library* panel > in the *Load Family* dialog, select the family to load > finally, click *Open*.

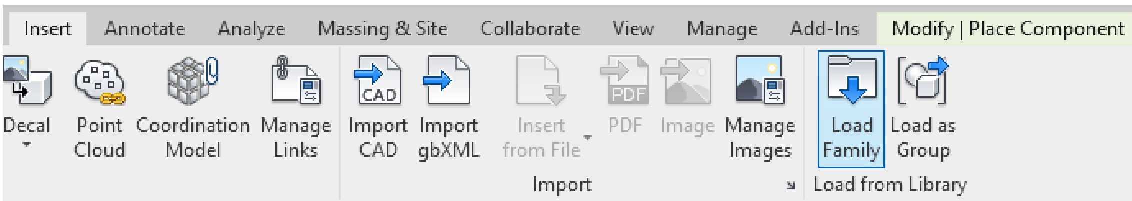


Figure 30: "Insert" Revit tab.

Hence, the family type is available to place in the project and displays in the appropriate category under *Families* in the Project Browser.

In the practical modeling process, it happens to have the possibility to import in the current project one element of a family that was already modeled by colleagues or other companies in other projects.

In this case, it is possible to: select the object in the project in which it was already modeled > click on *Edit Family,* in the *Mode* panel of the *Modify* tab > Press the *Load* *into Project* command inside the *Family Editor* panel > in the dialog, select the project where load the family > finally, press on *OK*.

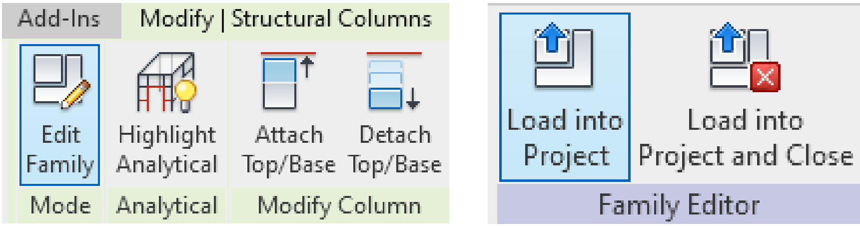


Figure 31: "Mode" (left) and "Family Editor" (right) Revit panels.

Because of their highly customizable nature, loadable families are the families that are most used. In the project, some families already modeled inside the projects of other subway stations, and other vent shafts are used.

5.7.3. In-Place families

In-place elements are customized elements created in the context of a project, for modeling unique geometry that it is not expected to reuse or geometry that must maintain one or more relationships to other project geometry (resizing or adjusting accordingly if the referenced geometry changes).

When an in-place element is modeled, Revit automatically creates an associated family, which contains a single-family type. It is possible to place copies of the same in-place element between projects, but not duplicate in-place family types to create multiple types.

For creating a model In-Place structural element: click on the *Model In-Place* command, which is available in the *Build* panel (of the *Architecture* tab) or in the *Model* panel (of the *Structure/System* panel) on the ribbon > in the *Family Category and Parameters* dialog, select a category for the element (it is the category under which the family for the in-place element will display in the Project Browser, in which it will schedule, and in which it is possible to control its visibility) > click *OK* > in the *Name* dialog, type a name > click *OK.*

Using the tools of the Family Editor, create the in-place element. Once having finished to create the in-place element, click *Finish Model*. [32]

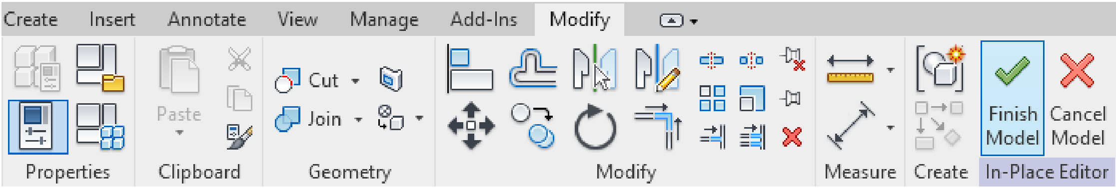


Figure 32: "Modify" and "Family Editor" Revit panels.

Being aware of the fact that in-place elements can increase file size and degrade software performance, this tool was used few times in the current case study. In particular, it was used for modeling the stairs internal to the subway station and the ones in correspondence of its two accesses.

5.8. Other useful Revit commands

5.8.1. Family Editor

The *Family Editor* is a graphical editing mode that allows to make changes to existing families or to create new families from scratch.

To open the *Family Editor*, it is possible to double-click an instance of the family in the drawing area or to select it and click on *Edit Family* inside the *Mode* panel of the *Modify | <Element>* tab.

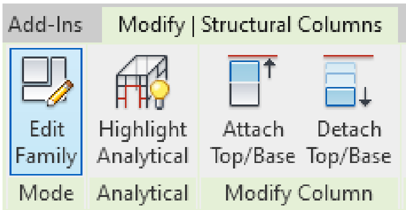


Figure 33: "Modify | Structural Columns" Revit tab.

A template including multiple views (such as plans and elevations) is opened. The Family Editor has the same look and feels like the project environment in Revit Architecture, but the availability of tools inside depends upon the type of family that is being edited. [34]

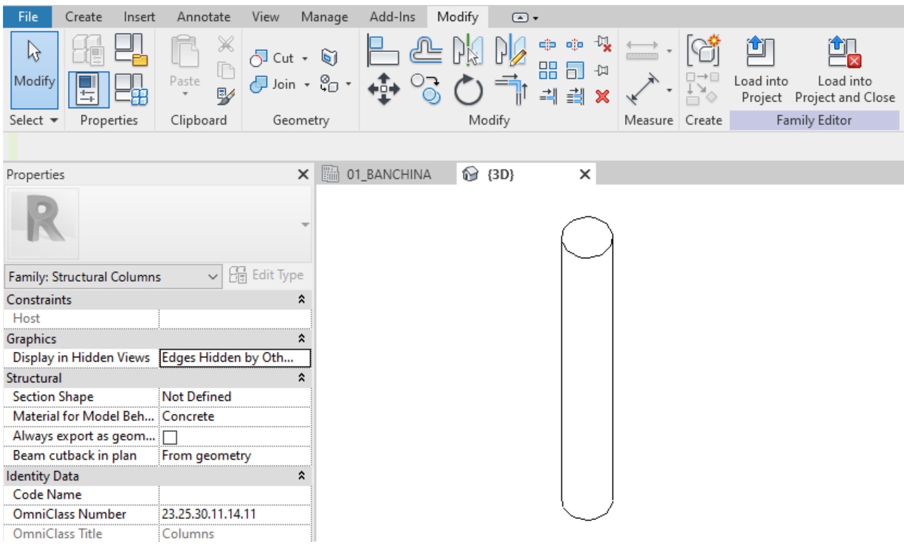


Figure 34: "Family Editor" of a column Revit instance.

5.8.2. Add another plan view to the project

From *View* tab, inside the *Create* panel, press on *Plan View* drop-down and then click on one among the options (for example on Structural plan); in the dialog, select a view type from the list (or click Edit Type to modify an existing view type or create a new view type) and select the level which want to create the plan view; finally, press *OK*.

