POLITECNICO DI MILANO

Master in

Building Information Modelling

Advance MEP Modelling
MEP BIM modelling with advanced third-party software
Integration towards Cost Definition and Quantity Take Off

Supervisor:
Claudio Mirachi PhD MSc Eng. – Polimi

In-Company Tutors
Giuseppe Medeghini MSc Eng.
Sigfrido Macchi Eng.

Author:

TUBI Otitooluwa

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SOMMARIO

La tesi prevede la creazione di un modello BIM avanzato e la sua integrazione con software di terze parti che consentirà i calcoli MEP e la mappatura QTO (tramite Teamsystem) nel quadro di una situazione reale per ottenere un risultato che consideri le condizioni incerte e i vincoli di un contesto reale. progetto mondiale. Il progetto live è un grattacielo residenziale di 18 piani (3 interrati) sviluppato privatamente nel cuore di Milano.

Il progetto crea un modello integrato che risponde ai seguenti obiettivi dettagliati:

- Integrare i calcoli MEP basati sullo sviluppo del modello BIM per ottimizzare il processo di progettazione e creare un ambiente di progettazione dinamico.

- Collegare il modello BIM al calcolo per creare un modello 5D integrato considerando sia il "quantity take off" (QTO) che la definizione dei costi per i sistemi MEP.

Il lavoro di tesi considera sia la dimensione procedurale che identifica quali sono i requisiti informativi per soddisfare gli obiettivi sopra menzionati, sia la dimensione pratica che applicherà i processi e i requisiti proposti in un caso di studio reale modellando tutti gli elementi richiesti e sviluppando i componenti richiesti (modellazione, calcoli, QTO, calcolo dei costi, ecc.).

Parole chiave: (Modellazione 5D, Modellazione avanzata, Definizione dei costi, MEP, MVD)

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ABSTRACT

The thesis explored the creation of an advance BIM model and its integration with third-party software that will allow MEP calculations and QTO mapping (via Teamsystem) within the framework of a live situation to achieve a result that considers the uncertain conditions and constraints of a real-world project. The live project is a privately developed 18 storey (3 Basement) high rise residential apartment building in the heart of Milan.

The dissertation project created an integrated model answering to the following detailed objectives:

- Integrate MEP calculations based on the BIM model development to optimize the design process and create a dynamic designing environment.

- Link the BIM model to the computation to create an integrated 5D model considering both "quantity take off" (QTO) and cost definition for the MEP systems.

The thesis work considers both the procedural dimension identifying what are the information requirements to satisfy the above-mentioned objectives and the practical dimension that will apply the proposed processes and requirements in a real-world case study modelling all the required elements and developing the required components (modelling, calculations, QTO, cost calculation, etc.).

Keywords: (5D Modelling, Advance Modelling, Cost Definition, MEP Design, MVD)

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1. INTRODUCTION

1.1. Research Problem Statement

The construction sector is already using Building Information Modelling (BIM), a first step in the digital transformation of the sector. During the COVID-19 lockdown, BIM was more widely adopted in the industry. (Fanyu Lin, 2020). However, there is still a huge productivity set back when it comes to workflow that deliver information requirements in our projects. The remarkable progress in technology has also created a fracture process, multiple software vendors with closed ecosystem ensures very little interoperability between software performing similar or complimenting function. This often resulting to loss of modelled information or rework of already modelled information. bSI has done a lot with IFC to bridge the gap with interoperability by creating MVDs and improvement on classification of objects and certification of vendors for compliance.

However, the process still requires a lot of technicalities leaving the need to define and redefine workflows for interoperability and Information modelling. This thesis will focus that challenge within the framework of the process leading to QTO.

1.2. Objectives

The aim of this dissertation is to develop an integrated model answering to the following detailed objectives:

- Integrate MEP calculations based on the BIM model development to optimize the design process and create a dynamic designing environment.

- Link the BIM model to the computation to create an integrated 5D model considering both quantities take off (QTO) and cost definition for the MEP systems.

The thesis work will consider both the procedural dimension identifying what are the information requirements to satisfy the above-mentioned objectives and the practical dimension that will apply the proposed processes and requirements in a real-world case study modelling all the required elements and developing the required components (modelling, calculations, QTO, cost calculation, etc.).

1.3. Research Methodology

This thesis project examines the QTO through the interoperability between software used for MEP calculation, modelling and Quantity take off. A live project commission of an MEP Consulting Service firm (Rethink Energy Srl), engaged to produce MEP and Energy Design Services for a privately developed 18 Storey (3 Basement) Apartment building in Milan. In order to guide the research process, a literature review of the main concepts that impact the research topic would be explored to provide a frame for the procedure to execute this project. Some of the issues to be considered in the literature review include the following.

- ISO 19650 Information Requirements

- MEP BIM modelling workflow
- IFC and Model view definition for geometrical data exchange
- Work Breakdown Structure, and
- Price List

The second phase of this methodology involves developing a conceptual framework for developing the Live project. The choice of Software also influenced by BEP, ensuring the fidelity and consistency of modelled information from calculations through to the QTO and the requirements for information exchange between each stage of the design.

The final stage is the execution of the proposed concept. The process of calculation, modelling, transfer of data to QTO software and take off itself would be documented, with sample data from each activity to validate or otherwise the concept proposal. The software used in the process would be examined, and there would be highlights on how interoperability and data fidelity was achieved between platforms. Where there are limitations due to specific real-life constraint derived from working on a live project, this would be expressed to redefine the framework of the research. AT the completion of the research process, lessons learnt, and improvements achieved would be share along with challenges and fields that require further research.

1.4.   Dissertation Structure
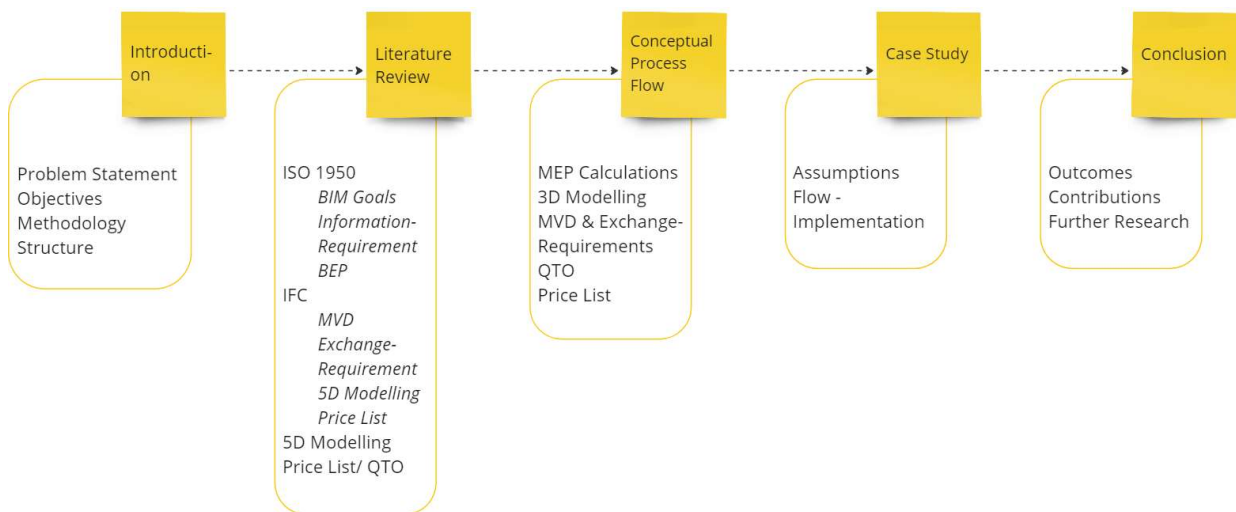
Figure 1: Dissertation Structure Overview.

This research is divided into 5 chapters (figure: 1), the first chapter introduces the reader to the need for this research, exploring the current issues at the time of study with BIM workflow integration in relation to MEP QTO, then it goes on to state the goal of the project and how this would be achieved through an outline methodology. Chapter two explores the study of the body of knowledge related to the thesis subject, ISO 19650 and its provision for Information requirement which sets the frame for any project under the BIM workflow, it also looks at IFC as a means of OpenBIM platform-agnostic exchange of modelled information, pricelist and the state of the art on 5D modelling itself.

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The Chapter on "Conceptual Process Flow" takes learning from all the literature review and the real-life project constraints like BEP and other project definitions and design a Process flow for implementing the objective of this thesis. It would refer to software, input documents like price list and BEP, the procedures to be undertaken under each of the five process sub-headings (MEP calculations, 3D Modelling, MVD and Exchange Requirements, and Quantity Take Off). The outlined framework in chapter 3 then provides a segway into the Chapter on Case Study, this is the section of the research that implements all framework defined while identifying the ongoing constraint and peculiarities of the live project and refocusing the research to deliver on the thesis objectives.

Finally, we would examine in chapter 5, the outcomes of the research, and its contributions to the body of works regarding MEP QTO while providing recommendations for further studies.

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2. LITRATURE REVIEW

2.1 Introduction

The success of a digital implementation is the ability to integrate the elements that make up the solution seamlessly. The same is true of BIM workflow implementation in MEP Design. The gaol is to produce data through the MEP design process that provides efficiently designed solution through calculations, information modelling, design coordination with other disciplines, value engineering and the production of Quantity take off for bidding and execution.

This chapter is focused on the review of literature and related to the subject of this dissertation, also to establish some framework on progress that has been made in the industry, some general definitions, workflows and practices related to Advance MEP modelling for quantity take off and cost definition.

2.2 ISO19650

The ISO 19650 standard is an international standard for managing information over the whole life cycle of a built asset using building information modelling (BIM) (BSI, 2023) This is achieved through setting an internationally recognised best practice for the creation, collaboration, and management of asset information, ISO 19650 benefits all stakeholders throughout the asset lifecycle, including clients, consultants, contractors, authorities & asset owners, and operators.. (McPherson, 2023). McPherson further listed the basic principles of ISO 19650 as follows:

- The client clearly defines project requirements, standards & milestones and communicates these to the delivery team.
- The delivery team plans a schedule and mobilises resources and technology to meet the client's requirements, standards & milestones.
- Information is collaboratively produced and managed between task teams (i.e., across disciplines).
- Information is managed in a common data environment (CDE) ensuring the right people work on the right information at the right time.
- Information produced is reviewed and approved at each level (task team, delivery team, project team), with access and sharing controlled accordingly.
- Information is created and archived with the ongoing operation and maintenance of the asset in mind.
- Ultimately, it ensures that built environment projects are delivered on time, within budget and to standard.

According to The International Standard Organisation (ISO)The six standards of ISO 19650 are outlined below:

ISO 19650-1: Organization and digitization of information about buildings and civil engineering works, including building information modelling -- Information management using building information modelling: Concepts and principles.

ISO 19650-2: Organization and digitization of information about buildings and civil engineering works, including building information modelling -- Information management using building information modelling: Delivery phase of the assets.

ISO 19650-3:2020 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling. Operational phase of the assets.

ISO 19650-4:2022 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling - Information exchange.

ISO 19650-5:2020: Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM). Information management using building information modelling. Security-minded approach to information management.

For successful BIM implementation, it is important to define clearly the goal of BIM activation. The definition starts from the project initiator (client) who identifies the needs and requirements of its organisation. This defines the participation of other individuals in the project and the nature of the information they produce. This ensures that all stakeholders have the same understanding of the anticipated outcomes. Goals need to be clearly defined and adapted to the specific organisational and project circumstances. To achieve the objectives, it is helpful to think about "BIM use cases," which focus on specific processes (both for construction and in operation), and the intended benefits BIM can deliver. From an operational perspective to be successful requires delivery and operational teams review specific operational processes to help clearly define how the use cases can help achieve specific operational, tactical and strategic goals. (Ashworth S., 2022).

Figure 2 : BIM Goals Map

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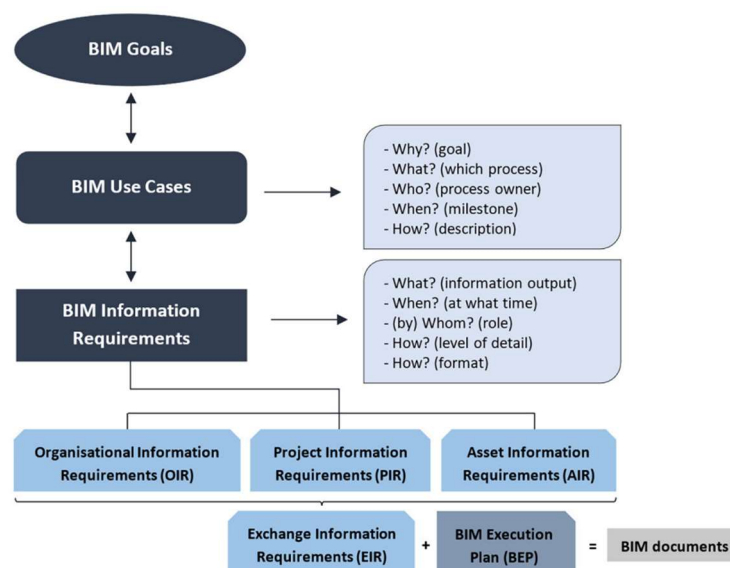
2.2.1. Information Requirements

ISO 19650-1 (Concept and Principles) defines information requirements as "specify for what, when, how and for whom information is to be produced" (ISO, 2018). But before all this, the appointing party must first establish the project's Information Manager(s). The Information Manager is one or more individuals from within their organisation or from a third party who leads the information management function for the project. (McPherson, 2023). With the information manager(s) now selected, the appointing party can now define the project's information framework.

ISO defines the information requirements into four unique activities:

2.2.1.1. Organisational information requirements (OIR)

"Explain the information needed to answer or inform high-level strategic objectives within the appointing party. These requirements can arise for a variety of reasons, including strategic business operation, strategic asset management, portfolio planning, regulatory duties or policymaking." This ensures appropriate information exchange for the organisation to meets the identified business case, the OIR is the kick off point for determining information requirement.

2.2.1.2. Project information requirements (PIR)

"Explain the information needed to answer or inform high-level strategic objectives within the appointing party in relation to a particular built asset project. A set of information requirements should be prepared for each of the appointing party's key decision points during the project." The key decision points in a Municipality Housing project for example may be Conceptual Design, Construction Budget etc.

2.2.1.3. Asset information requirements (AIR)

"Sets out managerial, commercial, and technical aspects of producing asset information. The managerial and commercial aspects should include the information standard and the production methods and procedures to be implemented by the delivery team. [...] A set of AIR should be prepared in response to each trigger event during asset operation and where appropriate should also refer to security requirements." The information required in the operation and maintenance of an asset throughout its lifecycle and how it should be delivered.

2.2.1.4. Exchange information requirements (EIR)

"Set out managerial, commercial, and technical aspects of producing project information. The managerial and commercial aspects should include the information standard and the production methods and procedures to be implemented by the delivery team." EIR are collectively defined from the OIR, PIR and AIR, and are developed per appointment. The appointing party sets EIR for their appointment with the lead appointed party, and the lead appointed party sets their own EIR for each appointment with their appointed parties. (McPherson, 2023) .
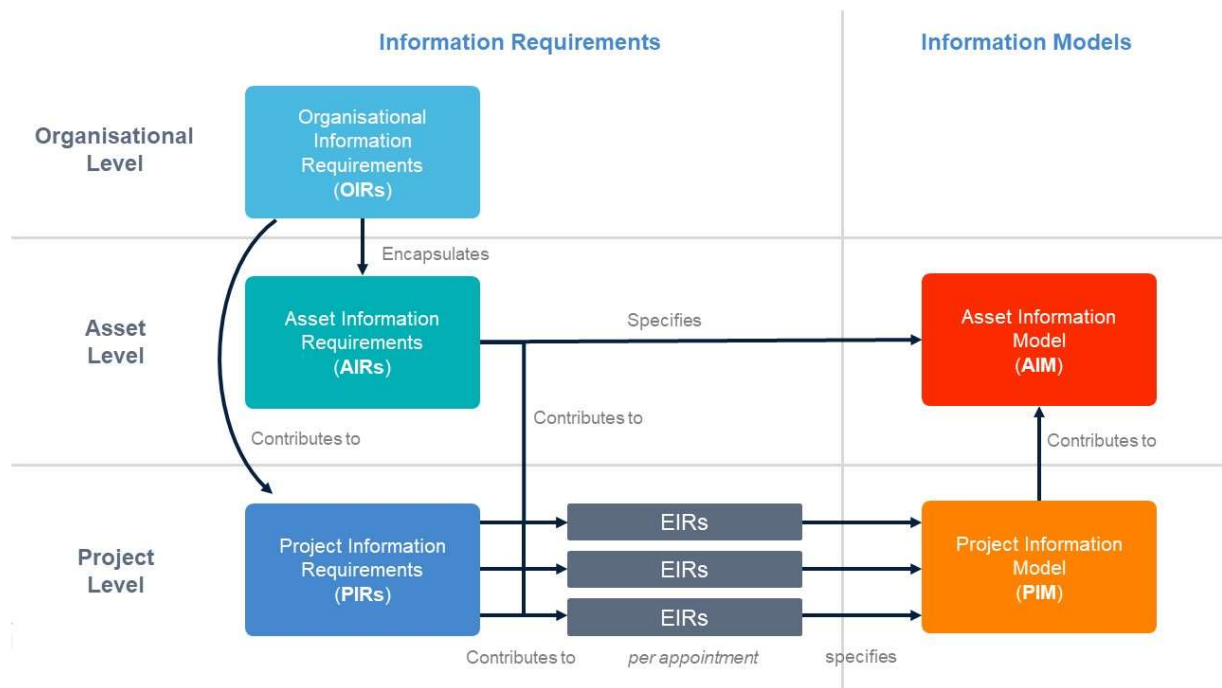
Figure 3: Flow of Information Requirements and Information Model Diagram (Source: Mitch McPherson)

2.2.2. BIM Execution Plan

A BIM Execution Plan is a response to EIR prepared by the appointing party, it is a document/resource that outlines how a project team (appointed parties) will use BIM workflows, tools, and techniques to achieve the desired project outcomes. It includes details such as the roles and responsibilities of those involved, the timeline for the project, and the deliverables that will be produced. It can also include information on the BIM quality management system to be used and the software and hardware that will be required (Plannerly, 2023) BIM Execution Plan (BEP) creates the framework within which the goals set for the project would be achieved. It is also a living document that should be developed by the project BIM manager and refined throughout the project's life cycle. (Talaat, 2019)

The development of a BEP is guided by the international standard ISO19650 which is "an international standard for managing information over the whole life cycle of a built asset using Building Information Modelling (BIM)" (BSI, 2023) as a response to Exchange Information Requirement (EIR) created by the appointing party, a document containing "the information that is needed to be delivered by a lead appointed party or by an appointed party at each information exchange (BSI, 2021) which is part of a list of information requirements originating from the procuring client or organisation (fig 1).
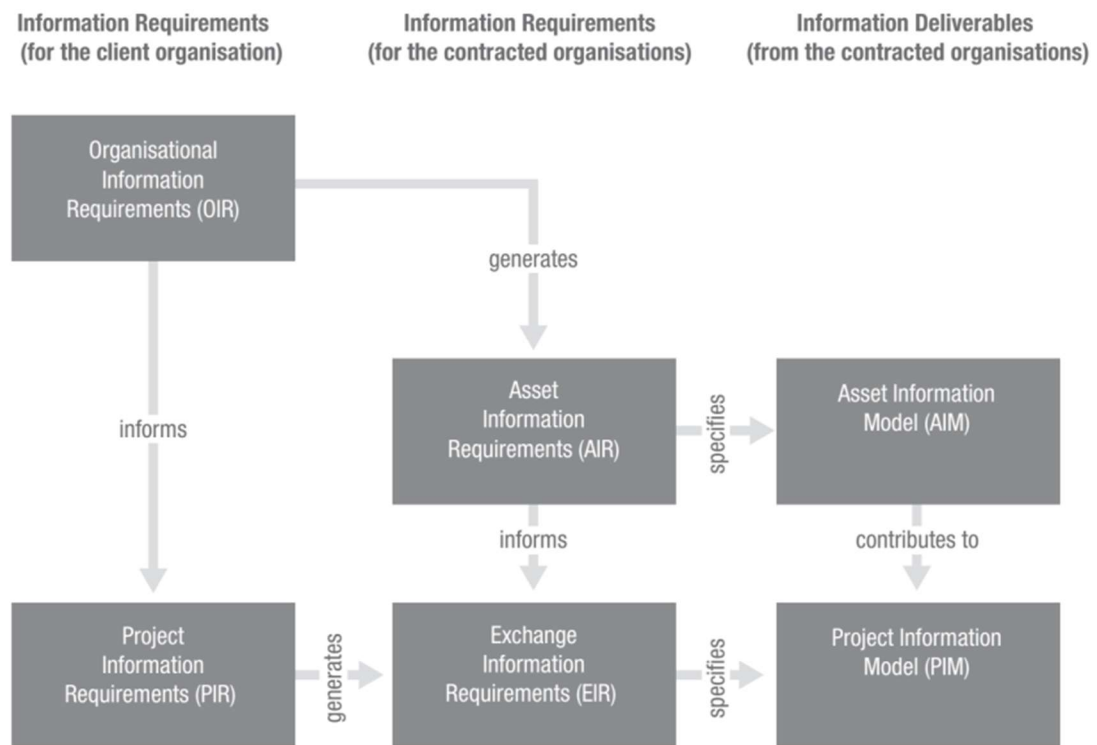
Figure 4: Client Originating Information requirement for Project Procurement. Source: Mark Baldwin (The BIM Manager:A Practical guide for BIM Project Management) 2019

2.2.2.1. Components of a BEP

A successful BEP specifies the roles and responsibility of each member of the team including approving parties and process. Key deliverables with their milestones and critical input requirements, collaboration process and responsibility matrix for issues like clash detection and resolution. Under the Information delivery, the responsibility matrix protocols and procedure for delivering information that meets client information requirement is also defined.

Along the lines of information production, technical details like naming convention, annotation and abbreviation standards, tolerance, version control, exchange format and data management should be specified.

2.2.2.1.1. *Project Summary and Key contacts:*

This refers to the information about the project (location, client, and timelines), scope, and key persons contact from key roles on the project. This may refer to contact of key person for each discipline, client, contractor, vendors, subcontractor etc.

2.2.2.1.2.   *BIM Goals and Objectives*

This section should document the strategic value and specific uses for BIM on the project as defined by the project team in the initial step of the planning procedure. (Computer Integration Construction Research, 2021). This also include the BIM uses throughout the lifecycle of the building (planning, design, construction operation and end of life). Listed objectives are project specific and tries to improve the life cycle performance in areas relating to reducing/ keeping project on schedule through project progress

tracking with 4D and 5D simulations, effective cost management (efficient design process, value engineering, automated quantity take off, seamless building data transfer to facilities, etc), quality control (energy efficiency modelling, quality design documentation, effective coordination system, etc).
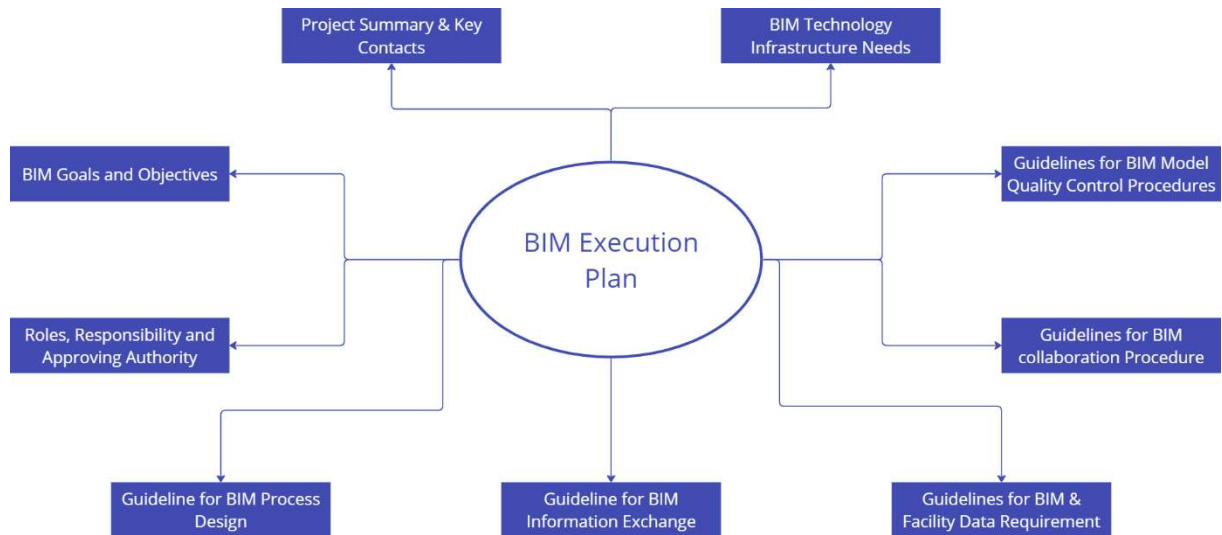
Figure 5: Components of a BIM Execution Plan (Based on the Penn State BIM Project Execution Guide).

