POLITECNICO DI TORINO

MASTER OF SCIENCE PROGRAM IN
CIVIL ENGINEERING

THESIS OF MASTER

Applicability of the BIM methodology in Construction Management for “PROMENADE” (Steel bridge with photovoltaic roof)

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It doesn't matter who you are, where you come from. The ability to triumph begins with you. Always."

– Oprah Winfrey

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Abstract

The AEC-industry has been lagging other types of production industries in terms of productivity development for the last 40 years. The reason for this has been described as to be a combination of the collaborative needs in performing construction projects combined with the fragmented nature of the AEC-industry. Building information modelling (BIM) has been presented as a way of addressing these issues and thereby improving productivity in construction projects.

When compared to traditional 2D CAD systems, BIM is a more efficient way of handling information connected to the project or the building. Adoption of BIM enables

changes in work processes that can streamline the performance in construction projects. Adoption of BIM is not only a change in technology; there is a need for substantial changes in work processes in order to make improvements to productivity. BIM is a tool to improve processes in order to reach certain goals, not a goal in own right.

The research carried out for this thesis aims to study the applicability of the BIM methodology in **Construction Management** discipline. In particular, the present work is focused on the case study of Promenade, which is the part of undergoing construction project called Torre Region Piemonte.

The work is divided into different phases: at first, the model of Promenade has been created in Revit 2019 in order to assess the potential and criticality of each element and their respective compatibility within the BIM tools used. In this context, creating a 4D and 5D model, that represents the BIM strength, implementing the alphanumeric information degree applicable to the model, and using it to have direct correspondence with the construction time schedule and a cost report, through the creation of a Gantt chart, implemented by the addition of labor and material resources. The results expected by the data implementation of the project, are to have a better management especially during the building site phase, for what concern costs and timing, detecting the project also during the construction phase, that allows a complete knowledge and the possibility to modify some aspects during construction, which aim is the improvement of the construction process.

Table of Contents

List of figures

List of Acronyms and File formats

AEC “Architecture engineering and Construction”

AIA “American Institute of Architects”

BEP “BIM Execution Plan”

BIM “Building Information Modeling, Model or Management”

BSI “British Standard Institute”

CAD “Computer Aided Design, Drawing, Drafting”

CDE “Common Data Environment”

CSC “Construction Specification Canada”

CSI “Construction Specification Institute”

FM “Facility Management”

iBIM Integrated Building Information Modeling

IFC Industry Foundation Classes

ISO International Organization for Standardization

LOD Level of Detail / Development

PM Project Management

WBS Work Breakdown Structure

.dwg Autodesk® Autocad® and Advance Steel® drawing format

.html Hypertext markup language

.mpp Microsoft Project file

.nwc Autodesk® Navisworks® cache file

.nwf Autodesk® Navisworks® file

.rvt Autodesk® Revit® model file

1.1 Introduction

The construction industry has experienced a gradual decrease in its labor productivity since the early 1960s. In the meantime, the non-farm industries such as the manufacturing industry have increased their labor productivity. The reduction of labor productivity in the construction industry requires more labor hours per contract dollar amount. This indicates that construction industry is lacking the development for labor saving ideas. Figure1 depicts the gap between the non-farm and construction industry labor productivity.

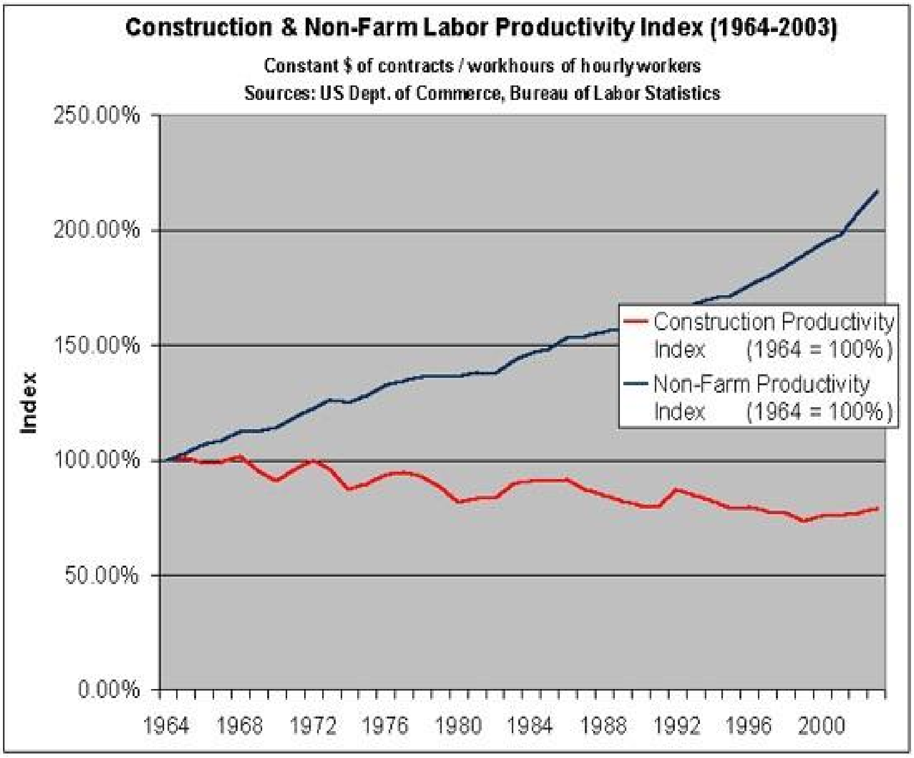


Figure 1: Construction and Non-Farm Labor Productivity Index (Teicholz, 2004)

The main causes of the lack of labor productivity in the construction industry are related to its fragmented nature due to traditional project delivery approach, traditional use of 2D Computer Aided Drafting (CAD) technology and the size of construction firms (Teicholz, 2004). First of all, the traditional construction project delivery approach, Design-Bid-Build, fragments the roles of participants during design and construction phases.

In other words, it hinders the collaborative involvement of the general contractor or the construction manager during the design phase of the project. Secondly, the use of common and traditional two-dimensional CAD drawings does not promote a true collaborative approach. Architects and engineers produce their own fragmented CAD documents to relay theirs designs to owners and contractors. These drawings are not integrated and usually pose conflicts of information which result in inefficiency in labor productivity. The estimators need to count and generate their own quantity take offs based on the produced CAD documents. Moreover, the 2D CAD approach does not promote the integration of the drawings with schedule and cost. Lastly, due to fluctuating demand and unique site-construction requirements the construction companies are very small specialized and regional firms as depicted in the bar chart below, figure 2.

Furthermore, the construction workers on the average are paid lower wages than the manufacturing industry. Therefore, firms do not have as much of an incentive or the resources to invest money in research and development of technology because of its high risks and costs. When the new methods and technologies are used, they are applied per project basis and are not adapted quickly in the construction industry.

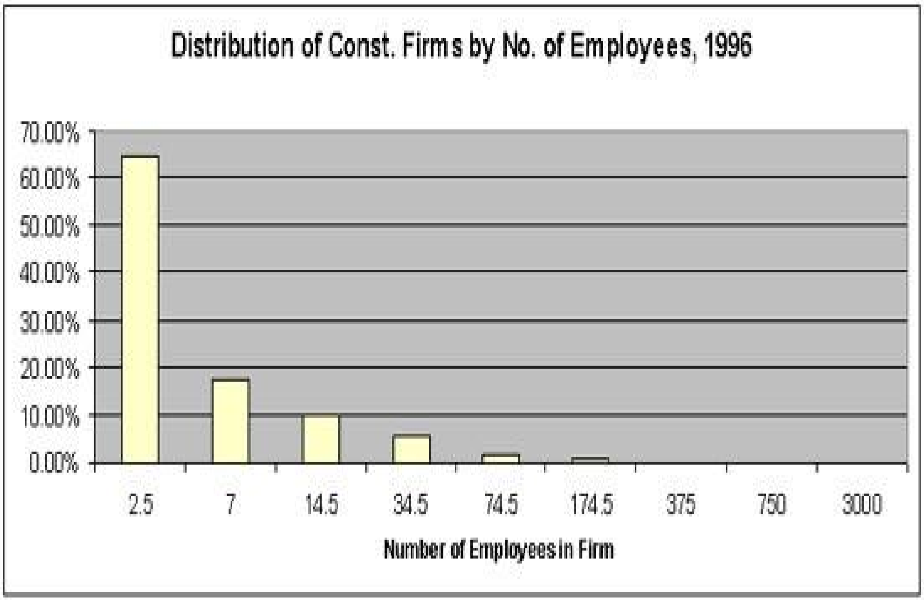


Figure 2: Distribution of Construction Company Size by Number of Employees (Teicholz, 2004)

One of the first steps towards the use of 3D technology in the construction industry was initiated as a 3D solid modeling in late 1970s. During this time, manufacturing industry carried out product design, analysis and simulation of the 3D products. 3D modelling in the construction industry was hindered “by the cost of computing power and later by the successful widespread adoption of CAD” (Eastman, 2008). The manufacturing industry realized, spent more resources in technology and seized the “potential benefits of integrated analysis capabilities, reduction of errors, and the move toward factory automation”. They worked together with modeling tool providers to reduce and eliminate the technological software setbacks.

Parametric modeling was widely adopted by manufacturing companies to design, engineer and manufacture products. For example, Boeing has been one of the industry leaders in using Dassault System’s (DS) 3D technology since 1986. Successful digital design and mock-up of 777 series with Computer Aided Three-Dimensional Interactive Application (CATIA) has led to the use of DS’s Product Lifecycle Management (PLM) for Boeing’s fuel-efficient 787 Dreamliner project. The manufacturing of the plane which included the design of revolutionary strong and light carbon fiber composites for its wings and fuselage, was outsourced outside of the USA from Italy’s Alenia Aeronauticato Japan’s Kawasaki Heavy Industries. Boeing required all of the team members to use the PLM solutions to avoid any interoperability delays. PLM provided 3D virtual design, development, and maintenance of the product while promoting collaboration thru information exchange via online communities. DS’s PLM package for 6,000 designers at the Dreamliner project included CATIA to virtually design 3D parametric object oriented products and resolve conflicts, Digital Enterprise Lean Manufacturing Interactive Application (DELMIA) to plan the manufacturing process and virtually simulate it and Enterprise Innovation VIA (ENOVIA) to share, update and manage product life cycle in a collaborative platform. Instead of designing in-house and providing the drawings to manufacturers, Boeing designers and its partner manufacturers all across the world collaboratively used the PLM tools to design, engineer and develop the Dreamliner 787 virtually. Overall, collaborative partnership and 3D PLM tools enhanced the diverse global teamwork to design and manufacture of the global 787 Dreamliner project 4 (Duvall, 2007). The manufacturing industry has fully grasped the concept of designing and virtually manufacturing in a collaborative platform. Construction industry has established the basis of object-oriented building product modeling in 1990s. Initially, certain market sectors such as structural steel utilized the parametric 3D modeling.

Recently, various BIM tools became readily available throughout the construction industry. This is a reward of construction industry’s dedication to Building Information Modeling for the last 20 years (Eastman, 2008). Construction industry has come to a point to realize the true benefits of technological advancement. The labor efficiency gap can be closed via the Building Information Modeling concept. Therefore, it is the intention of this project to study BIM and its tools to determine benefits and setbacks it poses to construction managers at risk.

In this project, the uses of BIM which include visualization, 3D coordination, prefabrication, construction planning and monitoring, cost estimation and record model were discussed in detail. Promenade project was presented as a case study to realize the actual uses and benefits of BIM. BIM tools were further analyzed by developing a prototype 3D,4D and 5D model.

Furthermore, BIM as the starter and Construction Management including 4D time scheduling and 5D cost Estimation were analyzed. The research concluded that although BIM tools do pose some shortcomings such as interoperability issues, the use of BIM is very beneficial to the construction managers.

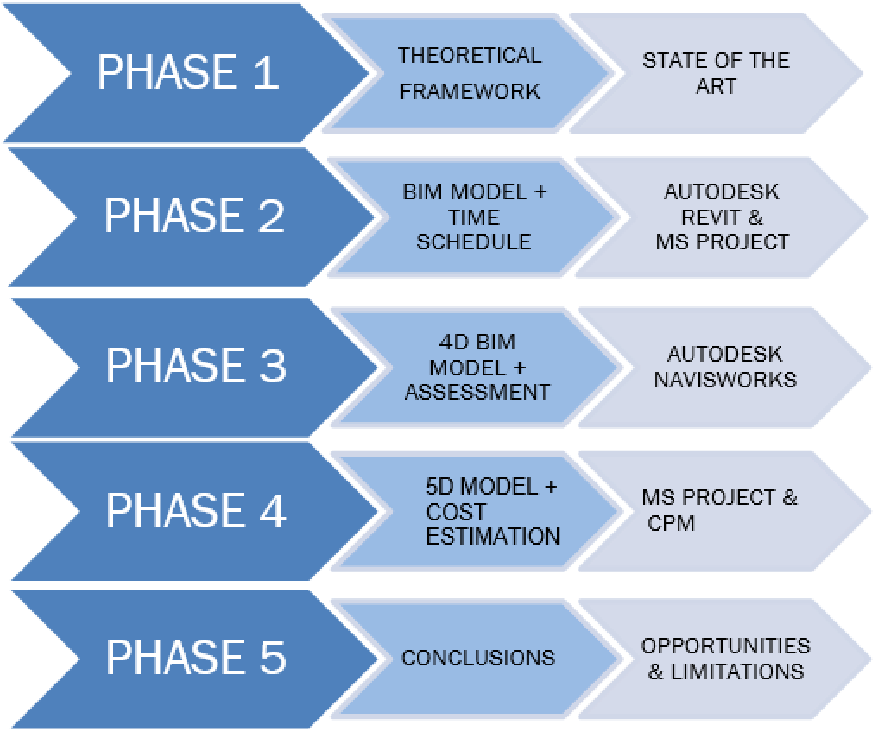
1.2 Background

This section discusses the role and use of Building Information Modeling from the Construction Management point of view. First BIM is reviewed and defined. The uses of Building Information Model, and the Building Information Model software and integrators are also discussed mainly from a construction manager perspective.

1.3 Research Methodology

This Master Thesis includes both theoretical and practical research. For the development of the theoretical part, an extensive literature review is performed mainly based on primary sources of information from scientific databases as well as other reliable electronic and paper-based sources. The opportunity to attend to the '1st National BIM Congress: EUBIM 2013' as well as the 'Conference of the European Group for Lean Construction: EGLC16', both celebrated at the Polytechnic University of Valencia, also supposed a great source of information.

The present work consists of 4 different phases to accomplish the aims and objectives set as illustrated by *'Figure 1.1'*. Phase 1 represents the literature review and the completion of the theoretical part of the study. The practical part involves Phase 2 and Phase 3. In Phase 2 the original BIM model is implemented in one of the available commercial BIM platforms: Autodesk Revit ® 2013. A time schedule is also produced in Microsoft ® Office Project 2010. In phase 3 the 4D BIM model is implemented using a commercial BIM tool by the same firm: Autodesk Navisworks Manage ® 2013. The time schedule and the BIM model from Phase 2 are merged to produce the 4D BIM model (*Figure 1.2*). This practical part also includes the assessment of the selected 4D BIM application by means of a series of simple examples showing its capabilities and paying special attention to the workflow and communication with the rest of employed tools. Finally, Phase 4 is the phase when conclusions are drawn up and opportunities and limitations presented as a result of the previous assessment.



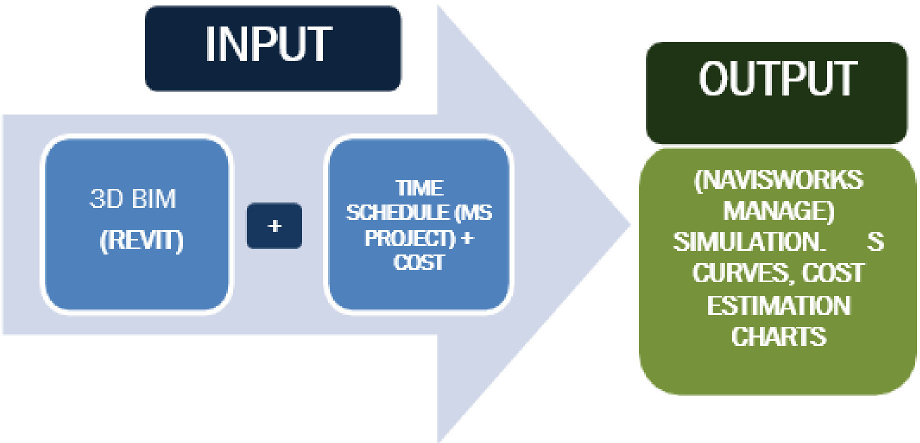


Figure 3: Overview of the project

1.4 Limitations

Since it was carried out individually, one of the main limitations of the present study is that of not being able to simulate a collaborative environment in the practical part. However, due to the visual ingredient of the applications it is assumed that they at least serve for a better understanding of processes when several people are dealing with them at a time.
The model utilized in the assessment part is really simple and it does not represent the characteristics of a real project. Indeed, as it was not required to test the functionalities of Navisworks, no regulations, nor specific design rules have been followed for its creation. Thus, navigability behaviour of Navisworks for processing massive working files has not been proved, although it has been checked that the original file is compressed up to a 90%. The assumed level of development is LOD100 with the use of generic elements representing a very initial stage of a project.

The present work has been referenced using Refworks according to the 'Harvard Style of Referencing.

1.4.1 What is BIM?

In the construction industry, Building Information Modeling (BIM) has become a requirement to manage projects more effectively. Contractors have seen the benefits of BIM and want to adopt this process for managing their projects (Blažević et al., 2014).
BIM can provide a digital visualization in 3D, but more importantly BIM systems store, besides geometric data, all necessary semantic data (function of the element, material properties, construction details, schedules, etc.) in the model. Moreover, it is a single model of the project for all stakeholders over all phases of the project. The benefits of the BIM technology begin at the conceptual design stage and cover the entire lifecycle (Abdirad, 2015). BIM establishes a collaboration process in the design and construction industry which gathers all project management skills around the same model (Bagdonas, 2014).
During the last three decades the construction industry has seen drastic improvement of the use of IT (Fisher et al. 2006). The latest and most promising in these developments is the use of Buildinginformation modelling (BIM) (Eastman at al. 2011). BIM can be described as a tool that enables storage and reuse of information and domain knowledge throughout the lifecycle of the project (Vanlande and Nicolle 2008). Therefore, BIM has a main role of coordinating and integrating the exchange of information and knowledge between different disciplines and phases within the project.

The use of BIM in a construction project both has the potential benefit of improving product quality and enabling more sustainable designs of buildings (Eastman et al. 2011).
Even though the economic and environmental benefits of BIM is widely acknowledged (Eastman et al. 2011; Howell and Batcheler 2005; Azhar et al. 2008; Fischer and Kunz 2006; Yusuf et al. 2009), the adoption of this new technology has been slow (Bernstein and Pittman 2005). This thesis aims to develop the understanding of the barriers limiting the implementation of BIM in the construction industry by studying different project participants‟ expectation of BIM.