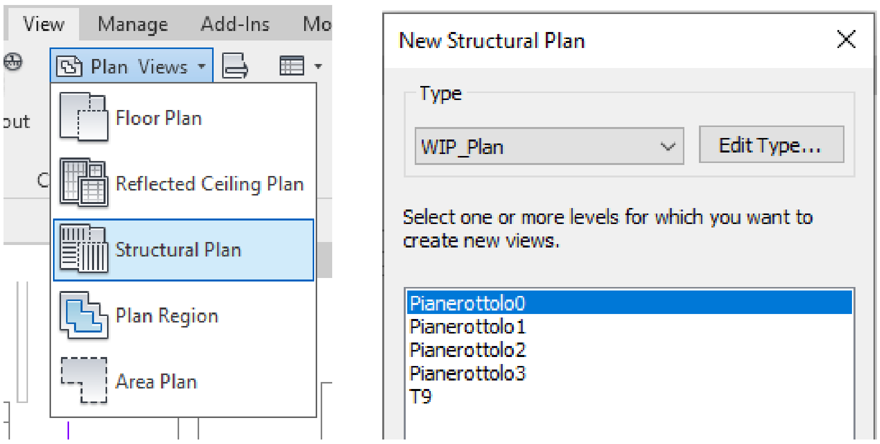


Figure 35: "Plan View" drop-down command and "New Structural Plan" dialog.

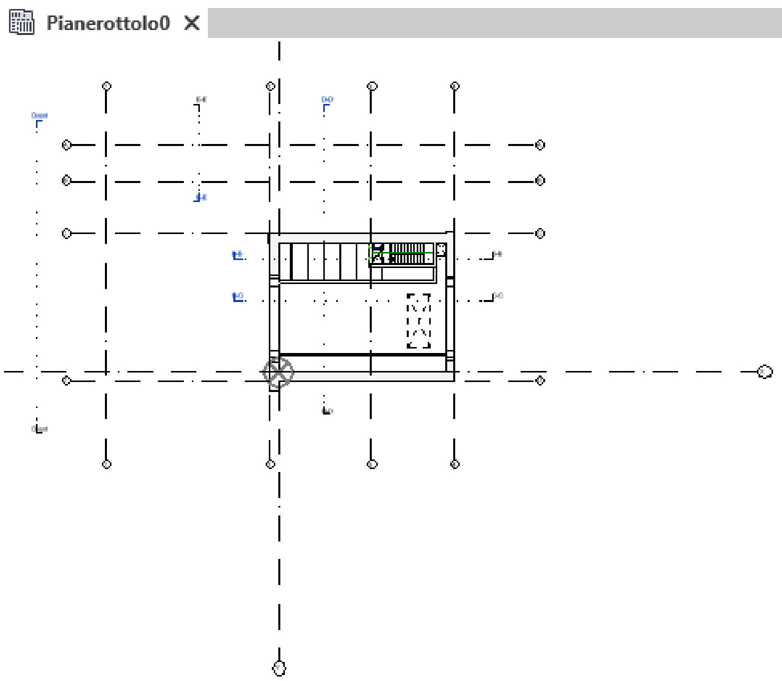


Figure 36: "Pianerottolo0" new plan view.

5.8.3. View Range

Every plan view has a property called view range (or visible range) that is controlled throughout the definition of four horizontal planes:

- *Top clip plane*, that represents the topmost portion of the primary view range;
- *Cut plane*, that determines the height at which certain elements in the primary view range are shown as cut;
- *Bottom clip plane*, that represents the bottommost portion of the primary view range;
- *Level plane*, which is an additional plane for the definition of the View depth (beyond the primary view range), changing which it is possible to show elements below the Bottom clip plane. [33]

Practically, these options can be controlled in the *View Range* dialog, accessible from the *View Range* button, in the *Properties* palette.

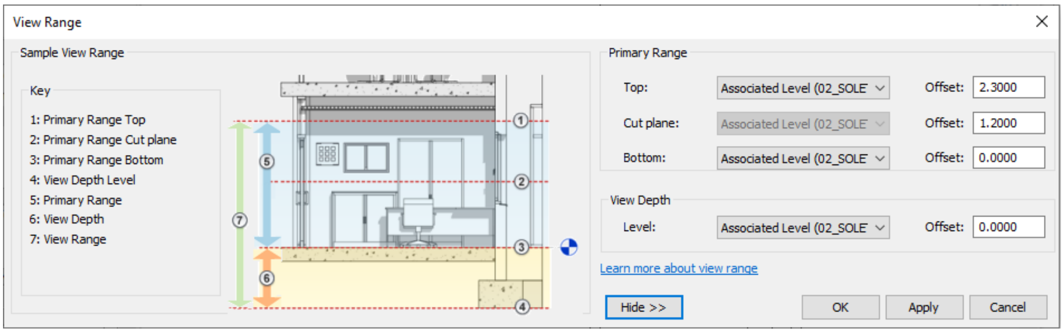


Figure 37: "View Range" Revit dialog of a plan view.

5.8.4. Add a Reference Plane

This command can be used for creating a section plan, so a new plane orthogonal with respect to any plan view.

In practice, on the *Architecture/Structure/Systems* tab on the ribbon, click *Reference Plane* in the *Work Plane* panel. On the *Draw* panel, click *Line* to draw the reference planes by dragging the cursor in the drawing area, or click *Pick Lines* to pick an existing line as the reference plane. This line figures as a dashed green line and represents the trace of the new plane.

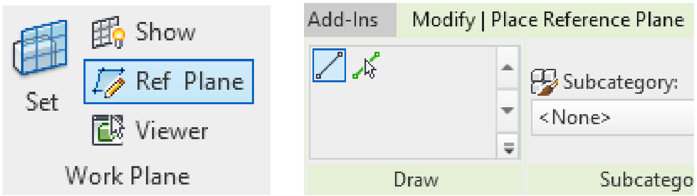


Figure 38: "Work Plane" and "Draw" Revit panels.

In the present work-study, this tool was used to move the stairs objects created as Model In-Place families in the plan view towards an orthogonal plan. So, after the creation of the new plane, select the object, press on *Edit In-Place* in the *Model* panel, and select the object again. Inside the In-Place Editor, press the *Pick New* button, click on *Work Plane*, and then on *Pick...*; in the dialog select *Pick a plane* and press *OK*. Hence, select the dashed green line representing the new reference plan created before, and place the object in the new plane, operating inside the drawing area.

5.8.5. Model lines and Detail Lines

For adding additional information to the model geometry (in form of lines, sketches, annotations and more), it is possible to use these two commands:

- from *Architecture/Structure* tab, press on *Model Line* button, inside the *Model* panel. These lines can be drawn only in plan views and are visible also in 3D;
- from *Annotate* tab, press on *Detail Line* button, inside the *Detail* panel. These lines can be drawn also in section views, but are only visible in the view where they are drawn.