2.2.2.1.3.   *Roles, Responsibilities and Approving Authority*

This involves the definition of individual roles and what task and deliverables they would undertake. Also, where approvals are required, it should be clearly stated who would grant such request and how the communication would be executed. Within this category, the skills required for each player has to be evaluated against required BIM use, to be certain that the players are competent to execute the role and plan skills upgrade in deficient areas.

2.2.2.1.4.   *Guidelines for BIM Process Design*

Using the previously defined BIM uses, the process Map identifies the various task, flows and approvals to be performed within the model use to achieve the goal. The information included within the process design should cover resources required to perform the BIM uses, a sequence of task or activities required to achieve the BIM uses and the deliverables from the process which makes up Information exchange.

2.2.2.1.5.   *Guidelines for BIM Information Exchange*

This defines the properties of the data exchange usually between responsible parties but also with a discipline. The information exchange is defined by file format, structure of data, version control, and would vary at each BIM use. It is also important to define exchange date and flows that lead up to the exchange so delays can be flagged early.

2.2.2.1.6.   *Guidelines for BIM and Facility Data Requirements*

This document from the owner expresses the requirements of the client during the operation of the building. This may include uses for energy management, maintenance and repairs, occupancy, water and

waste management. This information defines the content of the Information exchange at the operation phase of the project.

2.2.2.1.7.   Guidelines for BIM Collaboration Procedure

Activities that support interactions and management for Information modelling amongst responsible parties. This includes, clash detection and resolution, federation, common data environment, file organisation, project standards etc.

2.2.2.1.8.   BIM Quality Control Procedure

Setting out of activities that maintains the intended quality of project data. This includes Space programming, Design Check, Laws and regulation checks, Discipline checks, constructability checks etc.

2.2.2.1.9.   BIM Technology and Infrastructure Needs

The hardware, software and network infrastructure required to execute the plan should be defined. (Computer Integration Construction Research, 2021)

2.3   BIM MEP Modelling Workflow

BIM addresses the fragmented silos in the built industry through the collaborative practices that the workflows create. This is more critical when referring to MEP systems. As built projects get complex, and respond to technological and environmental challenges, the requirements for MEP systems and solutions are increasingly complex and demanding to manage. The traditional MEP coordination uses a process of sequentially overlaying and comparing drawings for multiple systems to detect and eliminate spatial and functional interferences among MEP systems, such multi-discipline efforts are time-consuming and expensive (Wang, Wang, Shou, & Guo, 2016)

Figure 3 shows the process flow in a design office for the modelling of MEP data towards Quantity take off, through the different stages of design. The initial inputs that kick off MEP design (Mechanical, Electrical and Plumbing) are the BIM execution Plan and the Architecture concept design model. Using the loading requirements of different spaces in the project, the engineer calculate the requirements spatial requirements for Equipment (equipment rooms, Risers, ceiling voids and raised/ underfloor services). This forms the basis of the Preliminary concept design for MEP Modelling. It should be said that the nature of information exchange and BIM uses determines the approach to the MEP modelling.

At the end of the preliminary design process, the concept proposal is reviewed with structural and Architectural development to ensure that alignment to Information exchange goals and resolve any pending conflict between the disciplines. The detailed Modelling phase refers to the modelling of all design elements, this includes riser ducts, pipes and cable trays, collector systems, and horizontal distribution systems. This stage ends with clash detection that incorporates "into the 3D MEP detail design model. At this stage, MEP designers can search unreasonable design scheme and fine-tune the clashes and issues with some optimizations and coordination based on their experience and available BIM tools in the software." (Wang, Wang, Shou, & Guo, 2016). The construction model is the final information modelling for the MEP design, it "is created based on design drawings, design specifications, construction specifications and construction expertise. In the 3D MEP construction design model, pipe insulation and permanent and temporary support structures (e.g., pipe supports and scaffoldings) will be added to the earlier design model at this stage. Then, the MEP construction model is able to identify the deviations of

structural and MEP components that can affect the realization of the MEP layout design especially in certain complex nodes." (Wang, Wang, Shou, & Guo, 2016) Each modelled object is assigned specification properties according defined Work Bread Down Structure in the Exchange Information Requirement and manufacturers information included in the price list which would aid the development of a Quantity take off that would inform the cost of construction.
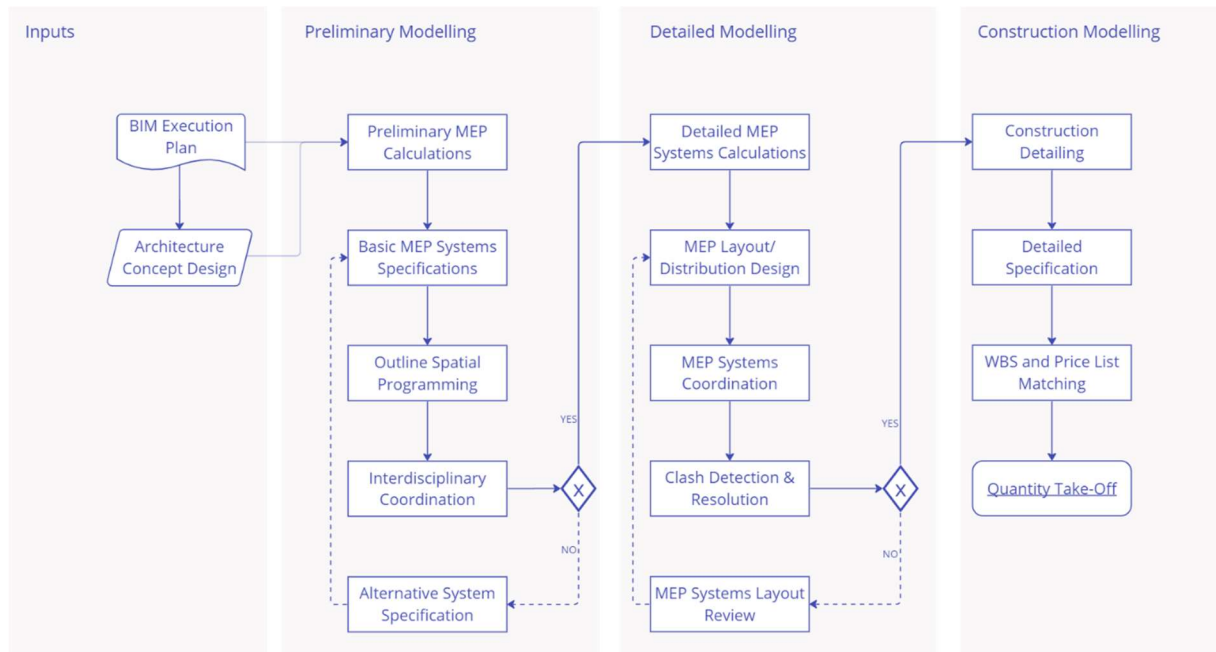
Figure 6: MEP Modelling Process Flow at Design Stage (Tubi Otitooluwa 2023)

2.4 IFC Schema for Quantity Take Off

2.4.1.   What is an IFC

IFC, or "Industry Foundation Classes", is a standardized, digital description of the built environment, including buildings and civil infrastructure. It is an open, international standard (ISO 16739-1:2018), meant to be vendor-neutral, or agnostic, and usable across a wide range of hardware devices, software platforms, and interfaces for many different use cases. More specifically, the IFC schema is a standardized data model that codifies, in a logical way, the identity and semantics (name, machine-readable unique identifier, object type or function), the characteristics or attributes (such as material, color, and thermal properties), and relationships (including locations, connections, and ownership) of objects (like columns or slabs), abstract concepts (performance, costing), processes (installation, operations), and people (owners, designers, contractors, suppliers, etc.). (buildingSMART International, 2022). The in an openBIM format which refers to "a universal approach to the collaborative design, realisation and operation of buildings, based on an open standard and workflow" (buildingSMART International, 2022)

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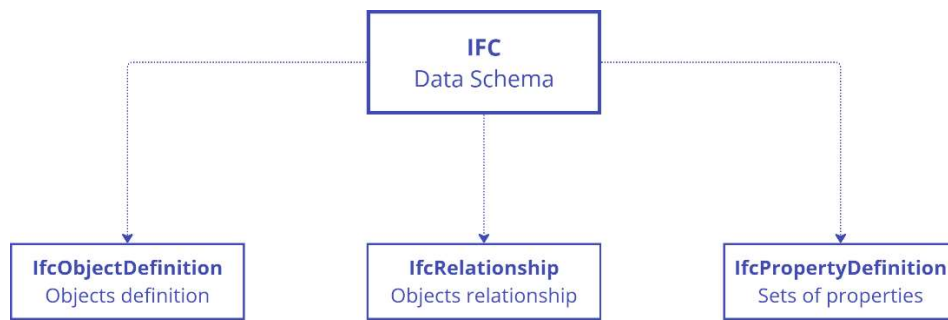
Figure 7: IFC Data Schema Entity Inheritance

The IFC defines a model integrated with hundreds of entities that are organized in a hierarchical manner (Acca, 2020). There are 3 key elements to the structure of an IFC file, which are, Object definition, Relationship and Property definition. As shown in the Figure 7: IFC Data Schema above.

2.4.1.1. IfcObjectDefinition

buildingSMART defines an IfcObjectDefinition as "the generalization of any semantically treated thing or process, either being a type or an occurrence". In other words, it defines the entities themselves. "Object definitions can be named, using the inherited *Name* attribute, which should be a user recognizable label for the object occurrence. Further explanations to the object can be given using the inherited *Description* attribute" (buildingSmartInternational, n.d.). This class contains all the useful objects to fully describe a construction asset. The word object refers to an abstract or tangible entity that represents the description of a construction part that we are digitizing. (Acca, 2020)
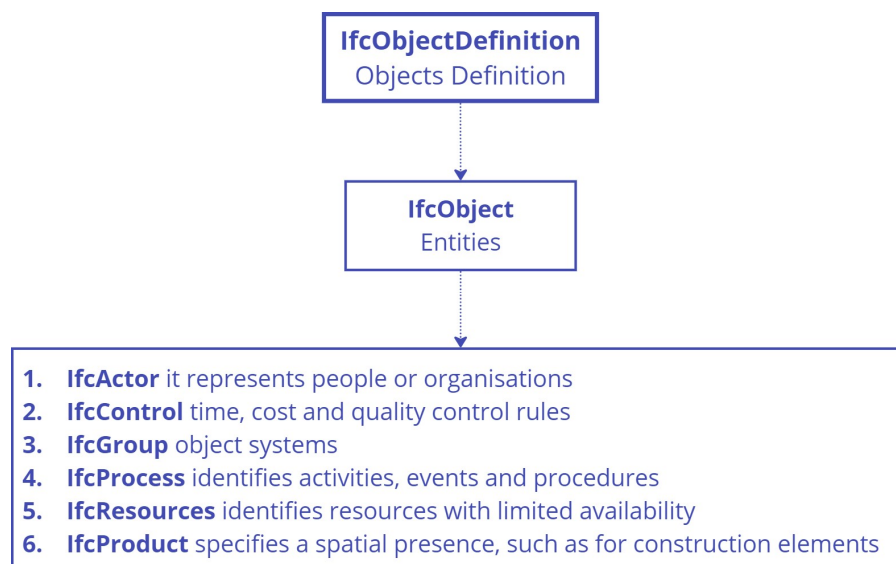
Figure 8: IFC Object Definition Entity Inheritance

The IfcObject can include:

- physically tangible objects, such as walls, beams or roofs
- physically existing objects, such as spaces or conceptual objects, like grids or virtual borders
- processes, such as work tasks and controls, like cost items, actors or people involved in the design process, etc. (Acca, 2020)

2.4.1.2. IfcRelationship

IfcRelationship is described as "the abstract generalization of all objectified relationships in IFC. Objectified relationships are the preferred way to handle relationships among objects. This allows to keep relationship specific properties directly at the relationship and opens the possibility to later handle relationship specific behaviours". (BuildingSmartInternational, n.d.). Figure 6 shows each type of relationship and the progressive relationships available withing each division.
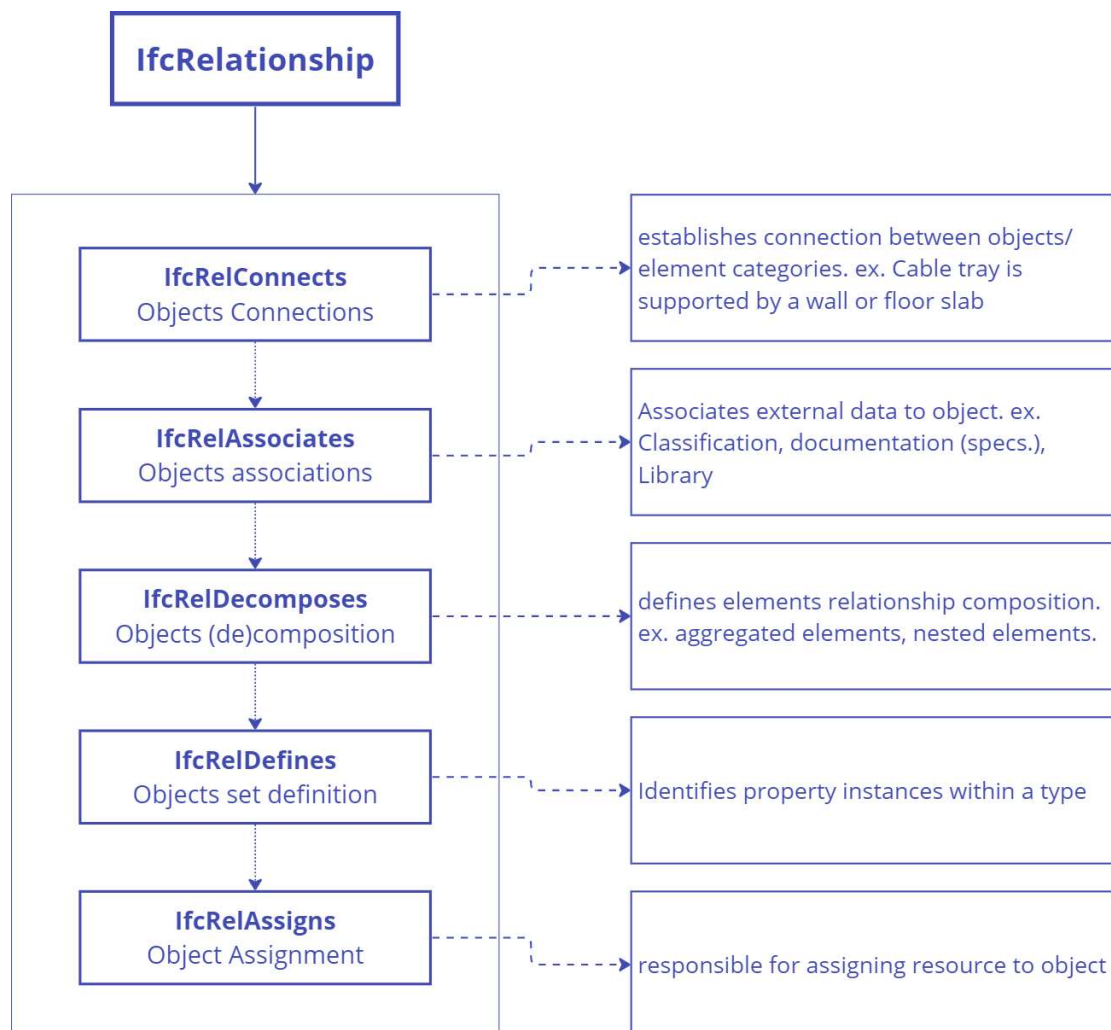
Figure 9: IfcRelationship Entity Inheritance Definition

2.4.1.3. IfcPropertyDefinition

Ifc Property Definition is defined as the generalization of all characteristics (ie. a grouping of individual properties), that may be assigned to objects. Currently, subtypes of IfcPropertyDefinition include:

- IfcPropertySetDefinitions is defines as a generalization of all individual property sets that can be assigned to an object or type object. The property set definition can be either, IfcPropertySet

(dynamically extendable property sets, this means no entity definition of the properties exists within the IFC specification. The declaration is done by assigning a significant string value to the Name attribute of the entity as defined in the entity IfcPropertySet and at each subtype of IfcProperty, referenced by the property set. Or they could be IfcDefinedPropertySet (statically defined property sets that exist within the IFC specification. The semantic meaning of each defined property set under this category is declared by its entity, and the meaning of the properties is defined by the defined name and data type of the explicit attribute representing it.

- IfcPropertyTemplateDefinition, a generalisation of all property and property set templates. Templates define the collection, types, names, applicable measure types and units of individual properties used in a project. The property template definition can be either IfcPropertySetTemplate (a collection of property templates that determine the definition of properties used within a project context) or IfcPropertyTemplate (a single template that determines the definition of a particular property used in the same project context) (BuildingSmartInternational, n.d.)
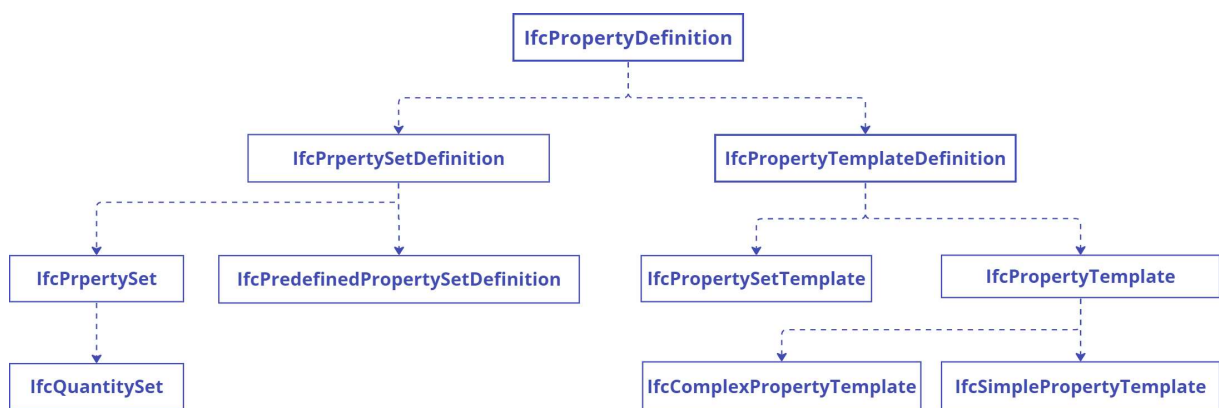
Figure 10: IfcPropertyDefinition Entity Inheritance Definition

2.4.2. Ifc Model View Definition (MVD)

" MVD, or "Model View Definition", is a specific implementation level of IFC to describe facilitate a specific use or workflow."

- as a line (or curve) segment between two points;
- as one of many types of 3D geometry for visualization and analysis (such as extruded solids or triangulated surfaces);
- as simple forms or with specific construction detail (capturing individual studs, pipe fittings, wiring, etc.)
- ...along with data such as engineering properties, responsible party, scheduling, and cost information.

Software vendors have the responsibility of implementing the MVDs to provide a single term of reference that allows for interoperability between software vendors and versions.

There are three significant (base) IFC implementation MVDs which have been developed or in development by the time of the thesis:

- Coordination view 2.0 (IFC 2x3)
- Alignment based Reference View (IFC 4.)

- Design transfer View (IFC 2x3, IFC 4.*).

b-Cert platform defines the reference view MVD basically for viewing and coordination purposes and referencing domain models to each other (e.g., for clash detection), and the Design Transfer View for purposes of exchanging IFC-models to be imported and used further on in other applications for design and evaluation tasks. Coordination view 2.0 on the other hand was developed originally to support the Exchange Requirements for the coordination of BIM-models from architects, structural and building service engineers during the design phase, essentially using IFC as a reference model for planning coordination. However, during the years more and more came into this MVD, which was for the purpose of design transfer. (b-Cert Platform, 2023)

According to Use Case Management Group of buildingSMART International, MVD suitable for QTO should aim for the following:

- Quantities can be comprehensibly derived from the model.
- The traceability of quantity approaches to the corresponding model is possible.
- Changes to the quantity structure can be easily documented.
- Updates can be incorporated more quickly and are less error prone.
- The interpretation of the model quantities becomes much more precise for the evaluating systems.
- The exchange data contains cost-relevant descriptive characteristics.
- Improved traceability of the quantities for service descriptions (which component quantities are contained in a service item)

LOD required for the model must contain minimum amount of information for cost determination, suggesting that authored model is at minimum LOD-K 300. For the Purpose of MVD, The IFC4 Schema (IFC4 Add2 TCI) serves as the basis for data and exchange and attribution (UCM buildingSMART Germany, 2022). Furthermore, the Model view can be extended with the support of additional exchange requirement specifying MEP Modelling and quantity take off.