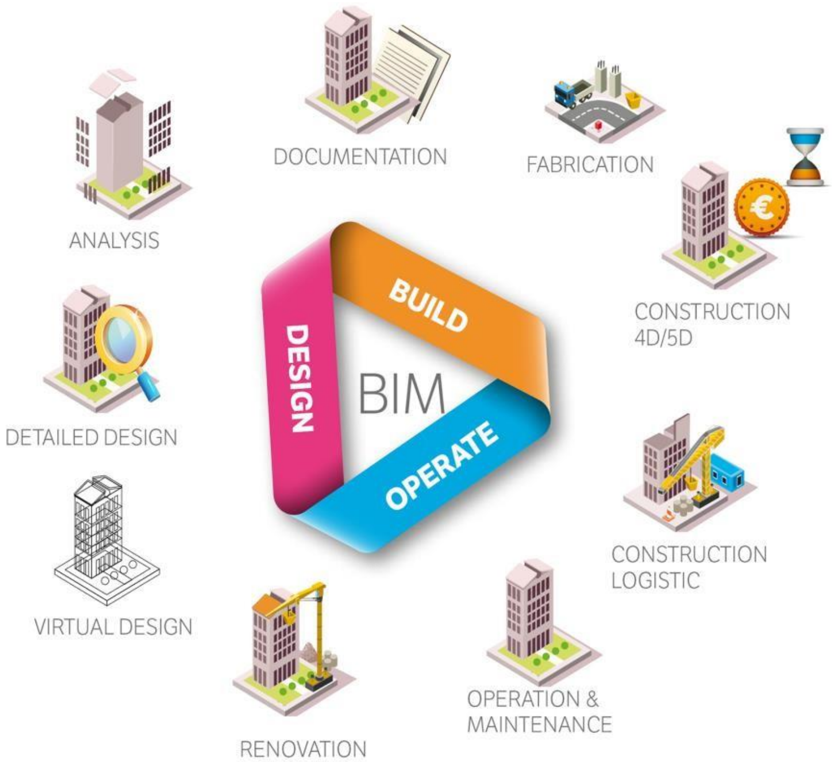


Figure 4:General overview of BIM

1.4.2 BIM Process/Dimensions

The main difference between BIM and conventional CAD technology is that BIM technology provides a 3D model of the building from which plans, sections and elevations are automatically generated. It is very easy to change or edit a component since all views are updated automatically. Also the model includes data and creates smart objects which have physical and functional characteristics (Azhar et al., 2012). Thus, BIM is able to hold all necessary data and provides a platform for information management for the whole project during the life cycle, reducing time, costs and delays (Brokaw and Mukherjee, 2012). How BIM affects various stages in the project life cycle is examined below.

Feasibility Analysis

Feasibility study is the first starting point of a project and project life cycle. It serves to make a decision if the project is reasonable or not (PMBOK Guide, 2000). It can be described as an alternative solution pile to choose the highest profit and benefit. Net Present Value (NPV), Internal Rate of Return (IRR) and Payback Period (PP) are commonly used to understand if the project is suitable. According to the nature of the construction projects, the uncertainty is at the highest level and it causes risks during the construction and operational stages. For this reason, the risks also must be calculated within the feasibility analysis (Firmansyah et al., 2006). BIM technology involves whole lifecycle of a construction project from the planning stage to decommissioning of the building (Dave, 2013). The main performance parameter for this study is the minimization of the cost by integrating project management and nD models using BIM technology.

3D Modeling

BIM offers high accuracy but only if data is input with the necessary high level of detail into the model. For this reason, the level of detail in the three-dimensional (3D) model is a key factor. Material properties, project parameters, family parameters, component properties, unit costs and details about suppliers need to be specified in the model (Aðalsteinsson, 2014). 3D models include geometrical (shape and dimension), topological (space), structural and additional information. All non-geometric data is called semantic data and is not included in traditional 2D models (Gimenez et al., 2015).

BIM-based Scheduling (4D Model)

Scheduling is directly related with activities integrated in time. At planning stage, during the construction or monitoring stages, firms use different scheduling methods. Several of the most common methods are Bar Charts, Gantt Charts or Critical Path Method (CPM). In today's construction world, firms utilize computational tools. There are several programs which produce schedules and reports (Bagdonas, 2014). BIM allows the building components in 3D model and tasks in the schedule to be linked and this creates the 4D model. It shows better visualization of the activities and helps developing a better communication among project professionals (Tsai et al., 2013). The main advantage of 4D models is the ability they provide to monitor and control the construction more effectively to save time and reduce the total cost. This model also manages resources and logistics of the jobsite (Bagdonas 2014). The construction simulation from BIM software (e.g. Navisworks) provides an important visualization of the 3D model in time during the construction stage (Brokaw and Mukherjee, 2012). Visualization is enhanced with the change of the color which symbolizes the activity change (Brito and Ferreirab, 2015).

BIM-based Cost Estimation (5D)

5D model is the integration of cost data into the BIM model (Blažević et al., 2014). Cost estimation is the main financial parameter for construction projects along with quantity take-off. The important thing to do is to make quantity take-offs and cost estimations in the preliminary design stage. It creates an outlook before the construction starts and if the cost is over budget, the design can be changed and revisions can be made. What is essential is to make these calculations accurately and precisely. Here BIM process is highly advantageous, because detailed calculations are almost immediate savings of time and effort. BIM generates accurate calculations if all required data have been included in the model (Bagdonas, 2014). These estimations are done by giving the unit cost as an input for BIM software for each type of component (Brokaw and Mukherjee, 2012).

Sustainability (6D)

If sustainability analysis is not carried out in the early stages of design, meeting performance requirements becomes difficult and costly. With using BIM technology, sustainability and performance analysis can be done throughout the design stages. Experts from various domains can carry out their analyses concurrently without disturbing each other. Architects and engineers can run building mass, light or energy analyses, contractors can be included into the project to control site conditions, logistics or supply chain (Azhar and Brown, 2009). The main goal of 6D models is the reduction of carbon footprints. Integrating the BIM model with energy analysis tools allows consideration of energy and carbon targets in design stages. Sustainability analysis does not only involve energy analysis but also considers water preservation, use of sustainable materials, reduction of material consumption, and use of recycled materials (Azhar and Brown, 2009; Smith, 2014).

Facility Management (7D)

7D is an integrated BIM model developed for life-cycle facility management (Wang, 2011). The BIM model that is used during construction serves as the as-built model and is passed on to the operation and maintenance phases. McArthur (2015) established four main challenges of facility management with integrating BIM. These challenges are "identify critical information required for sustainable operations", "manage information transfer between the BIM model and other facility management tools", "manage the level of effort to create the model" and "handle uncertainty where building documentation is incomplete". The main key factor is to collect and analyze the data and update the BIM model consistently (McArthur, 2015).

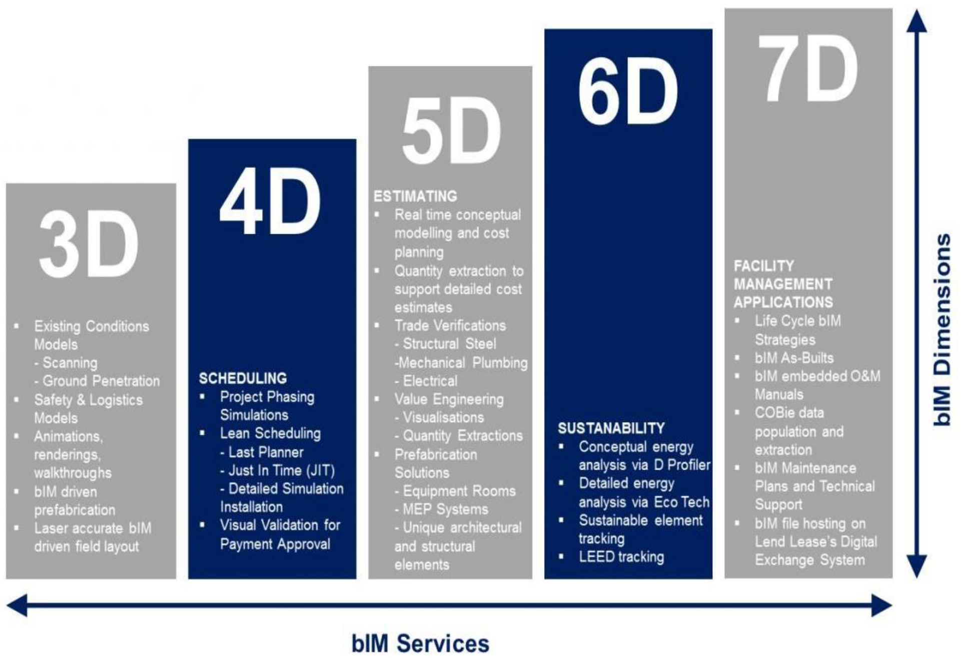


Figure 5: Product scheme to indicate the size of BIM

1.4.3 BIM Execution Plan (BEP)

BIM Execution Plan (BEP) can be defined as a detailed plan of carrying out a construction project using BIM technologies. It involves execution, monitoring and control steps with respect to BIM technology. This plan is specific to each project. It defines the goals and uses for utilizing BIM. It is an important plan to manage and integrate the deliverables of the project. BEP is prepared before the initiation of the project and defines a team, identifies BIM goals, and BIM uses to achieve the goals, specifies the tools to be utilized, responsibilities of each team member and collaborator and protocols for information exchange. It also identifies key performance indicators to track progress. Here, BIM is a tool to achieve the goals (Bloomberg et al., 2012)

1.4.4 (LOD)

The Level of Development (LOD) Specification is a reference that enables practitioners in the AEC Industry to specify and articulate with a high level of clarity the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process. The LOD Specification utilizes the basic LOD definitions developed by the AIA for the AIA G202-2013 Building Information Modeling Protocol Form1 and is organized by CSI Uniformat 20102. It defines and illustrates characteristics of model elements of different building systems at different Levels of Development. This clear articulation allows model authors to define what their models can be relied on for, and allows downstream users to clearly understand the usability and the limitations of models they are receiving.

The intent of this Specification is to help explain the LOD framework and standardize its use so that it becomes more useful as a communication tool. It does not prescribe what Levels of Development are to be reached at what point in a project but leaves the specification of the model progression to the user of this document. To accomplish the document's intent, its primary objectives are:

- To help teams, including owners, to specify BIM deliverables and to get a clear picture of what will be included in a BIM deliverable
- To help design managers explain to their teams the information and detail that needs to be provided at various points in the design process
- To provide a standard that can be referenced by contracts and BIM execution plans.

It should be noted that this Specification does not replace a project BIM Execution Plan (BIMXP), but rather is intended to be used in conjunction with such a plan, providing a means of defining models for specific information exchanges, milestones in a design work plan, and deliverables for specific functions.

LOD has two definitions:

Level of Detail (LOD): is basically how much the object is detailed, depends on the 3D modeling and how much is accurate and close to the reality.
Level of Development (LOD): is the degree of the information's associated to the object in the model, the degree to which project team members may rely on the information when using the model.

1.4.5 Fundamental LOD Definitions

LOD are divided in five categories in growing order for detail and information presents into it , is important to say that is not only unnecessary to model every object with the highest level but it can be also unproductive, because of the several time spent to reach an high LOD and the effect that has in terms of time and costs, LOD are divided in a growing scale:

- LOD 100: The Model Element may be graphically represented in the Model with a symbol or other generic representation but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.

- LOD 200: The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non- graphic information may also be attached to the Model Element.

- LOD 300: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.

- LOD 350: The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.

- LOD 400: The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.

- LOD 500: The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

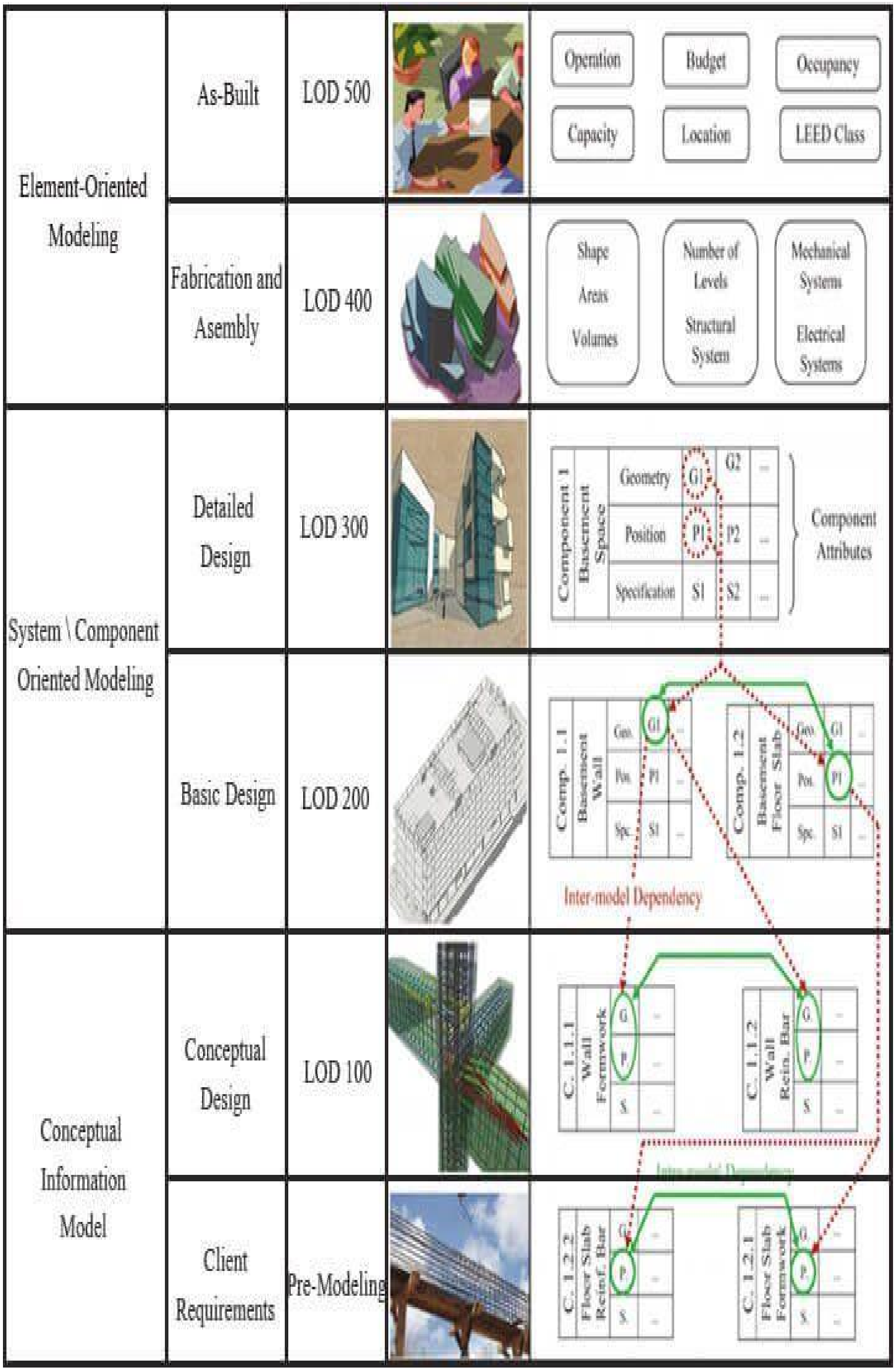


Figure 6: Fundamental chart of Level of detail

1.4.6 Interoperability concept

The widespread of Building Information Modelling processes increases the need to have a complete merging between the application fields. As they are plenty, it is impossible to find a unique software that can handle all the information assigned to each branch, or a single operator that can manage all the aspects regarding a building; for this reason, it is necessary to have some instruments that allow the data sharing among operators and software.
"Software interoperability is seamless data exchange at the software level among diverse applications, each of which may have its own internal data structure. Interoperability is achieved by mapping parts of each participating application's internal data structure to a universal model and vice versa." (NIBS, 2008) Analyzing the most famous definition of the terms it is possible to introduce two important aspects inner to this concept:) the fact that somehow many software that works in different ways have to communicate between each other, and consequently) that the process of interoperability can lead to a standardization due to the transformation from a model with an internal data structure to a universal one that has to be adapted in another environment.
Therefore, the information's quality to be shared is beyond the simple graphic data, as the BIM's elements are real objects made not only of geometrical features, but also materials, quantities, costs, temporal, energetic and structural ones. For this reason, the theme of data exchange was largely investigated by researchers, associations, software houses, industries, etc., building a proper ad-hoc technology, which evolves with the BIM applications and their needs.

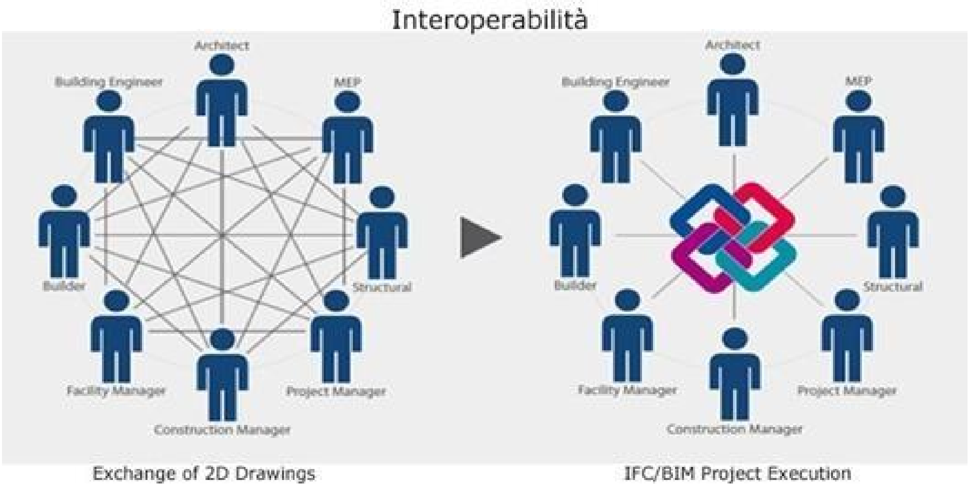


Figure 7: Sharing schemes comparison between 2D drawings and BIM models

1.4.7 BuildingSMART and exchange formats

Today, the exchange data format technology is carried on and developed by an international association, called BuildingSMART. Its activities comprehend the standardization of the processes, workflows and procedures for BIM, supporting the use, the publication and the promotion of open standards.

It is focalized on three standards that represent the levels of interoperability in the BIM environment: IFC (Industry Foundation Classes), IFD (International Framework for Dictionaries or Data Dictionaries) and IDM (Information Delivery Manual). All these three formats are receipted by

ISO (International Organization for Standardization), a regulatory corporation.