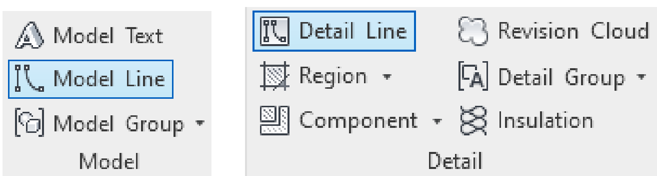


Figure 39: "Model" and "Detail" panels.

5.9. Georeferencing

Georeferencing means associating a digital model file with locations in physical space, coherently with the true geographical location.

In order to manage all the tools related to coordination systems and useful for the georeferencing in Revit, it is suggested to open the standard view of the project and, in the *View* tab, under the *Graphics* panel, click on *Visibility/Graphics*. In the dialog, under the *Model Categories* sheet, it is indicated to go through the *Site* options:

- the *Project Base Point*, which defines the origin of the project coordinate system, is used as a reference point for measurements across the site, and so it is referred to the local context. It is represented by a cross inscribed inside a circle; [35]
- the *Survey Point*, which identifies a real-world location near the model defines the origin of the survey coordinate system. It provides a real-world context for the model and is represented by a triangle with a pointer inside. [35]
- the *Internal Origin (*or *Startup Location)*, which is the starting point for the internal coordinate system, provides the basis for positioning all elements in the model, establishing the project coordinate system and the survey coordinate system. [36]

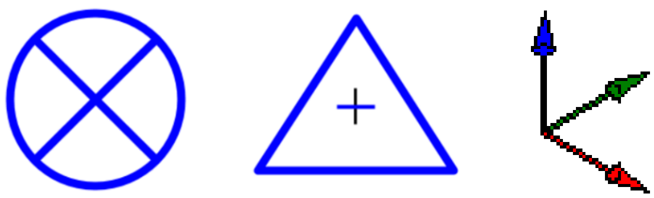


Figure 40: "Project Base Point", "Survey Point" and "Internal Origin" Revit symbols.

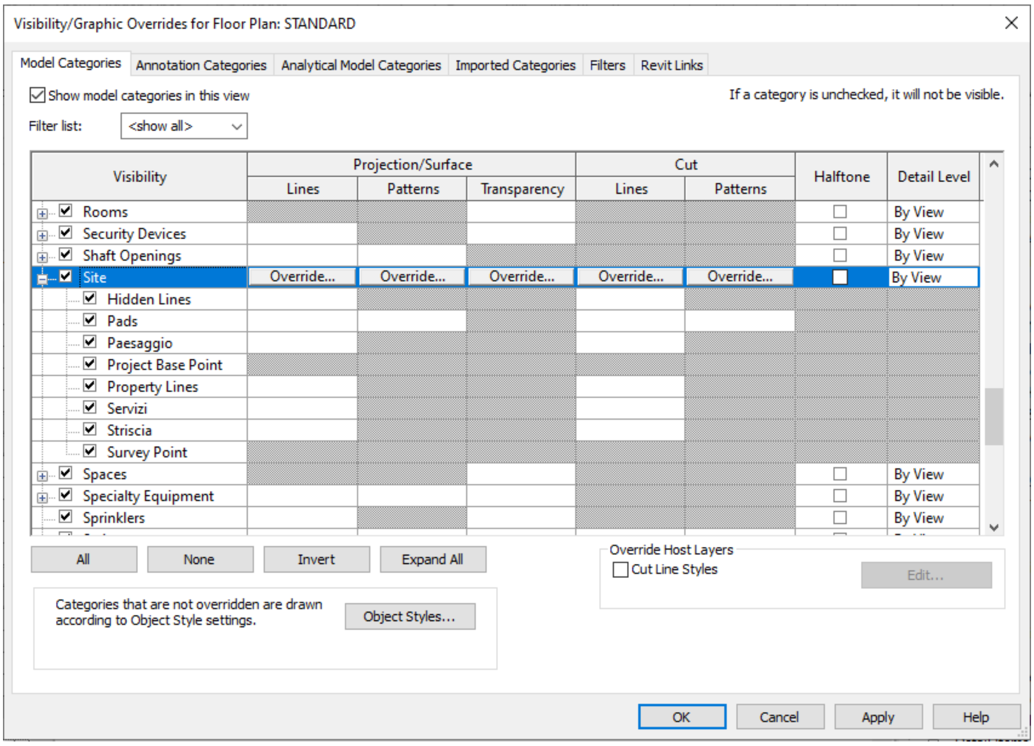


Figure 41: "Visibility/Graphic Overrides for Floor Plan: STANDARD" Revit dialog.

When a new model is created, by default the Project Base Point and the Survey Point are placed at the Internal Origin. So, it is necessary to move them both in the right position:

- to establish the project coordinate system, the decision was to move the *Project Base Point* to the left bottom internal corner of the building, for all the features considered (subway station and ventilation wells), for all the models created (STR, FUN and MEPs);
- to establish the survey coordinate system, it is necessary to move the *Survey Point* to a known real-world location, like a geodetic marker or at the intersection between two property lines.

It is just necessary to remember that the model geometry must be positioned within a 16 kilometers radius from the internal origin otherwise the high distance may reduce reliability and result in undesirable graphic behaviour.

Once the structural model is georeferenced, all the other models of the same feature can be quickly georeferenced, with respect to that master file. It means that for the functional and MEP models it is sufficient to follow the easy procedure explained below.

Open the two Revit projects, which are the master file already georeferenced and the file of the model that needs to be georeferenced. In the latter one, go to the *Manage* tab, and press the *Location* button under the *Project Location* panel. In the dialog, under the *Site* sheet, select the name of the site already defined and click *OK*. Hence, save the project and close it.

In the master file, insert the *Revit Link* of the previous file and place it exactly in the point of the model which respect to you want to get the georeferencing: on a plan view, use the Move and Rotate tool buttons of Revit for getting the *planimetric georeferencing*; inside a cross-section view, attach the linked model to a specific arbitrary level of the project for guaranteeing congruency in height and getting so the *altimetric georeferencing*.
Once the linked file is placed in the right position inside the model, in the *Manage* tab, under the *Project Location* panel, press the *Plan View* drop-down command and click on *Publish Coordinates*. Hence, In the Drawing Area select the linked model. Finally, save the project and close.

6. Results

As explained, the thesis deals with several different disciplines, each of which brings to the realization of a specific parametric three-dimensional model.

The results obtained from the Revit modeling operation cannot be merely reduced to the final graphical appearance of the 3D virtual representation of the geometries of the opera. The other prominent result is related to the strong potential of the parametrical aspect of the model: every single element is not simply drawn, but more specifically is modeled. It means that the model is based on the relation of various components to each other, or with numbers or characteristics that are precisely defined parameters. It follows a well-structured definition of the model, made by elements grouped and organized in categories, families and types, to which a set of data is attached. Hence, every modeled element is properly named and carries on inside data about its location in the space, about the geometry, the material which it is build up, the volume occupied, eventually the costs associated, and potentially many other further information.

Looking at the internal structured data on the Revit software, it is possible to appreciate those kinds of information, whereas looking at the Revit representation area, it is possible to acknowledge the geometries of the virtual model itself, in the 3D space.