2.5 Work Breakdown Structure

A work breakdown structure (WBS) in construction is a "deliverable oriented hierarchical decomposition of the work to be executed by the project team" (PMI, 2004). The WBS visually defines the scope into manageable chunks that a project team can understand, as each level of the WBS provides further definition and detail. The project team creates the project WBS by identifying the major functional deliverables and subdividing those deliverables into smaller systems and sub-deliverables. These sub-deliverables are further decomposed until the specific work packages required to produce the sub-deliverable are identified. (Tinger, 2019). The key principle of the WBS for a project is the 100 percent rule, according to this rule, the work breakdown structure must show the entire project scope, including all deliverables: design, engineering, and project management services. (Ramos, 2021) The rule applies at all levels within the hierarchy: the sum of the work at the "child" level must equal 100% of the work represented by the "parent"—and the WBS should not include any work that falls outside the actual scope of the project; that is, it cannot include more than 100% of the work. (Brotherton, Fried, & Norman, 2008)

There are 2 approaches organising the WBS:

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2.5.1. Deliverable-Oriented Work Breakdown Structure

A Deliverable-Based Work Breakdown Structure clearly demonstrates the relationship between the project deliverables (i.e., products, services or results) and the scope (i.e., work to be executed). Figure 8 is an example of a Deliverable-Based WBS for building a house. (WBS Software, 2023)
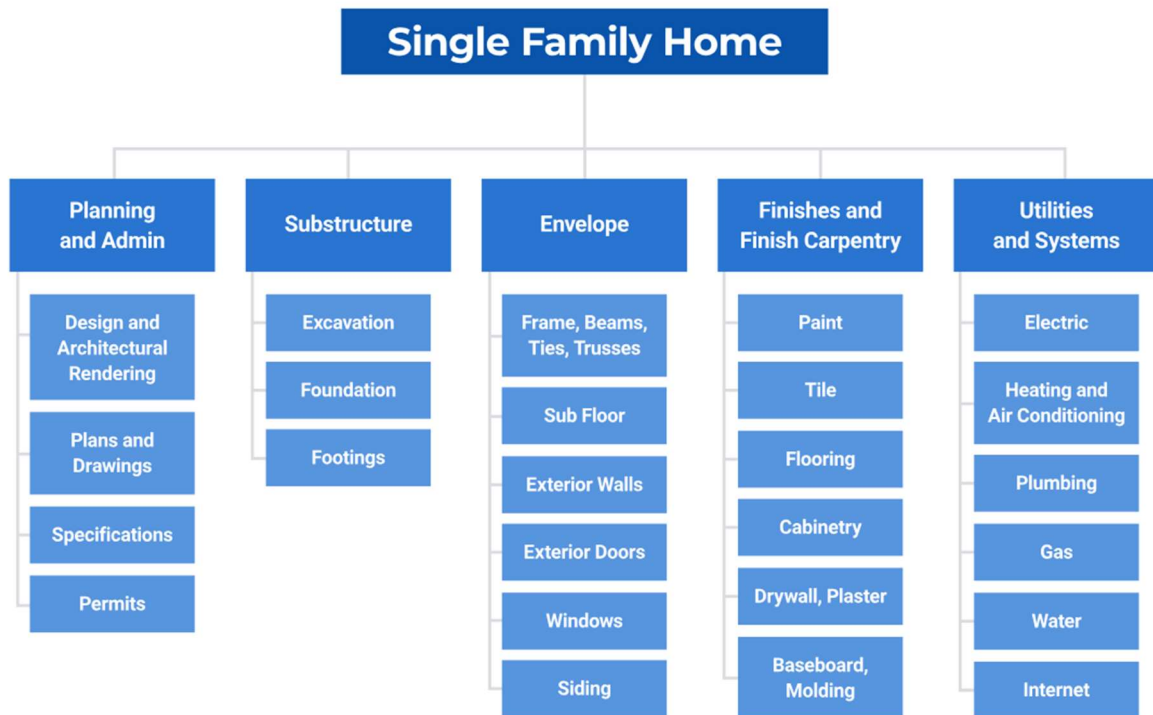
Figure 11: Deliverable-Based Work Breakdown Structure (Source: Smartsheet.com)

Here are the advantages of a Deliverable-Oriented WBS:

- It simplifies the process of cost estimating.
- It allows you to see the total work scope.
- It clarifies the relationships among elements.
- You can use it during all project phases.
- It's easier to modify as your project changes.
- It supports earned value management. (Ramos, 2021)

This method would be used in categorizing our elements during quantity take due to the ability to categorise by work packages, elements, disciplines etc.

2.5.2. Phase-Based Work Breakdown Structure

Also known as a process-oriented, task-oriented, or activity-oriented work breakdown structure. The team divides the project into its component activities. In the graphical representation of a phase-based WBS, these activities often proceed in chronological order. (Ramos, 2021)
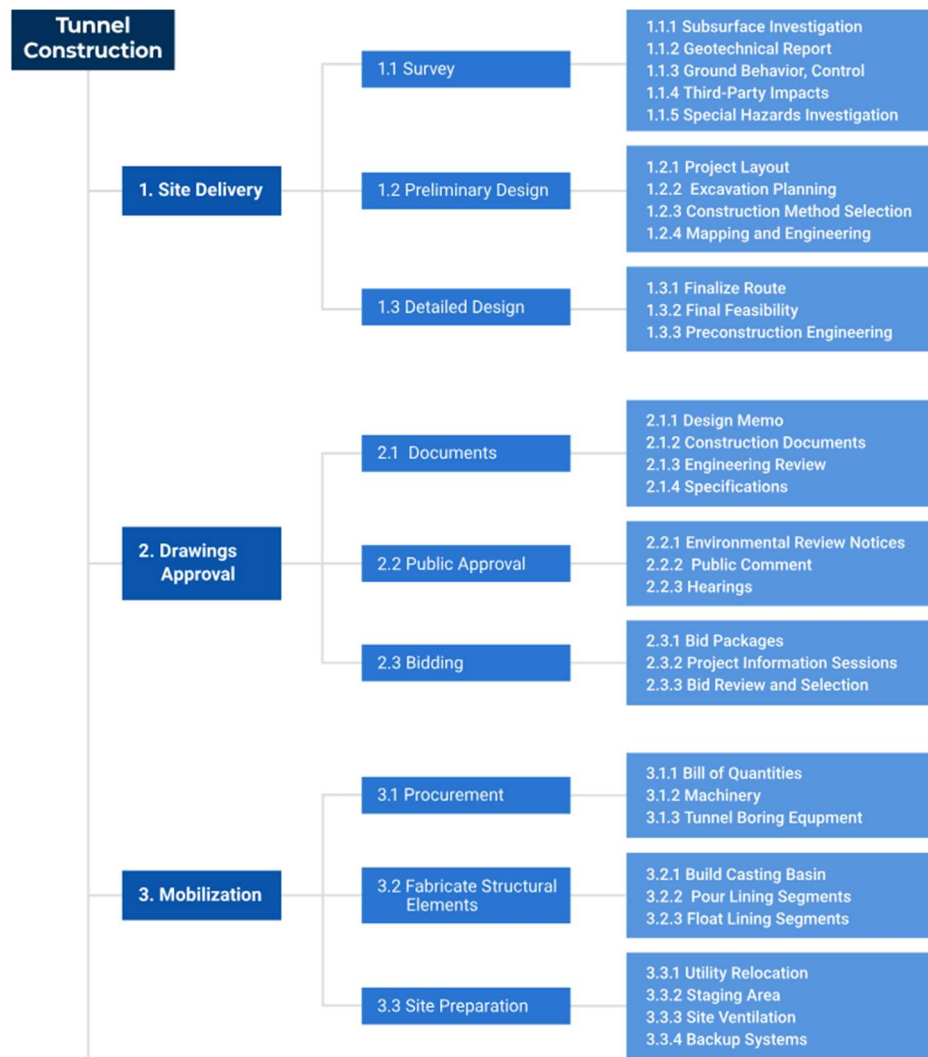
Figure 12: Phase-Based Work Breakdown Structure for A Tunnel Project (Source: Smartsheet.com)

The phase based WBS arose in part to ease the transition from a deliverable WBS to a project schedule. Planners translate the deliverables into activities and milestones, then create a project schedule network diagram. This diagram, which consists of boxes and corresponding arrows indicating the flow of work, is the basis of the project schedule (Ramos, 2021)

2.6 MEP 5D Modelling

BIM has increasing level of information layer referred to as Dimensions. 5th Dimension of BIM refers to the financial cost layer of information introduced to the model. Arguably, cost is not a dimension therefore may not be the best fitting nomenclature for the activity. It is best practice to outline the specific requirements of the information to be added. "For example, is the team expected to be providing capital or operational costs? Are these costs expected to be pre-tender estimates or a record of as-built costs? Who is responsible for adding this information? What method of measurement is to be used?" (Stephen, 2021). Developing certainty in cost, design and buildability reduces risk and creates better projects with sustainable profits. (Mitchell, 2012)

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(Xia, Cheah, & Mohd, 2016) opined that accuracy in cost estimation is crucial in early stages of construction projects, as it is a crucial factor in decision-making and funding. Inaccurate estimation can lead to cost overruns and project delays. However, early project estimation is often difficult due to information gaps. The introduction of Cost definition to building elements provides the opportunity of integrating current market prices of elements and attending cost to construction materials and processes. One of the main elements for the evaluation of the "cost dimension" of a project is the cost of materials, often referred to as Material/ Quantity Take-Off. "Most BIM tools are able to prepare a preliminary quantity take off, but this service actually depends on model to have required properties. Even if the BIM tool prepare the quantity of an element, these applications tend to lack the function to perform cost estimation, which is usually done using different software. The data exchange between cost estimator software and BIM tools is often compile via IFC" (Taghaddos, Mashayekhi, & Sherafat, 2019).

To complete the material Quantity take-off process, a Database of most recent prices of construction materials is required the match the material quantities. This database is often referred to as Price list. The document is administered by the QTO software which has the capacity to manipulate data (either in IFC or Authoring Software house native QTO program) and combine materials based on predefined Work breakdown Structure.

2.7 Price List

A price list in the context of AEC is an up-to-date cost of carrying out a task. This frequently includes cost like material, installation, transportation, labour, enabling works, and other attending cost required to complete the task. A price list could be public or private, in the case of public works, publicly issued price list is employed to provide a fair basis for costing and bid.
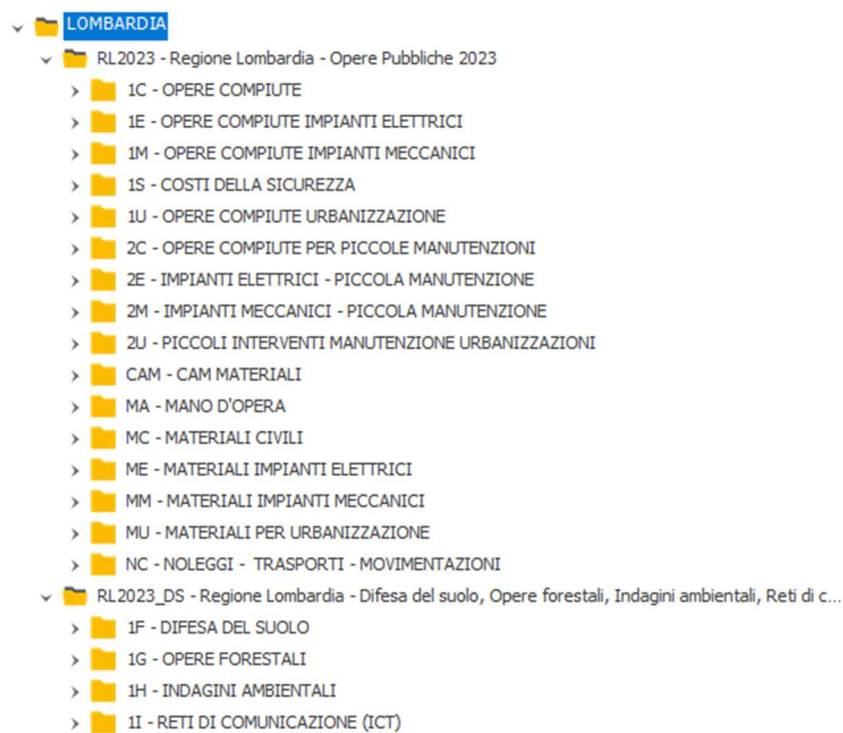
Figure 13: Lombardy Price List for Public Works Category, showing structure for Major, Minor Works and Cost of Individual elements of Price list.

However, it is possible that a private company collate real-time prices from producers, contractors and suppliers and have a real-time market price list. For example, the structure of the Lombardy Public Works price list has 3 categories. Figure 10

Category 1: Inclusive cost of Executing works (Major works)

Category 2: Inclusive cost of Executing works (Small projects/ Maintenance works)

Category 3: Cost of Individual elements (Transportation, Material, Labor, certification etc.)

When the total cost of executing the works is considered, the item in the price list contains material cost, and provides allowance for cost like transportation, labour, certification, measurement unit and unique identifier codes for each item in the price list. See. figure 11.

Figure 14: Complete Price List showing breakdown of elements that make up the total cost of executing the works.

3. CONCEPTUAL PROCESS FLOW

3.1. Introduction

The goal of this thesis is to create a quantity take-off document from MEP model, using quantities generated from the model during the design stage. This goal requires that the initiation for the project follows a predetermined process that includes establishing the required information exchange for the project through the BEP. The MEP engineers with the aid of BIM authoring tool (in this case Revit) and reference files like the BEP and Architecture and/or structural Concept design models produces the MEP 3D model and attending specifications through an iterative process of review, clash detection, resolution and evaluation of options a. The quantities of materials in the model are extracted through IFC Schema that is suitable for the extraction of material definitions that would be required for price mapping. A database of updated prices of materials is then mapped against the quantities extracted using established measurement units. Thereafter, formatted into work packages that speaks to exchange information requirements for Bill of Quantities.

The process flow concept has been designed to consider the following objectives:

i.   Work packages as described in the WBS documentation of the BIM execution plan and to provide some flexibility for custom work packages that might be required for value engineering of the project.

ii. Integration of MEP calculations into BIM model development for the purpose of optimizing the design process and creating a dynamic design environment.

iii. OpenBIM accessibility of BIM authoring tool produced data for the purpose of 5D modelling and data manipulation for Quantity take off and MEP cost definition.

3.2. Process Map.

We have already established the key inputs to this process would be the BIM Execution Plan, Work Breakdown Structure, Adopted Price list, and the conceptual models for Architecture and/or structure. We would know examine in more detail, the key activities in the process flow to create the MEP Quantity Take Off.

3.2.1. MEP Calculation

Calculations for Ventilations, plumbing, electrical and mechanical systems is initiated form examining the occupancy, regulation and comfort requirements of each room in the project. These requirements inform the cooling load of ventilation systems, sanitary designations, cold and hot water supply, heating requirements and wastewater capacity of each unique space. The resulting figures are then aggregated into cluster spaces (eg. Apartments, common areas, public areas etc) determining the capacity/ requirements by these clusters, then by floors. Service risers also referred to as vertical connectors also sized to collect horizontal branches on floors and transfer to the service or equipment zones for supply or discharge. The process of calculating the distribution sizes and the equipment capacity would be carried could be carried out with a software or a spreadsheet that could be connected to the authoring tool to provide seamless update when there is a design iteration that impacts the parameters of the calculations.

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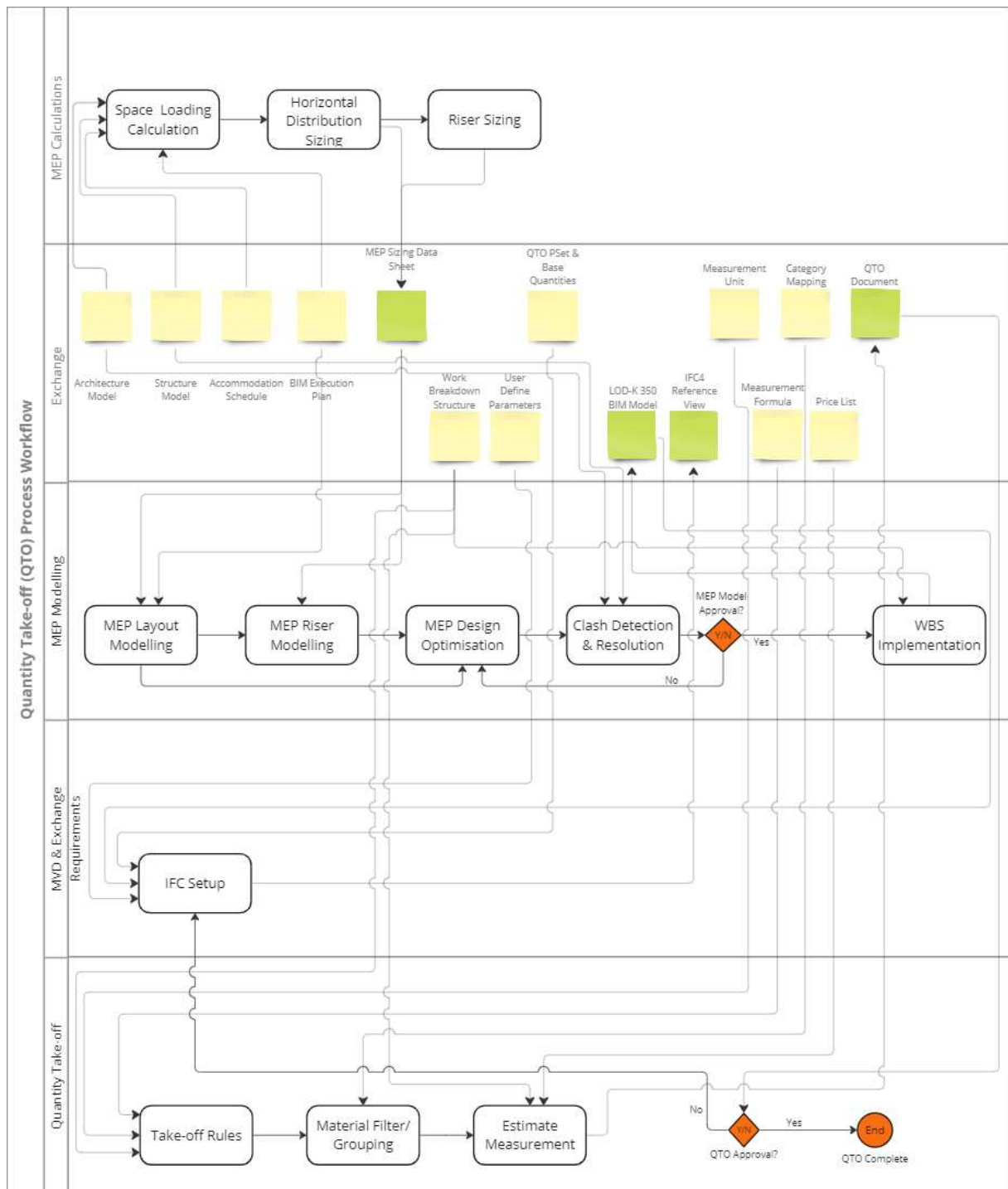
Figure 15: MEP Quantity Take-off (QTO) Process Workflow (Source: Tubi Otitooluwa, 2023)

3.2.2.   MEP Modelling

The MEP Modelling goes hand in hand with MEP calculations, as capacity determines layout and distribution choices and vice-versa. The key activity at the stage is the modelling of components and continuous iteration of the design to ensure an effective layout that meets code requirements and BEP goals. It is best practice to develop each MEP discipline modelling in a separate file or create a

Workshared environment that allows for each discipline a workset or multiple worksets that organises their development. The workset would be managed to ensure healthy modelling practice within each discipline. During the modelling, the MEP disciplines are constantly coordinated to ensure an efficient systems design, space optimisation (risers, ceiling voids and under floor and floor soffit) and avoid clashes between the discipline, for example, it is good practice to allows for electrical services above plumbing if they must run parallel due to pipe gradient and potential leak in future.

3.2.3. WBS Implementation

As expatiated in the literature review, the deliverable based hierarchical structure of the WBS would be used to capture data about the materials in the work packages predicted in the BEP by assigning relevant category of the WBS to modelled elements. The WBS is introduced as a set of Shared parameters in the authoring software and applied to modelled elements, the assignment is thereafter inspected with schedules to verify accuracy and capture of elements required.

3.2.4. MVD and Exchange Requirements

The exchange requirements for the purpose of QTO is considered for the purpose of this exercise, the primary exchange requirement. Within this requirement is the need to capture information about the quantities, volume, units and dimensions of modelled elements. As explored in the literature review, IFC4 reference view with the add-in for further exchange requirements for quantity Take-off would be used. Likewise, it is important to verify that our software for quantity Take-off supports IFC4 Schema.

3.2.5. Quantity Take Off

A CPM software which allows progressive exploration of QTO as the project information develops and integrates with other project data through the cause of the project life cycle as defined in the BEP would be used to generate the QTO. This is to ensure seamless and lossless information exchange through as the information requirement for different stages of the project changes. For example, the software should provide or support exchange of information for bill of quantities and enabling works for bidding and bid management, accounting, cost and project management during construction and maintenance plan during facilities management. The process of QTO would begin with the establishment of measurement units for the alignment of IFC and price list measurement, thereafter, using the filter to aggregate the materials by category and unique instances, then prescribing the formular for extracting measurement, the take-off rules are created assigning the price list to material by measurement units e.g. (Weight, unit, length, area). The rule for unique instances is thereafter applied to the IFC model also applying the WBS which would categorise the materials by work packages as defined in the exchange requirement.

3.2.6. Price List

For the purpose of QTO, the model adapted is the price list originating from the practical experience of a private organisation, retrieving updated information of cost of materials, labour and attending cost to come up with unit cost of materials. As explored in the literature review, the price list is broken down to the different elements that make up the sum i.e. (Material cost, attending cost, labour cost etc) or a lump sum per unit if the material. The priority of the price list organisation is to ensure proper coding of items and data compatibility with the information model in the IFC file.

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4. CASE STUDY

4.1. Introduction

BIM workflow for MEP Design had seen a lot of improvement over time, a major pivot to this exponential leap is the ability to author models in BIM Software. To fully optimize this benefit, it is important to optimise data retention at the multiple stages of a project. Therefore, the interoperability between MEP systems calculation should seamlessly operate the MEP modelling in authoring tools and the Modelled information should have no loss of data in the building lifecycle. This case study would focus on the interoperable development of information from the systems calculation up until the modelling, cost definition and Quantity Take Off phases of a project.

4.2. Project Overview

The project is a 18-floor residential building located in the heart of Milan, Italy. The building sits on a 2,754sqm corner piece with 121 apartments of 2, 3, 4 and penthouses. The building is made up of three connected towers each served by a core consisting of a bank of lift, escape stairs and service risers. The cores are linked by common lobbies that connects apartments attached to each core. The middle tower (Scala 1) consists of 19 floors, while Scala 2 has 9 floors, and the last core Scala 3 consist of 6 floors.