The first one, IFC data model is most used format to share the detail of each model. IFC is the format for the information exchange, and also the one more linked to the users. It defines a structured model of data, object-oriented, which contains a system for classifying and describing not only the geometrical or physical attributes of the objects like walls, slabs, etc., but also the quantities, costs and the temporal sequences of elaborations.
The specification related to the data model are defined by MVD (Model View Definition): given that IFC is built to satisfy many different configurations, level of details and users, a MVD provides a way to indicate what information are specifically needed for a particular use. It can be useful in a contract, defining what data must be provided according to a specific validation model

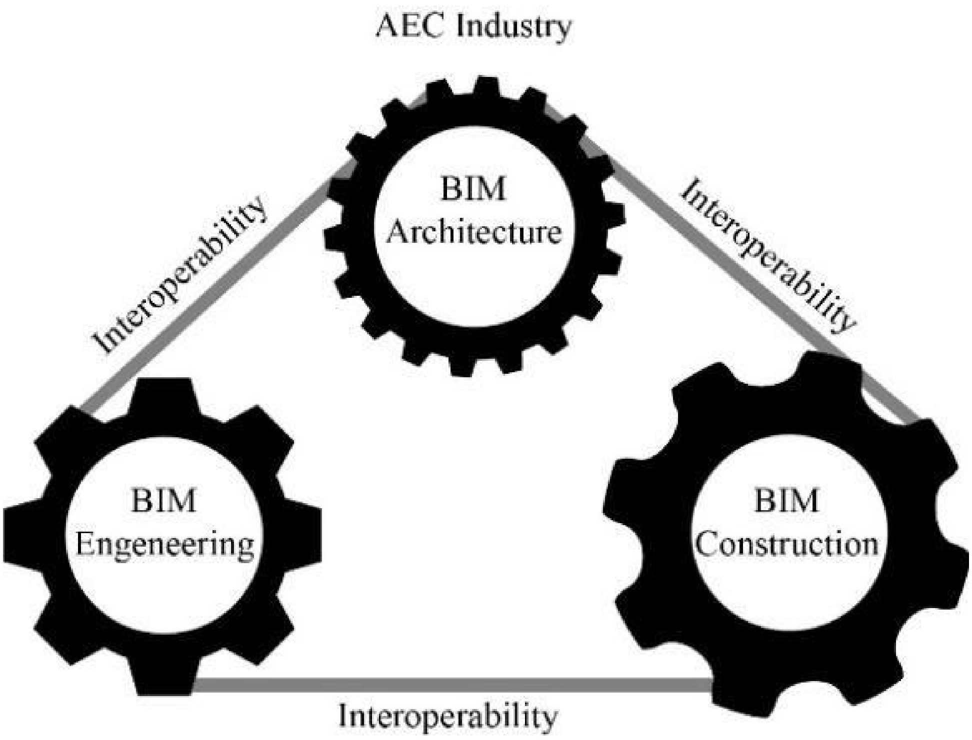


Figure 8: Data exchange format

When analysing the level on interoperability in IFC, Steel et al. (2012) consider it in four different levels.

- File level interoperability - This covers the ability for different tools to successfully exchange files.
- Syntax level interoperability - This covers the ability for different tools to successfully parse files without errors. This also covers the ability for different tools to interoperate without errors.

- Visualization level interoperability - This covers the ability for different tools to correctly visualise the exchanged model.
- Sematic level interoperability - This covers the ability for different tools to come to the same understanding of the meaning of a model being exchanged.

The problem with interoperability within the construction industry is the width of the domain itself, different projects can range from anything from a simple one family house to large airports. This breadth has been problematic to IFC and its interoperability because no one tool implements all of its language (Steel el al 2012).
Because of the fragmented and collaborative nature of the AEC-industry interoperability is an important issue. BIM has many viable advantages over CAD, but the ability to share intelligent building information is critically important (Howell and Batcheler 2005). In order to maximize many of the benefits BIM enables regarding productivity and design quality the challenges with interoperability must be addressed (Steel et al. 2012).

1.4.8 Problem Statement

The AEC-industry has a historically low increase of productivity when compared with other industry. BIM has been introduced by many as a way of addressing this problem, but even while the development of BIM has continued for many years the adoption rate is still slow. There are currently a lot of research developing theories on why, focusing on different barriers limiting the usefulness of BIM or limiting the ability to adopt BIM in construction projects. How these different theories interact is however not very well documented. There is a need to develop the understanding of how these barriers combine and in what way they can be bridged. There is also no clear consensus of which actor, if any, that should drive the development and adoption of BIM in orderto address this low productivity rate.

1.4.9 International BIM Standards

The advantages, opportunities and savings of using BIM processes are so evident that many countries around the world has already begun to integrate Building Information Modeling and implement it in their current industry standards and their tendering procedures policies.
There is currently a plan for publishing the first international BIM standards later this year 2018, and there are two further ones to be released in early 2020 [14]. It is said that these new standards will substitute the previous BS 1192 and PAS 1192 standards, published by the BSI

and currently used and applied in the UK. These new standards will be labeled as the BS EN ISO 19650 'Organization of information about construction works – Information management using building information modeling'series, divided in four distinct parts (so far): BS EN ISO 19650-1 'Concepts and principles', and BS EN ISO 19650-2 'Delivery phase of assets', which will replace respectively the current BS 1192-1 and PAS 1192-2. These two first parts of the new BS EN ISO 19650

are under development at the moment and are set to be released in late 2018. At the same time, the two additional parts of the same international BIM standards are scheduled for 2020 and are currently in progress. Those will be BS EN ISO 19650-3 'Operational phase of assets', and BS EN ISO 19650-5 'Specification for security-minded building information modeling, digital built environments and smart asset management', which will replace respectively the current PAS 1192-3 and PAS 1192-5. These new international standards are meant to be a reference point and a landmark for the use of BIM in the AEC industry and clarify the present normative fragmentation among the many national regulations, in advantage of the whole global construction industry.

Another fundamental international standard about BIM is the IFC standard: the acronym stands for 'Industry Foundation Classes', and it is basically an open file format that should allow the exchange of information among different licensed software, facilitating the interoperability between them. This standard is regulated by the ISO 16739:2013 and is carried on by building SMART, an international organization for the standardization of BIM information, as a neutral product data set for the collection of information about the building during its life cycle. In fact, IFC is a set of file formats, each with its own specific features and uses.
Until the adoption of the international BIM standards, the BS 1192 and PAS 1192 standards published by the BSI remain valid in Great Britain, while also being kept as references outside the UK. This country has been one of the leaders in the field, being among the first countries to make the use of BIM for government projects mandatory for any firm willing to take part in tenders. This is because of the introduction, in 2011, of targets for the capital costs reduction in the public sector by 20%, for faster delivery, and for the reduction of carbon emissions by 50% by 2019 [16]. A large number of aspects were considered to achieve those targets, and it is clear that the use of BIM was considered one of the key components in the strategy. Moreover, to achieve the 20% reduction of procurement costs, part of the Government's Construction Strategy, since 2016 BIM Level 2 (Figure 4) has been made mandatory for all centrally-procured construction projects, which means that the entire AEC industry was quickly forced to adapt not to be left behind in the process .
This already had the result of positively increasing the awareness about BIM and its adoption raised from 48% in 2015 to 54% in 2016, and this number is only expected to rise significantly in current and future years.

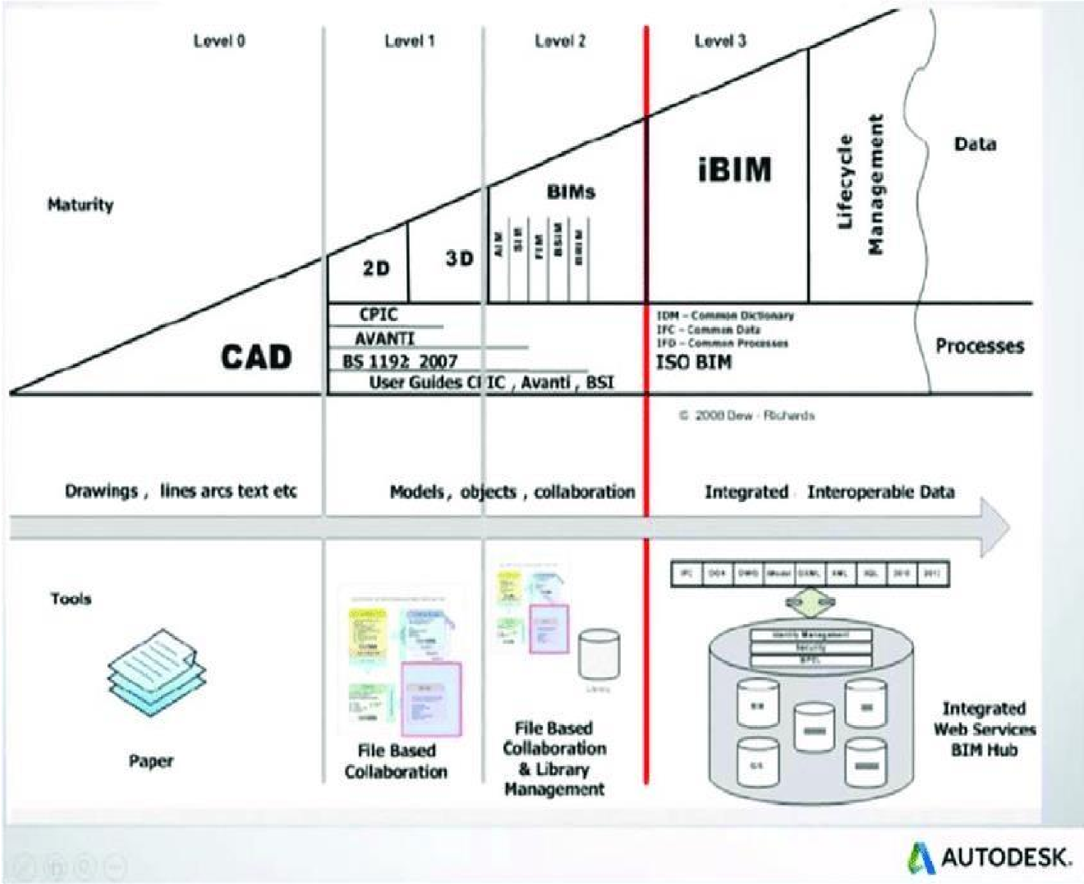


Figure 9: BIM maturity level

What substantially is 'Level 2 BIM' is briefly but quite eloquently illustrated in the 'B/555 Roadmap' published by the BSI, which explains the different stages of information modeling and data management in construction projects, from simple CAD to an auspicial total integration of BIM in shared web- based platforms. The B/555 Roadmap therefore presents four different so- called 'Maturity Levels' of BIM evolution through time, with all of the current and future normative standards that regulate the building production and management throughout all of those. The four levels are described as follows:

- Level 0: 'Unmanaged CAD probably 2D, with paper (or electronic paper) as the most likely data exchange mechanism';
- Level 1: 'Managed CAD in 2 or 3D format using BS 1192:2007 with a collaboration tool providing a common data environment, possibly some standard data structures and

- formats. Commercial data managed by standalone finance and cost management packages with no integration'

- ***Level 2:*** *'Managed 3D environment held in separate discipline 'BIM'* tools with attached data. Commercial data managed by an ERP. Integration on the basis of proprietary interfaces or bespoke middleware could be regarded as 'pBIM' (proprietary). The approach may utilise 4D program data and 5D cost elements';

- ***Level 3:** Fully open process and data integration enabled by IFC/IFD.* Managed by a collaborative model server. Could be regarded as iBIM or integrated BIM potentially employing concurrent engineering processes.

Despite Level 3 BIM being out of reach for now, this is the auspicial ultimate goal of the AEC industry for future years, as it could provide a new way of creating and sharing building data throughout the whole industry, provide contractual framework that could help develop a truly cooperative working environment.

1.4.10 Italian BIM Standards

On March 14, 2019 UNI EN ISO 19650: 2019 was published by the Italian Standardization Body, entitled:
Organization and digitization of information relating to construction and civil engineering works, including Building Information Modeling (BIM) - Information management through Building Information Modeling - Part 1: Concepts and principles - Part 2: Asset handover phase
The Italian standard follows the implementation by CEN, on 19 December 2018, of the EN ISO 19650-1 and EN ISO 19650-2 standards.
In fact, we remind you that following international agreements (known as the "Vienna Agreement") between the ISO (International Organization for Standardization - International, non-governmental and independent Standardization Body -) and the CEN (European Committee for Standardization - Standardization Body European), the latter is bound to the transposition without modifications of the technical regulations issued by the ISO and falling within the agreement itself.
The relevance of what happened last December concerns not only the supranational sphere, where it will certainly be possible and legitimate to refer to ISO 19650 (internationally) and EN ISO 19650 (European level) in contracts relating to the industry's own activities construction, but also in the Italian context, where the agreements stipulated in the European treaties provide for the validity in the respective member countries of the European technical regulations, as a priority compared also to previous national regulations.
UNI 11337, Italian technical legislation nearing completion, will have to be revisited, although possibly in contrast with 19650, and will become a national appendix (in force, therefore exclusively in Italy) to the international text.

ISO 19650

The first two parts of the standard approved:

- ISO 19650 - Organization of information about construction works - Information management using building information modeling - Part 1: Concepts and Principles
- ISO 19650 - Organization of information about construction works - Information management using building information modeling - Part 2:
  Delivery phase of the assets

they respectively address the general aspects of the BIM process and the information flow of the development phase of the real estate project.
In particular, the first part frames the information flow of the building process in the wider horizon of Project Management, schematically indicating the reference framework standards

Key

AIM Asset Information Model

PIM Project Information Model

A Start of delivery phase (see 3.2.11) – transfer of relevant information from AIM to PIM

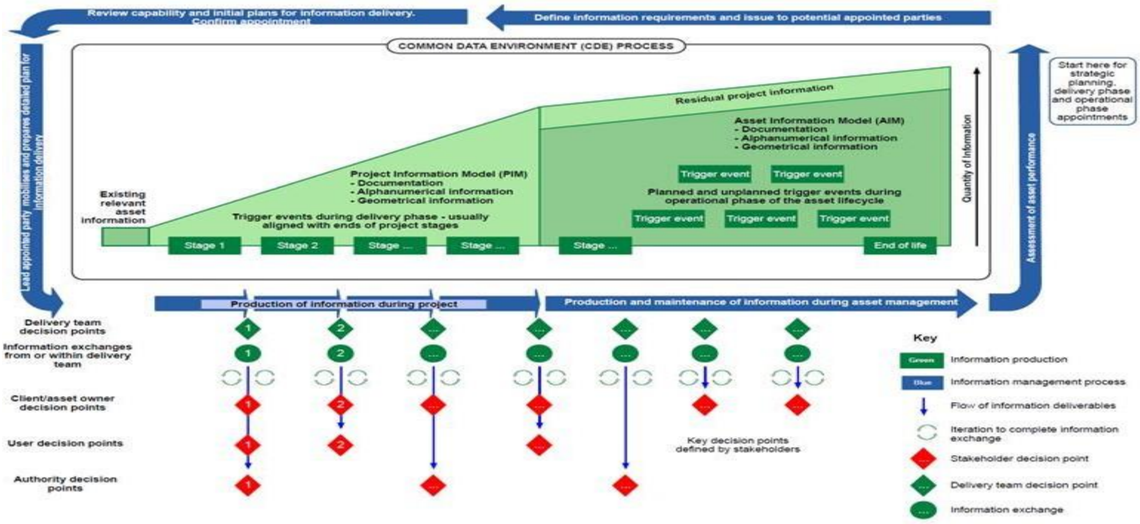
B Progressive development of the design intent model into the virtual construction model (see 3.3.10 Note 1)

C End of delivery phase – transfer of relevant information from PIM to AIM

Generic project and asset information management life cycle

Figure 10: Project and asset information management life cycle ISO 19650-1

From the point of view more properly of the life cycle of the real estate, then, the entire information flow is shown in a synthetic and exemplary figure (see Figure #) with the highlighting of the various intermediate moments of evaluation, verification and approval, in which the client is also called to express himself on the fulfillment of the initially expressed design requirements.



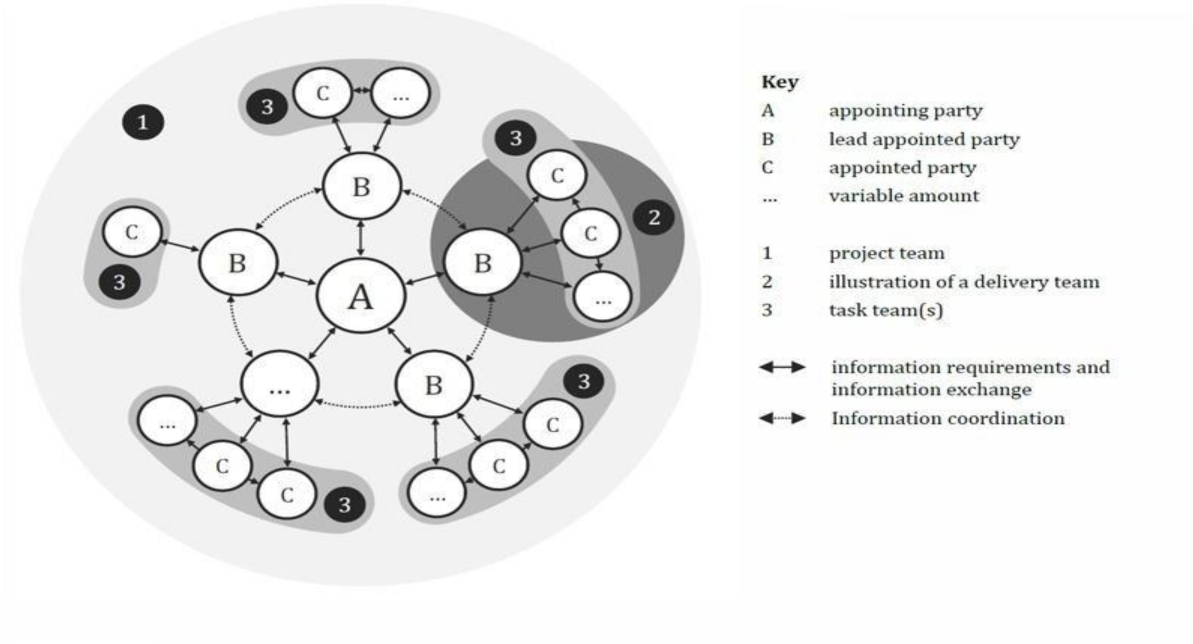
Overview and illustration of the information management process

Figure 11:Overview of information management process Source: ISO 19650-1

We would like to briefly draw attention to the influence that the (pre) British standards have had on the drafting of the ISO texts, which is also evident from the similarity of the two figures shown above (and taken from ISO 19650-

1) with the analogous ones present in PAS 1192-3.

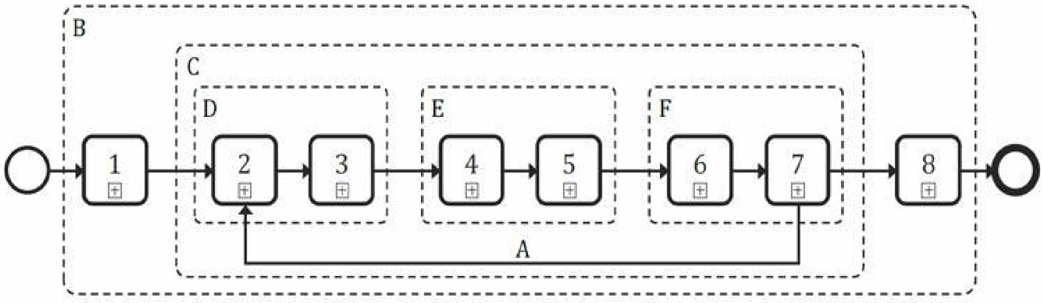
The second part, then, enters more specifically into the information process, dealing first of all with the protagonists, specifying their position within the process chain and related roles and functions (see Figure #).



Interfaces between parties and teams for the purpose of information management

Figure 12: Interfaces between parties and teams for information management ISO 19650-2

The text then enters the description of the various evolutionary stages of the information process on time, detailing the path, of course always from the methodological point of view and the objectives of each individual step (see Figure #).