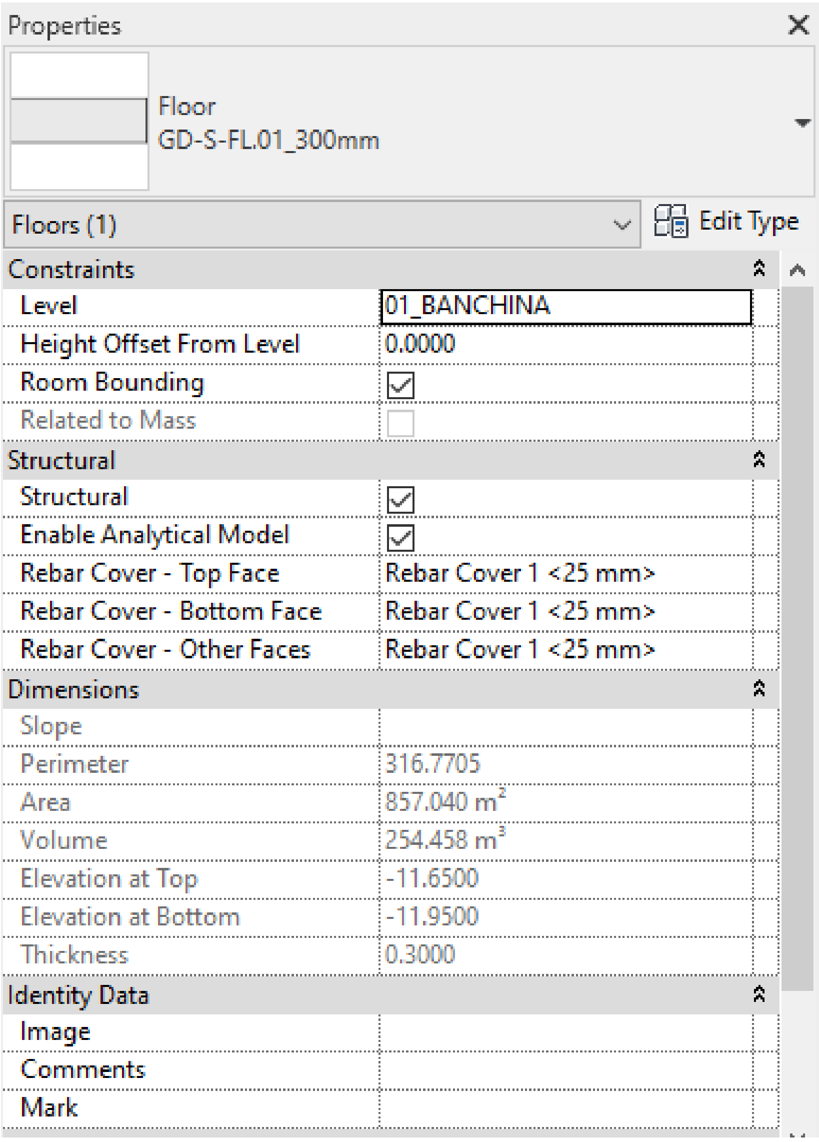


Figure 42: Properties palette (example of data associated with a floor element).

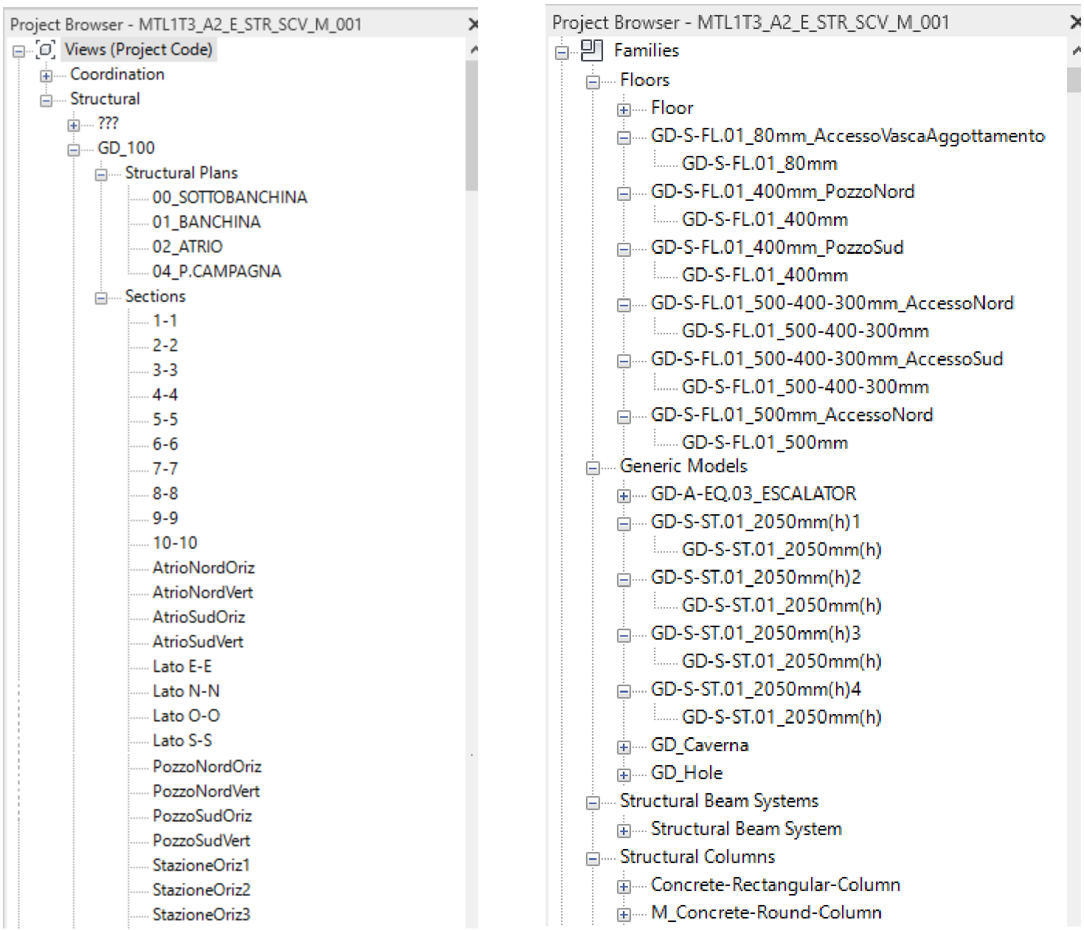


Figure 43: Project Browser (Views on the left and Families on the right).

6.1. STR models

The geometries of the case studies analyzed (already largely described in chapter 3) take form in the virtual Revit *Structural models*, examples of which are showed below.

At first, it is reported the case of the Cascine Vica subway station, together with its two accesses and its two vent shafts.