Figure 16: 3D Axonometric View of Federated Discipline Model

- Basement (B01 – B03): Parking Garages, Storage and Technical Services Areas
- Ground Level (L00): Technical Services Areas, lift core receptions, Commercial Areas, Bicycle storage.
- L01-L06: Residential Apartments on all three core zones
- L07: Residential Apartments and Roof Technical Area on Core 3 Zone roof
- L08-09: Apartments (Cores 1 and 2)
- L10: Apartments (Core 1) and Roof Technical Area on Core 2 Zone roof
- L11-14: Apartments
- L15-17: Penthouses
- L18: Technical Area on Core 1 Zone Roof.
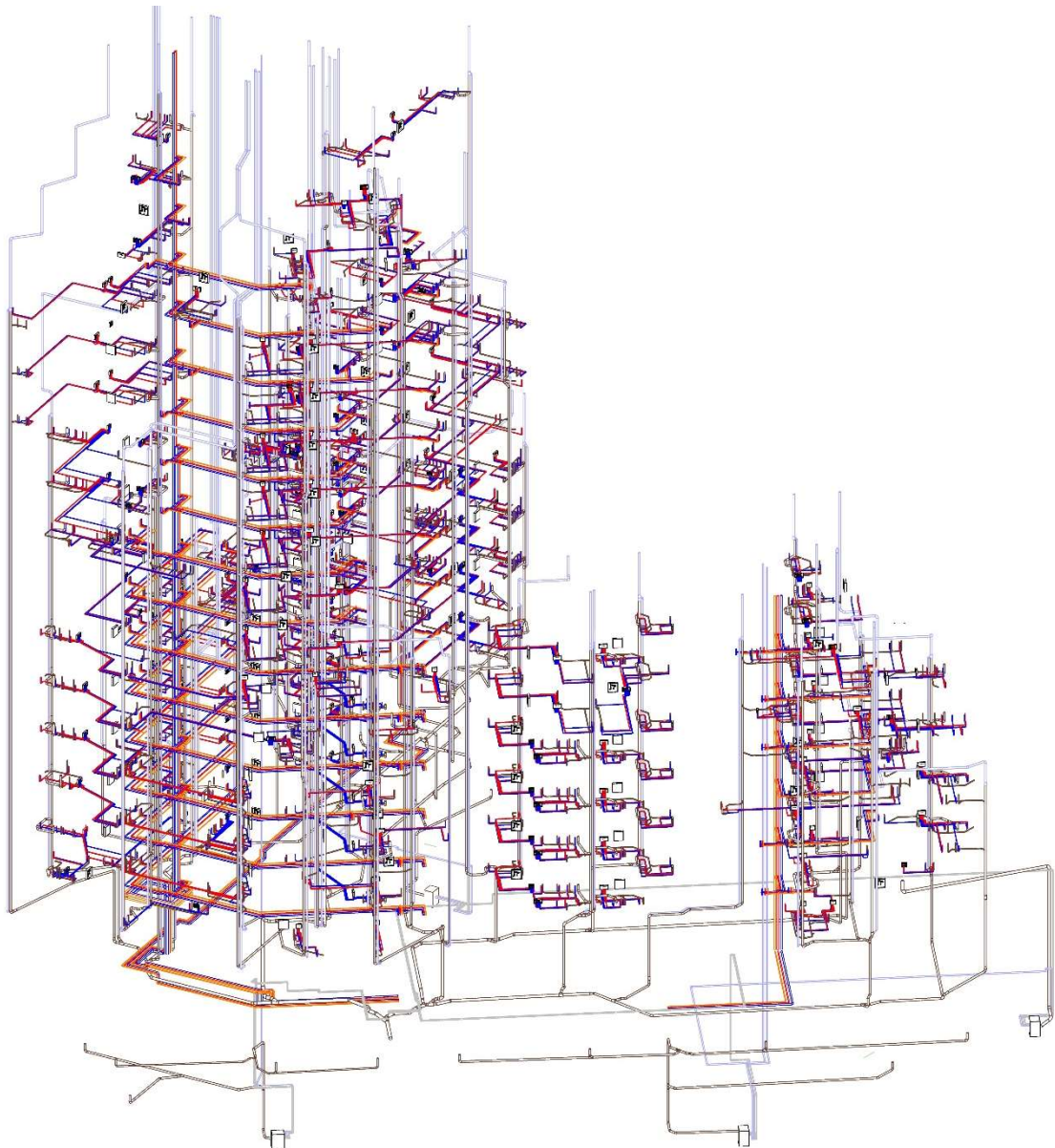
Figure 17: 3D Axonometric View of Plumbing Systems (Wastewater, Hot and Cold Water)

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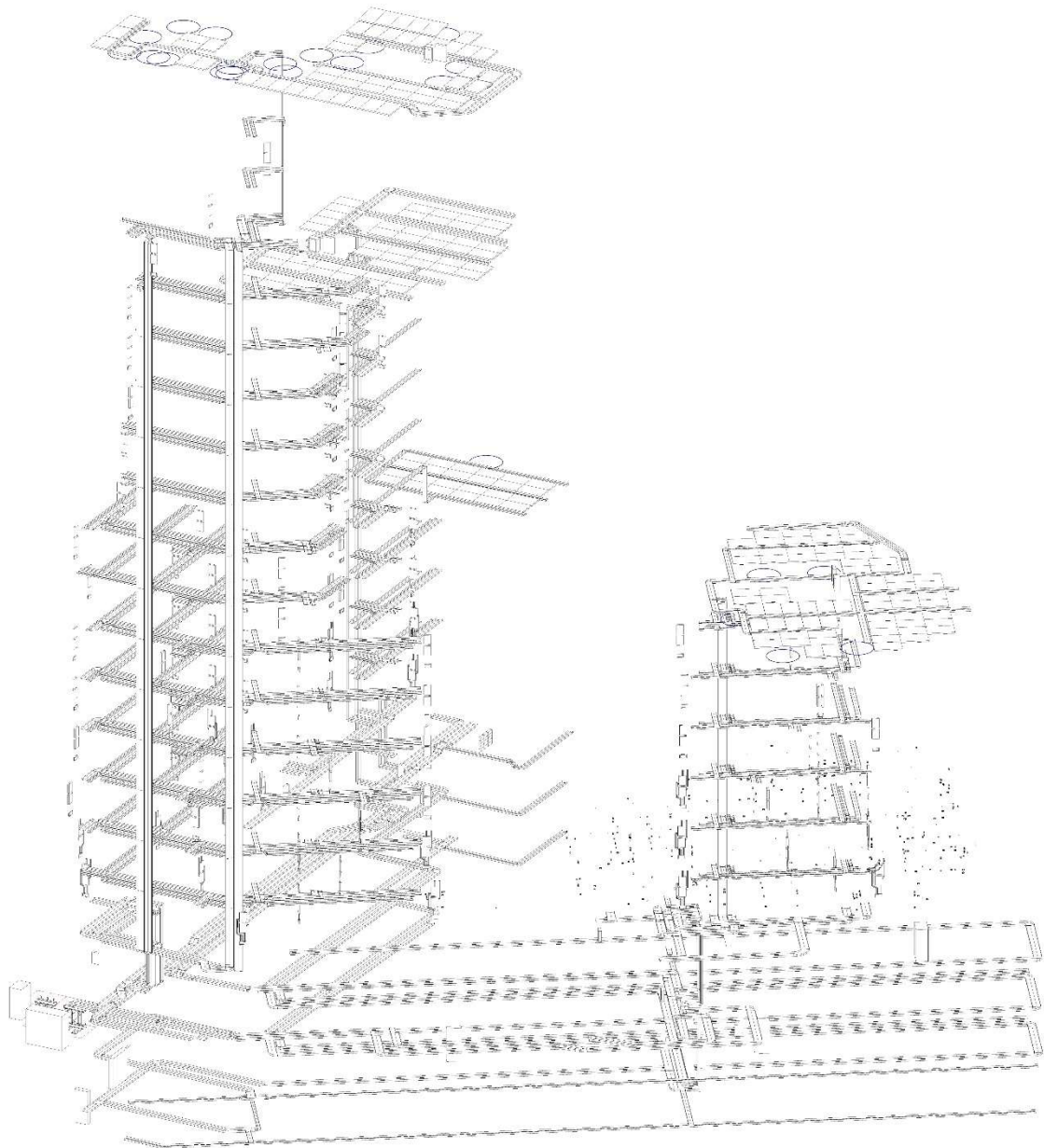
Figure 18: 3D Axonometric View of Electrical Systems (Raw Power and Extra Low Voltage)

4.2.1. Information Process Overview

Piazzale Accursio (the Project) is being developed with reference to the UNI 11337-1:2017 standard. The stage of the information process of the buildings of the assignment is identified as "*Planning*" consisting of the Spatial Functional, Authorization and Technological (The stages and phases of the information process have no direct correspondence with the levels of the design according to the regulatory framework of public works). It is also possible to define that the final and executive project levels, identified according to the binding legislation on procurement, can be considered part of the digital information process. In particular, the final design is part of the authorization information phase, while the executive project is part of the technological information phase. This pGI refers exclusively to the authorization and technological phase and therefore to the development of the Definitive and Executive Project.
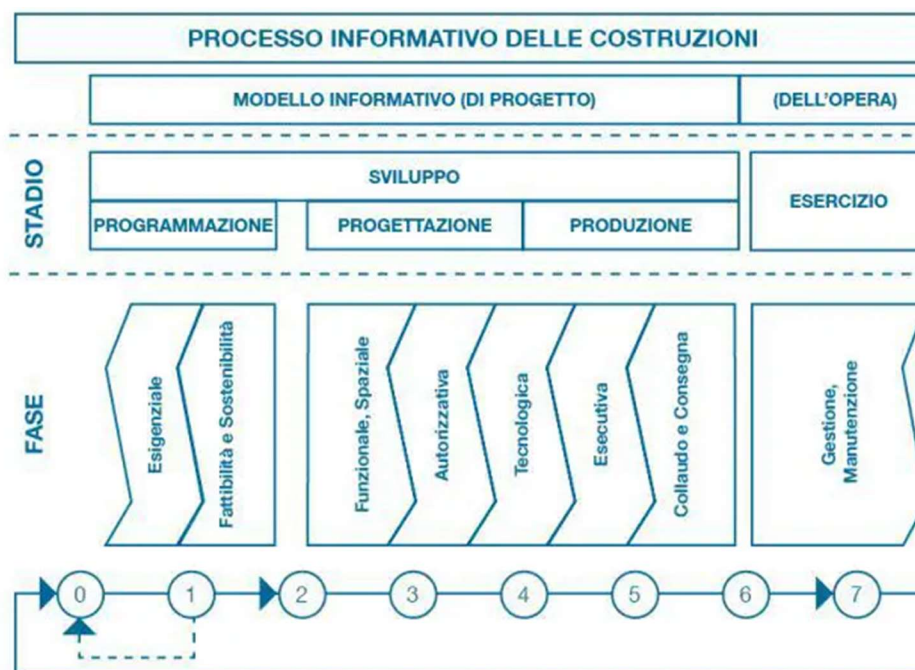
Figure 19: UNI 11337-1:2017 information process of construction

4.2.2. Project Team Structure.

Accursio P22-41 (The project) project is a (type of procurement). The private client has employed a list of professionals to execute the design and execution contract management of the project consisting of a team. The Energy, Mechanical, Electrical, Plumbing and Extra Low Voltage solutions is being designed by Rethink Energy Srl. The rest of the design and management disciplines for the project are as shown in the table below.

Discipline	Code	Role	
Project Manager	PR	Electrical and Special Systems	EL
Architecture	AR	Fire Prevention Systems	AN
Structure	ST	Sanitary Water Systems and Wastewater Disposal	IS
Rainwater Disposal	PL	Air Conditioning and Ventilation	ME
BIM Manager	BM		

Table 1: List of Disiplines/ Roles on Project Piazzale Accursio

Each organisation has a BIM coordinator in-house who is responsible for the implementation of BIM workflow for the project within the organisation. The BIM Coordinator at Rethink energy would additional be responsible for the integration, clash detection and resolution between MEP systems, and ensuring compliance of Exchange requirements to specifications in the BEP.

4.2.3. Software.

This section indicates the types of software that was utilized for the execution of the requested services. In the course of the project, all updates to subsequent versions of the platforms was updated and agreed by the entire project team to avoid inconsistencies and malfunctions in the general workflow.

Scope	Discipline	Software	Native Format	Information Exchange Format
Architectural Design	BIM Modelling	Autodesk Revit 2022	.rvt	.rvt .ifc
	2D Documentation	Autodesk AutoCAD 2018-2022 Microsoft Office 365	.dwg .docx .xlsx. .pptx	.dwg .pdf
	Computational Estimate	TBD		
Structural Design	BIM Modelling	Autodesk Revit 2022	.rvt	.rvt .ifc
	2D Documentation	Autodesk AutoCAD 2018-2022 Microsoft Office 365	.dwg .docx .xlsx. .pptx	.dwg .pdf
	Computational Estimate	STR CPM Vision	.xls	
	Analysis and Calculation	Midas GEN	.mgt	.ifc
MEP Design	BIM Modelling 2D Documentation	Autodesk Revit 2022 Autodesk AutoCAD 2018-2022 Microsoft Office 365	.rvt .dwg .docx .xlsx. .pptx	.rvt .ifc .dwg .pdf
	Computational Estimate	STR CPM Vision	.xls	
Model and Code Checking	Interference and inconsistencies check	Bimpool, Autodesk Navisworks	.nwf	.bcf .pdf
	Issue tracking	Bimpool	-	-
	Model Federation	Bimpool, Autodesk Revit 2022, Autodesk Navisworks	.rvt .nwd	
Project Coordination	Common Data Environment	Bimpool	-	-

Table 2: List of project software infrastructure

Including the software listed above for MEP, BIM vision software was used to inspect IFC export files for suitability of exports before exchange requirement is issued. All software license used for the MEP serviced on this project was provided by Rethink Energy Srl.

4.2.4. Project Assumptions.

At the start of this thesis, the project had just resumed its Detailed Design "Progetto definitive" phase with some recalibration to the MEP services, therefore the Workflow was set at this point and would influence largely the solutions that were used for this project. Furthermore, below is a list of constraints and assumptions that have been made to stay within the confines of this thesis proposal as espoused in the abstract.

- Calculation, modelling and QTO was only considered in full for Portable Water Supply and Wastewater Disposal Systems in the project, the principles to be explored in one discipline can be adapted to the other MEP service, due to the incomplete nature of the Climatization information at the beginning of the thesis.
- Modelled information does not contain terminal elements for both plumbing and electrical systems as they were under the scope of Architecture/ interior and were not provided at the analysis stage of this thesis.

- Models for analysis were developed to LOD300, 350, with some elements carrying information about interface with other building systems but no information on fabrication, installation details and enabling works required.
- Price list data employed was a private list developed overtime from the experience of consultants and frequently updated information from contractors in the Italian market (Milano precisely). The private price list was preferred as it is more up to date and there is no requirement to use the public price list since it is a private lead project.

4.3. Process Flow Implementation.

4.3.1. MEP Calculation

As reference in the chapter on Conceptual Process Flow, the process of calculating the sizing of MEP systems began from the accommodation schedule. The specific information required were the area of each space requiring ventilation, number of terminals required for each unique space (in case of electrical services), number and type of wet areas utilities in each apartment. This data is then measured against ideal cooling and heating temperature targets for spaces with climatization, rating of electrical outlets and supply and discharge flows requirement for wet areas. Calculation under the scope of this thesis would be limited Plumbing services. Samples of the calculations would be presented in the body of the thesis, however for full review the documentation shall be made available as an addendum to the thesis document.

The calculations for effluent capacity and network were done using spreadsheets (Microsoft Excel, part of the office 365 license provided for the thesis).

4.2.1. Wastewater Capacity Calculations.

A standardized breakdown of the wet area utilities in each space was collected in a spreadsheet and the unit of discharge (DU) was applied to get the unit of discharge required for a wet room ie. Kitchen, restroom and Laundry (see figure 17).

On the plan for each level, collector points were located and coded (prefix: S..) maximum of 4m from a utility point without connecting utilities across different apartments. The resulting collectors were then mapped on a spreadsheet against wet areas by floors to calculate the Unit of discharge of level collectors. (See Table: 3)

4.2.1.1. Wastewater Unit of Discharge.

Using Figure 20: Unit of Discharge By Unique Wet Area measurement, the units are applied to the wet areas under each category to result in unit of discharge for each discharge pipe.
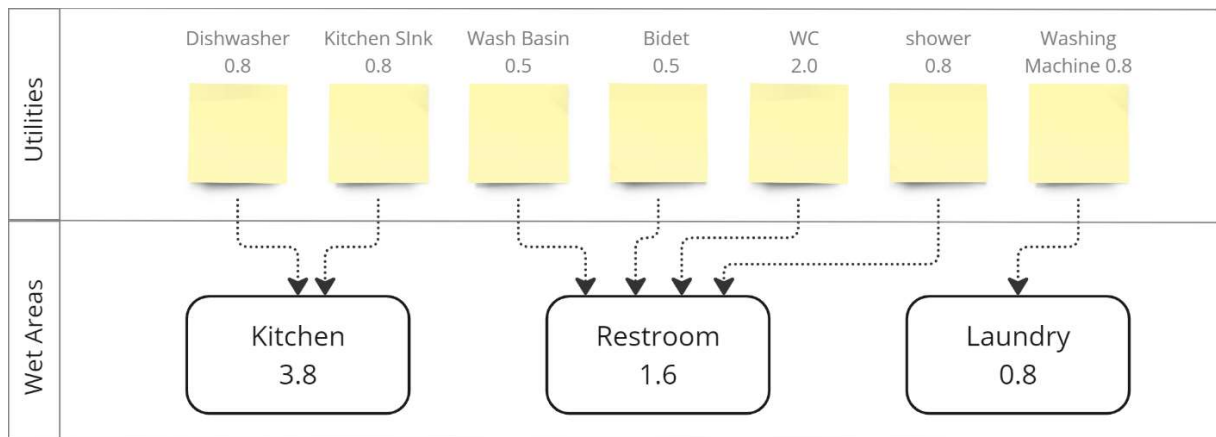
Figure 20: Unit of Discharge By Unique Wet Area

Example:

S01 has 4 Bagni and 4 lavanderia between levels L01 and L04
Total DU for Bagni =   *3.8*
DU for Lavanderia =   *0.8*
S01 DU =   *Bagni (3.8*4) + Lavenderia (0.8*4)*
            15.2 + 3.2
            18.4

Equation 1: Determining the Discharge Unit Value of a Discharge Pipe.

4.2.1.2. Wastewater Pipe Dimensioning.

To determine the diameter of each discharge pipe, the water flow is determined by multiplying the square root of DU by coefficient of frequency (k). the value derived is the litre/ second capacity of the pipe. The diameter for the horizontal section of the discharge pipe is determine at 50% capacity and considering a 1.0% slope, the next pipe in size with larger water flow capacity is selected. Table 4: Discharge Pipe Sizing Spreadsheet

Example:

S01 Water Flow (Waste) L/s =   *K-Coefficient of Frequency * √ DU*
            0.5 * √18.4
            2.1 L/s
Vertical Column   *110mmø at 5.6L/s*
Horizontal Collector at 1% slope =   *110mmø at 2.5L/s (50% capacity)*

Equation 2: Determining Vertical and Horizontal Pipe sizes for Wastewater collectors.

Zone 1

		L00	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
S17	Bagni		1	1	1	1	1	1	1	0		
	Cucine		1	1	1	1	1	1	1	0		
	Lav.		0	0	1	1	1	1	1	1		
S16	Bagni		0	0	0	0	1	1	1			
	Cucine		0	0	0	0	0	0	0			
	Lav.						1	1	1			
S15	Bagni											
	Cucine											
	Lav.											
S14	Bagni		0	0	1	1	1					
	Cucine		1	0	0	0	0					
	Lav.		1	1	1	1	1					
S13	Bagni		0	0	1	1	1	0	0			
	Cucine		0	0	0	0	0	1	1			
	Lav.		1	1	1	1	1	1	1			
S12	Bagni		1	1	0	0	1	0	0	0	0	
	Cucine		0	0	1	1	1	1	1	0	0	
	Lav.		0	1	0	0	0	0	0	1	1	
S11	Bagni		1	0	0	0	0	0	0	0		
	Cucine		0	0	1	1	1	0	0	0		
	Lav.		1	1	0	0	1	1	1	1		
S10	Bagni		0	0	0	0	0	0	0	0	0	
	Cucine		1	1	1	1	1	0	0	0	0	
	Lav.		1	0	0	0	0	1	0	1	1	
S09	Bagni		1	1	1	1	1	0	0	0	0	3
	Cucine		0	1	0	0	0	0	0	0	0	3
	Lav.		0	1	0	0	0	0	0	0	0	3
S08	Bagni		1	1	0	1	1	0	0	0	0	1
	Cucine		0	0	0	0	0	0	0	0	0	0
	Lav.		0	1	1	1	1	1	0	1	1	1
S07	Bagni		0	1	1	0	0	0	0	0	0	1
	Cucine		1	1	0	0	0	0	0	0	0	1
	Lav.		0	0	1	1	1	1	1	1	1	1
S06	Bagni		1	1	0	0	0	0	0	0	0	3
	Cucine		0	0	0	0	1	1	0	0	0	1
	Lav.		0	0	1	1	1	0	0	1	1	3
S05	Bagni		1	1	0	0	1	1	0	1	1	
	Cucine		0	0	0	0	0	0	0	0	0	
	Lav.		0	1	0	1	1	1	1	1	2	
S04	Bagni		0	0	0	1	0	0	1	0		
	Cucine		0	1	0	0	0	1	0	1		
	Lav.		0	1	0	0	0	0	0	0		
S03	Bagni		1	1	1	0						
	Cucine		1	1	0	1						
	Lav.		0	1	1	1						
S02	Bagni		1	0	1	1						
	Cucine		0	1	0	0						
	Lav.		1	1	1	1						
S01	Bagni											
	Cucine											
	Lav.											

	Totale Bagni	Totale Cucine	Totale Lav.
S17	8	7	7
S16	3	0	3
S15	0	0	0
S14	2	0	4
S13	7	2	3
S12	2	0	0
S11	0	5	0
S10	9	5	0
S09	0	0	0
S08	6	0	5
S07	10	0	0
S06	0	10	1
S05	7	0	3
S04	2	0	7
S03	1	0	0
S02	4	4	0
S01	4	0	4

Table 3: Sample Spreadsheet Aggregating Wet Areas by Discharge Collector Points (4m max. distance)

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	INDIVIDUAL DISCHARGE PIPE			VERTICAL COLUMNS			HORIZONTAL		CAPACITY	50%
Discharge Pipe	K - Coefficient of frequency	DU - Unit of Discharge	Qww - Water flow (waste) [L/s]	PIPE DIAMETER	Qmax - Flow Capacity [L/s]	VERIFY	SLOPE [%]	PIPE DIAMETER TUBAZIONE	Qmax - Flow Capacity [L/s]	VERIFY
S01	0.5	18.4	2.1	110	5.6	OK	1.0	110	2.5	OK
S02	0.5	21.6	2.3	110	5.6	OK	1.0	110	2.5	OK (7 %)
S03	0.5	3.8	1.0	110	5.6	OK	1.0	110	2.5	OK
S04	0.5	13.2	1.8	110	5.6	OK	1.0	110	2.5	OK
S05	0.5	29	2.7	110	5.6	OK	1.0	125	4.1	OK
S06	0.5	16.8	2.0	110	5.6	OK	1.0	110	2.5	OK
S07	0.5	38	3.1	110	5.6	OK	1.0	125	4.1	OK
S08	0.5	26.8	2.6	110	5.6	OK	1.0	125	4.1	OK
S09	0.5	8	1.4	110	5.6	OK	1.0	110	2.5	OK
S10	0.5	34.2	2.9	110	5.6	OK	1.0	125	4.1	OK
S11	0.5	8	1.4	110	5.6	OK	1.0	110	2.5	OK
S12	0.5	7.6	1.4	110	5.6	OK	1.0	110	2.5	OK
S13	0.5	32.2	2.8	110	5.6	OK	1.0	125	4.1	OK
S14	0.5	10	1.6	110	5.6	OK	1.0	110	2.5	OK
S15	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S16	0.5	13.8	1.9	110	5.6	OK	1.0	110	2.5	OK
S17	0.5	47.2	3.4	110	5.6	OK	1.0	125	4.1	OK
S18	0.5	14.6	1.9	110	5.6	OK	1.0	110	2.5	OK
S19	0.5	22.8	2.4	110	5.6	OK	1.0	110	2.5	OK (4.5 %)
S20	0.5	42.8	3.3	110	5.6	OK	1.0	125	4.1	OK
S21	0.5	8.6	1.5	110	5.6	OK	1.0	110	2.5	OK
S22	0.5	16.8	2.0	110	5.6	OK	1.0	110	2.5	OK
S23	0.5	15.2	1.9	110	5.6	OK	1.0	110	2.5	OK
S24	0.5	23.8	2.4	110	5.6	OK	1.0	110	2.5	OK (2.4 %)
S25	0.5	47.2	3.4	110	5.6	OK	1.0	125	4.1	OK
S26	0.5	8	1.4	110	5.6	OK	1.0	110	2.5	OK
S27	0.5	4	1.0	110	5.6	OK	1.0	110	2.5	OK
S28	0.5	19	2.2	110	5.6	OK	1.0	110	2.5	OK
S29	0.5	23	2.4	110	5.6	OK	1.0	110	2.5	OK (4.1 %)
S30	0.5	26.6	2.6	110	5.6	OK	1.0	125	4.1	OK
S31	0.5	21.6	2.3	110	5.6	OK	1.0	110	2.5	OK (7 %)
S32	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S33	0.5	30.6	2.8	110	5.6	OK	1.0	125	4.1	OK
S34	0.5	17.8	2.1	110	5.6	OK	1.0	110	2.5	OK
S35	0.5	26.6	2.6	110	5.6	OK	1.0	125	4.1	OK
S36	0.5	35.8	3.0	110	5.6	OK	1.0	125	4.1	OK
S37	0.5	30	2.7	110	5.6	OK	1.0	125	4.1	OK
S38	0.5	31.4	2.8	110	5.6	OK	1.0	125	4.1	OK
S39	0.5	12.4	1.8	110	5.6	OK	1.0	110	2.5	OK
S40	0.5	26.6	2.6	110	5.6	OK	1.0	125	4.1	OK
S41	0.5	7.2	1.3	110	5.6	OK	1.0	110	2.5	OK
S42	0.5	30.6	2.8	110	5.6	OK	1.0	125	4.1	OK
S43	0.5	8	1.4	110	5.6	OK	1.0	110	2.5	OK
S44	0.5	28.6	2.7	110	5.6	OK	1.0	125	4.1	OK
S45	0.5	1.6	0.6	110	5.6	OK	1.0	110	2.5	OK
S46	0.5	10	1.6	110	5.6	OK	1.0	110	2.5	OK
S47	0.5	3.8	1.0	110	5.6	OK	1.0	110	2.5	OK
S48	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S49	0.5	47.2	3.4	110	5.6	OK	1.0	125	4.1	OK
S50	0.5	4.6	1.1	110	5.6	OK	1.0	110	2.5	OK
S51	0.5	19	2.2	110	5.6	OK	1.0	110	2.5	OK
S52	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S53	0.5	4.6	1.1	110	5.6	OK	1.0	110	2.5	OK
S54	0.5	49.6	3.5	110	5.6	OK	1.0	125	4.1	OK
S55	0.5	5.4	1.2	110	5.6	OK	1.0	110	2.5	OK
S56	0.5	8.6	1.5	110	5.6	OK	1.0	110	2.5	OK
S57	0.5	3.8	1.0	110	5.6	OK	1.0	110	2.5	OK
S58	0.5	8.4	1.4	110	5.6	OK	1.0	110	2.5	OK
S59	0.5	19.8	2.2	110	5.6	OK	1.0	110	2.5	OK
S60	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S61	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S62	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S63	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S64	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S65	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S66	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S67	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S68	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S69	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S70	0.5	0	0.0	110	5.6	OK	1.0	110	2.5	OK
S71	(LOC. ANTINC.)	PT-09	5.6	125	7.6	OK	1.0	160	7.7	OK
S72	(LOC. ISB SCALA A)	PT-05	0.2	110	5.6	OK	1.0	110	2.5	OK
S73	(LOC. IDRICO SCALA A)	PT-08	0.2	110	5.6	OK	1.0	110	2.5	OK
S74	(CENTRALE TERM. SCALA C)	PT-01	0.2	110	5.6	OK	1.0	110	2.5	OK
S75	(CENTRALE TERM. SCALA C)	PT-02	0.2	110	5.6	OK	1.0	110	2.5	OK
S76	(CENTRALE IDR SCALA C)	PT-03	0.2	110	5.6	OK	1.0	110	2.5	OK
S77	(CENTRALE IDR SCALA C)	PT-04	0.2	110	5.6	OK	1.0	110	2.5	OK
S78	(CENTRALE IDR STACCATO SCALA C)	PT-06	0.2	110	5.6	OK	1.0	110	2.5	OK
S79	(LOC. ISB SCALA B)	PT-07	0.2	110	5.6	OK	1.0	110	2.5	OK
S80	(LOC. RIFIUTI SCALA A SX)		0.2	110	5.6	OK	1.0	110	2.5	OK
S81	(LOC. RIFIUTI SCALA A DX)		0.2	110	5.6	OK	1.0	110	2.5	OK
S82	(LOC. RIFIUTI SCALA B)		0.2	110	5.6	OK	1.0	110	2.5	OK
S83	(LOC. RIFIUTI SCALA C)	PT-01	0.2	110	5.6	OK	1.0	110	2.5	OK
	TOTALE	1094.6								

Table 4: Discharge Pipe Sizing Spreadsheet

4.2.1.3. Wastewater Pipe Transfers and Sizing.

Transfer pipes are categorized into two. Vertical transfer pipes and horizontal transfer pipes. When a collector pipe descends to a level that it no longer collects wastewater from utilities and its in proximity to another vertical pipe, the two pipes merge their capacity into one pipe. Therefore, using the same principles of converting DU to pipe diameter we arrive at the sizes of the transfer pipes (vertical and Horizontal).