Activities

1	assessment and need	A	information model progressed by subsequent delivery team(s) for each appointment
2	invitation to tender	B	activities undertaken per project
3	tender response	C	activities undertaken per appointment
4	appointment	D	activities undertaken during the procurement stage (of each appointment)
5	mobilization		
6	collaborative production of information	E	activities undertaken during the information planning stage (of each appointment)
7	information model delivery		
8	project close-out (end of delivery phase)	F	activities undertaken during the information production stage (of each appointment)

Information management process during the delivery phase of assets

Figure 13: Information management process during delivery phase ISO 19650-2

The drafting of the two normative texts, as mentioned, required numerous efforts and compromises.
One of the most challenging aspects was the containment (elimination) of terminology and references to contractual aspects.
In fact, for countries with a more punctually organized state and legislative structure, the presence of a reference technical standard with well- defined references could have introduced an element of conflict and / or a constraint to future regulatory developments within them.
For this reason, expressions such as "appointed party" or "appointing party" ("designated party" and "designated party") have been introduced to indicate, in a generic way, those figures who in a contract (in Italy) are defined as the foster company and Client.
For the same reason, the famous acronym EIR (Employer Information Requirements, according to the original Anglo-Saxon definition) has instead taken on the new definition of Exchange Information Requirements, thus focusing the meaning on the activity rather than on the subjects requesting the fulfillment of specific information requirements.

1.5 Case Study

1.5.1 “Promenade” Piedmont Region

The case study discussed in this thesis is the Promenade, a roof with photovoltaic roof, located in the complex of the Tower of the Piedmont Region, near the Lingotto-Benghazi metro station, between Fiat Avio north complex, via Nice to East, via Passo Buole south and west Lingotto station.

Figure 14:Location of the project

The candidate was required to model the canopy with photovoltaic roof of the East-West Promenade in the external areas of the building complex "District 2" located in Via Passo Buole 22, Turin. Specifically, the request was to model the above structure, which will have the function of connecting the station of Lingotto already existing one and the metro currently under construction for a length of about 260 meters, using a modeling software BIM, Revit 2019.


Figure 15: Canopy with photovoltaic roof of the Ease-west Promenade

The lower structure of a steel bridge is one of the essential elements of a whole steel bridge structure. In this thesis we are also dealing with the same kind of structure. The construction works of this structure are complex and extensive. In the process of planning the construction works for this element, thorough and well-designed plan is vital in order to avoid construction failures or defects that could lead to project failure. Therefore, in the construction planning process for the lower structure steel bridge, a detailed construction process and activities, including its resources are needed for guiding the process effectively and comply with the project requirements. The decomposition of the construction works into work packages is important to minimize mistakes, which is by using a definitive work breakdown structure (WBS) and its detailed dictionary for each work packages.

The research carried out for this thesis aims to study the applicability of the BIM methodology in **Construction Management** discipline. In particular, the present work is focused on the case study of Promenade, which is the part of undergoing construction project called Torre Region Piemonte.

1.5.2 BIM for Promenade

BIM approach is widely used in now a day's projects, due to the complexity of these type of structures, and for the need they have to be always under control and to be detected with accuracy, because of the special environment required. Especially in a structure like Promenade which relates to the entire project of Torre Regione Piedmont and needs a lot of management and skills to complete the task according to the times scheduled.

The use of BIM for this kind of facilities can be pretty useful, thanks to the control of information, it could be made a better plan for the facility management, or manage some other aspects of the building, such as energy consumption, activities organization, actually to detect any aspect of the building during the life-cycle. Of course, this approach is also important during the design stages, as already described it brings many advantages such as: saving times thanks to a detailed 3-dimensional project of any elements meant to avoid clash between construction items. Thanks to the seven dimensions of BIM methodology described in the previous chapter, meant to detect construction organization in construction phase focused on saving time trough planning every activity in building site, predicting costs and managing sustainability in terms of energy balance.

1.5.3 Software used for Facility:

For the development of the practical part of this work 3 different computer programs were used: Autodesk Revit ® 2019, Microsoft ® Office Project 2016 and Autodesk Navisworks Manage ® 2016.

Autodesk Revit ® 2013

Autodesk Revit ® 2013 is one of the BIM design software platforms available in the market. It makes possible implementing the BIM methodology and it has been used to create the BIM model for the practical part of this study. In this case, Revit has served as a design tool to create a simple 3D model for later exporting it to Autodesk Navisworks Manage ® 2013, including all the information at the element level.

Although Revit itself has a built-in application for construction planning including time, it is a complex and laborious way to organize the different phases, and it does not fully serve for 4D sequencing. The *'Phases'* tool allows the user to visualize modifications over time in a given project as well as assigning different phases to each of the elements of the model, which is really useful to store life-cycle information of a building. It is therefore possible to create snapshots of the different phases the building has gone through. However, due to the existence of Navisworks for 4D simulation, which is a much more powerful tool for this purpose, this option is not aim of further investigation.

Microsoft ® Office Project 2016

Microsoft Project has a lot of features for setting up projects and running automated reports based on progress, budget, time tracking, and more. We'll take you through the steps needed to set-up a timeline, add and schedule tasks, add resources, setup dependencies, generate reports, and track progress.
Microsoft ® Office Project 2016 is a project management software application for construction planning. It has been used to complete the time schedule, defining the activities, their duration and the sequential relationships. The final schedule has been imported in Autodesk Navisworks Manage ® 2013 in order to create the 4D model.

Autodesk Navisworks Manage ® 2016

The Autodesk Navisworks product family provides 3 different versions, each of them including more or less features: (1) Autodesk Navisworks Freedom, (2) Autodesk Navisworks Simulate and (3) Autodesk Navisworks Manage. The version used to implement the practical part is Autodesk Navisworks Manage ® 2013 since it includes all the features, although the Simulate version would be enough for 4D BIM purposes.
Autodesk Navisworks Manage ® 2016 is a BIM design review tool with 4D BIM capabilities thanks to the integration of the *'Timeliner'* function. It has other useful functions, such as, clash detection for project coordination. Navisworks was not conceived to provide the opportunity to modify a model, but it is rather a review, coordination and simulation tool. None of the actions in Navisworks modifies the original file and neither the model data contained in it.
The function within Navisworks that is going to be used most often is the *'Timeliner'*. It has a built-in scheduling application to manage tasks, although as it has been mentioned a more powerful tool will be used to that end: Microsoft ® Office Project 2016. In order to deal with external data sources, there is a dialog to add, delete and refresh them. Furthermore, Navisworks *'Timeliner'* allows visualizing the model status over different dates thanks to the *'Simulate'* tab.

Dynamo

Dynamo is an application that can be downloaded as free software and run alone or as plug-in to Revit. It is a visual programming tool that aims to be accessible to both non-programmers and programmers alike. It gives users the ability to visually script behavior, define custom pieces of logic, and script using various textual programming languages. Once Dynamo is installed it enables users to use Virtual Programming to process data and compose custom algorithms. User can create geometries, manipulate models in Revit or within Dynamo itself very easy by coupling code blocks which are programmed to execute a task assigned to them. Figure 2.6 illustrates a typical workflow in Dynamo. Usually, what known from grasshopper is that that the workflow goes from left to right but in Dynamo it ca go both ways.

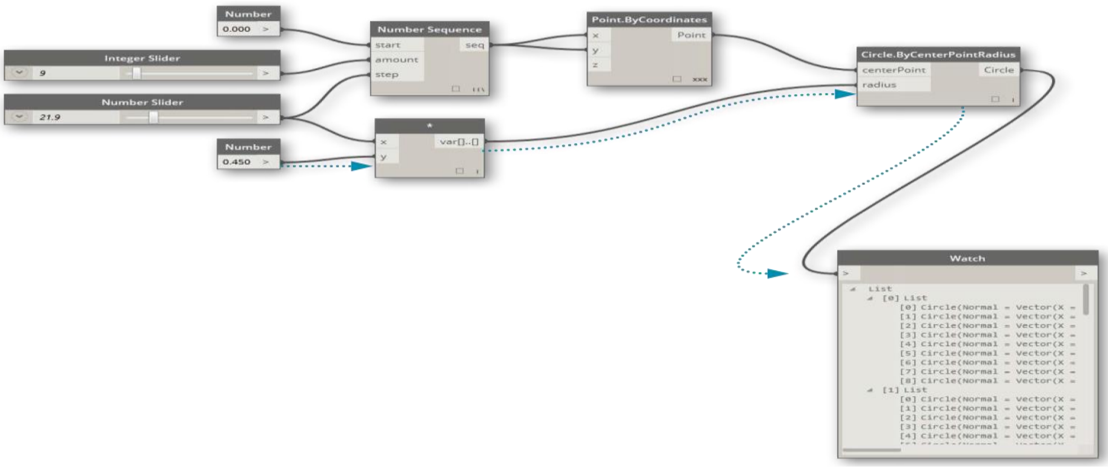


Figure 16: Program flow in Dynamo

1.6 What is Construction Management

To summarize, Construction Management is the discipline that handles the building during the final phase of the project before handing over to the owner. This implies arranging material schedules, construction operations, sequence of activities, crew organization, health and safety, construction site designing, and time management, verification of installations, update documentation cost, and all those practices that make possible the physical realization of buildings.
This means that CM is what is necessary to transform a design into a real structure, and sometimes the activities of a construction manager begin a lot earlier than expected, potentially even from pre-design. Among the activities and tools of the construction manager, there are the very known and useful so-called ‘breakdown structures’: these structures help subdivide and deconstruct the project in smaller, manageable packages. The main example of breakdown structure is the WBS, namely the Work Breakdown Structure: it is a hierarchical structure in which bigger elements, such as macro-categories, main building disciplines, or major deliverables, are divided into smaller ones, in an iterative process, until elementary components or activities are covered. Other examples of similar structures are Cost Breakdown Structure and Organization Breakdown Structure.

Moreover, since the CM will almost certainly have to deal with time and cost management, another very useful Project Management tool that will help them dealing with the design and construction phases of a project is the Gantt chart. This particular type of graph shows all the activities of a project, just like a WBS, but representing them as horizontal bars placed along a timeline, so that one can see at the same time the activity itself, its duration, its start and finish date, and all the material and human resources (that can be written above the bar) needed for the completion of each task. This type of representation allows the PM (or, in this case, the

CM) to keep trace of the costs of each activity and task along the life of the project, since resources can be assigned to tasks, and cost can be assigned to each resource employed. In a BIM working environment this becomes the management of 4D and 5D dimensions of the information model, which are the most important in construction

1.6.1 Use of BIM in Construction Management

There are many uses of Building Information Modeling for each project participant. Figure depicts these uses for the planning, design (preconstruction), construction and operation (post construction) phases:

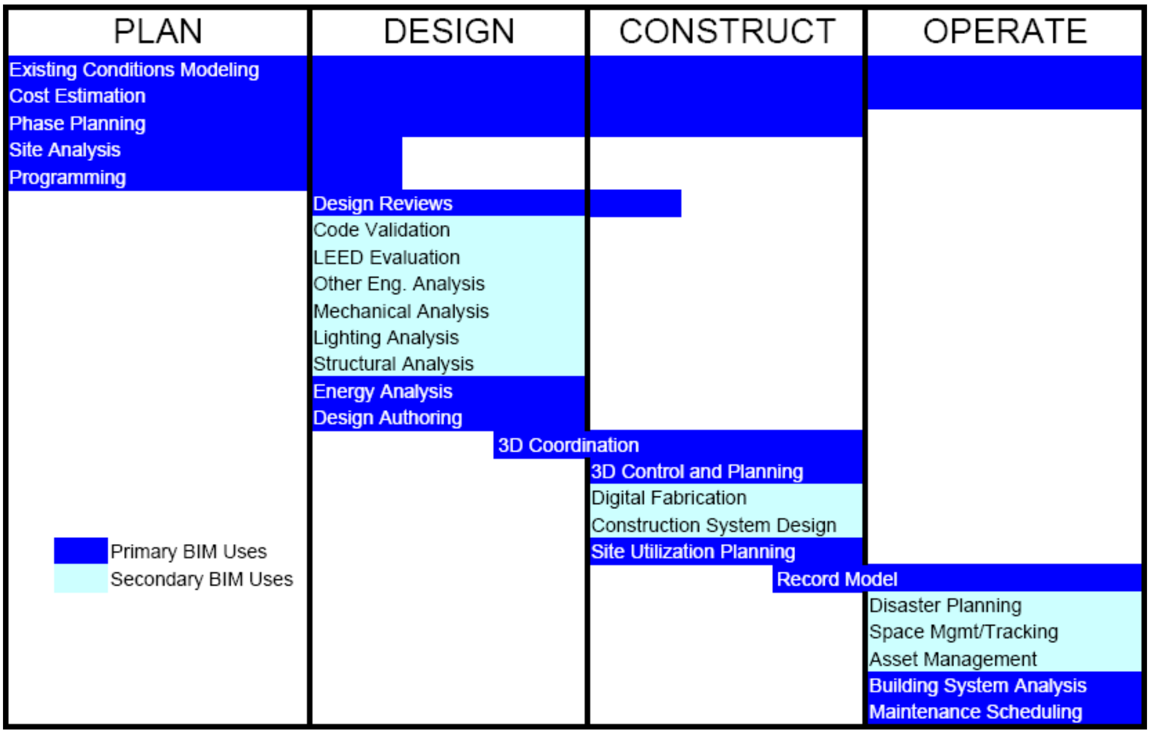


Figure 17: BIM Uses throughout a Building Lifecycle (Messner, 2009)

During the design phase, the use of BIM can maximize its impact on a project since the ability to influence cost is the highest. The team can creatively come up with ideas and provide solutions to issues before problems become high cost impacts to the project. This can be realized through the cooperation and coordination of the entire project staff. Therefore, it is extremely important to have a good collaboration. The use of BIM especially enhances the collaborative efforts of the team. The architect and engineer can test their design ideas including energy analysis. The construction manager can provide constructability, sequencing, value and engineering reports. They can also start 3D coordination between subcontractors and vendors during early stages of design. The owner can visually notice if the design is what he is looking for. Overall, the BIM promotes the collaboration of all of the projection participants.
There are beneficial uses of BIM during the construction phase. However, the ability to impact the cost in a project reduces as depicted in figure 3 as the construction progresses. Several uses include sequencing, cost estimation, fabrication and onsite BIM.

These uses are later discussed in detail During the post construction phase, maintenance scheduling, building system analysis, asset management, and space management and tracking, disaster planning, and record modeling can a record model can help to maintain the building throughout its lifecycle. Ideally, the building automation systems (BAS) which controls and monitors the use of mechanical and electrical equipment can be linked to the record model to provide a successful location-based maintenance program. Furthermore, building system analysis including energy, lighting, and mechanical can be used to measure building's performance. Moreover, upgrades may be initiated to various equipment and components of the building.

Building Information Modeling (BIM) is a great visualization tool. It provides a three-dimensional virtual representation of the building. During the bidding phase of the project, the construction manager can provide renderings, walkthroughs, and sequencing of the model to better communicate the BIM concept in 3D.

Visualization provides a better understanding of what the final product may look like. It takes away thought process of bringing the different traditional 2D views together to come up with the 3D view of a detail. Furthermore, virtual mock-ups such as laboratories or building envelope can be provided to the designer and the owner. This would help to visualize, better understand, and make decisions on the aesthetics and the functionality of the space. As depicted in figure 5 and presented in the BIMForum Conference in San Diego, virtual mockups can be used to review 3D shop drawing of the building envelope (Khemlani, 2011). The virtual mockups help to communicate and collaborate among the project participants. It promotes planning and sequencing the curtain wall construction. Even though a virtual mock up is cost efficient in comparison to a physical mock-up, a physical mock-up may still be required if a member such as casework drawer or an assembly of the building such as a curtain wall need to go through a series of physical tests. Hence, virtual mock-ups could become a good standard to initiate the mockup process and an actual mock-up may be necessary after the virtual mockup is approved.

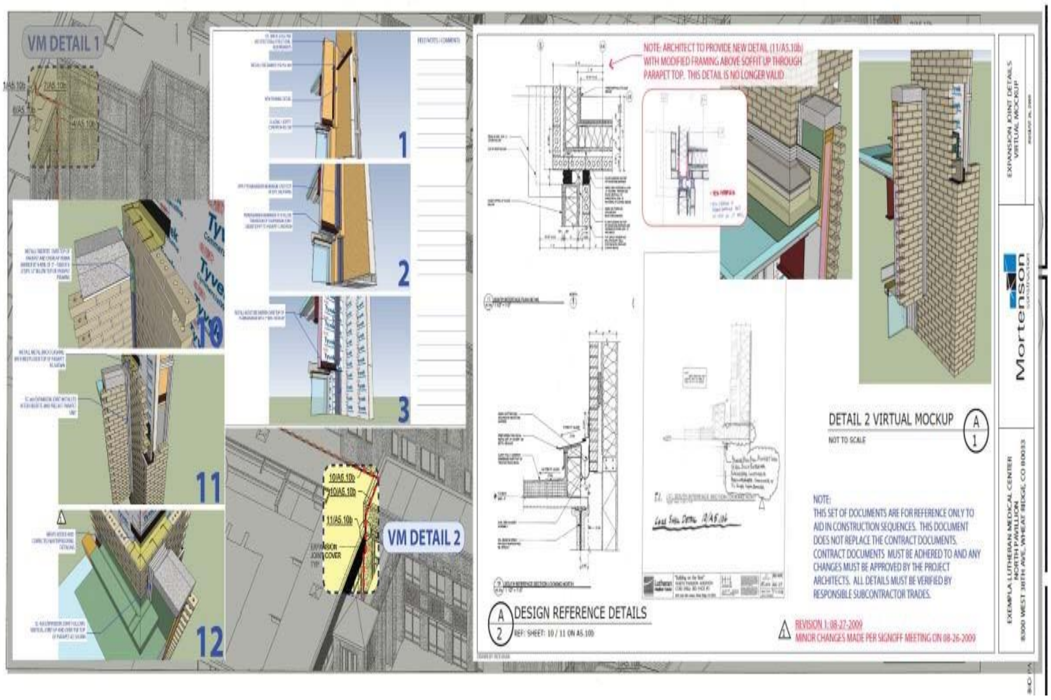


Figure 18: Exterior envelope virtual mockup for 3D shop drawing review

1.6.2 Work Breakdown Structure (WBS)

Breaking work into smaller tasks is a common productivity technique used to make the work more manageable and approachable. For projects, the **Work Breakdown Structure (WBS)** is the tool that utilizes this technique and is one of the most important project management documents. It singlehandedly integrates scope, cost and schedule baselines ensuring that project plans are in alignment. Usually, the project managers use this method for simplifying the project execution. In WBS, much larger tasks are broken down to manageable chunks of work. These chunks can be easily supervised and estimated.

WBS is not restricted to a specific field when it comes to application. This methodology can be used for any type of project management.

Following are a few reasons for creating a WBS in a project:

- Accurate and readable project organization.
- Accurate assignment of responsibilities to the project team.
- Indicates the project milestones and control points.
- Helps to estimate the cost, time and risk.
- Illustrate the project scope, so the stakeholders can have a better understanding of the same.

A good Work Breakdown Structure is created using an iterative process by following these steps and meeting these guidelines:

1. GATHER CRITICAL DOCUMENTS

   a) Gather critical project documents.
   b) Identify content containing project deliverables, such as the Project Charter, Scope Statement and Project Management Plan (PMP) subsidiary plans.

2. IDENTIFY KEY TEAM MEMBERS

   a) Identify the appropriate project team members.
   b) Analyze the documents and identify the deliverables.