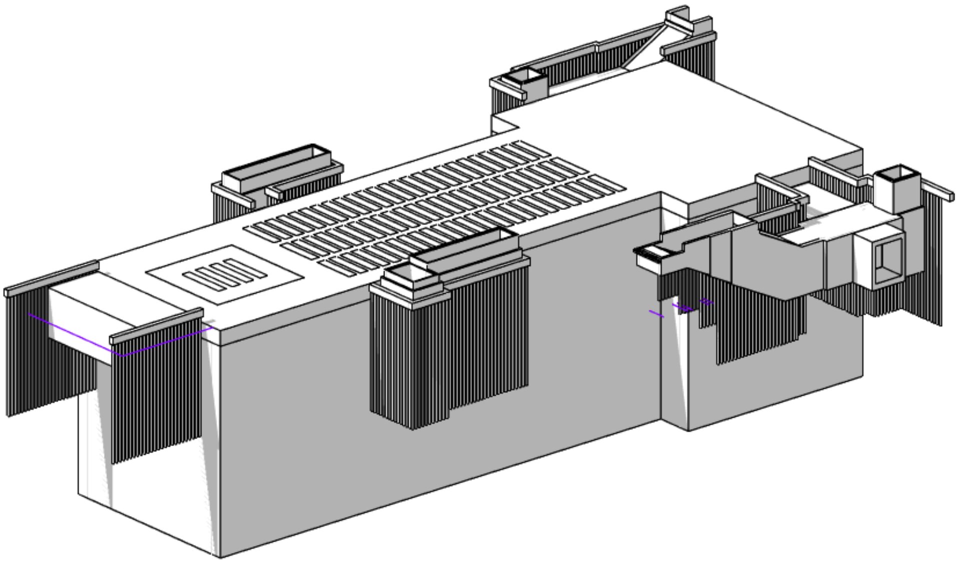


Figure 44: 3D view of the Cascine Vica subway station STR model.

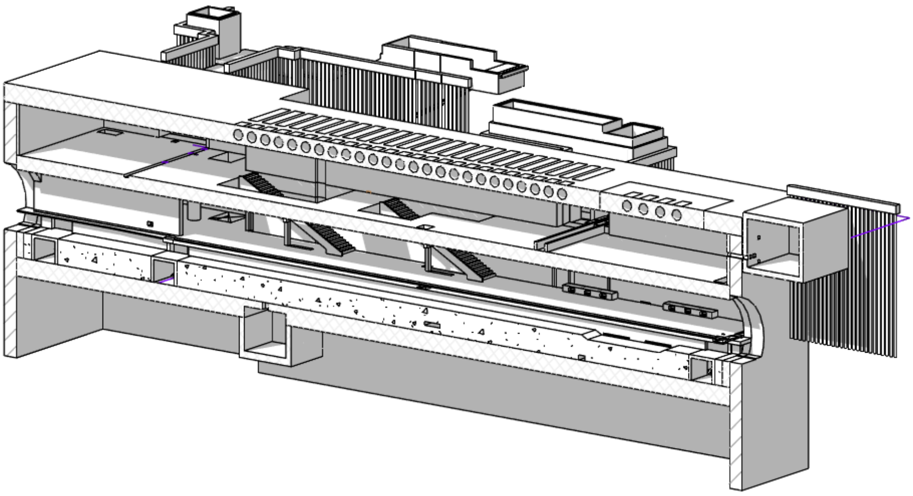


Figure 45: 3D cutaway view of the Cascine Vica subway station STR model.

Thereafter, also the structural models of the two inter-section wells PC3 and PC4 are shown.

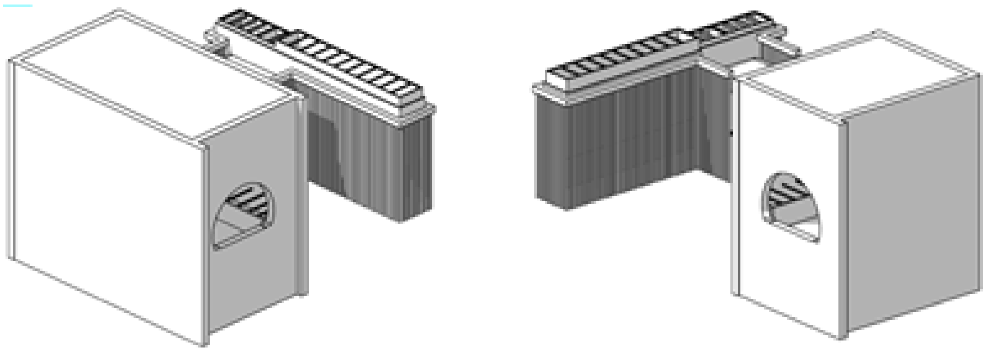


Figure 46: 3D views of the PC3 (left) and PC4 (right) vent shaft STR models.

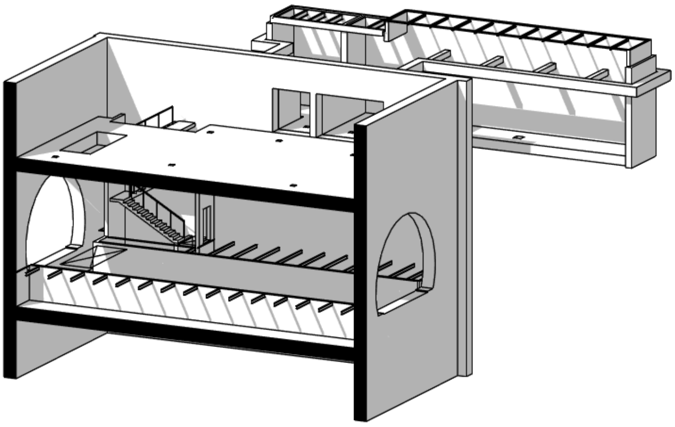


Figure 47: 3D view and cutaway of the PC3 vent shaft STR model.

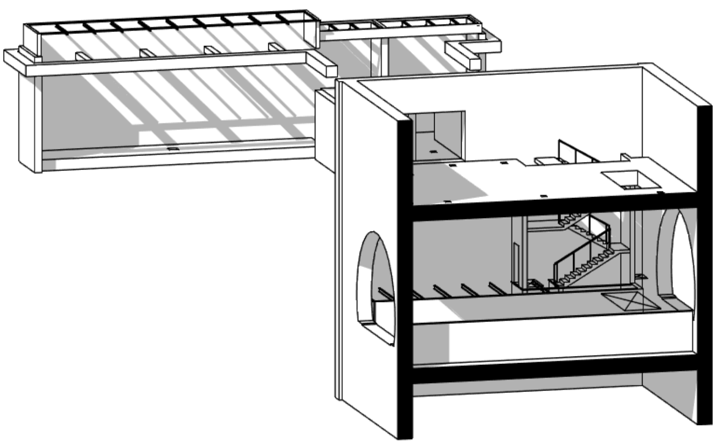


Figure 48: 3D view and cutaway of the PC4 vent shaft STR model.

6.2. FUN models

Functional models include non-bearing partition walls, concrete refill elements, reinforced concrete cage for electrical equipment, floating floor, doors, parapet railings (for stairs, railway platform and cavaedium), vertical ladders, landing grids and access floor hatch grids.