DISCHARGE NETWORK - VERTICAL						
RETE	K - Coefficient of frequency	DU - Unit of Discharge	Qww - Water flow (waste) [L/s]	PIPE DIAMETER	Qmax - Flow Capacity [L/s]	VERIFY
S30+S51+S56+S28+S47	0.5	77	4.4	160	12.4	OK
S33+S59+S34+S35	0.5	94.8	4.9	125	7.6	OK
S40+S41+S46	0.5	43.8	3.3	110	5.6	OK
S36+S37	0.5	65.8	4.1	125	7.6	OK
S25+S49+S29+S31+S27+ S26	0.5	151	6.1	160	12.4	OK
S22+S23	0.5	32	2.8	110	5.6	OK
S14+S16+S58+S18+S17+ S19	0.5	124.4	5.6	160	12.4	OK
S22+S23	0.5	32	2.8	110	5.6	OK
S11+S12+S55	0.5	21	2.3	110	5.6	OK
S33+S59+S34+S35	0.5	94.8	4.9	110	5.6	OK
S07+S08	0.5	64.8	4.0	110	5.6	OK
S05+S06	0.5	45.8	3.4	110	5.6	OK

Table 5: Discharge Network Vertical Network Transfer Pipes

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Advance MEP Modelling – BIM modelling with advance third-party software Integration towards Cost Definition and Quantity Take Off

DISCHARGE NETWORK - HORIZONTAL - 50% FILLING					
RETE	DU - Unit of Discharge	Qww - Waste Water Flow [L/s]	Pipe Diameter	Qmax - Flow Capacity [L/s]	VERIFICA
S05+S06	45.8	3.4	125.0	4.1	OK
S07+S08	64.8	4.0	125.0	4.1	OK
S11+S12+S55	21	2.3	110.0	2.5	OK
S10+S53	38.8	3.1	125.0	4.1	OK
S14+S16	23.8	2.4	110.0	2.5	OK
S14+S16+S17+S18+S58	94	4.8	160.0	7.7	OK
S14+S16+S17+S18+S58+S19	116.8	5.4	160.0	7.7	OK
S22+S23	32	2.8	125.0	4.1	OK
S25+S49	94.4	4.9	160.0	7.7	OK
S33+S59	50.4	3.5	125.0	4.1	OK
S33+S59+S31+S30	98.6	5.0	160.0	7.7	OK
S33+S59+S31+S30+S27+S29	125.6	5.6	160.0	7.7	OK
S25+S49+S33+S59+S31+S30+S27+S29	220	7.4	160.0	7.7	OK
S25+S49+S33+S59+S31+S30+S27+S29+S26+S59	247.8	7.9	200.0	14.2	OK
S51+S56	27.6	2.6	125.0	4.1	OK
S51+S56+S28	46.6	3.4	125.0	4.1	OK
S51+S56+S28+S47	50.4	3.5	125.0	4.1	OK
S34+S35	44.4	3.3	125.0	4.1	OK
S36+S37	65.8	4.1	125.0	4.1	OK
S40+S41+S46	43.8	3.3	125.0	4.1	OK
S11+S12+S55+S54	70.6	4.2	160.0	7.7	OK
S07+S08+S11+S12+S55+S54	135.4	5.8	160.0	7.7	OK
S07+S08+S11+S12+S55+S54+S09	143.4	6.0	160.0	7.7	OK
S07+S08+S11+S12+S55+S54+S09+S03	147.2	6.1	160.0	7.7	OK
S10+S53+S52	38.8	3.1	125.0	4.1	OK
S05+S06+S10+S53+S52	84.6	4.6	160.0	7.7	OK
S07+S08+S11+S12+S55+S54+S09+S03+S05+S06+S10+S53+S52	231.8	7.6	160.0	7.7	OK
S07+S08+S11+S12+S55+S54+S09+S03+S05+S06+S10+S53+S52+S57	235.6	7.7	160.0	7.7	OK
S07+S08+S11+S12+S55+S54+S09+S03+S05+S06+S10+S53+S52+S57+S04	248.8	7.9	200.0	14.2	OK
S07+S08+S11+S12+S55+S54+S09+S03+S05+S06+S10+S53+S52+S57+S04+S02	270.4	8.2	200.0	14.2	OK
S13+S43	40.2	3.2	125.0	4.1	OK
S42+S50	35.2	3.0	125.0	4.1	OK
S13+S43+S42+S50	75.4	4.3	160.0	7.7	OK
S13+S43+S42+S50+S38	106.8	5.2	160.0	7.7	OK
S34+S35+S13+S43+S42+S50+S38	151.2	6.1	160.0	7.7	OK
S51+S56+S28+S47+S34+S35+S13+S43+S42+S50+S38	201.6	7.1	160.0	7.7	OK
S44+S45	30.2	2.7	125.0	4.1	OK
S40+S41+S46+S44+S45	74	4.3	160.0	7.7	OK
S40+S41+S46+S44+S45+S39	86.4	4.6	160.0	7.7	OK
S36+S37+S40+S41+S46+S44+S45+S39	152.2	6.2	160.0	7.7	OK
S51+S56+S28+S47+S34+S35+S13+S43+S42+S50+S38+S36+S37+S40+S41+S46+S44+S45+S39	353.8	9.4	200.0	14.2	OK
S20+S21	51.4	3.6	125.0	4.1	OK
S14+S16+S17+S18+S58+S19+S20+S21	168.2	6.5	160.0	7.7	OK
S14+S16+S17+S18+S58+S19+S20+S21+S24	192	6.9	160.0	7.7	OK
S22+S23+S14+S16+S17+S18+S58+S19+S20+S21+S24	224	7.5	160.0	7.7	OK
S25+S49+S33+S59+S31+S30+S27+S29+S26+S59+S22+S23+S14+S16+S17+S18+S58+S19+S20+S21+S24	471.8	10.9	200.0	14.2	OK
S51+S56+S28+S47+S34+S35+S13+S43+S42+S50+S38+S36+S37+S40+S41+S46+S44+S45+S39+S25+S49+S33+S59+S31+S30+S27+S29+S26+S59+S22+S23+S14+S16+S17+S18+S58+S19+S20+S21+S24	825.6	14.4	200.0	14.2	OK
S72+S78	-	0.4	110.0	2.5	OK
S72+S78+S73	-	0.6	110.0	2.5	OK
S74+S75+S76+S77	-	0.8	110.0	2.5	OK
S80+S81	-	0.4	110.0	2.5	OK
S72+S78+S73+S80+S81	-	1.0	110.0	2.5	OK

Table 6: Discharge Network Horizontal Network Transfer Pipes

4.2.2. Cold and Hot Water Distribution Systems Calculations.

The water supply for the building would be broken into 2 to ensure reasonable pressure across all floors. Levels L01-L09 would be supplied by a pressure pipe while the other upper floors would be served by the second pressure pipe. This providing Two water supply systems at Stair Zone/ Core 1.

4.2.2.1. Water Supply Unit of Charge.

The process of determining the size of pipe is initiated by identifying the Unit of Charge (UC) for the supply of water (Hot, Cold and Both). Figure 21: Water Supply Unit of Charge for Wet Areas 1 (Hot, Cold and Combined) and Figure 22:Water Supply Unit of Charge for Wet Areas 2 (Hot, Cold and Combined) show the list of value for cold water (AFS) Hot Water (ACS) and Combined (AFS+ACS) for each of the identified wet areas in the building.

Figure 21: Water Supply Unit of Charge for Wet Areas 1 (Hot, Cold and Combined)
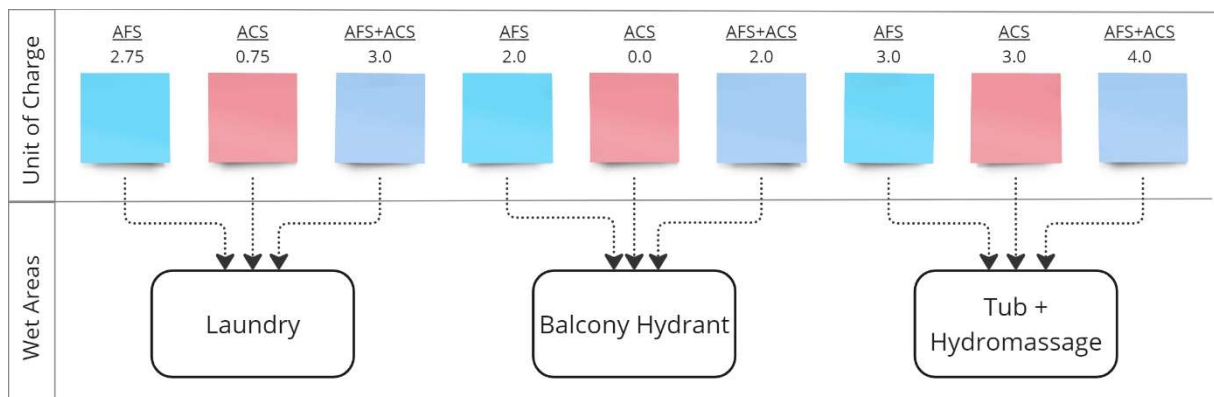
Figure 22:Water Supply Unit of Charge for Wet Areas 2 (Hot, Cold and Combined)

4.2.2.2. Water Supply Pipe Dimensioning.

To determine the dimension for the pipe supply for each unique group of spaces eg. Apartment, Commercial area, common area etc. the sum of UC for wet areas in the space is added together to determine the total UC for cold, hot and combined supply in each apartment. The following calculation is applied:

$$if(x = 0, 0, if(x < 1, 0.1 \times 3600, if(x < 100, (\exp(\ln(x)^{0.317}))^{5.7536}, if(x < 1000, (\exp(\ln(x)^{0.3623}))^{5.3688}, (\exp(\ln(x)^{0.391}))^{5.0791}$$

Equation 3: Formula for deriving Flow rate of Water Supply

For Example:

Apartment 01A1A2A3 has a UC value (x) of 20.25 the flow rate of the Cold-water supply for the apartment using the formula above is:

IF(20.25=0,0, ...): Since 20.25 is not equal to 0, it proceeds to the next nested IF statement.

IF(20.25<1,0.1*3600, ...): 20.25 is not less than 1, so it doesn't use the value 0.1*3600. It proceeds to the next nested IF statement.

$IF(20.25 < 100, (EXP(LN(20.25)^{0.317}))^{5.7536}, ...)$:

20.25 is less than 100, so it calculates the expression:

$$(\exp(\ln(20.25))^{0.317}))^{5.7536}$$
$$\ln(20.25) = 3.003$$
$$3.003^{0.317} = 1.137$$
$$\exp(1.137) = 3.115$$
$$3.115^{5.7536} = 3489.69 L/h$$

The same process is applied for hot water and combined water supply until all the apartments and unique group of spaces are rated. See the following tables for details(Table 7: Example Cold Water Supply Pipe Sizing Spreadsheet by Apartment Requirements.

To calculate the Diameter of the Supply pipes, we shall convert the Flow Rate from L/h to m/s and supply the formula below:

Ø of Pipe = $\left(\sqrt[2]{4 \times flow\ rate \div 1000 \div 3600 \div 3.14 \div Max_v}\right)1000$

Flow rate = 3489.69 L/h

Max_v = 2 m/s

Ø of Pipe = 35.15mm

Recommended pipe size shall be next size of pipe, DN40.

To determine the diameter of the pipe supplying water each to level, a similar formula is applied, only the UC considered for the "flow rate" equation would be a sum of the UCs of the apartments and unique group of spaces with wet areas on the floor only. Thereafter, the standard pipe diameter with flow rate value bigger but closest to the calculated value is adopted to supply water to the level. See Table 10

The next level of calculation would be to determine the diameter of the pipe supplying water to each zone/ core. Zone 1 however based on our classification earlier was divided into two areas to ensure adequate pressure on the upper floors (10-18). Applying same equation we arrive at the diameter for the pipes serving the zones (Table 11) and eventually supply pipes to be linked to public water supply (see Table 12).

Level/ Plan	Stairs Zone	Apartment Code	No. of Restrooms	AFS (Cold Water Supply)				
				UC	Portata [l/h]	Ø$_i$ [mm]	DN [Acciaio]	DN [Multistrato]
L.00	A.b	Common Area	2	7.5	1319	15.27	DN25	DN26
L.00	B	Common Area	1	3.75	537	9.75	DN20	DN20
L.00	C	Common Area	1	3.75	537	9.75	DN20	DN20
L.01	A.b	01A1A2A3	2	20.25	3490	24.85	DN40	DN40
L.01	A.b	01A4	1	14.25	2547	21.23	DN32	DN32
L.01	A.b	01A5+A6A7	1	14.25	2547	21.23	DN32	DN32
L.01	A.b	01A8	2	20.25	3490	24.85	DN40	DN40
L.01	A.b	01A9	1	14.25	2547	21.23	DN32	DN32
L.01	A.b	01A10	1	14.25	2547	21.23	DN32	DN32
L.01	A.b	01A11	2	20.25	3490	24.85	DN40	DN40
L.01	B	01B1	2	20.25	3490	24.85	DN40	DN40
L.01	B	01B2B3	1	14.25	2547	21.23	DN32	DN32
L.01	B	01B4	2	20.25	3490	24.85	DN40	DN40
L.01	C	01C1	2	20.25	3490	24.85	DN40	DN40
L.01	C	01C2C3C4	2	20.25	3490	24.85	DN40	DN40
L.01	C	01C5C6	2	20.25	3490	24.85	DN40	DN40
L.02	A.b	02A1A2	1	14.25	2547	21.23	DN32	DN32
L.02	A.b	02A3	1	14.25	2547	21.23	DN32	DN32
L.02	A.b	02A4A5	1	14.25	2547	21.23	DN32	DN32
L.02	A.b	02A6A7	1	14.25	2547	21.23	DN32	DN32
L.02	A.b	02A8	2	20.25	3490	24.85	DN40	DN40
L.02	A.b	02A9	1	14.25	2547	21.23	DN32	DN32
L.02	A.b	02A10	1	14.25	2547	21.23	DN32	DN32
L.02	A.b	02A11	2	20.25	3490	24.85	DN40	DN40
L.02	B	02B1	2	20.25	3490	24.85	DN40	DN40
L.02	B	02B2B3	1	14.25	2547	21.23	DN32	DN32
L.02	B	02B4	2	20.25	3490	24.85	DN40	DN40
L.02	C	02C1	2	20.25	3490	24.85	DN40	DN40
L.02	C	02C2C3	1	14.25	2547	21.23	DN32	DN32
L.02	C	02C4C5	1	14.25	2547	21.23	DN32	DN32
L.02	C	02C6	2	20.25	3490	24.85	DN40	DN40
L.03	A.b	03A1A2	1	14.25	2547	21.23	DN32	DN32
L.03	A.b	03A3	1	14.25	2547	21.23	DN32	DN32
L.03	A.b	03A4A5	2	20.25	3490	24.85	DN40	DN40
L.03	A.b	03A6A7	1	14.25	2547	21.23	DN32	DN32
L.03	A.b	03A8	2	20.25	3490	24.85	DN40	DN40
L.03	A.b	03A9	1	14.25	2547	21.23	DN32	DN32
L.03	A.b	03A10	1	14.25	2547	21.23	DN32	DN32
L.03	A.b	03A11	2	20.25	3490	24.85	DN40	DN40
L.03	B	03B1	2	20.25	3490	24.85	DN40	DN40
L.03	B	03B2B3	1	14.25	2547	21.23	DN32	DN32
L.03	B	03B4	2	20.25	3490	24.85	DN40	DN40
L.03	C	03C1	2	20.25	3490	24.85	DN40	DN40
L.03	C	03C2C3	1	14.25	2547	21.23	DN32	DN32
L.03	C	03C4C5	2	20.25	3490	24.85	DN40	DN40
L.03	C	03C6	2	20.25	3490	24.85	DN40	DN40
L.04	A.b	04A1A2	1	14.25	2547	21.23	DN32	DN32
L.04	A.b	04A3	1	14.25	2547	21.23	DN32	DN32
L.04	A.b	04A4A5	1	14.25	2547	21.23	DN32	DN32
L.04	A.b	04A6A7	1	14.25	2547	21.23	DN32	DN32
L.04	A.b	04A8	2	20.25	3490	24.85	DN40	DN40
L.04	A.b	04A9	1	14.25	2547	21.23	DN32	DN32
L.04	A.b	04A10	1	14.25	2547	21.23	DN32	DN32
L.04	A.b	04A11	2	20.25	3490	24.85	DN40	DN40
L.04	B	04B1	2	20.25	3490	24.85	DN40	DN40
L.04	B	04B2B3	1	14.25	2547	21.23	DN32	DN32
L.04	C	04C1	2	20.25	3490	24.85	DN40	DN40
L.04	C	04C2C3	1	14.25	2547	21.23	DN32	DN32
L.04	C	04C4C5	1	14.25	2547	21.23	DN32	DN32
L.04	C	04C6	2	20.25	3490	24.85	DN40	DN40

Table 7: Example Cold Water Supply Pipe Sizing Spreadsheet by Apartment Requirements

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Level/ Plan	Stairs Zone	Apartment Code	No. of Restrooms	UC2	ACS (Hot Water Supply)			
					Portata [l/h]3	Øi [mm]4	DN [Acciaio]5	DN [Multistrato]6
L.00	A.b	Common Area	2	1.5	75	3.65	DN15	DN14
L.00	B	Common Area	1	0.75	360	7.98	DN15	DN20
L.00	C	Common Area	1	0.75	360	7.98	DN15	DN20
L.01	A.b	01A1A2A3	2	8.25	1466	16.11	DN25	DN32
L.01	A.b	01A4	1	5.25	858	12.32	DN25	DN26
L.01	A.b	01A5+A6A7	1	5.25	858	12.32	DN25	DN26
L.01	A.b	01A8	2	8.25	1466	16.11	DN25	DN32
L.01	A.b	01A9	1	5.25	858	12.32	DN25	DN26
L.01	A.b	01A10	1	5.25	858	12.32	DN25	DN26
L.01	A.b	01A11	2	8.25	1466	16.11	DN25	DN32
L.01	B	01B1	2	8.25	1466	16.11	DN25	DN32
L.01	B	01B2B3	1	5.25	858	12.32	DN25	DN26
L.01	B	01B4	2	8.25	1466	16.11	DN25	DN32
L.01	C	01C1	2	8.25	1466	16.11	DN25	DN32
L.01	C	01C2C3C4	2	8.25	1466	16.11	DN25	DN32
L.01	C	01C5C6	2	8.25	1466	16.11	DN25	DN32
L.02	A.b	02A1A2	1	5.25	858	12.32	DN25	DN26
L.02	A.b	02A3	1	5.25	858	12.32	DN25	DN26
L.02	A.b	02A4A5	1	5.25	858	12.32	DN25	DN26
L.02	A.b	02A6A7	1	5.25	858	12.32	DN25	DN26
L.02	A.b	02A8	2	8.25	1466	16.11	DN25	DN32
L.02	A.b	02A9	1	5.25	858	12.32	DN25	DN26
L.02	A.b	02A10	1	5.25	858	12.32	DN25	DN26
L.02	A.b	02A11	2	8.25	1466	16.11	DN25	DN32
L.02	B	02B1	2	8.25	1466	16.11	DN25	DN32
L.02	B	02B2B3	1	5.25	858	12.32	DN25	DN26
L.02	B	02B4	2	8.25	1466	16.11	DN25	DN32
L.02	C	02C1	2	8.25	1466	16.11	DN25	DN32
L.02	C	02C2C3	1	5.25	858	12.32	DN25	DN26
L.02	C	02C4C5	1	5.25	858	12.32	DN25	DN26
L.02	C	02C6	2	8.25	1466	16.11	DN25	DN32
L.03	A.b	03A1A2	1	5.25	858	12.32	DN25	DN26
L.03	A.b	03A3	1	5.25	858	12.32	DN25	DN26
L.03	A.b	03A4A5	2	8.25	1466	16.11	DN25	DN32
L.03	A.b	03A6A7	1	5.25	858	12.32	DN25	DN26
L.03	A.b	03A8	2	8.25	1466	16.11	DN25	DN32
L.03	A.b	03A9	1	5.25	858	12.32	DN25	DN26
L.03	A.b	03A10	1	5.25	858	12.32	DN25	DN26
L.03	A.b	03A11	2	8.25	1466	16.11	DN25	DN32
L.03	B	03B1	2	8.25	1466	16.11	DN25	DN32
L.03	B	03B2B3	1	5.25	858	12.32	DN25	DN26
L.03	B	03B4	2	8.25	1466	16.11	DN25	DN32
L.03	C	03C1	2	8.25	1466	16.11	DN25	DN32
L.03	C	03C2C3	1	5.25	858	12.32	DN25	DN26
L.03	C	03C4C5	2	8.25	1466	16.11	DN25	DN32
L.03	C	03C6	2	8.25	1466	16.11	DN25	DN32
L.04	A.b	04A1A2	1	5.25	858	12.32	DN25	DN26
L.04	A.b	04A3	1	5.25	858	12.32	DN25	DN26
L.04	A.b	04A4A5	1	5.25	858	12.32	DN25	DN26
L.04	A.b	04A6A7	1	5.25	858	12.32	DN25	DN26
L.04	A.b	04A8	2	8.25	1466	16.11	DN25	DN32
L.04	A.b	04A9	1	5.25	858	12.32	DN25	DN26
L.04	A.b	04A10	1	5.25	858	12.32	DN25	DN26
L.04	A.b	04A11	2	8.25	1466	16.11	DN25	DN32
L.04	B	04B1	2	8.25	1466	16.11	DN25	DN32
L.04	B	04B2B3	1	5.25	858	12.32	DN25	DN26
L.04	C	04C1	2	8.25	1466	16.11	DN25	DN32
L.04	C	04C2C3	1	5.25	858	12.32	DN25	DN26
L.04	C	04C4C5	1	5.25	858	12.32	DN25	DN26
L.04	C	04C6	2	8.25	1466	16.11	DN25	DN32