3. DEFINE LEVEL 1 ELEMENTS

   a) Define the Level 1 Elements. Level 1 Elements are summary deliverable descriptions that must capture 100% of the project scope.
   b) Verify 100% of scope is captured. This requirement is commonly referred to as the 100% Rule.

4. DECOMPOSE (BREAKDOWN) ELEMENTS

a) Begin the process of breaking the Level 1 deliverables into unique lower Level deliverables. This "breaking down" technique is called Decomposition.
b) Continue breaking down the work until the work covered in each Element is managed by a single individual or organization. Ensure that all Elements are mutually exclusive.
c) Ask the question, would any additional decomposition make the project more manageable? If the answer is "no", the WBS is done.

5. CREATE WBS DICTIONARY

a) Define the content of the WBS Dictionary. The WBS Dictionary is a narrative description of the work covered in each Element in the WBS. The lowest Level Elements in the WBS are called Work Packages.
b) Create the WBS Dictionary descriptions at the Work Package Level with detail enough to ensure that 100% of the project scope is covered. The descriptions should include information such as, boundaries, milestones, risks, owner, costs, etc.

6. CREATE GANTT CHART SCHEDULE

a) Decompose the Work Packages to activities as appropriate.
b) Export or enter the Work Breakdown Structure into a Gantt chart for further scheduling and project tracking.

In the process of achieving the outcome, project activities are limited by budget, schedule and quality, known as triple constraints. These three constraints are important parameters for project organizers who are often associated with project objectives. Planning a project is quite complicated in breaking down work into smaller work elements. In addition, unclear job descriptions can result in project losses, scalable and uncontrolled project scope, project cost swelling, errors in determining project time targets resulting in delays in the construction process of a project due to the timing of project implementation. Therefore, it needs a standard or guideline used in planning to avoid problems that could hamper the project.

The initial phase of project planning in the scope of management, after defining the scope of work and the needs of the project is carried out the development of Work Breakdown Structure (WBS) on the construction project. To define each work packet as specified on the WBS properly requires a WBS dictionary. The WBS dictionary is used during the planning process, especially when planning the resources needed to prepare the project plan.

1.6.3 4D BIM

The addition of the time attribute to a *3D (x,y,z)* environment results in what it is broadly known as *4D (x,y,z,t)* environment. This extra feature provides the model with more dynamism in terms of representing the behaviour of the building elements along time, extending in this way its usage for other purposes. Introducing time in the BIM environment is seen by the author as a way to make the time constraint more likely to be fulfilled.

In principle, BIM and 4D technology are separate concepts and have had different progression from their conception. Nevertheless, it is believed that their combination in the same working methodology could help enhance certain processes and it seems especially interesting for contractors (Eastman et al., 2011).
It is believed that advanced ICT are able to ease the on-time delivery of projects to the project team by the introduction of geometry in traditional construction schedules. In the following section, the application of 4D technologies to the AEC sector is to be analyzed.
At the time of representing a building, traditional design tools usually present its final and completed state without paying attention to its variation over time (McKinney & Fischer, 1998). As a result, one of the main limitations of 3D models is their incapability to display the precise status of the construction progress (Wang et al., 2004). However, planners require of a more dynamic view of the sequence in order to be able to visualize intermediate stages. Apart from that, the traditional tools employed for planning, such as bar-charts and diagrams do not facilitate the visualization of the process because they do not display spatial features and require of a high level of abstraction to create a mental representation (Koo & Fischer, 2000; Chau et al., 2003 & 2004). Even though experience is a strong point for planning there is a need to reduce risks by leaving less space to improvisation and consequently to possible inadequate interpretations. 4D technology came to light in order to address all the problems, leading static models towards a more dynamic context by the introduction of the time variable: 3D + time.

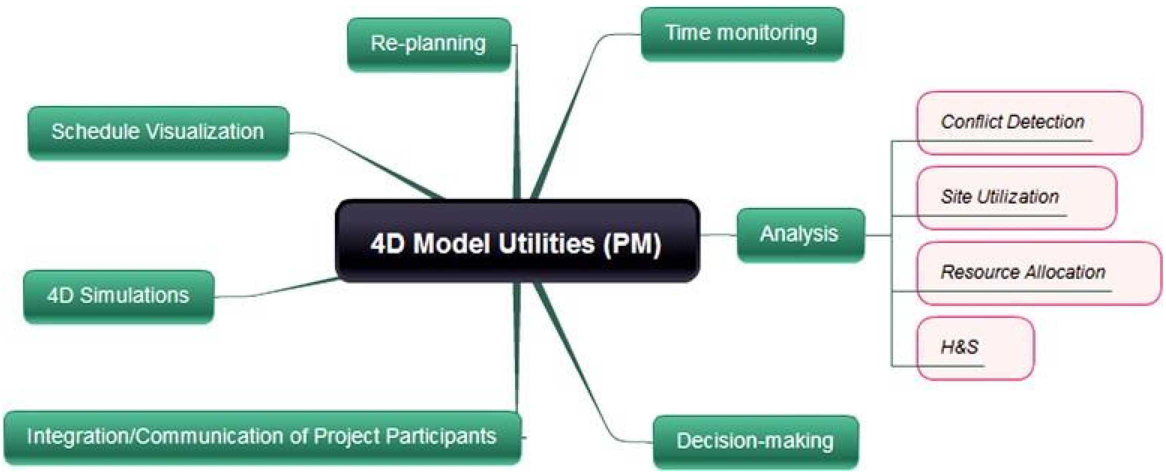


Figure 19: 4D Model Utilities for Project Management (CM) Functions

1.6.4 Requirements of 4D BIM tools

Even though the usages of 4D BIM have been already explained, the performance varies from application to application. As a tool to be used by contractors, BIM applications with 4D capabilities need to satisfy several requirements and some of them are listed below (Eastman et al., 2011):

- **Import capabilities:** on the one hand, these tools are required to import models from BIM design tools. The conservation of the information contained in them is essential for advanced 4D modelling. On the other hand, the ability to bring in time schedules from planning software is also substantial. Another thing to consider is whether the application is compatible with the IFC file format for interoperability with different software.

- **Export/Output capabilities:** the way in which the tool is organized to facilitate the sharing of files containing the 4D model between project members is a factor to analyze. The size of the output file is as well important to assure a good navigability. Apart from that, the application should be able to easily generate static snapshots and preferably video files to visualize dynamic simulations.

- **Merge and update options for the BIM model:** it is really interesting the application to have the ability to combine different models for 4D modelling. Indeed, it is common different disciplines to work independently (in a coordinated way) in their model to merge them later in a single one. Having synchronization possibilities with the original files is another requirement.

- **Data reorganization:** the vast number of elements that BIM models tend to count with makes really difficult the 4D modelling process in its raw format. The opportunity to reorganize all the items beforehand fairly simplifies their following selection and linking procedure.

- **Temporary elements and equipment:** it are also interesting to visualize temporary components and machinery in the simulations to make up an idea of how the building site would look like in a specific moment in time. This is useful to foresee their maneuverability on site as well. Therefore, the possibility to upload these components is a strong point of these tools.

- **Animation:** some elements may require to be presented in an animated manner while running a simulation. This is the case of moving machinery such as trucks, cranes and the like, and it would help to better represent the dynamism of the building site.

- **Automatic linking:** in order to accelerate the time-consuming process of linking geometry to activities, automatic linking options are a must-have feature for a 4D modelling tool. This is achieved by applying rules of diverse nature in the mapping process and especial attention is to be paid to the naming or coding of activities. Standardizing this process would be really helpful for an effective linking in the future projects.

One important concept is the fact that paper-based documentation and 4D do not go together, since it is much more visual to present a movie, instead of a picture. The more interaction with the 4D model the users have, the more information can be obtained.

1.6.5 5D BIM

BIM 5D model with open interfaces integrating the series of software, Revit, Tekla, Magi CAD, such as the establishment of the model, while integrating Project, Excel, Word and other office software, schedule and data. After the BIM 5D model integrates the project model and related attribute information, it can query the construction progress of the project, the construction design drawings, the list price, the contract terms and other construction information through the model. BIM 5D information-based data integration platform based on BIM technology can realize timely sharing and transmission of information of all participants of construction projects, and timely provide the data information needed in construction management, which is helpful to improve the meticulous management level of construction stage. BIM 5D modeling and implementation is mainly the integration of the following parts:
BIM 5D= Model + Data + Sharing + App
In the design stage ˈusing the BIM5D helps to advance the detection of construction drawings, to reduce the construction or construction to do after the design changes caused by the cost and duration loss ;in the construction phase we can achieve overall control of the project, a reasonable formulation of construction Plan, do a good job on-site construction management, and accurate completion of the scene of the staff and resource allocation, to minimize the loss caused by workers and other workers; in the operation and maintenance phase of the project through the construction simulation and collision using 5D detailed information, we can develop a reasonable maintenance and repair plan, Dimensional management, reduce the difficulty of operation and maintenance management. However, this study mainly discusses the application of BIM 5D in the construction phase of project management. The main application of BIM 5D construction management platform in the construction phase includes site layout simulation and optimization, virtual construction, visualization, progress control, cost control, At the same time, the BIM model of the construction project needs to be updated in real time according to the actual construction information of the construction site, so as to ensure the BIM model and on-site construction.

BIM 5D platform with the current application in the construction phase achieves the following functions to facilitate the construction management.

- Virtual visualization

Through the simulation of construction, the construction process, the key nodes and other construction process show the formation of virtual video technology the form of three-dimensional animation to reduce the construction site, visualization can be achieved by playing analog video in the construction of the end.

- Construction simulation

According to the construction organization, the construction process is simulated first, then the construction sequence and construction method are adjusted and optimized, and the construction process is refined to obtain the optimal construction plan. Construction simulation includes construction schedule simulation, construction program simulation, construction site layout and so on. Through construction simulation can not only control the construction schedule, but also to ensure the quality of construction and avoid the extension of time limit.

- Construction planning and adjustment

With BIM technology, it can extract the construction quantities, resource input, contract revenue and

expenditure and other related information according to the layout of the construction schedule on time. What's more, with BIM 5D platform for automatic resource and labor analysis, according to the actual situation of the scene to adjust the allocation of resources. Ensuring the progress of the construction of real-time update query based on BIM technology, the main construction of BIM 5D construction information query results shown in Fig.

Figure 20: 5D construction information map at the main construction stage

The construction progress of the site and the progress of the plan were compared to analyze whether the construction schedule is reasonable or not. If the time lag or ahead of schedule, it is must to take appropriate measures to ensure that the construction period of the project can be scheduled or early delivery.

- Project improvement and cost control

With the BIM 5D platform, which integrates various professional models and integrates the professional information, the engineering quantity can be extracted automatically according to the position, time and specialty. The engineering quantity of the construction project can be collected and statistically calculated according to the engineering quantity, list price, contract price to achieve revenue, cost, budget, three-count contrast, cost control. BIM 5D model can realize the automatic calculation of engineering quantities and the quantities of all dimensions such as time, location and professional, and directly view the cost information and generate the bill of quantities.

According to the specific requirements of the project and the construction organization plan, filtering reasonably and extracting accurately the project-related information on the basis of the time range, floor area, component type, schedule, resource requirements and other requirements, and developing funding plans and material progress Plan and arranging reasonably construction resources to improve material management efficiency, saving project costs.

2 Chapter

2.1 Methodology scheme

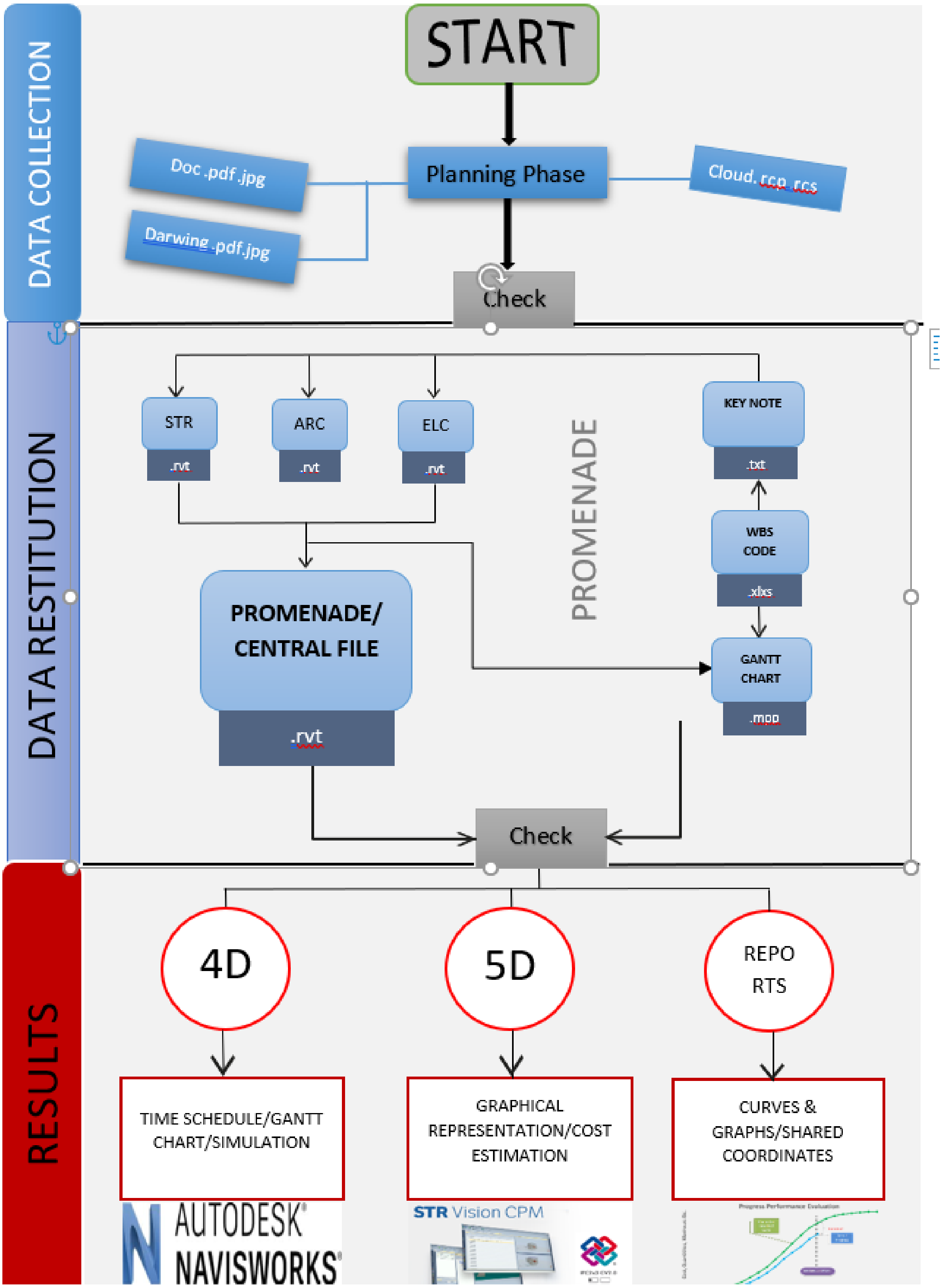


Figure 21: Methodology scheme

2.1.1 Data Collection

The first practical step was to collect data from all the available resources, aimed to find the information about the structure so the beginning of modelling can be started. As we are working on the part of a mega project as mentioned above that Promenade is the part of an ongoing project called Torre Regione Piedmonte (TRP) so the initial drawings were provided by the management of Torre Regione with details.

First part of drawings available in both pdfs were provided by the concerned Engineer of TRP which is also available in CAD form.

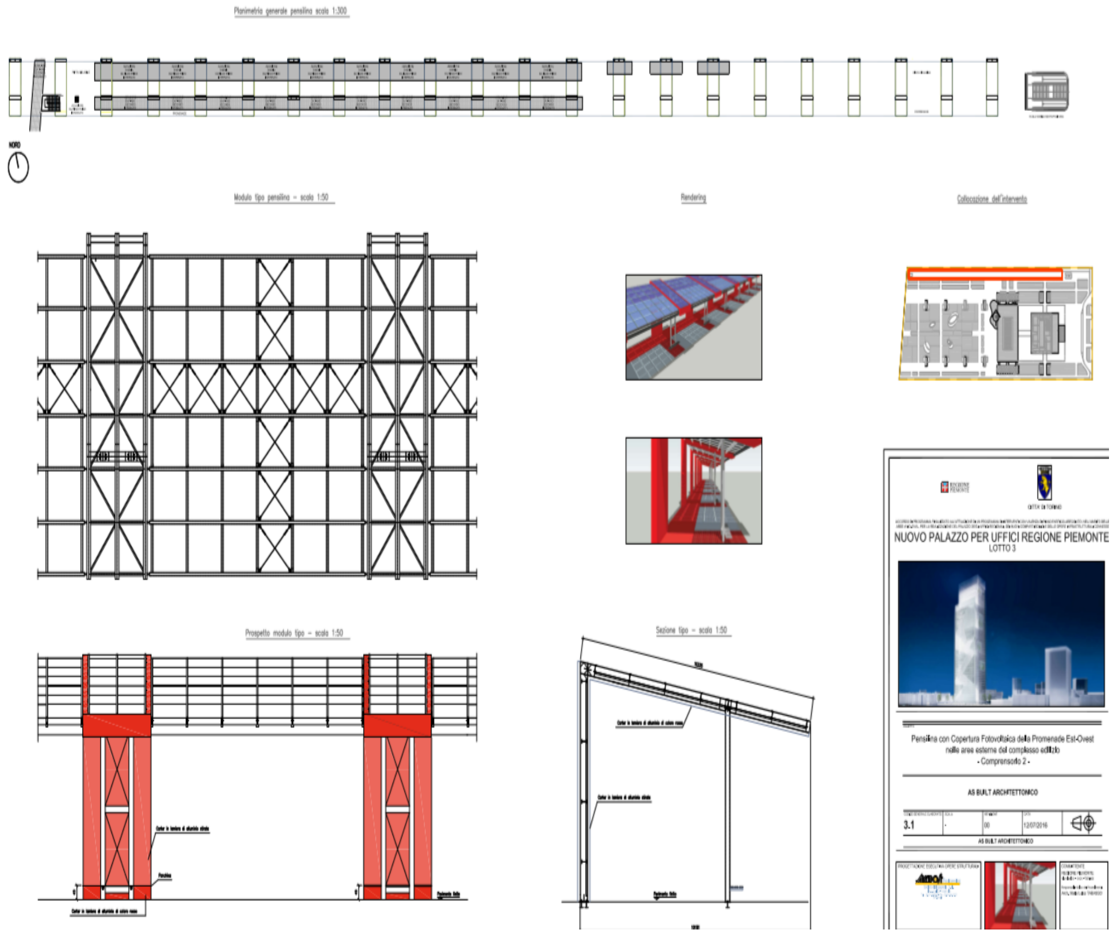


Figure 22:Detail drawing of Promenade in pdf

This drawing contains all the plan view of structure called Promenade which gives a basic understanding to start the practical work by modeling it on Revit or BIM software. We started to model on Revit 2019 but to have a clear view of details we also need some other drawings like section details.