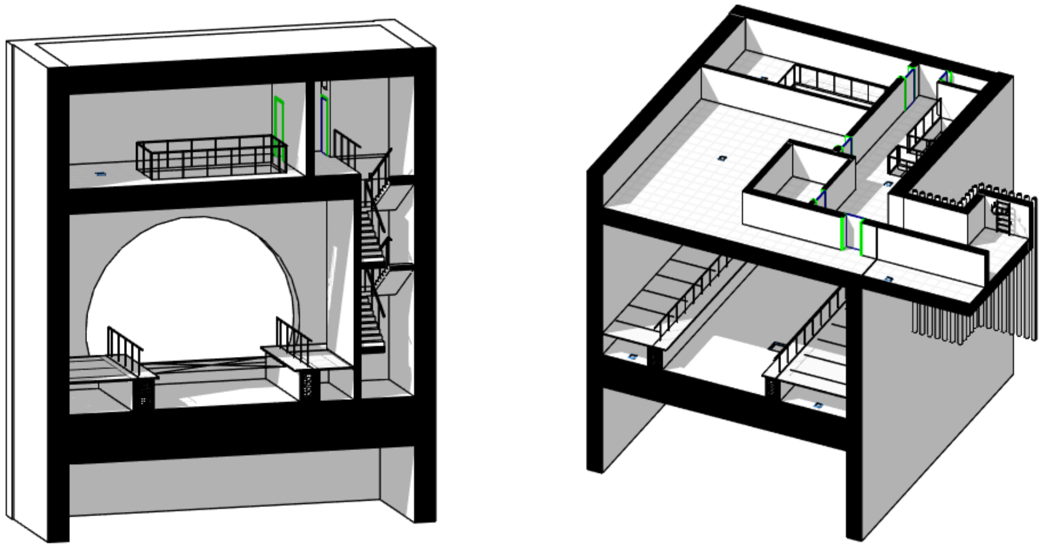


Figure 49: 3D cutaway views of the PC3 vent shaft FUN model.

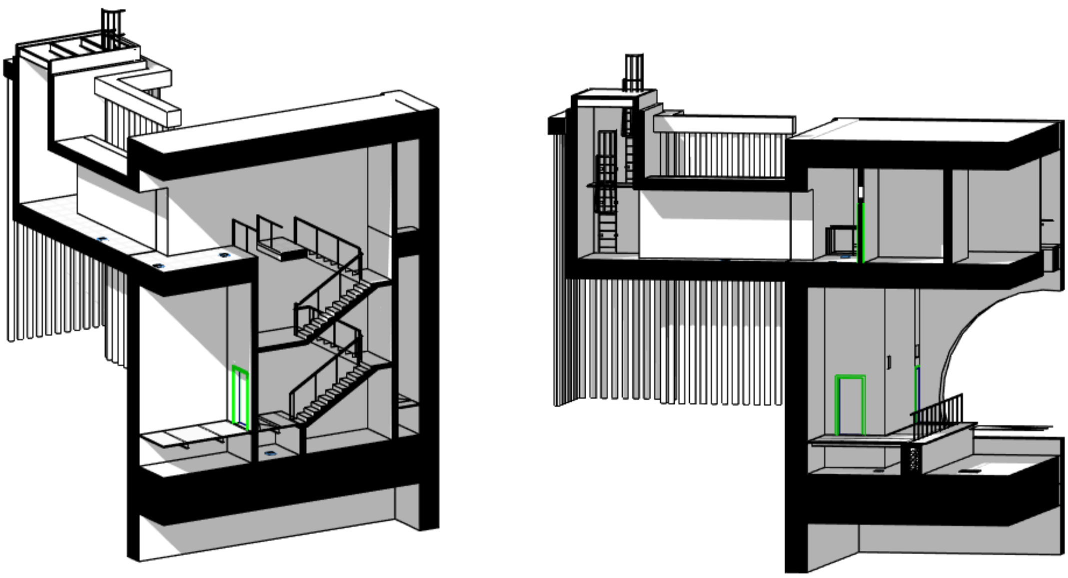


Figure 50: 3D cutaway views of the PC4 vent shaft FUN model.

6.3. IVC models

For both the vent shafts, *Ventilation and Air Conditioning system models* include electric fans (in green), dampers with actuators (in orange), and sound-absorbing silencers for ventilation systems (in red). They all place all into the technical rooms of the PIANO SOLETTONE TECNICO storey.

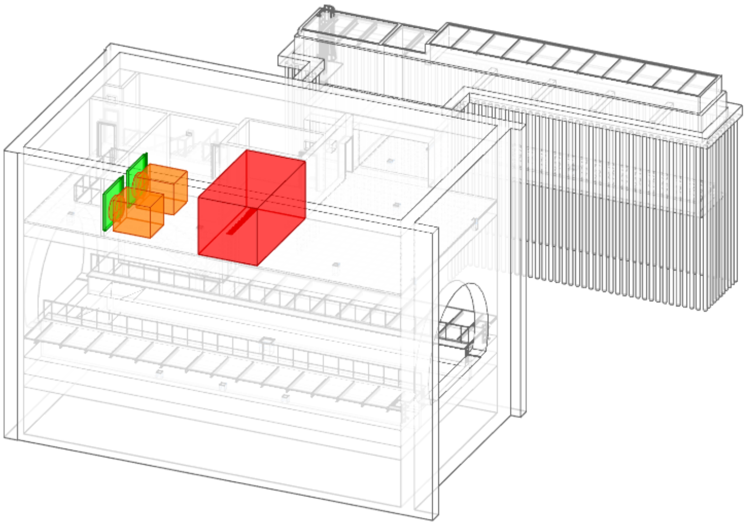


Figure 51: 3D view of the PC3 vent shaft IVC model.

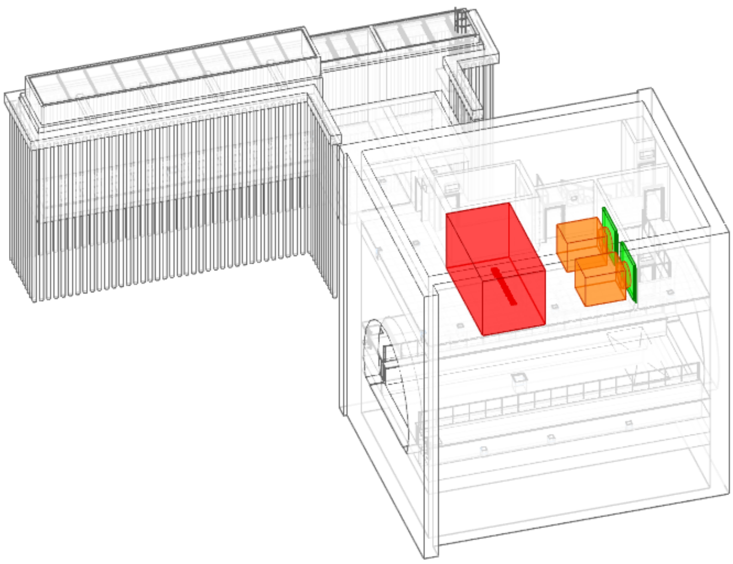


Figure 52: 3D view of the PC4 vent shaft IVC model.