Table 8: Example Hot Water Supply Pipe Sizing Spreadsheet by Apartment Requirements

Level/ Plan	Stairs Zone	Apartment Code	No. of Restrooms	ACS+AFS				
				UC7	Portata [l/h]8	Øi [mm]9	DN [Acciaio]10	DN [Multistrato]11
L.00	A.b	Common Area	2	8	1417	15.84	DN25	DN32
L.00	B	Common Area	1	4	591	10.22	DN20	DN20
L.00	C	Common Area	1	4	591	10.22	DN20	DN20
L.01	A.b	01A1A2A3	2	23	3887	26.23	DN40	DN40
L.01	A.b	01A4	1	16	2834	22.39	DN32	DN40
L.01	A.b	01A5+A6A7	1	16	2834	22.39	DN32	DN40
L.01	A.b	01A8	2	23	3887	26.23	DN40	DN40
L.01	A.b	01A9	1	16	2834	22.39	DN32	DN40
L.01	A.b	01A10	1	16	2834	22.39	DN32	DN40
L.01	A.b	01A11	2	23	3887	26.23	DN40	DN40
L.01	B	01B1	2	23	3887	26.23	DN40	DN40
L.01	B	01B2B3	1	16	2834	22.39	DN32	DN40
L.01	B	01B4	2	23	3887	26.23	DN40	DN40
L.01	C	01C1	2	23	3887	26.23	DN40	DN40
L.01	C	01C2C3C4	2	23	3887	26.23	DN40	DN40
L.01	C	01C5C6	2	23	3887	26.23	DN40	DN40
L.02	A.b	02A1A2	1	16	2834	22.39	DN32	DN40
L.02	A.b	02A3	1	16	2834	22.39	DN32	DN40
L.02	A.b	02A4A5	1	16	2834	22.39	DN32	DN40
L.02	A.b	02A6A7	1	16	2834	22.39	DN32	DN40
L.02	A.b	02A8	2	23	3887	26.23	DN40	DN40
L.02	A.b	02A9	1	16	2834	22.39	DN32	DN40
L.02	A.b	02A10	1	16	2834	22.39	DN32	DN40
L.02	A.b	02A11	2	23	3887	26.23	DN40	DN40
L.02	B	02B1	2	23	3887	26.23	DN40	DN40
L.02	B	02B2B3	1	16	2834	22.39	DN32	DN40
L.02	B	02B4	2	23	3887	26.23	DN40	DN40
L.02	C	02C1	2	23	3887	26.23	DN40	DN40
L.02	C	02C2C3	1	16	2834	22.39	DN32	DN40
L.02	C	02C4C5	1	16	2834	22.39	DN32	DN40
L.02	C	02C6	2	23	3887	26.23	DN40	DN40
L.03	A.b	03A1A2	1	16	2834	22.39	DN32	DN40
L.03	A.b	03A3	1	16	2834	22.39	DN32	DN40
L.03	A.b	03A4A5	2	23	3887	26.23	DN40	DN40
L.03	A.b	03A6A7	1	16	2834	22.39	DN32	DN40
L.03	A.b	03A8	2	23	3887	26.23	DN40	DN40
L.03	A.b	03A9	1	16	2834	22.39	DN32	DN40
L.03	A.b	03A10	1	16	2834	22.39	DN32	DN40
L.03	A.b	03A11	2	23	3887	26.23	DN40	DN40
L.03	B	03B1	2	23	3887	26.23	DN40	DN40
L.03	B	03B2B3	1	16	2834	22.39	DN32	DN40
L.03	B	03B4	2	23	3887	26.23	DN40	DN40
L.03	C	03C1	2	23	3887	26.23	DN40	DN40
L.03	C	03C2C3	1	16	2834	22.39	DN32	DN40
L.03	C	03C4C5	2	23	3887	26.23	DN40	DN40
L.03	C	03C6	2	23	3887	26.23	DN40	DN40
L.04	A.b	04A1A2	1	16	2834	22.39	DN32	DN40
L.04	A.b	04A3	1	16	2834	22.39	DN32	DN40
L.04	A.b	04A4A5	1	16	2834	22.39	DN32	DN40
L.04	A.b	04A6A7	1	16	2834	22.39	DN32	DN40
L.04	A.b	04A8	2	23	3887	26.23	DN40	DN40
L.04	A.b	04A9	1	16	2834	22.39	DN32	DN40
L.04	A.b	04A10	1	16	2834	22.39	DN32	DN40
L.04	A.b	04A11	2	23	3887	26.23	DN40	DN40
L.04	B	04B1	2	23	3887	26.23	DN40	DN40
L.04	B	04B2B3	1	16	2834	22.39	DN32	DN40
L.04	C	04C1	2	23	3887	26.23	DN40	DN40
L.04	C	04C2C3	1	16	2834	22.39	DN32	DN40
L.04	C	04C4C5	1	16	2834	22.39	DN32	DN40
L.04	C	04C6	2	23	3887	26.23	DN40	DN40

Table 9: Example Combined Water Supply Pipe Sizing Spreadsheet by Apartment Requirements

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HOT AND COLD WATER SUPPLY BY LEVEL													
		AFS (Cold Water Supply)				ACS (Hot Water Supply)				ACS+AFS (Hot and Cold Water Supply)			
Livello/ Piano	Stairs Zone	UC	Portata [l/h]	Øi [mm]	DN [Acciaio]	UC2	Portata [l/h]3	Øi [mm]4	DN [Acciaio]	UC6	Portata [l/h]7	Øi [mm]8	DN [Acciaio]9
L.01	A.b	117.75	12771	47.53	DN50	45.75	6646	34.29	DN40	133	13928	49.64	DN50
L.02	A.b	126.00	13404	48.70	DN50	48	6882	34.89	DN50	142	14585	50.80	DN50
L.03	A.b	132.00	13854	49.51	DN50	51	7189	35.66	DN50	149	15084	51.66	DN50
L.04	A.b	126.00	13404	48.70	DN50	48	6882	34.89	DN50	142	14585	50.80	DN50
L.05	A.b	117.75	12771	47.53	DN50	45.75	6646	34.29	DN40	133	13928	49.64	DN50
L.06	A.b	123.75	13233	48.39	DN50	48.75	6959	35.09	DN50	140	14441	50.55	DN50
L.07	A.b	81.00	9887	41.82	DN50	33	5198	30.33	DN40	92	10750	43.61	DN50
L.08	A.b	87.00	10365	42.82	DN50	36	5558	31.36	DN40	99	11273	44.66	DN50
L.09	A.b	60.75	8133	37.93	DN50	24.75	4131	27.04	DN40	69	8877	39.63	DN50
L.10	A.a	60.75	8133	37.93	DN50	24.75	4131	27.04	DN40	69	8877	39.63	DN50
L.11	A.a	60.75	8133	37.93	DN50	24.75	4131	27.04	DN40	69	8877	39.63	DN50
L.12	A.a	60.75	8133	37.93	DN50	24.75	4131	27.04	DN40	69	8877	39.63	DN50
L.13	A.a	60.75	8133	37.93	DN50	24.75	4131	27.04	DN40	69	8877	39.63	DN50
L.14	A.a	46.50	6725	34.49	DN50	19.5	3378	24.45	DN32	53	7389	36.16	DN50
L.15	A.a	29.25	4728	28.92	DN40	14.25	2547	21.23	DN32	34	5319	30.68	DN40
L.16-17	A.a	35.25	5469	31.11	DN40	17.25	3033	23.16	DN32	41	6130	32.93	DN40
L.01	B	54.75	7561	36.58	DN50	21.75	3709	25.62	DN40	62	8249	38.20	DN50
L.02	B	54.75	7561	36.58	DN50	21.75	3709	25.62	DN40	62	8249	38.20	DN50
L.03	B	54.75	7561	36.58	DN50	21.75	3709	25.62	DN40	62	8249	38.20	DN50
L.04	B	34.50	5380	30.85	DN40	13.5	2420	20.69	DN32	39	5905	32.32	DN40
L.05	B	20.25	3490	24.85	DN40	8.25	1466	16.11	DN25	23	3887	26.23	DN40
L.06	B	20.25	3490	24.85	DN40	8.25	1466	16.11	DN25	23	3887	26.23	DN40
L.07	B	20.25	3490	24.85	DN40	8.25	1466	16.11	DN25	23	3887	26.23	DN40
L.08	B	20.25	3490	24.85	DN40	8.25	1466	16.11	DN25	23	3887	26.23	DN40
L.09	B	26.25	4335	27.69	DN40	11.25	2027	18.94	DN32	30	4824	29.22	DN40
L.01	C	60.75	8133	37.93	DN50	24.75	4131	27.04	DN40	69	8877	39.63	DN50
L.02	C	69.00	8877	39.63	DN50	27	4435	28.01	DN40	78	9642	41.30	DN50
L.03	C	75.00	9392	40.76	DN50	30	4824	29.22	DN40	85	10207	42.50	DN50
L.04	C	69.00	8877	39.63	DN50	27	4435	28.01	DN40	78	9642	41.30	DN50
L.05	C	60.75	8133	37.93	DN50	24.75	4131	27.04	DN40	69	8877	39.63	DN50
L.06	C	54.75	7561	36.58	DN50	21.75	3709	25.62	DN40	62	8249	38.20	DN50

Table 10: Cold, Hot and Combined Water Supply Pipe Sizing by Level Requirement

Stairs Zone												
	AFS				ACS				ACS+AFS			
Scala	UC	Portata [l/h]	Øi [mm]	DN [Acciaio]	UC2	Portata [l/h]3	Øi [mm]4	DN [Acciaio]	UC6	Portata [l/h]7	Øi [mm]8	DN [Acciaio]9
A.b	979.50	49110	93.21	DN100	382.5	28066	70.47	DN65	1107	52864	96.71	DN100
A.a	354.00	26737	68.78	DN65	150	15155	51.78	DN50	404	29037	71.68	DN80
B	309.75	24567	65.93	DN65	123.75	13233	48.39	DN50	351	26594	68.59	DN65
C	393.00	28544	71.06	DN80	156	15573	52.49	DN50	445	30823	73.85	DN80

Table 11: Hot, Cold and Combined Water Supply Pipe Sizing by Building Core Zone Requirement

Presure Lines												
	AFS				ACS				ACS+AFS			
Scala	UC	Portata [l/h]	Øi [mm]	DN [Acciaio]	UC2	Portata [l/h]3	Øi [mm]4	DN [Acciaio]5	UC6	Portata [l/h]7	Øi [mm]8	DN [Acciaio]9
Bassa	1682.25	67838	109.56	DN125	662.25	39153	83.23	DN100	1903.00	72891	113.56	DN125
Alta	354.00	26737	68.78	DN65	150.00	15155	51.78	DN50	404.00	29037	71.68	DN80
									2307.00	81428	120.03	DN125

Table 12: Building Water Supply Pressure Line Pipe Sizing (Hot, Cold and Combined).

4.3.2. MEP Modelling

Further to the disclosure about the setup of the models in the previous chapter, calculation and modelling activities were carried out simultaneously. Each Discipline was set up as an independent Revit file, with sample Revit files supplied by the project BIM Managers. To start each model (Mechanical, Electrical, Plumbing) Architecture and Structural files were linked into the new file using their shared coordinate as reference point. For the purpose of this thesis, we shall explore MEP modelling of the Plumbing Services in our analysis.

The key elements of the success of the modelling phase of this project are in physical and meta-data representation of modelled elements for the purpose of QTO and eventually construction documentation. QTO relies on the properties and mapped parameters related to modelled elements to provide prescriptive cost of construction, therefore care was taking in the selection of materials, setting up and cleaning of families to ensure that only required information is introduced into the model. For plumbing, the authoring tool plumbing families were used, with modification to the diameters to match results of the pipe sizing calculations.
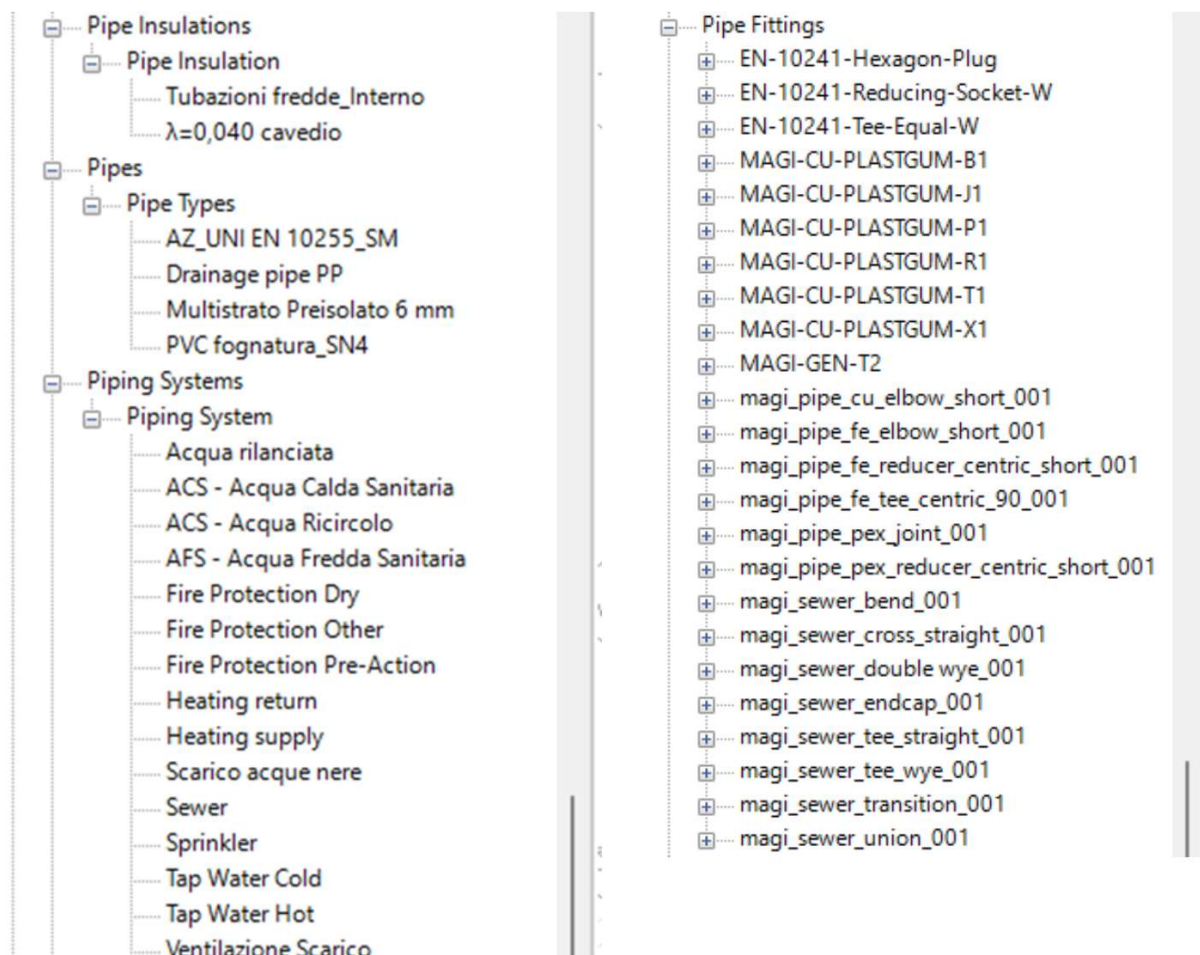
Figure 23: Directory of Plumbing Systems, Pipes, Insulations and Fittings Families.

The pipe families used for Water Supply and Waste Water Disposal are:

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1. Steel Pipes: Recirculated water, Domestic Hot and Cold Water (Risers and Distribution)
2. PVC Pipes: Wastewater Discharge Pipes and Exhaust Ventilation Pipes
3. Pre-insulated Ventilation Pipes: Tap Water Hot, Tap Water Cold
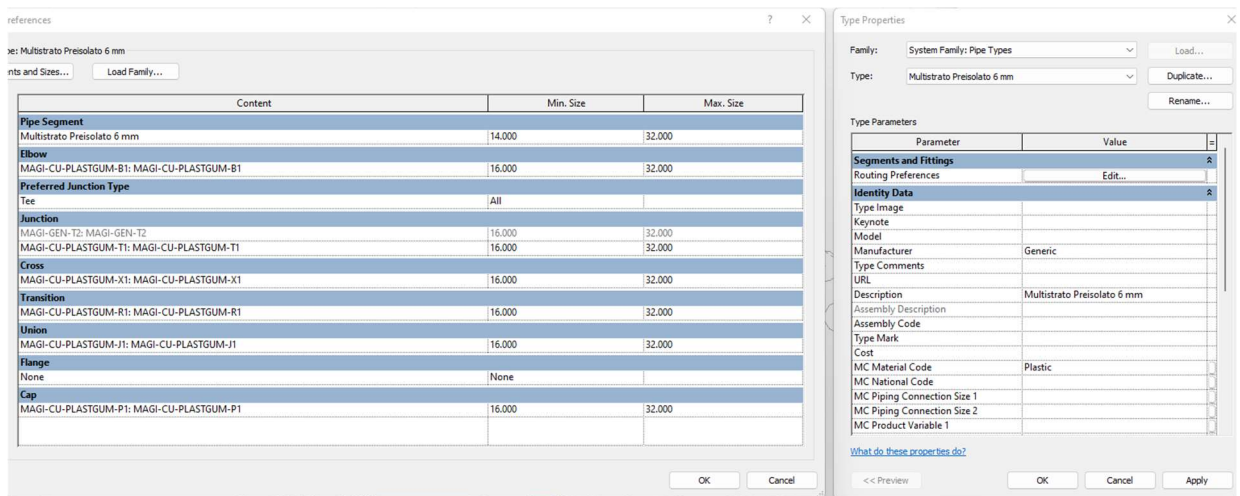
Figure 24: Pre-insulated Multilayer pipe showing Dimensions and Fittings Properties.

Figure 25: Level L01 showing Zones, Wet Areas, Water Supply Distribution and Wastewater Discharge Points.

For each pipe type and size, pipe fittings and insulation (type and thickness) where applicable were also assigned. Figure 21 shows the properties of a multilayer pipe with related families and their dimensions.

Figure 26: Level L01, Showing layout of Plumbing Pipes (Water Supply, Wastewater Discharge)

4.3.3. WBS Implementation

The WBS as defined in the BEP was to enable the definition of cost during design stage based on several criteria. For example, cost of each apartment, common facilities, each discipline (heating, cooling, ELV, etc) in the building, cost by floor or zone, also cost of sellable (commercial) footprint against cost of common areas. Etc.

4.3.3.1. Revit WBS Parameter Setup

To implement the WBS in Revit, Parameters were created using the Shared Parameter function in Revit. Using the agreed naming convention for the project, Shared parameters, grouped under the text category in the properties tab and assigned to all elements in the discipline of each file (in this case Electrical). Figure 25 shows the Shared Parameter being created in Revit environment.

Code	Description
00	Exernal&Basement
01	Building 01

Code	Description
AR	Architettura
ST	Strutture
IS	Impianto idrico sanitario e smaltimento a
ME	Climatizzazione e ventilazione
EL	Impianti elettrici e speciali
PL	Smaltimento acque meteoriche
AN	Impianti antincendio

Code	Description
B03	Basement -3
B02	Basement -2
B01	Basement -1
L00	Ground Floor
L01	1st Floor
L02	2nd Floor
L03	3rd Floor
L04	4th Floor
L05	5th Floor
L06	6th Floor
L07	7th Floor
L08	8th Floor
L09	9th Floor
L10	10th Floor
L11	11th Floor
L12	12th Floor
L13	13th Floor
L14	14th Floor
L15	15th Floor
L16	16th Floor
L17	17th Floor
L18	18th Floor
L19	19th Floor
MLV	Multiple Levels
000	No Levels (for technical documents)

Code	Description
HCE	Horizontal Connection
VCE	Vertical Connection
PBA	Public spaces (unheated)
APT	Appartments
EXA	External Areas
LTE	Loggias and Terraces
FAC	Facade
PIL	Pilotis -open spaces
ROO	Roofing
TEC	Technical spaces
UNA	Undergound Technical spaces
UNB	Underground Box
UNC	Underground Cellar
UND	Parking distribution
GEN	Generic

Code	Description
10	Scavi
20	Rinterri
30	Fondazioni
40	Fondazioni speciali
50	Magrone
60	Opere di contenimento
70	Muri e setti strutturali in c.a.
80	Pilastri strutturali in c.a.
90	Travi strutturali in c.a.
100	Solai e solette strutturali in c.a.
110	Scale strutturali in c.a.
120	Rampe strutturali in c.a.
130	Pilastri strutturali in acciaio
140	Travi strutturali in acciaio
150	Solai e solette strutturali in lamiera
	...
200	Massetti
210	Pavimentazioni esterne
220	Pavimentazioni interne
230	Zoccolini
240	Zerbini
250	...
300	Muri perimetrali di facciata
310	Facciata ventilata
320	Sottostruttura facciata ventilata
330	Facciate vetrate ai piani terra
340	...
340	Cappotto
350	Carter
360	Davanzali
370	Elementi di decoro
380	Elementi fiorirera o muretti divisori
390	Finitura cappotto
400	Murature - partizioni interne -
410	Intonaci
420	Intonaci antincendio
430	Intonaci di finitura
440	Isolamenti termici
450	isolamenti acustici
460	....
500	Impermeabilizzazioni
510	Lattonerie
520	Copertura
530	...
600	Controsoffitti tradizionali
610	Controsoffitti REI
620	Rivestimenti
630	Tinteggiature
640	...
700	Trattamenti impermeabilizzanti
710	Trattamenti intumescenti
720	Canne fumarie/areazioni
730	...
800	Serramenti
810	Serrande
820	Soglie
830	Monoblocco per ventilazione
840	Motorizzazione avvolgibile
850	Avvolgibile
860	Zanzariera
870	Porte interne
880	Porte cantine
890	Porte REI
900	Ascensori
910	Opere in pietra
920	Cancelli e recinzioni
930	Parapetti
940	Frames
950	Grigliati
960	Raccolta acque
970	Verde comune
980	Terreno
990	Giardini privati
1000	...
2400	Impianto ascensori
2410	...
2500	Approntamenti di cantiere