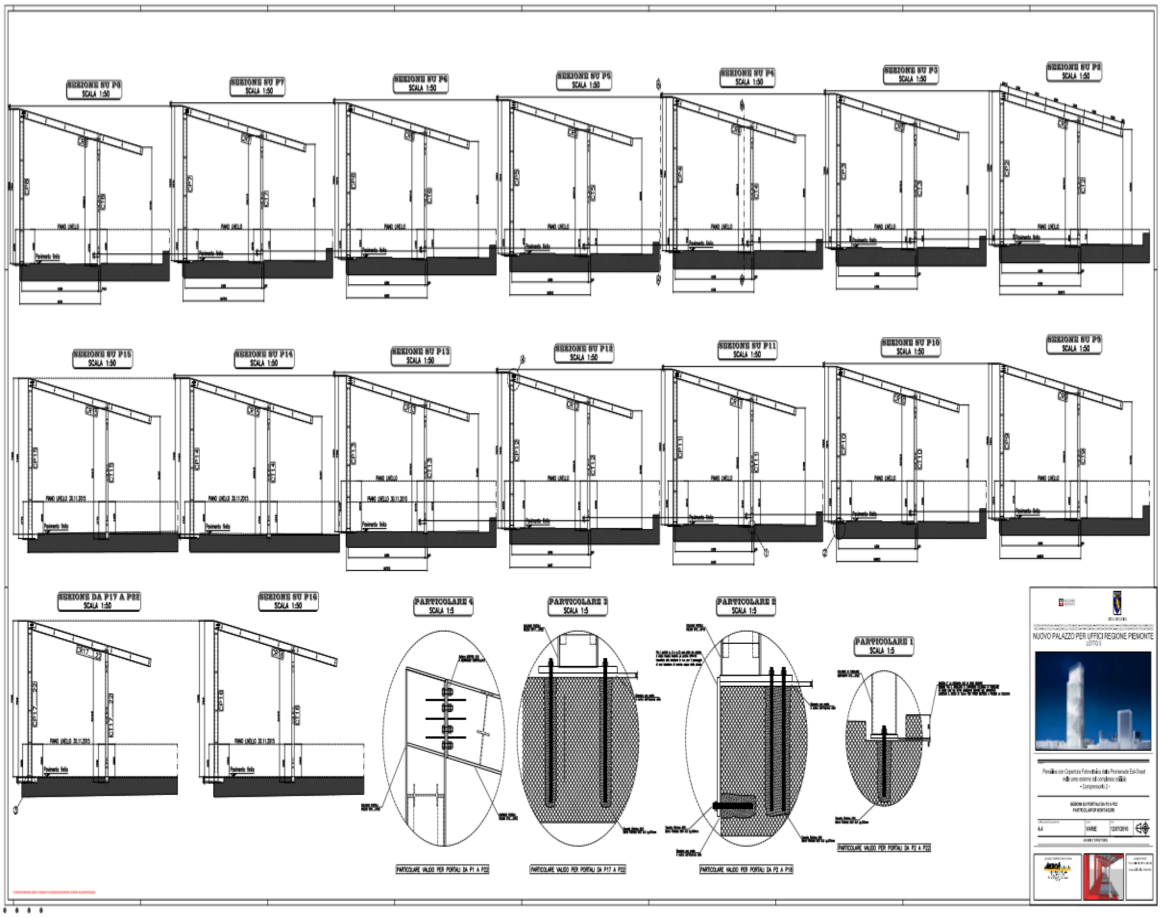


Figure 23: Details of section used in drawings of Promenade

Those two drawings include all the details which you need to start the basic of your 3D model in Revit. As mentioned, these drawings came directly from the Torre regione management and technical staff specially designers, so they are very rich detailed drawings and have all the accuracy and high detail level.

There will be some specific data needed to further put the details of the modelling and for the time scheduling and cost estimation but to start modelling the structure those given drawings are enough to give these drawings a 3D view in BIM software.

2.1.2 Common Data Environment (CDE)

The British Standard BS 1192-2007 considers that a Common Data Environment (from now on CDE) approach should be adopted in order to allow information to be shared between all members of the project team. A CDE is basically an online place for collecting, managing and sharing information among a team working on a project. It also appears in the Italian standard UNI 11337-1 but with its acronym in Italian is ACDat. It is defined as "an environment of organized collection and sharing of data related to models and digital documents, referring to a single work or to a single complex of works".

The international standard ISO 19650 declares that each information container should be in one of three states: Work in progress (WIP), shared or published. The CDE is the place where information changes from one status to another. Firstly, WIP information changes into shared status when the task team manager approves the information, checking that the model is suitable and follows the standards. The following status change from shared to published is made by the employer, who authorizes all the information that follows the client's requirements. The standard recommends the existence of an archive state where all the information container transactions are shown. The archive is also used for future reference and use.

The use of a Common Data Environment facilitates collaboration between team members and helps to avoid duplications and mistakes. Studies have determined that coordination inefficiency increment costs between 20 and 25% (Mills, 2015). For this reason, the use of CDE is becoming increasingly popular.

This thesis involves a number of students which have been working on the project because as mentioned above this project is a mega project which includes Architecture, MEP, Structural design.

2.1.3 3D Modelling

The first step was to convert all 2D drawings of "Promenade", which was given in pdf format and in Autocad 2D into 3D modelling. For modelling of 3D , we need to have basic drawings so according to that basic drawings ,it is proper to use BIM 3D modelling software to model the structure. In our case, we have used Autodesk Revit 2019 to model our structure as shown in figure below.

The geometry of this Revit model is simple steel bridge with interfaces and connections which is the part of a Residential building and also used as a connecting structure. This building is located in Turin, a roof with photovoltaic roof, located in the complex of the Tower of the Piedmont Region, near the Lingotto-Benghazi metro station.

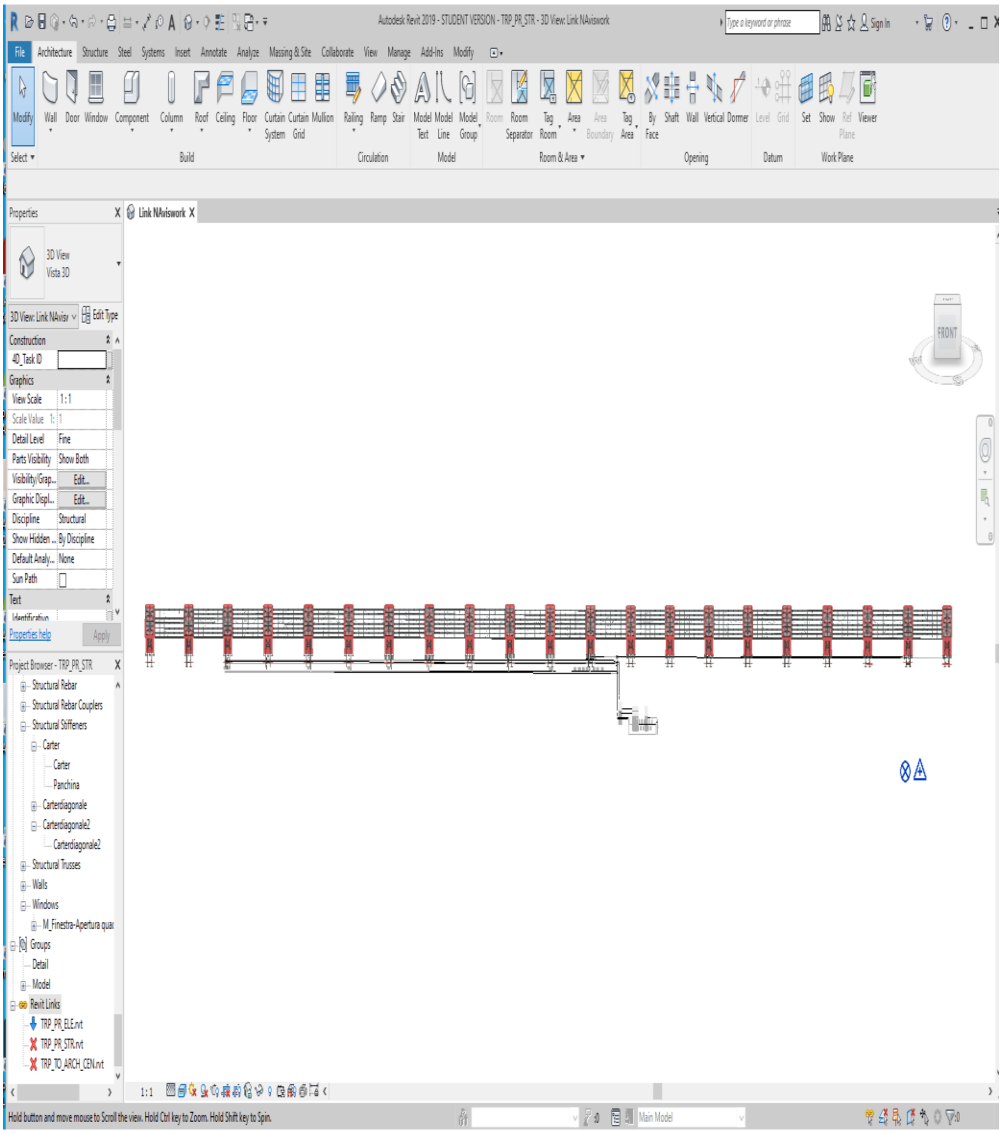


Figure 24: 3D model of Promenade in Revit

2.1.4 Shared Coordinates

Shared coordinates can be one of the most difficult tasks to understand within Revit (or any other BIM software for that matter!). The confusion can be directly compounded when working with multiple software platforms that use different methods to set coordinate systems and approaches to positioning. Yet, they are also one of the most essential procedures required when setting up a project to coordinate and for the alignment of models on a site for all disciplines and consultants.

When you combine multiple models and files in a single project, use shared coordinates to establish the positions of the files in relation to each other.

In order to position the information stored in the project in the same position across all available platforms. It is ultimately a language that can communicate with multiple different software platforms simultaneously in order to provide consistency between all types of models included in a project. This process should be one of the first steps of a project and setting it properly and

as early as possible will save time and money throughout a project when cross-linking models together for coordination.
This is where shared coordinates play an important role so for if we want to export our 3D model from Revit into Navisworks with each and every detail and want to create a time schedule then we should use a shared parameters or shared coordinate process.
As the name Shared parameters indicates the meaning of itself that it is the process of recognizing the details of one model into another so that it will be easy to work with interconnected modelling which is also called as interoperability.

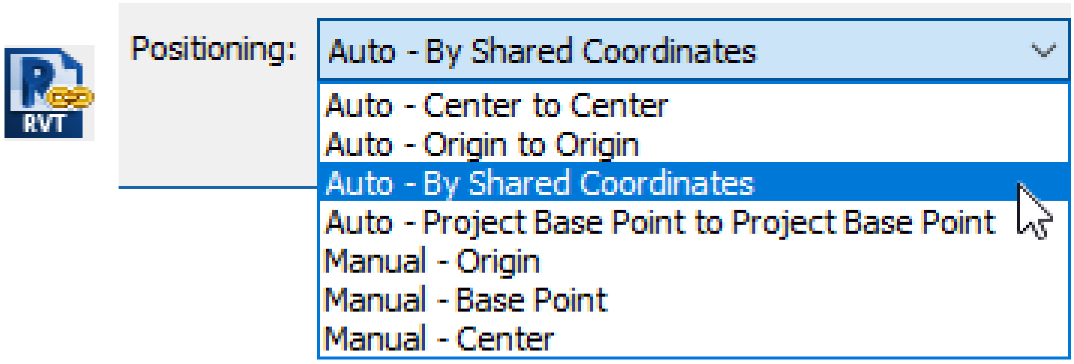


Figure 25: Shared coordinate process in Revit

The Shared Coordinate system is like a virus that spreads around. The virus starts from the linked Revit site Model. It then spreads around to the architecture model, to the structure model, to the linked CAD files, etc. Once the virus infected all the models, you can link any file together and they will automatically position themselves if you use the Auto - By Shared Coordinates positioning option.
This figure shows the basic concept of shared coordinates.

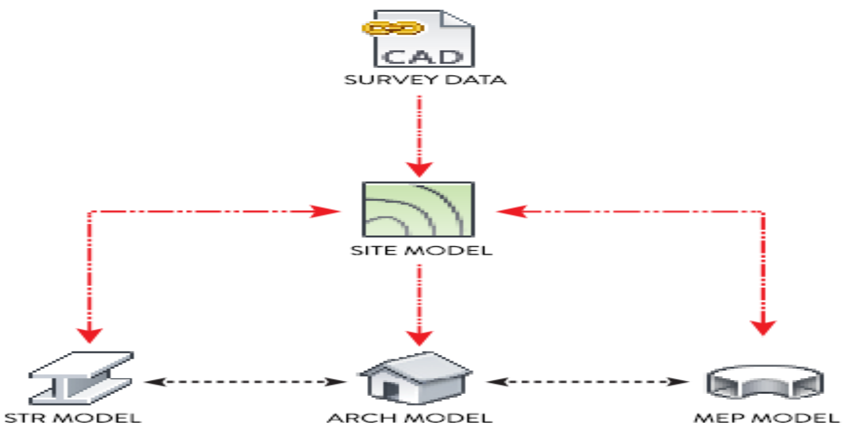


Figure 26:Basic concepts of shared coordinates

2.1.5 Linking shared parameters

To create a new parameter that we can use to link our building parameters into our construction tasks, we create shared parameter.
Switch to “manage tab-shared parameters-create new parameters” as shown in the figure below.
The reason to create shared parameters is that now we can use that same parameter consistently in many different project files and appear in schedules and tags.

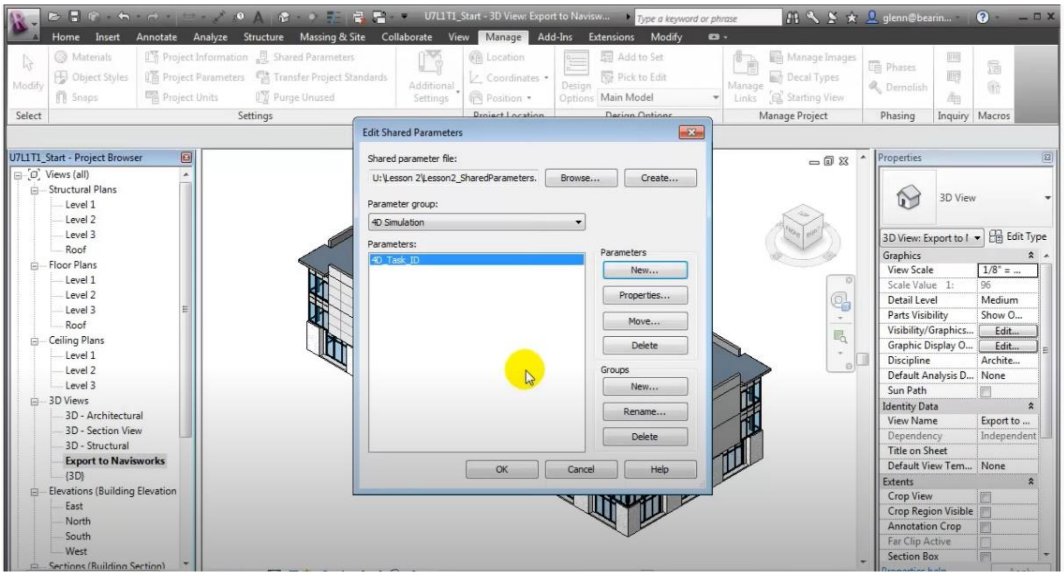


Figure 27:Creating shared parameters in Revit

Having created the “shared parameters”, now let’s create a “Project parameters” and associated it with each of the different project elements (in our case: Promenade).
To do that, we use to create project parameters as shown in the figure.
“Manage tabs-project parameters-add new parameter.

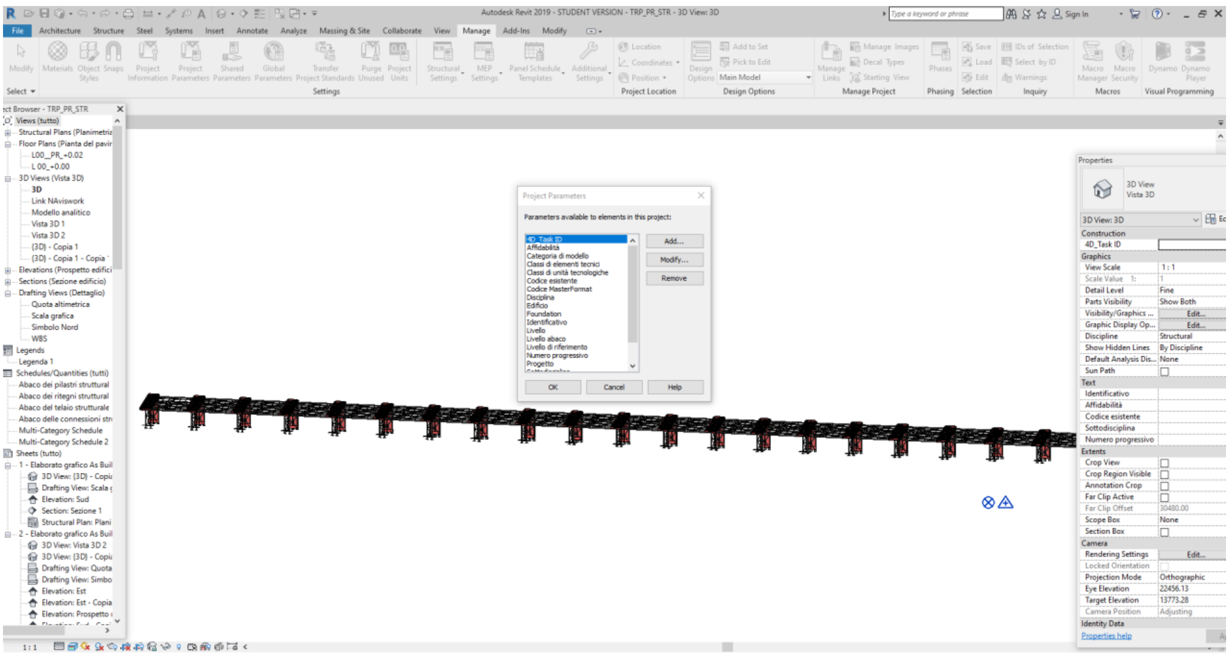


Figure 28: Project parameters

After adding new parameters ,we will choose "shared parameters" which we already defined and we will choose that 4D task id (which is the identification code, used in Revit for this project) and then further group these parameters as "group parameters-construction" and then we can choose the elements that we want to associate with our project.