6.4. IIA models

The two *Fire protection & Water-sanitation facilities system models* contain two fire extinguishers (in red), a mechanical equipment box (in orange), a water catchment piping system (in cyan), and a plumbing system (in blue).

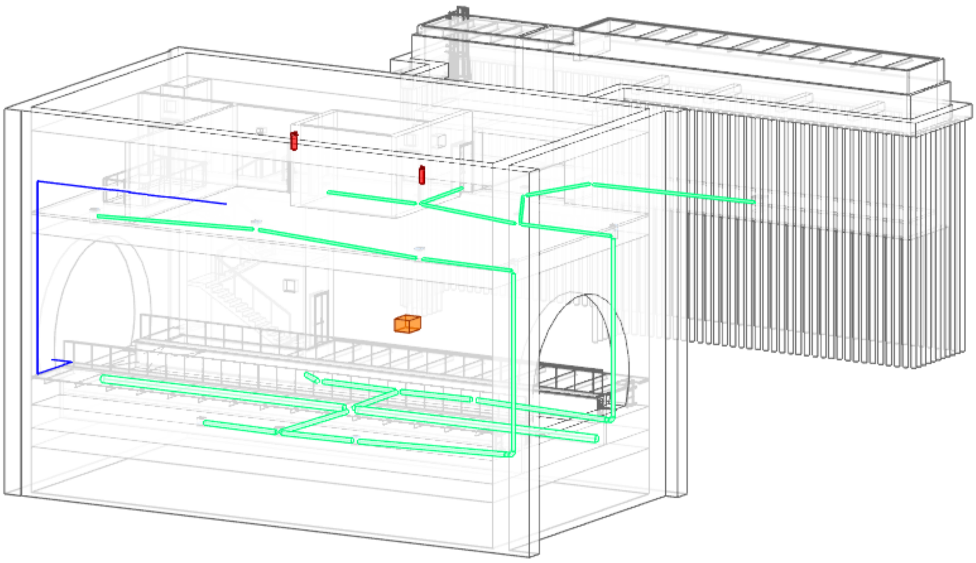


Figure 53: 3D view of the PC3 vent shaft IIA model.

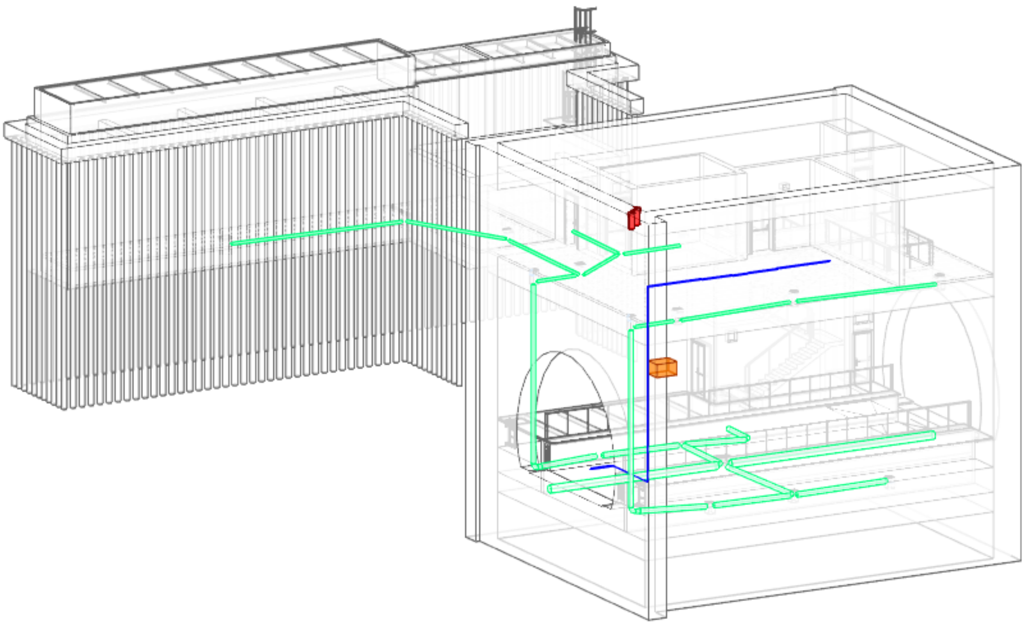


Figure 54: 3D view of the PC4 vent shaft IIA model.

6.5. IEL models

The *Electrical systems models* of the two examined vent wells include lighting fixtures with the corresponding control switches (in yellow), galvanized steel cable trays with conduits (in red and blue) and various electrical equipment (in orange), including control units and detection panels for accesses, lights, fans, water catchment and firefighting.

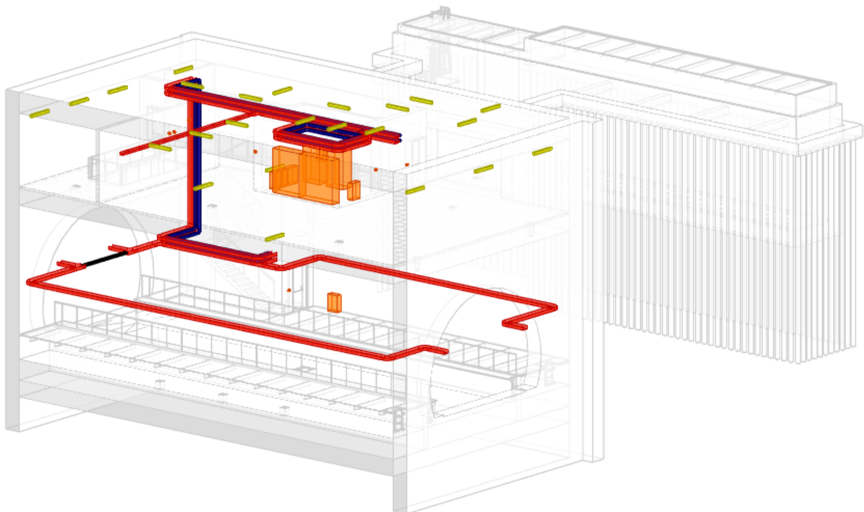


Figure 55: 3D view of the PC3 vent shaft IEL model.

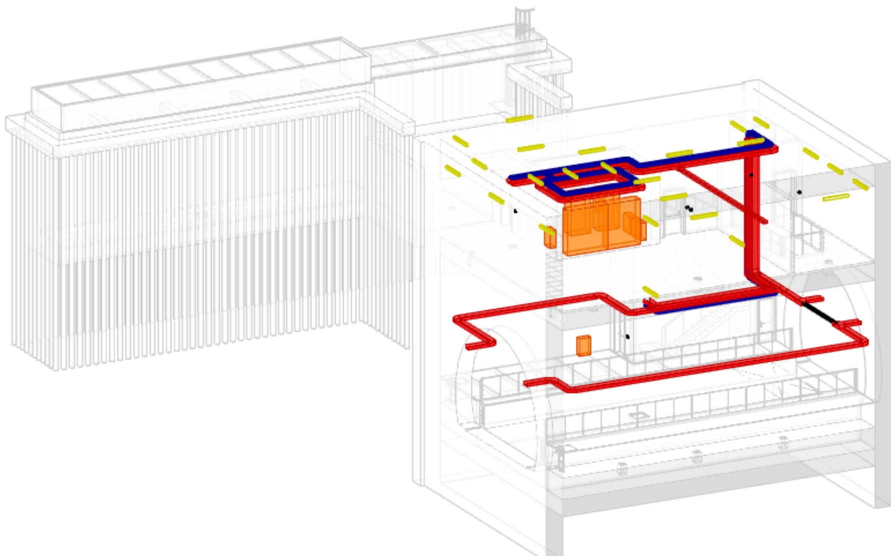


Figure 56: 3D view of the PC4 vent shaft IEL model.