Code	Description
L01_A1A2A3	Apartment 001
L01_A4	Apartment 002
L01_A5+A6A7	Apartment 003
L01_A8	Apartment 004
L01_A9	Apartment 005
L01_A10	Apartment 006
L01_A11	Apartment 007
L01_B1	Apartment 008
L01_B2B3	Apartment 009
L01_B4	Apartment 010
L01_C1	Apartment 011
L01_C2C3C4	Apartment 012
L01_C5C6	Apartment 013
L02_A1A2	Apartment 014
L02_A3	Apartment 015
L02_A4A5	Apartment 016
L02_A6A7	Apartment 017
L02_A8	Apartment 018
L02_A09	Apartment 019
L02_A10	Apartment 020
L02_A11	Apartment 021
L02_B1	Apartment 022
L02_B2B3	Apartment 023
L02_B4	Apartment 024
L02_C1	Apartment 025
L02_C2C3	Apartment 026
L02_C4C5	Apartment 027
L02_C6	Apartment 028
L03_A1A2	Apartment 029
L03_A3	Apartment 030
L03_A4A5	Apartment 031
L03_A6A7	Apartment 032
L03_A8	Apartment 033
L03_A09	Apartment 034
L03_A10	Apartment 035
L03_A11	Apartment 036
L03_B1	Apartment 037
L03_B2B3	Apartment 038
L03_B4	Apartment 039
L03_C1	Apartment 040
L03_C2C3	Apartment 041
L03_C4C5	Apartment 042
L03_C6	Apartment 043
L04_A1A2	Apartment 044
L04_A3	Apartment 045
L04_A4A5	Apartment 046
L04_A6A7	Apartment 047
L04_A8	Apartment 048
L04_A09	Apartment 049
L04_A10	Apartment 050
L04_A11	Apartment 051
L04_B1	Apartment 052
L04_B2B3	Apartment 053
L04_C1	Apartment 054
L04_C2C3	Apartment 055
L04_C4C5	Apartment 056
L04_C6	Apartment 057
L05_A1+A11	Apartment 058
L05_A2+A3	Apartment 059
L05_A4A5	Apartment 060
L05_A6A7	Apartment 061
L05_A8	Apartment 062
L05_A09	Apartment 063
L05_A10	Apartment 064
L05_B1+B2B3	Apartment 065
L05_C1+C2	Apartment 066
L05_C3+C4C5	Apartment 067
L05_C6	Apartment 068
L06_A1+A11	Apartment 069
L06_A2+A3	Apartment 070
L06_A4A5	Apartment 071
L06_A6A7	Apartment 072
L06_A8	Apartment 073
L06_A09	Apartment 074
L06_A10	Apartment 075
L06_B1+B2B3	Apartment 076
L06_C1	Apartment 077

Figure 27: Project WBS Categories

There are 7 levels Shared parameters created from the WBS categories as follows (figure 24):

- WBS_01 - Project
- WBS_02 - Building
- WBS_03 - Discipline
- WBS_04 - Level
- WBS_05 - Compartment
- WBS_06 - Work Categories
- **WBS_07 - Apartment
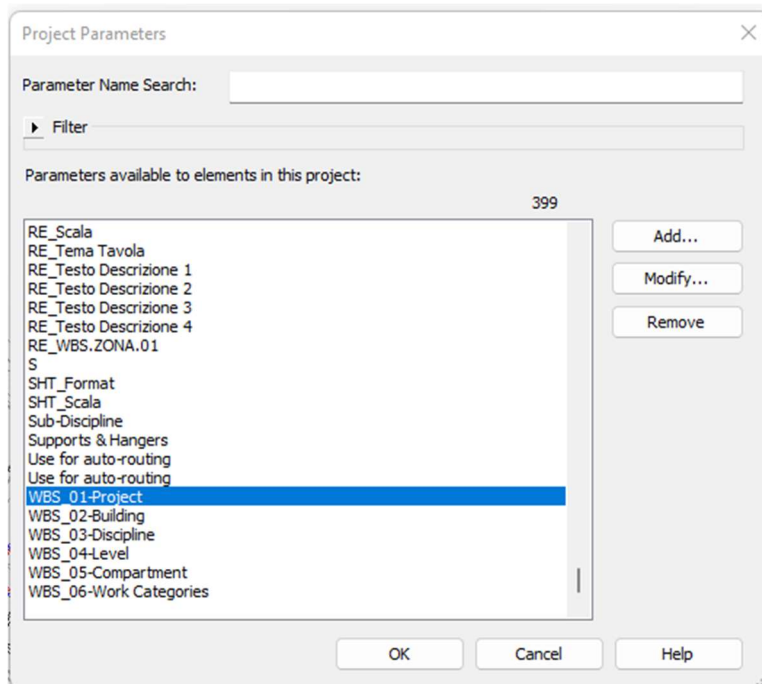
Figure 28: WBS Project Parameters in Revit

4.3.3.2. Assigning WBS Properties
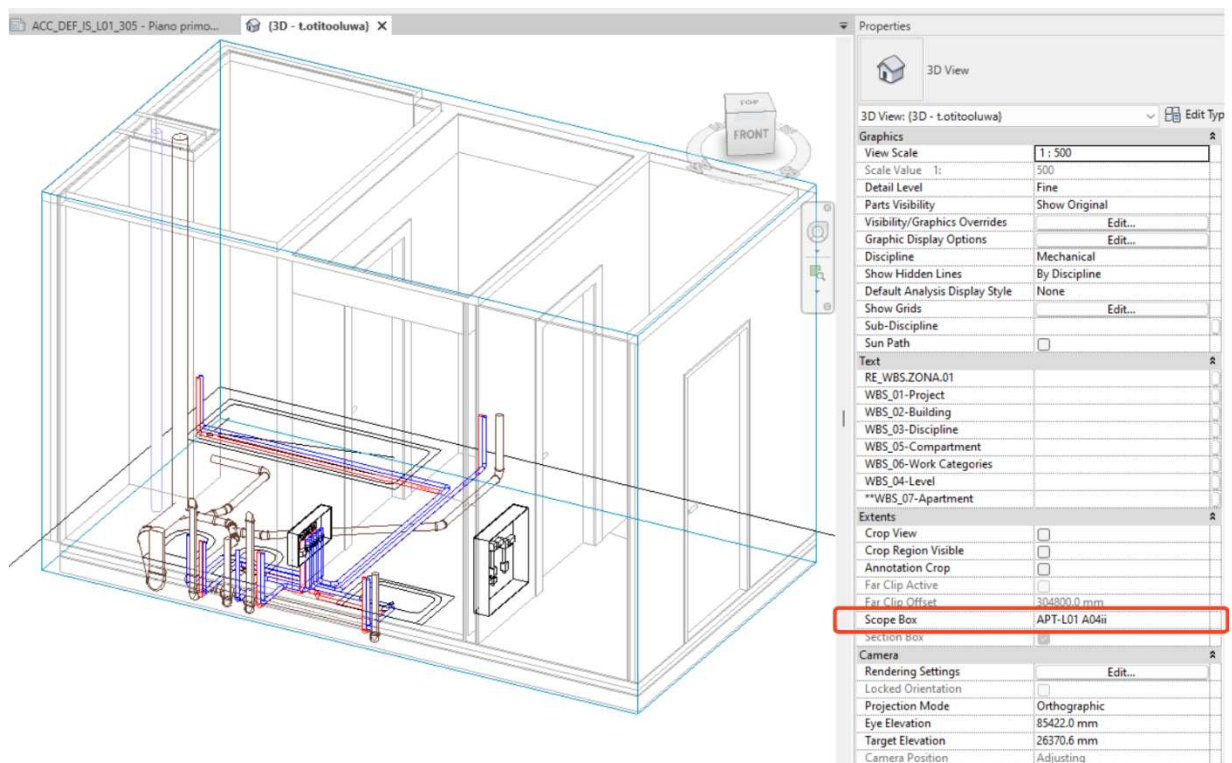
Figure 29: Revit Scope Box Tool Isolating Model Elements for WBS Application

In other to assign the WBS properties just created the modelled elements, 3D scope Boxes were used to Isolate modelled elements by room bounded space. The scope boxes were named based on the description

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of the rooms they were generated. Figure 26 shows a scope box 3D view (apartment L01-A04), modelled elements within the scope view were then assigned WBS properties according to the categories.
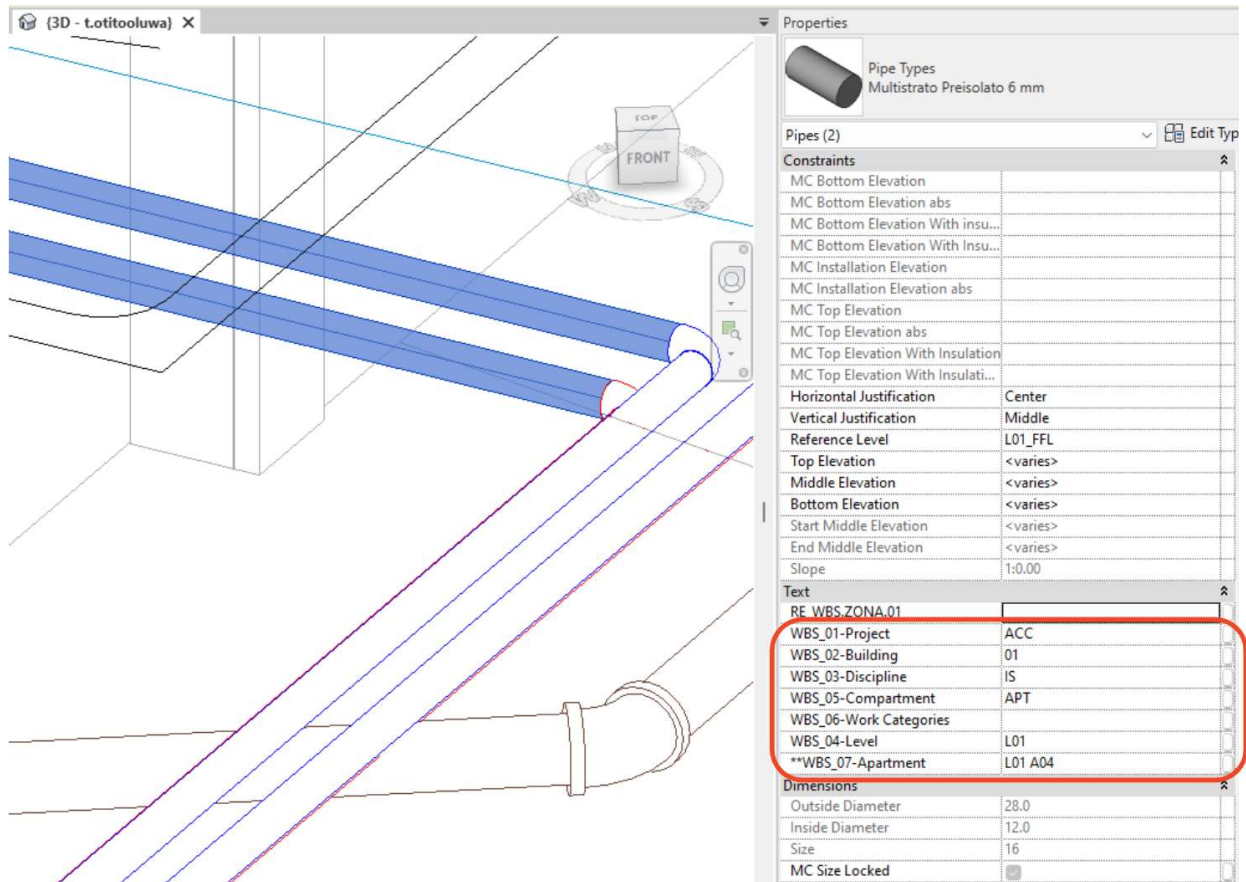
Figure 30: Modelled Pipes showing WBS Properties after Application.

When the assignment of WBS properties is complete, the WBS data of each modelled element can be seen on the properties tab Revit. Figure 27 shows 2 multi-layer pipes on the In the Building above ground (WBS_02) in the Plumbing discipline (WBS_03) on level L01 (WBS_04) in an apartment (WBS_05) called A04 (**WBS_07), In this instance (work category WBS_06) properties has not been assigned as the modelling was still on-going.

4.3.4. MVD and Exchange Requirements

The MVD is a milestone format which we need to ensure would transfer the critical information we require to carryout QTO at this stage. The literature review provided information about two main MVD that would be appropriate for this stage (2x3 coordination View, and 4.0 reference view) with a recommendation for 4.0. There was no specified MVD in the BEP document, therefore both MVDs were tested for this exchange to see which would be most suitable. IFC 4.0 Reference view was eventually favoured because it provided better and more consistent dimensions for the geometry of the pipes in its QTO properties.

4.3.4.1. IFC Export Setup

To prepare the Revit file for Export, IFC shared parameter file was used to apply parameters that would map the information contained in the model into IFC. The Parameters mapped are in two categories.
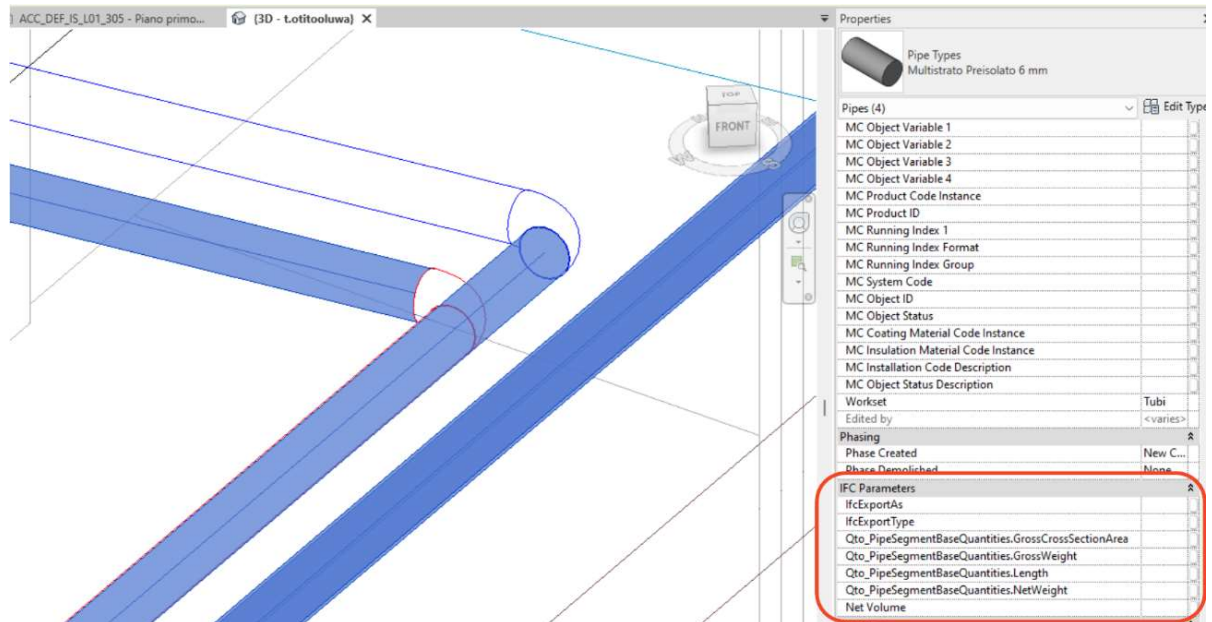
Figure 31: IFC Shared Parameters Mapped into Revit Model
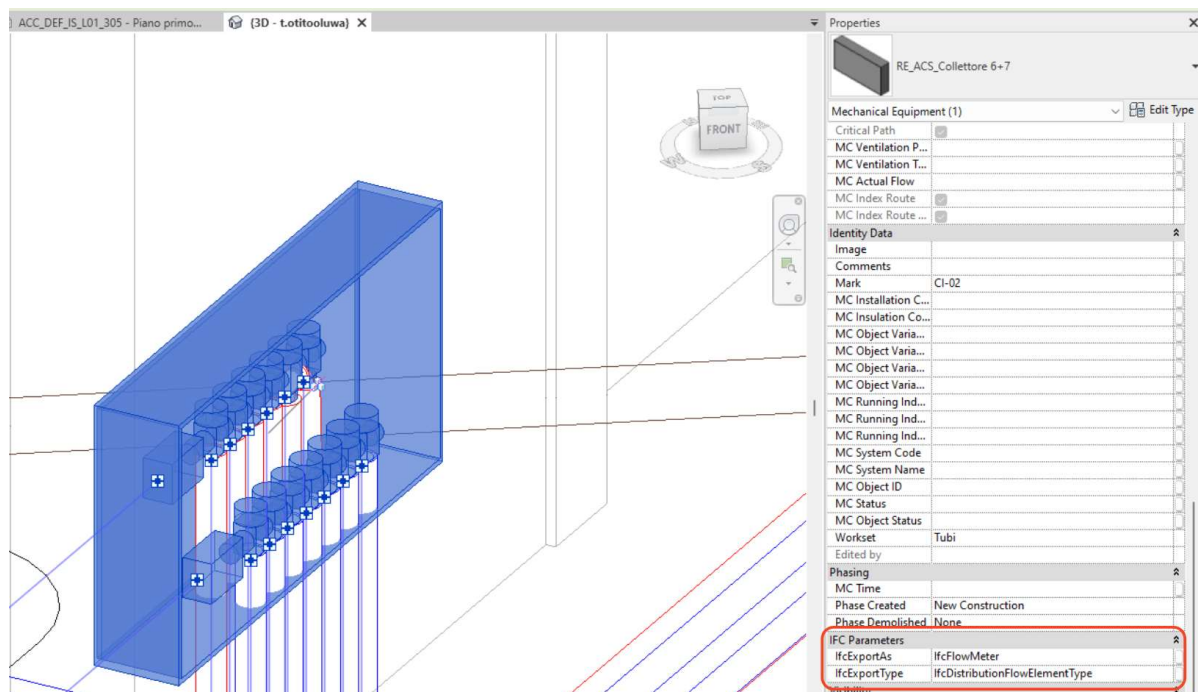
Figure 32: Hot/ Cold Water Collecttore IFC Custom Mapping

- Family Mapping Parameters: the is the IfcExportAs and IfcExportType, these two families were used do provide custom mapping for categories of family which may not export to the right Ifc class. This sometimes happens with mechanical equipment.

- QTO Parameters Mapping: This are properties under the "Qto_PipeSegmentBaseQuantities", the parameter maps geometrical data from Revit families into IFC. Properties like Length, Gross weight, Length, Net weight, Diameter etc.

Finally, as a verification measure, a schedule of the pipes was created with the dimension properties of the pipes, the property schedule would be exported into IFC as (IFCPipeQuantities) and used as a validation tool for the QTO values and to provide additional volumetric dimensional data for estimation. The values contain geometry values and calculated values (Net Cross Section Area) which is a factor for calculating quantities for one of the plumbing pipes. Figure 30.

Figure 33: Sheduled Pipe Quantities for IFC Mapping

Another User defined set of parameters is created to Map the Values of the WBS to the IFC model. Using the Default User Defined Parameter Sets file in revit, the WBS was populated specifying the name and index of each parameter. This would be used during export for mapping.

Figure 34: User Defined Parameters Format for IFC Export

During the export, according to figure 32, export setup was modified, on the general pane, IFC4.0 Reference View was selected, the exchange requirement was also set at MEP Reference Exchange, only visible element as picked at the "additional Content" window and the "PropertySet" window, common

properties and Base Quantities was checked. For validation, of exported quantities, schedules containing PSet/ Ifc/ Common was exported. Finally, the user defined properties file was mapped to the set up. The coordinates were also confirmed to be shared coordinate before final export was done. Figure 32
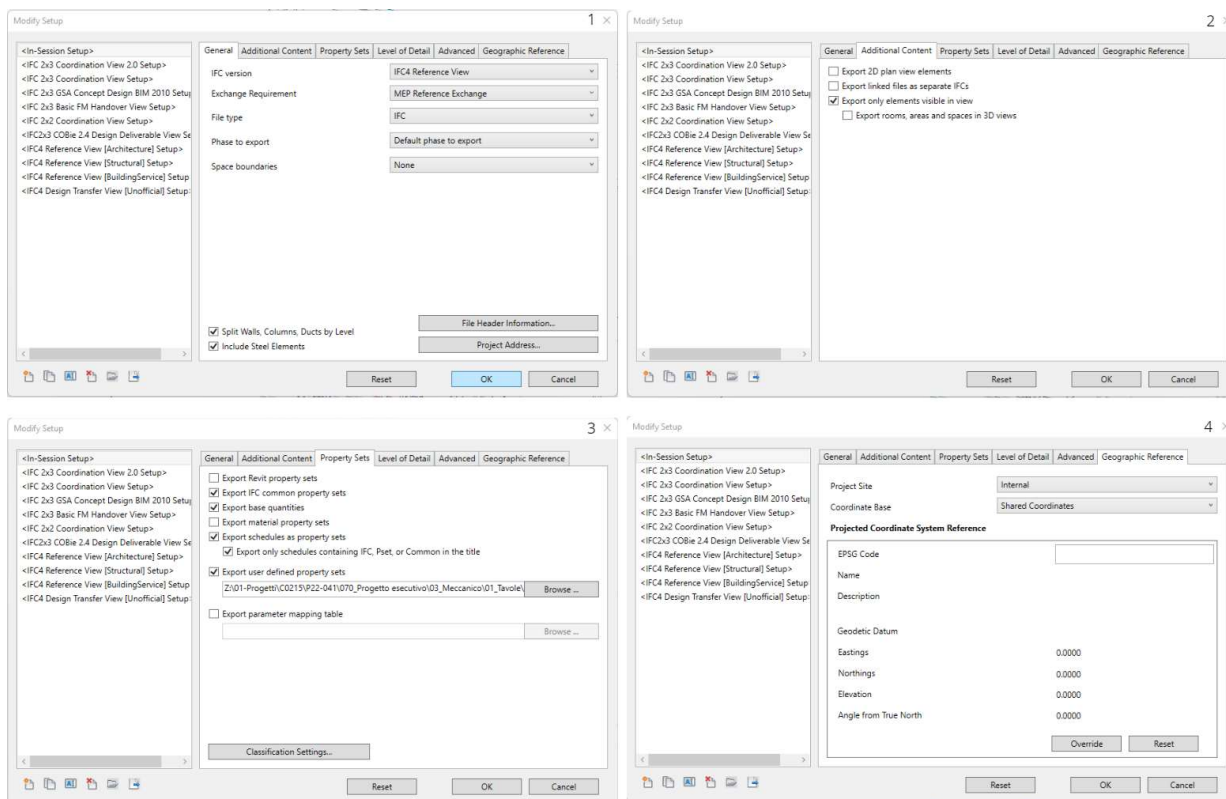
Figure 35: Revit IFC Export Window

4.3.4.2. IFC File Inspection

After the Ifc export is complete, an investigation of the file properties was done in two BIMViewer softwares (BIMVision and KITModel Viewer). The goal of this exercise was to ensure that our exported Ifc file contains, and the geometry data modelled. We would check for the structure of the Ifc file in Figure 33. The file has the correct hierarchy from Project to site, then Building Storey thereafter elements on each floor. The next test would be the Mechanical equipment (Hot/ Cold Water Collecttore), checking the Ifc Properties shows that the ExportAs parameter exported the elements into the right category. Also, Figure 34 shows that the WBS parameters export functions.