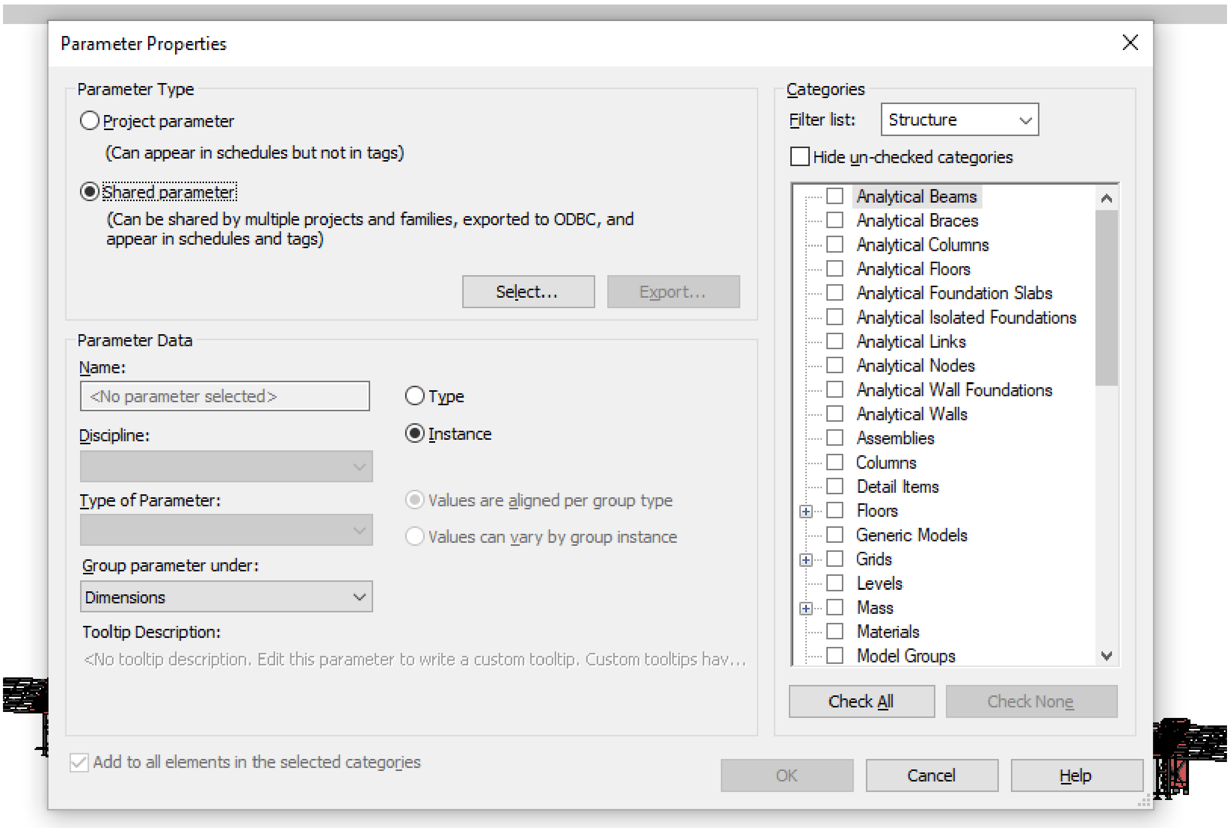


Figure 29: Creating parameters through parameters properties

2.1.6 Coding

After creating the shared parameters within the model, the main part is to link these parameters with each Revit family and parameter used inside the model to give them a unique identification so that it will be easy to recognize these families if you work with same model by exporting into another *BIM software*.

In this case, we already had 3D Revit model of Promenade, now for exporting that model into Navisworks to calculate the time schedule and do the simulation for 4D process , I need to assign codes to each of the Revit family to help me identify easily by exporting into any other software which in our case is *Navisworks Manage* .

After creating all the parameters as discussed above ,the next step is to select all the task associated with families inside Revit and give them the "identification code" which is also known as Work breakdown structure code (WBS code) ,which will help us identify these elements into time scheduling management or Navisworks to do the 4D simulation also.

To do so, we will go to the Microsoft project file in which we have created estimated time schedule of each activity along with WBS code to each family task (e.g 1.1.1), these codes will be explained later in “work breakdown structure topic”.

The WBS creation was the first step to have a complete knowledge of any task required to accomplish the project. As shortly explained in the introduction chapter the Work Breakdown Structure is aimed to decompose in a hierarchical way all the activities connected to the project, in this case activities are strictly connected to materials required, based on the Piedmont price list.

The task id associated with each family is given below. For example, for the task “site clearing” is 1.1 and for the task “columns is 2.2” as shown in figure below.

ID	WBS	Name	Duration	Start	Finish	Predecessors
1	1	1. Preparation of construction site	11 days	25 November 2019 08:00	09 December 2019 17:00	
2	1.1	1.1 Site clearing	1 day	25 November 2019 08:00	25 November 2019 17:00	
3	1.2	1.2 General excavation	3 days	26 November 2019 08:00	28 November 2019 17:00	2
4	1.3	1.3 Transporting of materials	1 day	29 November 2019 08:00	29 November 2019 17:00	3
5	1.4	1.4 Placing formwork and reinforcement	3 days	02 December 2019 08:00	04 December 2019 17:00	4
6	1.5	1.5 installing other utilities	1 day	05 December 2019 08:00	05 December 2019 17:00	5
7	1.6	1.6 pouring concrete	2 days	06 December 2019 08:00	09 December 2019 17:00	6
8	1.7	1.7 complete task	1 day	09 December 2019 08:00	09 December 2019 17:00	
9	2	2. Structure	99 days	10 December 2019 08:00	24/04/2020 17:00	1
10	2.1	2.1 Foundation	23 days	10 December 2019 08:00	09 January 2020 17:00	
11	2.1.1	2.1.1 Excavation	3 days	10 December 2019 08:00	12 December 2019 17:00	
12	2.1.2	2.1.2 Framework	2 days	13 December 2019 08:00	16 December 2019 17:00	11
13	2.1.3	2.1.3 Slab	3 days	17 December 2019 08:00	19 December 2019 17:00	12
14	2.1.4	2.1.4 Lean Concrete	1 day	20 December 2019 08:00	20 December 2019 17:00	13
15	2.1.5	2.1.5 Reinforcement	6 days	23 December 2019 08:00	30 December 2019 17:00	14
16	2.1.6	2.1.6 levelling	2 days	31 December 2019 08:00	01 January 2020 17:00	15
17	2.1.7	2.1.7 Concrete	1 day	02 January 2020 08:00	02 January 2020 17:00	16
18	2.1.8	2.1.8 Grouting	5 days	03 January 2020 08:00	09 January 2020 17:00	17
19	2.2	2.2 Columns	12 days	10 January 2020 08:00	27 January 2020 17:00	10
20	2.2.1	2.2.1 Pillars	6 days	10 January 2020 08:00	17 January 2020 17:00	
21	2.2.1.1	2.2.1.1 IPE330	6 days	10 January 2020 08:00	17 January 2020 17:00	18
22	2.2.2	2.2.2 Rectangular & square hollow sections	6 days	20 January 2020 08:00	27 January 2020 17:00	20
23	2.2.2.1	2.2.2.1 TCAR200*6	6 days	20 January 2020 08:00	27 January 2020 17:00	21
24	2.3	2.3 Beams	21 days	28 January 2020 08:00	25 February 2020 17:00	19
25	2.3.1	2.3.1 Main Beams	9 days	28 January 2020 08:00	07 February 2020 17:00	
26	2.3.1.1	2.3.1.1 Beam IPE360	9 days	28 January 2020 08:00	07 February 2020 17:00	23
27	2.3.2	2.3.2 Secondary Beams	12 days	10 February 2020 08:00	25 February 2020 17:00	
28	2.3.2.1	2.3.2.1 Beams IPE200	6 days	10 February 2020 08:00	17 February 2020 17:00	26
29	2.3.2.2	2.3.2.2 Beams HE260A	6 days	18 February 2020 08:00	25 February 2020 17:00	28
30	2.4	2.4 Framing	43 days	26 February 2020 08:00	24/04/2020 17:00	24
31	2.4.1	2.4.1 rectangular hollow section (RHS)	5 days	26 February 2020 08:00	03 March 2020 17:00	
32	2.4.1.1	2.4.1.1 300*100*8	5 days	26 February 2020 08:00	03 March 2020 17:00	29
33	2.4.2	2.4.2 Square hollow section (SHS)	6 days	04 March 2020 08:00	11 March 2020 17:00	31
34	2.4.2.1	2.4.2.1 800*80*3	6 days	04 March 2020 08:00	11 March 2020 17:00	32
35	2.4.3	2.4.3 Hollow circular sections	9 days	12 March 2020 08:00	24 March 2020 17:00	33
36	2.4.3.1	2.4.3.1 TRON70*2.5	9 days	12 March 2020 08:00	24 March 2020 17:00	34
37	2.4.4	2.4.4 Rectangular & square hollow sections	6 days	25 March 2020 08:00	01/04/2020 17:00	35

Figure 30: Time schedule of elements

And then we will return to Revit software to enter these codes manually. we are doing it manually because this project does not have much families but if the project is ,long and then the uniformat process should be followed.

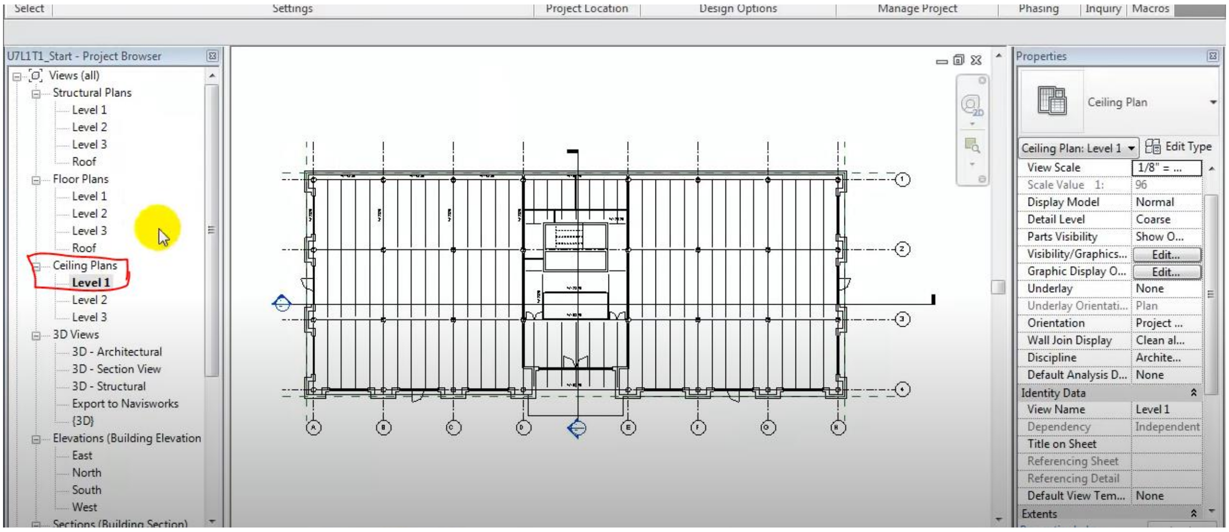


Figure 31: Process of providing codes

We should be careful to select the view which we should use to make it easier to select each of the different types of structure elements. For example, for beam and columns we should switch over to ceiling plan view in Revit, where we can select all the elements and use “filter” option to select particular item to which you want to associate the code as shown in figure below.

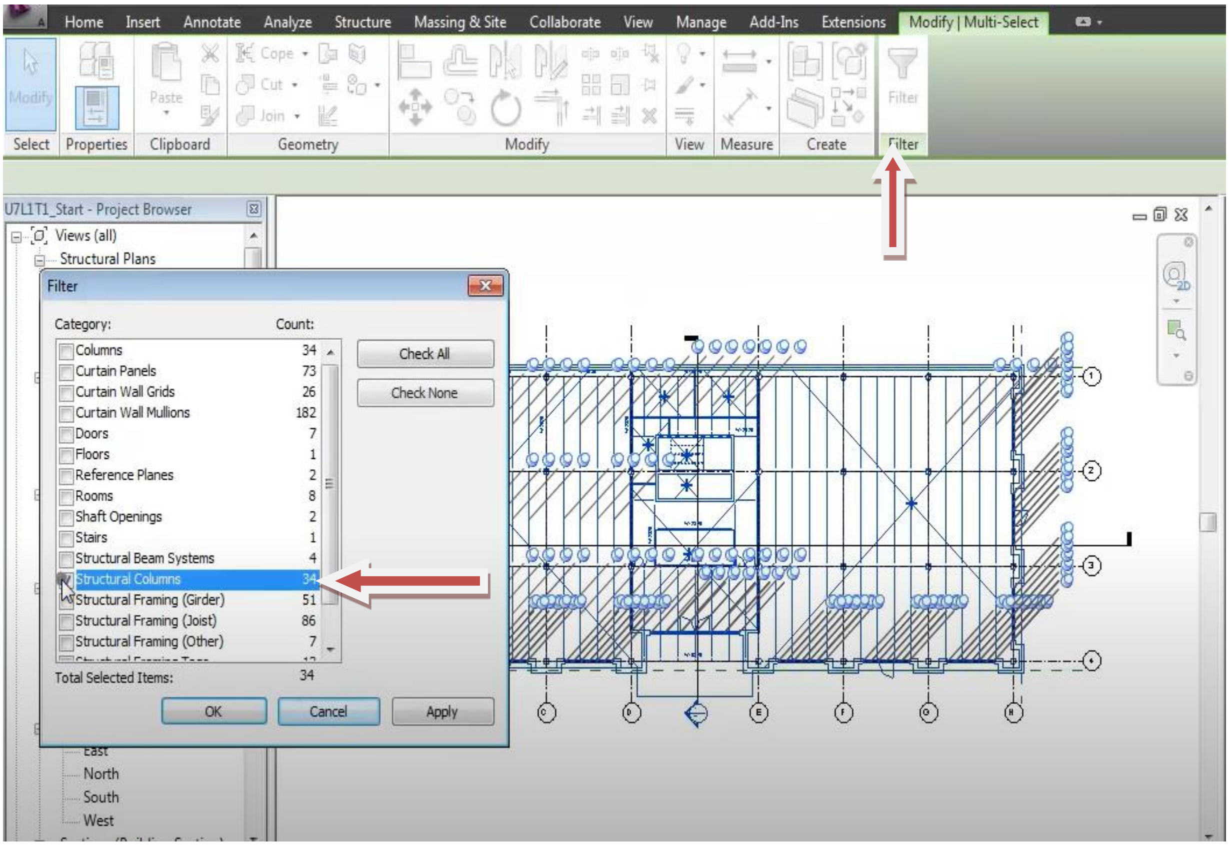


Figure 32: Assigning the WBS codes to elements

After completing that task, now we can assign code in “4D-task ID” which we had created as a group parameter inside Revit.

To do that, we will select each family item in Revit model as mentioned above about all the process and select every item of same family used in that project by using filter command as it shown above.

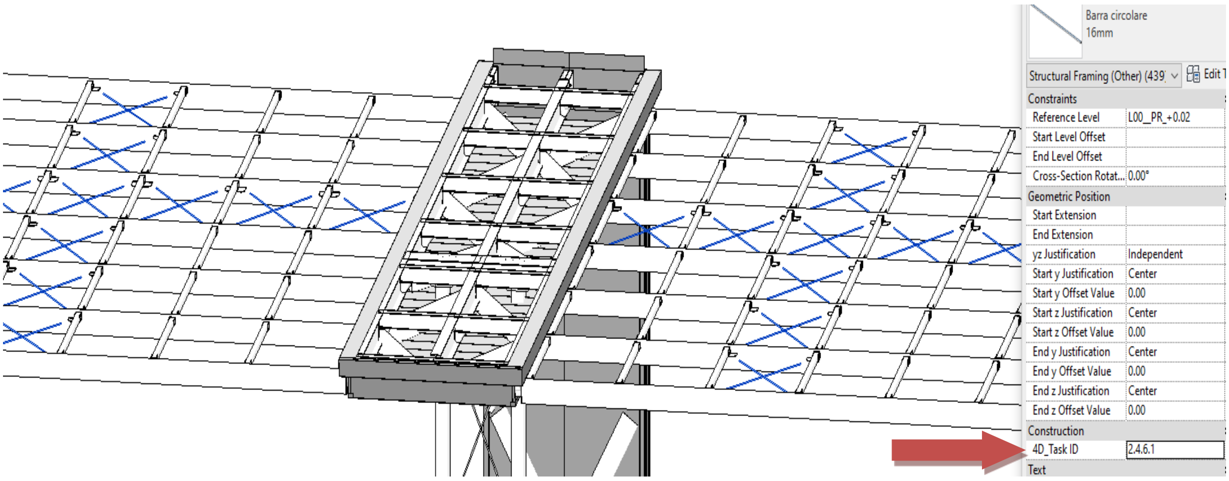


Figure 33: Assigning WBS codes to each element

This figure shows the specific coding according to the WBS code, which we have provided inside Revit model to give each family used in project an identification, so when exported into Navisworks, it will be easy to export that model and work onto that because now these models are linked with each other.

The process of giving identification code to each family is, select the family used inside project, as we know that the project has been consisted of same families to select all the families of same pattern and give them code. In the figure shown above, you can see the blue color, which indicates that these families are same so they can be identified as one code.

2.2 CONSTRUCTION MANAGEMENT

2.2.1 Work Breakdown Structure WBS

WBS (Work Breakdown Structure) creation is a process for dividing or breaking project deliverables and project work into smaller components for easier arrangement. The main objective of making WBS is to facilitate the planning and controlling costs, schedule and technical content of the project. Therefore, WBS manufacture is done during the initial phase of project development.

WBS-oriented deliverables provide the following benefits to the project, i.e.
- Better communication between sponsors, stakeholders and team members,
- More accurate estimates for jobs, risks, timelines and costs,
- Increase confidence that the project has been 100% identified,
- As the foundation for project control.