7. Conclusions

With the rising adoption of the Building Information Model (BIM) for asset management within the architecture, engineering, construction, and owner-operated sectors, research and practice in this field have been increasingly attracting more attention.

In particular, this thesis represents the attempt to implement a complete smart parametric model, able to manage the real cases of some facilities belonging to the subway line infrastructure. The experience with BIM methodology permitted to perform the modeling process from the beginning, starting just from the data of the project provided by designers, in the form of technical drawings and reports.

The Revit software used is complex and it needs time to have to practice with its tools. Nevertheless, once the modeler becomes confident, he immediately takes awareness about the very high potential of this technology, especially in comparison with the more common and older AutoCAD software approach.

The current generations of designers, modelers, and more in general users, have had the valuable possibility to have used both the methodologies (and so the corresponding software). This allows actually understanding the differences between the methods and also gives awareness of their limits.

Despite the heavy and long initial setting phase of the problem setup, as the model is going to be built, the modeler will understand the efficiency of this way of operating: the result will be a well-structured parametric model, which will make simpler also the working life of all other users.

7.1. Advantages

The present work carried out represents a practical application aimed at highlighting the large benefits of BIM processes and tools, besides some criticalities (that are treated in the following paragraph about future developments). Among the advantages, it was possible to demonstrate and acknowledge many of the strengths studied:

- BIM provides a faster solution to generate and process the integration of information in a shared environment. Practically, it can strongly simplify the sharing of data among colleagues involved in the same working process.
- It translates into the opportunity to have all the information about a facility essentially in one place so that anyone who requires data can easily tap them. [20]
- One direct consequence is the promotion of cooperation among working parties and the improvement of the viewing of the project for various stakeholders. It brings to a reduction of errors during the pre-construction and construction stages, through better visualization for staff training [16]
- Moreover, it is quite intuitive to understand how this effective communication, cooperation, and management mode would be a close linkage between people and processes. [17]
- BIM gives the possibility of using models created by all participants to the building process, at different times and for different purposes. This is the reason for which it is possible to speak about a shared digital representation, founded on open standards for interoperability. [5, 20]
- BIM ensures that the quality of the information is protected from its creation through its sharing and use: only properly authorized people can get access, and only to that subset of the information to which they should have access. [20]
- LOD specification improves communication between contractors and helps the designer identify when something is worth being modeled and when becomes a time

waste. Following the indications of the customer (who required a LOD C, in the present study case), the modeler knows what eventually let outside the model, on the basis of the already mentioned legislations.

- as the modeler works, he progressively understands the future use of the information that is going to insert and develop. It is a fundamental aspect of a successful BIM implementation, also regarding future tasks, quality control issues, and methods to develop the model with respect to the interoperability with other different software. [20]
- BIM guarantees quality and efficiency throughout the entire building lifecycle in the creation, updating, managing, derivation, and communication of information among stakeholders at various levels. [20]
- Specifying the parameters that will be used helps the designers to avoid information inconsistencies and consequently, it eases the hard work of a possible changing of the parameter values.
- The model is a digital representation of the physical and functional characteristics of a facility, and not only a simple three-dimensional geometrical representation. For this reason, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions. It is possible to practically think about possible problems encountered during the execution phase of the works, or future changes, for which it should be necessary to redesign some functional and MEP systems or reinforce and extends some structural elements.
- So, every important aspect can be readily captured, stored, researched, and recalled as needed to support real property acquisition and management, occupancy, operations, remodeling, new construction, and analytics.
- Since it is an object-oriented, intelligent, and parametric digital representation of the facility, it is possible to quickly extract and analyze views and data appropriate to various users' needs. The parametrization allows performing quite easily updates

about information attached to the modeled elements and also geometric variations of the model itself.

As a counterpoint of all these advantages which create many opportunities for improved efficiency, data aggregation can lead to significant risks, which should be wisely managed.

Moreover, 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 about making an investment not only in training personal but also in technology. [20]

7.2. Future development

The development of BIM use should touch the areas of representation, performance simulation, transaction and exchange, documentation, automation, standardization, and guidance. So, the need is to promote research and practice towards developing and testing new strategies to address deficiencies relating to functional, informational, technical, and organizational issues. [19]

A purpose for the future is represented by the development of smart asset management able to integrates artificial intelligence, machine learning, and data analytics. It has the aim to create dynamic digital models that are able to learn and update the status of the physical counterpart from multiple sources. [4, 18]

More concretely, thinking about the present work faced within this thesis, future developments should surely consist in solving interferences between different models (for example between MEP models and functional/structural models), in improving both the horizontal and vertical interoperability between software (limiting the loss of data), in promoting optimizations of the overall existing tool of the BIM, and in evolving the visualization and navigability of the model (throughout the advanced tools of virtual reality).

It is possible to embody all the mentioned topics about future enhancements, improving and extending the dimensions of the BIM:

- 4D analysis, which proposes a new approach for conflict and dynamic safety analysis during construction. It is mainly linked to *scheduling* and is accomplished through construction simulation, construction management, and dynamic collision detection of site facilities. [12]
- 5D analysis, which is grounded on the identification of project financing scenarios and in the analysis of the cash flow (estimated cash inflow, and cash outflow patterns for equipment, manpower, and materials). Those tools are mainly linked to *estimating* and are fundamental support for making appropriate decisions for different designs, for considering payment scheme alternatives, and in general for managing construction projects, also for maintenance. [13]
- 6D analysis, which provides an insight into the relevant dynamic information about intervals and costs, for the execution of maintenance works, condition monitoring, and real-time structural simulations, in the whole building lifecycle asset management. It is mainly related to *sustainability* and is useful for reducing errors during the pre-construction and construction stages and for promoting efficient asset and project management. [14]
- 7D analysis, through which it is possible to control many performance parameters of a building, looking into a series of solutions based on the place in which it is set, within the whole sustainable design process. It is mostly connected to *facility management applications* and one of its possible developments could be represented by the navigability of the model by means of virtual reality. [6, 15]

Additionally, a further focus should be done on when it becomes necessary to share or pass a bundle of information to another organization, which may or may not be using the same tools, or to move it on to another phase of work. It should be possible to safely and almost instantaneously (through a computer-to-computer communication) share or move just the right bundle of information without loss or error and without giving up appropriate control.

A focus on the interaction and impact of a smart asset with diverse stakeholders (including customers and the general public) needs to be better understood. [18]

Lastly, it is possible to imagine the attempt to extend the smart asset management at building/infrastructure to city-level development.

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