Figure 36: Exported IFC Structure
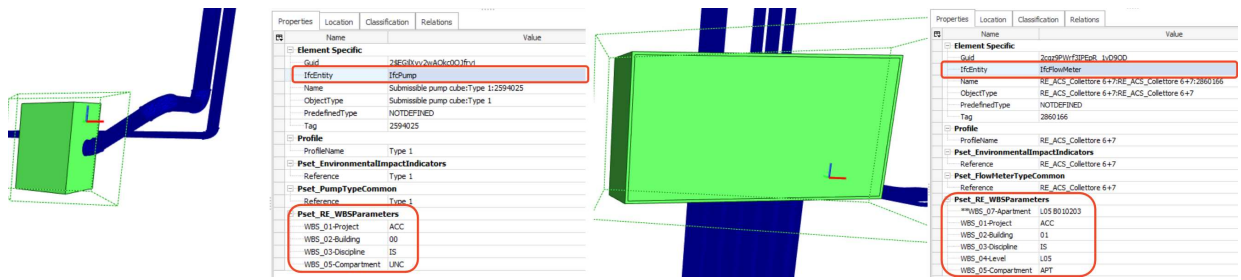
Figure 37: MEP Equipement Ifc Validation
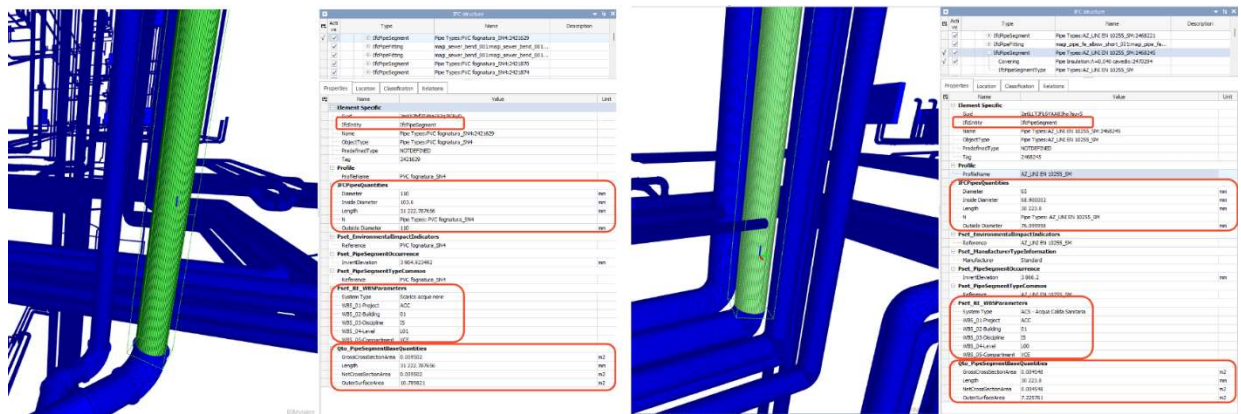
Figure 38: IFC Export Pipes Properties Validation

4.3.5. Quantity Take Off

Quantity Take-off for the MEP services was done using STR Vision CPM (STR) software, and the price list was Provided by Rethink Energy, being a private Price list updated frequently based on market prices and contractors priced bills. The process involves the following activities, creating filters for the elements in the Ifc, then Creating the Take of rule for unique type of element. Only after this can we use the parametric function of the software to apply WBS and the save rules and filters to applied to the rest of the elements in the model to develop a comprehensive QTO of the design. The Image below figure 38 show a map of the process.
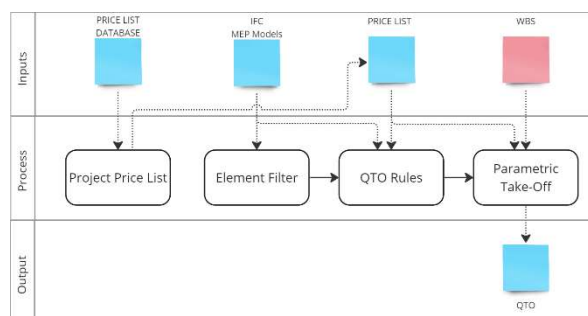
Figure 39: QTO Process Map using STR Vision CPM

4.3.5.1. Price List Mapping.

The price list other than having the cost per unit measure of an object, also contains information like labour cost, transportation and enabling works to execute the task (it was detailed in the concept chapter).

The first action was to access the organisations price list database and extract into the project, price list of objects in the Ifc model. For this exercise, a list of modelled objects by Type was scheduled in Revit and exported into excel. This list was thereafter cross referenced against the price list to extract price list codes of unique objects in the model.

Table 13 : List of Revit Objects by Type (Electrical and Plumbing)

Figure 40: STR Project Price List after Extraction from Database.

The table above shows sample List of Plumbing and Electrical objects in the Ifc models. When the project price list is eventually extracted from the database into project STR file, the prices become available for mapping when the Take Off rules are calculated. Finally, project Units in STR are validated to ensure alignment between the unit of measurement in STR and IFC.

4.3.5.2. Object Filter Template.

Assigning property to objects happen in categories. Using the hierarchy common to the categories, filers are created to filter every unique object in the project with the breakdown below. The figure shows filters for elements of three and four levels. The level breaks down objects by reference level in the project, while the category classify object by IfcType eg,(IfcFlow, IfcPipe) etc. The next level is the categories, when each object type is classified by the category they belong in the type. Within each object type we may have other characteristics that classify objects, eg. Pipe diameters, this is the next property used to categorise the object. Each unique category is named and save as a filter Template which would be used at the Parametric Costing stage.
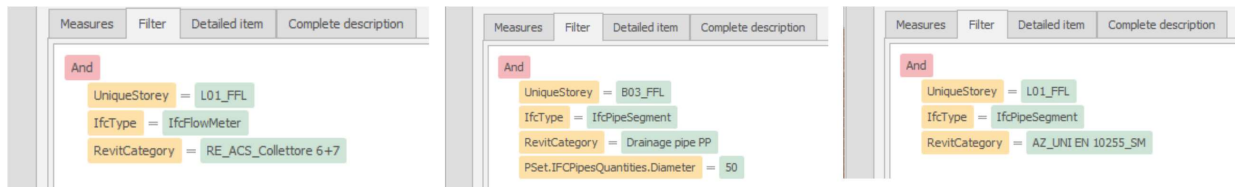
Figure 41 : Levels of Filter to Categorise IfcObjects in STR
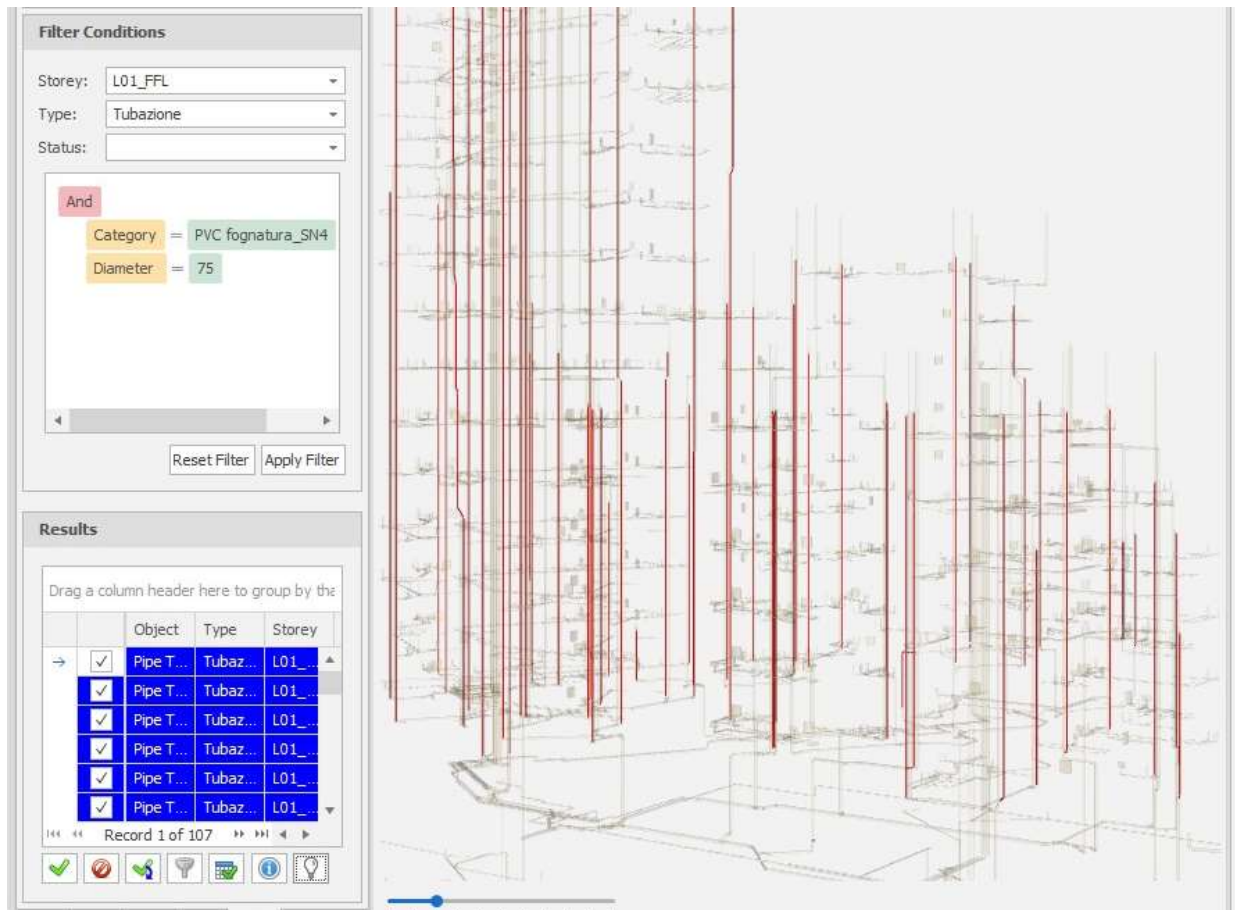
Figure 42: IfcObject filter for PVC pipe 75mm Diameter.

4.3.5.3. Take Off Rules.

The take-off rule specifies how the price unit of the object would be applied to the objects in a filter list of common properties. The item price per unit, unit of measurement and the derived quantity of the object is multiplied to get the total cost of every occurrence of the object in the IFC model. Figure 42 shows the take-off rules for Steel pipe AZ UNI EN 10255. The pipes unit of measurement is in KG but the pipes are produced in difference Diameters and thickness. To make the geometrical values suitable for take-off, all the pipe diameters are converted to weight using the value of steel per cubic meter.

Based on the QTO_PipeSegmentBaseQuantities, we have the Outside diameter, Inside diameter, length of the pipe. Using the formula below we can derive the net cross-sectional area (A) of the pipe.

$$A = \pi r^2 (exterior\ Pipe\ cross\ sectional\ area) - \pi r^2 (interior\ Pipe\ cross\ sectional\ area)$$

When this is multiplied by the length of the pipe we get the volume of the pipe which we can multiply by the weight of steel per meter cube.

Weight of steel pipe (W) is $W = A_m \times L_m \times 7850$

When A is net cross-sectional area of pipe (m^2), L is Length of pipe in meters and 7850 is the weight in kg/m^3.

Figure 43: STR Take-off Rule and Filter for a Steel Pipe with Kg/m^3 unit of Measurement

4.3.5.4. Parametric BIM Estimate.

This is a process that applies the saved take off rules, filters and project WBS to all the objects in the IFC model. The earlier processes under QTO have been to set up template for filter or measurement of objects with similar properties. This step applies all the templates active in the project to the entire IFC file. It also maps the WBS parameter created in STR to the IFC WBS properties so the eventual quantities can be analysed by WBS properties.

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Figure 44: Sample Project Take Off Rules for the Project.

Figure 45: WBS Mapping in STR Parametric Take Off

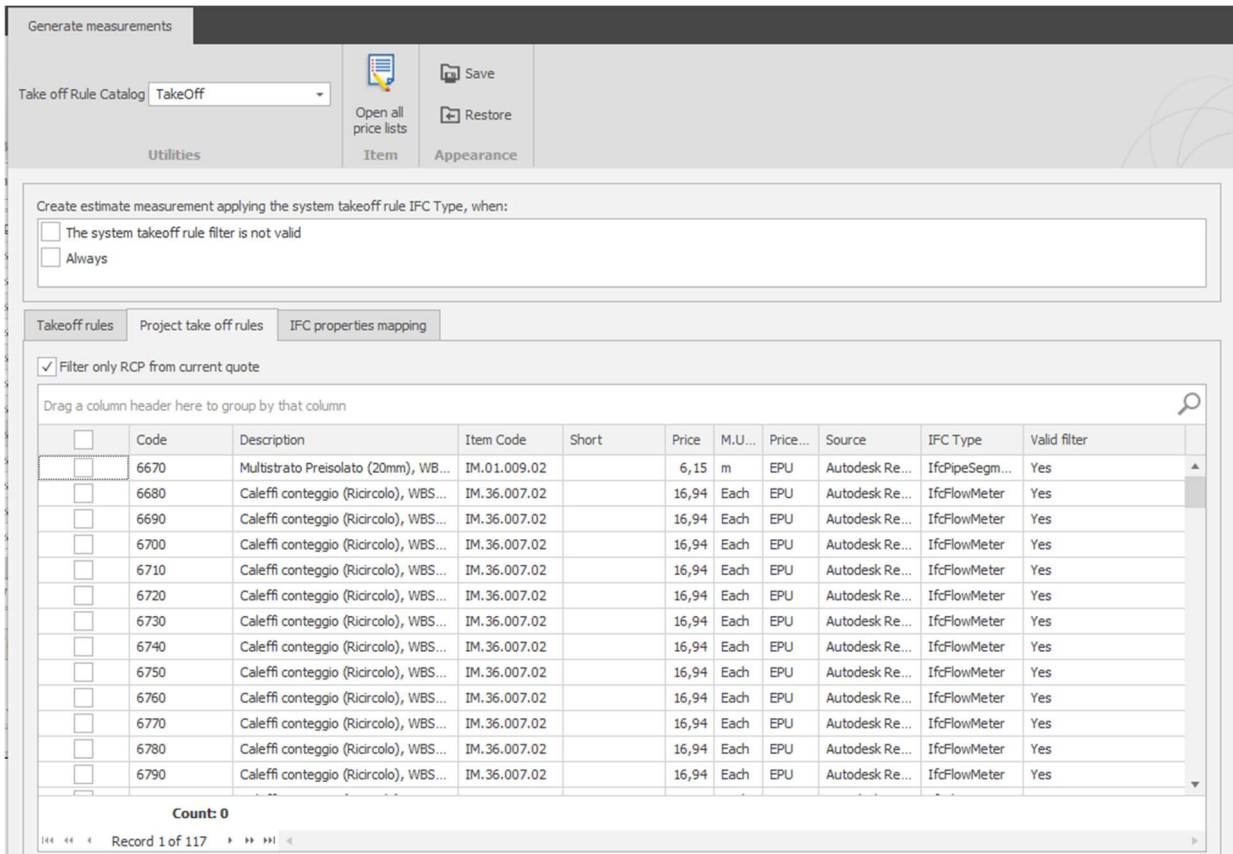| Progr.	Type	Entry type	Item	UM code	UM descr	Quantity	Price	Item Ref	Code WBS_01 Project	Desc. WBS_01 Project	Code WBS_02 Building	Code WBS_03 Discipline	Descr. WBS_03 Discipline	Code Custom field 4	Code WBS_04 Level	Code WBS_05 Compartment	Code WBS_06 Work Categories	Code Wbs_07 Apartment
10	Measured	Factors	IM.01.009.02	M	n	620.00	6.15	IM.01.009.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_01_TUBAZIONI	LC1	A**		LC1.D04
20	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C0506
30	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C010203O4
40	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C01
50	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A11
60	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A01A02A03
70	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A04
80	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A10
90	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A05A06A07
100	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A08
110	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A09
120	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C01
130	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.D04
140	Measured	Factors	IM.36.007.02	CAD	Each	1.00	16.94	IM.36.007.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.E0203
150	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.D001
160	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C0506
170	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C010203O4
180	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C01
190	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A11
200	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A04
210	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A10
220	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A05A06A07
230	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A01A02A03
240	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A09
250	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.A08
260	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.C01
270	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.D001
280	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.E0203
290	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.D04
300	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.C0506
310	Measured	Factors	IM.06.012.02	CAD	Each	2.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.C010203O4
320	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.A01A02A03
330	Measured	Factors	IM.06.012.02	CAD	Each	6.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.A02A03
340	Measured	Factors	IM.06.012.02	CAD	Each	2.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.A04
350	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.A09
360	Measured	Factors	IM.06.012.02	CAD	Each	4.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.A05A06AC7
370	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.A11
380	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.D001
390	Measured	Factors	IM.06.012.02	CAD	Each	1.00	51.81	IM.06.012.02	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_06_CONTABILIZ	LC1	A**		LC1.E0203
400	Measured	Factors	IM.06.005.04	CAD	Each	2.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.D04
410	Measured	Factors	IM.36.005.04	CAD	Each	2.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C0506
420	Measured	Factors	IM.36.005.04	CAD	Each	2.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C010203O4
430	Measured	Factors	IM.36.005.04	CAD	Each	2.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C01
440	Measured	Factors	IM.36.005.04	CAD	Each	2.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A11
450	Measured	Factors	IM.36.005.04	CAD	Each	2.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A05A06AC7
460	Measured	Factors	IM.36.005.04	CAD	Each	4.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		L1.A01A024AC3
470	Measured	Factors	IM.36.005.04	CAD	Each	4.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		L1.A05A06AC7
480	Measured	Factors	IM.36.005.04	CAD	Each	2.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		L1.A01A024AC3
490	Measured	Factors	IM.36.005.04	CAD	Each	2.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		L1.A01A02A03
500	Measured	Factors	IM.36.005.04	CAD	Each	2.00	31.29	IM.36.005.04	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A08
510	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A09
520	Measured	Factors	IM.36.006.01	CAD	Each	3.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C010203O4
530	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C01
540	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.C0506
550	Measured	Factors	IM.36.006.01	CAD	Each	2.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A11
560	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.D04
570	Measured	Factors	IM.36.006.01	CAD	Each	2.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.E001
580	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		L1.A05A06AC7
590	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.E004
600	Measured	Factors	IM.36.006.01	CAD	Each	1.00	28.00	IM.36.006.01	ACC	Piazzale Accu C1	IS		Domestic Water and Wastewate: Disposal Sy	LC1_36_IDRICO	LC1	A**		LC1.A08

Figure 46: Sample QTO Schedule with Costing and WBS Integrated.

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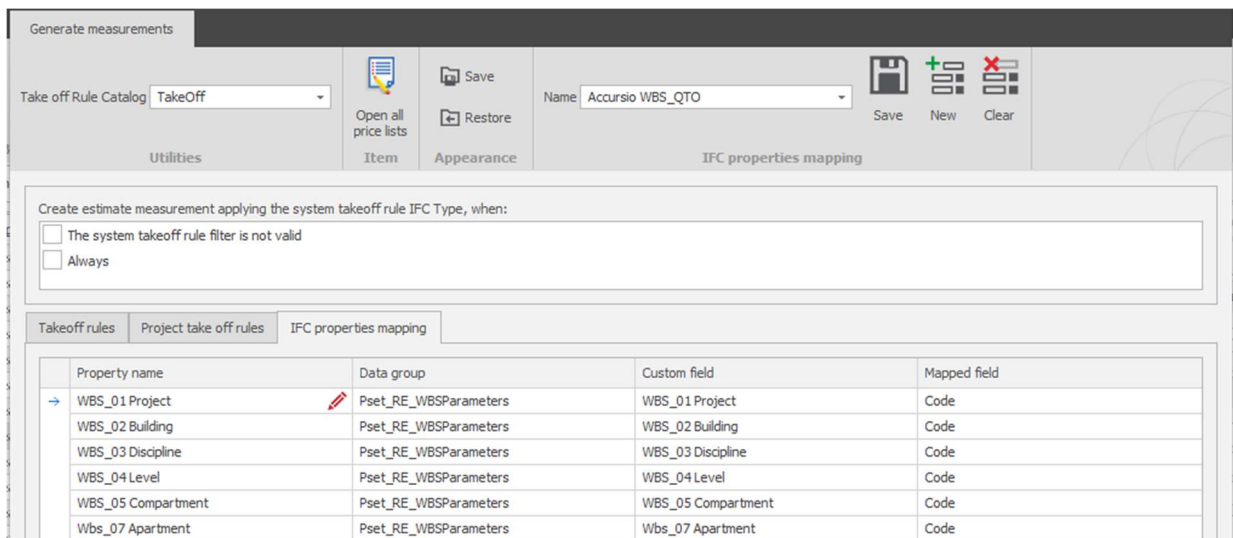
5. CONCLUSIONS

The goal of this dissertation was to attempt to achieved QTO of a project by focusing on the integration of the processes that lead to that information requirement. For this purpose, we examine key principles that impact on the theme of the thesis, subjects like ISO 19650 and its information requirement as it impacts framing the requirements of a project on an organisation, project and asset level, while also examining requirements for exchange of information to achieve the goals of the earlier requirements. We looked at IFC as a means of platform-agnostic transfer of information modelled, in particular geometrical data as it relates to MEP modelling and the interoperability of price list data with information coming out of model authoring environment. A workflow to achieve the thesis goal was proposed based on learnings from the literature review, the implementation was done on a real-life project which provides the conditions typical of any project execution challenges.

Calculations involved in the MEP design was carried out using Macro Enabled Spreadsheets to determine supply and discharge pipes flow rates and sizing. For the purpose of this thesis only the water supply and wastewater disposal systems were examined as the principles espoused by the conceptual process flow could be applied to any system design within building construction. The immediate benefit of using the spreadsheet was the flexibility provided in the design of the systems, and design adjustments when there is a change to the architecture of the project. The results could be derived quickly and transferred into the authoring tool. 3D modelling happened simultaneously as the calculation, so we could receive immediate feedback from calculation or design as to what needed to be adjusted in the design. The other advantage of the spreadsheet calculation is the platform-agnostic solution that it offers, providing design input to the BIM authoring software. This input is then used in modelling the design solution. Revit Autodesk was used to author the 3D model, with the help of the platform families modified to fit the requirements of the MEP design calculation and outline specifications. A recommendation coming out of this exercise is to clear the project file of other object families and object types that have not been identified for the project and ensure proper naming convention of the pipes and objects with relational association (eg fittings). Also, an area worth research is the options for bi-directional interoperability between spreadsheets and Revit for the purpose of geometrical definition as this would make the process of design and updates require less effort.

The transfer of information model to QTO platform was done with the help of IFC 4.0 reference view, the choice of this MVD was made because it is the most advance, domain specific IFC format which also preserves the geometrical properties of the file from the authoring tool. User defined Psets were mapped unto the Ifc to transfer user defined properties like WBS unto the Ifc export, and IFC properties like IfcExportAs, Qto_BaseQuantities and Qto_IfcPipeQuantities were mapped to extract geometrical data from the native model. The result was inspected in an IFC viewer for validation of transferred information and after a few try the information was satisfactory. An observation at this point is that calculated values in BIM authoring softwares contained in schedules did not transfer to IFC, this could be because the value is relational and not embedded in any object property. A further research question would be to investigate how extended (calculated) geometrical data values in BIM authoring tools can be embedded in IFC so the information derived in that environment can transfer with the traditional information modelled.

Finally, the process of QTO was performed in STR Vision CPM with the import of IFC data and mapping of WBS into the platform. For this purpose, a private price list was used. Filters were created to categorise IfcObjects and Take off rules were applied to each filtered group. In the BIM parametric environment of the platform WBS was mapped to each filtered group and a list of quantities was generated. The result of this exercise is very important to the prediction of the cost of construction projects, this is why there has been so much emphasis on leveraging the BIM model to develop this data. Research and my interaction on this project show that this quantity take offs are at best plus or minus 50% away from the final cost of the project, a finding which is very alarming. It has also been established that increasing efforts in detailed modelling does not proportionately increase the accuracy of the estimate, this frustration leading to many organisations referring back to good old historic data to predict project cost. Further research to determine pathway to improving the accuracy of QTO in comparison to eventual construction cost would be a very valuable area of study to the industry.

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	Three Dimension
4D	Fourth Dimension (Time)
5D	Fifth Dimension (Costing)
ACS	Hot Water Supply
AEC	Archtecture Engineering and Construction
AFS	Cold Water Supply
AIR	Asset Information Requirement
BEP	BIM Execution Plan
BIM	Building Information Modelling
BoQ	Bill of Quantities
BS	British Standard
bSI	Building Smart International
CDE	Common Data Environment
CPM	Construction Project Management
DU	Discharge Unit
EIR	Exchange Information Requirement
IFC	Industry Foundation Classes
ISO	International Standard Organisation
k	Coefficient of Frequency
LOD	Level of Development
LOIN	Level of Information Need
MEP	Mechanical, Electrical & Plumbing
MVD	Model View Definition
OIR	Oganisational Information Requirements
PIR	Project Information Requirements
PMI	Project Management Institute
Pset	Parameter Sets
Qset	Quantity Sets
QTO	Quantity Take Off
RIBA	Royal Institute of British Architects
UC	Unit of Charge
WBS	Work Breakdown Structure