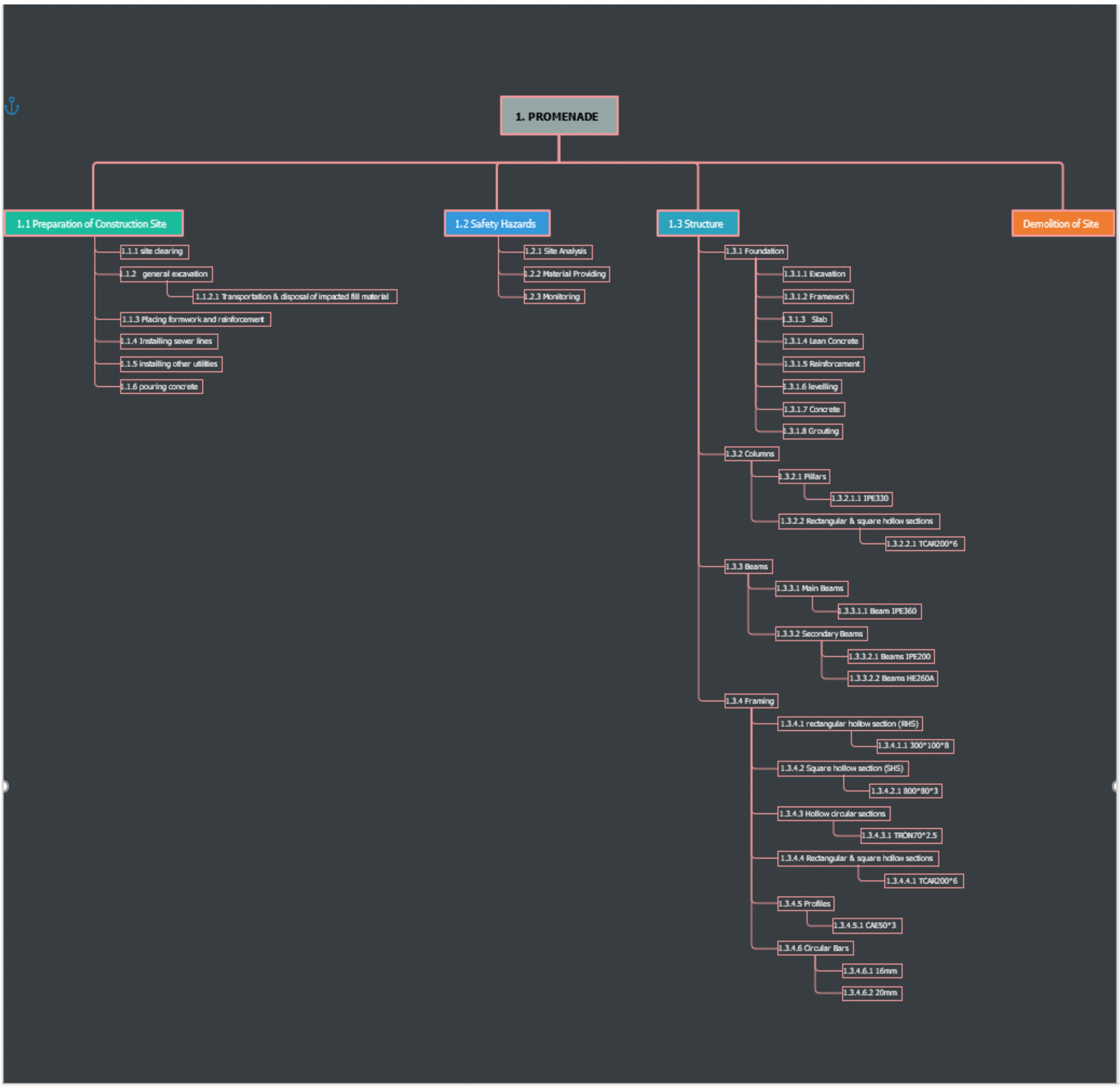
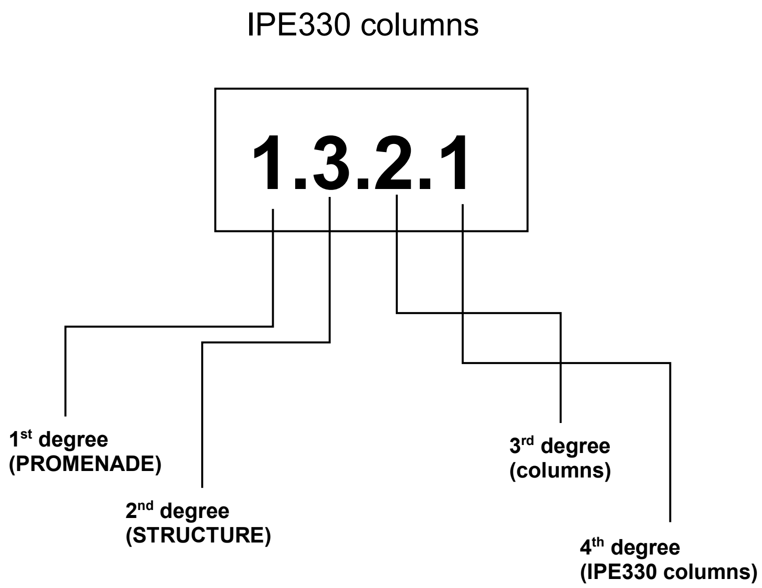


Figure 34: Work breakdown structure (WBS) module

The development of WBS in this THESIS has the following objectives:

1. Identify and arrange work packages on the lower structure Promenade construction work.
2. Identify the various methods of implementation carried out on the work package of substructure in Promenade.
3. Identify the required activities of each implementation method on the substructure work package.
4. Identify the resources of each activity of each implementation method on the packet required in the work of substructure in Promenade.
5. Identify the form of WBS dictionary on the lower structure of Promenade.

The WBS is represented by a numeric division separated by a point, every
number represent a degree of the scale as shown below.



This shows the clear decomposition of the structure and also its clear and easy to understand the hierarchy of the whole structure.it is also possible to add as many tasks as you want so the basic concept of creating a work breakdown structure as mentioned previously is to have an clear overview which is also being shown in the example given above.

2.2.2 Gantt Chart

Gantt Charts are a way to graphically show progress of a project. Management of a project is made easier if it is viewed as small manageable items where the dependencies are visually illustrated, parallel processes are discovered, the overall processing time determined, and progress tracked. The tasks of a project can be quite complex and dependent on each other. With a project management tool, such as a Gantt chart, all subtasks of a task can be viewed graphically.

This activity of Gantt chart is created by using project management software *Microsoft project 2016*. Microsoft Project is a project management software program developed and sold by Microsoft, which is designed to assist a project manager in developing a plan, assigning resources to tasks, tracking progress, managing the budget, and analyzing workloads.

The application creates critical path schedules, and critical chain and event chain methodology third-party plug-ins are also obtainable. Schedules can be resource leveled, and task networks are visualized in a Gantt chart. Additionally, Microsoft Project can identify divergent classes of the users. These different classes of users can have differing access levels to projects, views, and other data. Customization of aspects in Microsoft Project such as calendars, views, tables, filters, and fields are stored in an enterprise global which is accessible by all users.

The subtasks of the relocation-process appear on the y-axis, and the timeline on the x-axis. The bars show when a task should start and when it will be finished. Blue bars show tasks which have been completed.

Task Name	Duratior	Start	Finish
Stage 1 (1-5 Panels)	0 days	Fri 19/06/20 8:00 AM	Fri 19/06/20 8:00 AM
3.1(I) Structure	**141 days**	**Fri 10/01/20 8:00 AM**	**Fri 24/07/20 5:00 PM**
3.1(I) Foundation	**18 days**	**Fri 10/01/20 8:00 AM**	**Tue 4/02/20 5:00 PM**
3.2.1(I) Columns	**12 days**	**Mon 27/04/20 8:00 AM**	**Tue 12/05/20 5:00 PM**
3.2.1.1 Pillars	**6 days**	**Mon 27/04/20 8:00 AM**	**Mon 4/05/20 5:00 PM**
3.2.1.1.1 IPE330	6 days	Mon 27/04/20 8:00 AM	Mon 4/05/20 5:00 PM
3.2.2 Rectangular & square hollow sections	**6 days**	**Tue 5/05/20 8:00 AM**	**Tue 12/05/20 5:00 PM**
3.2.2.1 TCAR200*6	6 days	Tue 5/05/20 8:00 AM	Tue 12/05/20 5:00 PM
3.3.1(I) Beams	**21 days**	**Wed 13/05/20 8:00 AM**	**Wed 10/06/20 5:00 PM**
3.3.1.1 Main Beams	**9 days**	**Wed 13/05/20 8:00 AM**	**Mon 25/05/20 5:00 PM**
3.3.1.1 Beam IPE360	9 days	Wed 13/05/20 8:00 AM	Mon 25/05/20 5:00 PM
3.3.2 Secondary Beams	**12 days**	**Tue 26/05/20 8:00 AM**	**Wed 10/06/20 5:00 PM**
3.3.2.1 Beams IPE200	6 days	Tue 26/05/20 8:00 AM	Tue 2/06/20 5:00 PM
3.3.2.2 Beams HE260A	6 days	Wed 3/06/20 8:00 AM	Wed 10/06/20 5:00 PM
3.4(I) Framing	**32 days**	**Thu 11/06/20 8:00 AM**	**Fri 24/07/20 5:00 PM**
3.4.1 rectangular hollow section (RHS)	**5 days**	**Thu 11/06/20 8:00 AM**	**Wed 17/06/20 5:00 PM**

Figure 35: Timeline of sub-tasks

In Microsoft project To have a more tidy organization the software make relationship between the tasks, and there can be four relations types:

- **End - Start**: Is the more common relationship used, the following activity begins when the previous ends.

- **Start - Start**: Two or more activities begins at the same time.

- **End - End**: Two activities are connected by the final date, so they can start in different moments but have to finish on the same date.

- **Start - End**: The selected activity has to end when the other starts.

As previously shortly introduced in MS Project is possible to load for any task the correspondent resources, that allow a highest control level, through the working team organization, avoiding tasks overlapping, guarantee a precise workers organization.

To have a complete time schedule, and a detailed organization, is also important to insert into MS Project other parameters aimed to specify some significant aspects in the building site organization:

- Homogeneous working groups:

  First step is to divide all tasks in main group, to better understand which tasks should stay in the same group, aimed to organize in a temporal way all the process, the subdivision helps to monitor the activities and the workers.

- Intervention squad:

Understand the employees number required to accomplish the project is one of the first step, is important to estimate who is doing a determinate task and when. For example, in an excavation task one will move the excavator, two will place the ground and possibly a fourth helping in case of need.

- Costs:

As said in the Gantt chart are insert also the costs in form of resources, costs can be about material and human, they were obtained from the Piedmont prices list.

- Working hours:

It's also mandatory to insert a working hours program, that simply define the daily working hours, it was insert a normal time schedule. The final report shows the total amount of working hours, aimed to provide the possibility to manage it adapting to the necessities and possible issues.

- Working days:

  That define the working days in a normal week, it was insert a normal working week from Monday to Friday, from 8 to 12 then from 1 to 5 that result a normal 40 hours work week for all the employees.

- Works overlapping:

  To avoid tasks overlapping, then a multiple employee assignment at the same time, MS Project shows an advisement, the overlapping can be planned in a fair way it is split into more employees, clearly it results wrong if one employee has more than one task assigned at the same time.

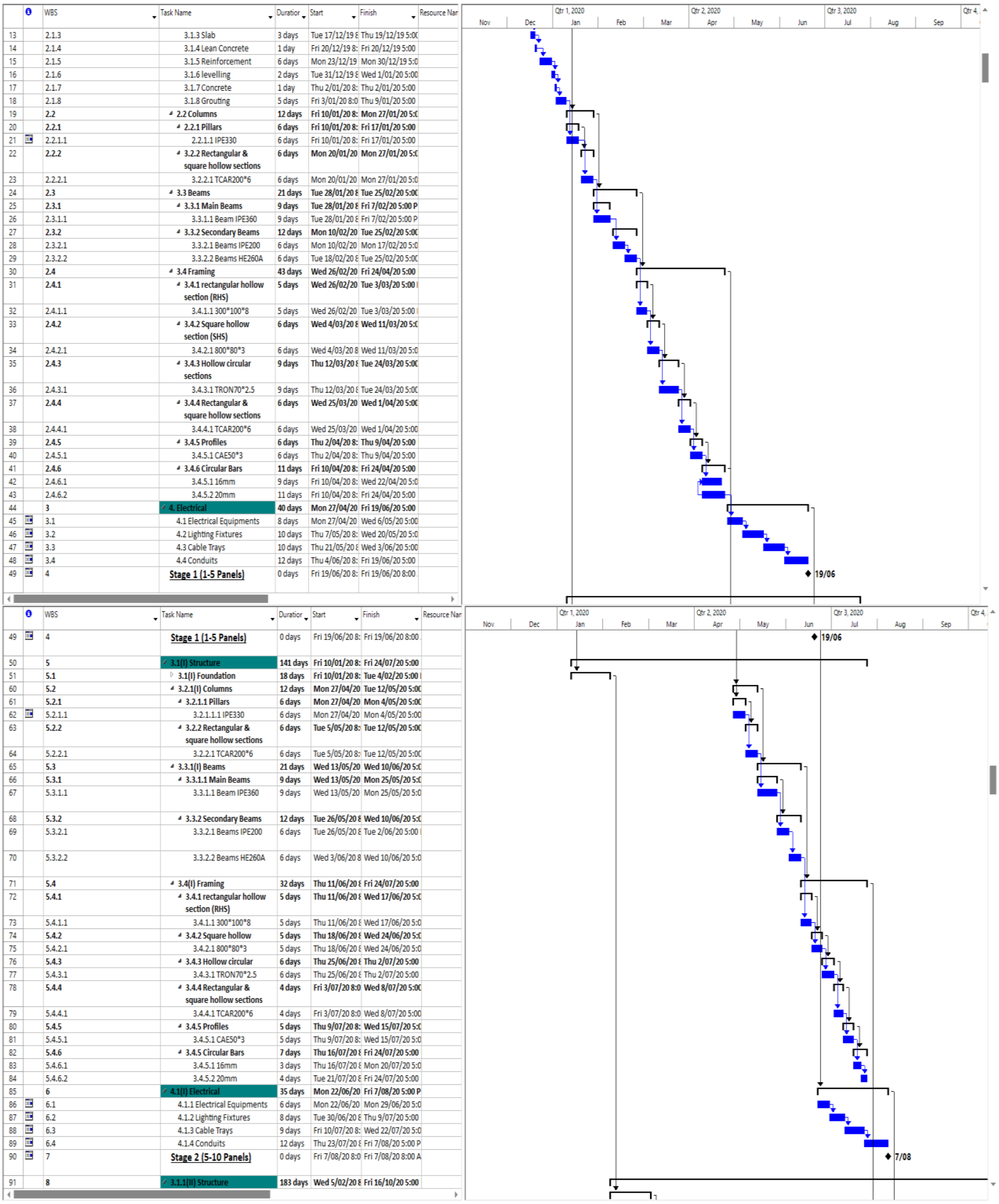
The whole scheme of Gantt chart is shown below. In the Gantt chart made to have a detailed time schedule is possible to understand how complex can be a construction management process, if for such as a small dimension project, constituted by a basic level of complexity, were managed many tasks combined with resources and costs.

All the tasks represents a Type in the Revit model, associated by the WBS code insert in Revit as Key Note passing through the process previously described, and in MS Project as a value present in the last column of the previous picture, inserting the WBS code manually, that means some errors can be done during this data filling phase.

The first column in the Gantt chart represent a task numbering, basically in temporal order, as though in the work program. In the following column are written the tasks names, in terms of a short description, just to easily identify the tasks, beside was created automatically a WBS code by MS Project, that match with the one create by myself that is compositing the activity code used in the construction management process. Every task then has a initial and final date, established by the construction manager.

Then the second column contain the WBS code applied also to the Revit model useful to have a direct connection between the element and the correspondent task in the simulation software, as Navisworks that will be treat in the following pages.

The chart composed by horizontal lines representing the tasks, easily readable where the length represent the craft duration, and with a proper symbology are also represented the relationship between the activities, further at every lines are associated the resources needed to accomplish the selected activity.



		WBS	Task Name	Duration	Start	Finish	Resource Nar
13		2.1.3	3.1.3 Slab	3 days	Tue 17/12/19 8	Thu 19/12/19 5:00	
14		2.1.4	3.1.4 Lean Concrete	1 day	Fri 20/12/19 8:	Fri 20/12/19 5:00	
15		2.1.5	3.1.5 Reinforcement	6 days	Mon 23/12/19	Mon 30/12/19 5:0	
16		2.1.6	3.1.6 levelling	2 days	Tue 31/12/19 8	Wed 1/01/20 5:00	
17		2.1.7	3.1.7 Concrete	1 day	Thu 2/01/20 8:	Thu 2/01/20 5:00	
18		2.1.8	3.1.8 Grouting	5 days	Fri 3/01/20 8:0	Thu 9/01/20 5:00	
19		**2.2**	**2.2 Columns**	**12 days**	**Fri 10/01/20 8:**	**Mon 27/01/20 5:0**	
20		**2.2.1**	**2.2.1 Pillars**	**6 days**	**Fri 10/01/20 8:**	**Fri 17/01/20 5:00**	
21		2.2.1.1	2.2.1.1 IPE330	6 days	Fri 10/01/20 8:	Fri 17/01/20 5:00	
22		**2.2.2**	**3.2.2 Rectangular & square hollow sections**	**6 days**	**Mon 20/01/20**	**Mon 27/01/20 5:0**	
23		2.2.2.1	3.2.2.1 TCAR200*6	6 days	Mon 20/01/20	Mon 27/01/20 5:0	
24		**2.3**	**3.3 Beams**	**21 days**	**Tue 28/01/20 8**	**Tue 25/02/20 5:00**	
25		**2.3.1**	**3.3.1 Main Beams**	**9 days**	**Tue 28/01/20 8**	**Fri 7/02/20 5:00 P**	
26		2.3.1.1	3.3.1.1 Beam IPE360	9 days	Tue 28/01/20 8	Fri 7/02/20 5:00 P	
27		**2.3.2**	**3.3.2 Secondary Beams**	**12 days**	**Mon 10/02/20**	**Tue 25/02/20 5:00**	
28		2.3.2.1	3.3.2.1 Beams IPE200	6 days	Mon 10/02/20	Mon 17/02/20 5:0	
29		2.3.2.2	3.3.2.2 Beams HE260A	6 days	Tue 18/02/20 8	Tue 25/02/20 5:00	
30		**2.4**	**3.4 Framing**	**43 days**	**Wed 26/02/20**	**Fri 24/04/20 5:00**	
31		**2.4.1**	**3.4.1 rectangular hollow section (RHS)**	**5 days**	**Wed 26/02/20**	**Tue 3/03/20 5:00**	
32		2.4.1.1	3.4.1.1 300*100*8	5 days	Wed 26/02/20	Tue 3/03/20 5:00	
33		**2.4.2**	**3.4.2 Square hollow section (SHS)**	**6 days**	**Wed 4/03/20 8**	**Wed 11/03/20 5:0**	
34		2.4.2.1	3.4.2.1 800*80*3	6 days	Wed 4/03/20 8	Wed 11/03/20 5:0	
35		**2.4.3**	**3.4.3 Hollow circular sections**	**9 days**	**Thu 12/03/20 8**	**Tue 24/03/20 5:00**	
36		2.4.3.1	3.4.3.1 TRON70*2.5	9 days	Thu 12/03/20 8	Tue 24/03/20 5:00	
37		**2.4.4**	**3.4.4 Rectangular & square hollow sections**	**6 days**	**Wed 25/03/20**	**Wed 1/04/20 5:00**	
38		2.4.4.1	3.4.4.1 TCAR200*6	6 days	Wed 25/03/20	Wed 1/04/20 5:00	
39		**2.4.5**	**3.4.5 Profiles**	**6 days**	**Thu 2/04/20 8:**	**Thu 9/04/20 5:00**	
40		2.4.5.1	3.4.5.1 CAE50*3	6 days	Thu 2/04/20 8:	Thu 9/04/20 5:00	
41		**2.4.6**	**3.4.6 Circular Bars**	**11 days**	**Fri 10/04/20 8:**	**Fri 24/04/20 5:00**	
42		2.4.6.1	3.4.5.1 16mm	9 days	Fri 10/04/20 8:	Wed 22/04/20 5:0	
43		2.4.6.2	3.4.5.2 20mm	11 days	Fri 10/04/20 8:	Fri 24/04/20 5:00	
44		3	**4. Electrical**	**40 days**	**Mon 27/04/20**	**Fri 19/06/20 5:00**	
45		3.1	4.1 Electrical Equipments	8 days	Mon 27/04/20	Wed 6/05/20 5:00	
46		3.2	4.2 Lighting Fixtures	10 days	Thu 7/05/20 8:	Wed 20/05/20 5:0	
47		3.3	4.3 Cable Trays	10 days	Thu 21/05/20 8	Wed 3/06/20 5:00	
48		3.4	4.4 Conduits	12 days	Thu 4/06/20 8:	Fri 19/06/20 5:00	
49		4	**Stage 1 (1-5 Panels)**	0 days	Fri 19/06/20 8:	Fri 19/06/20 8:00	

		WBS	Task Name	Duration	Start	Finish	Resource Nar
49		4	**Stage 1 (1-5 Panels)**	0 days	Fri 19/06/20 8:	Fri 19/06/20 8:00	
50		**5**	**3.1(I) Structure**	**141 days**	**Fri 10/01/20 8:**	**Fri 24/07/20 5:00**	
51		**5.1**	**3.1(I) Foundation**	**18 days**	**Fri 10/01/20 8:**	**Tue 4/02/20 5:00**	
60		**5.2**	**3.2.1(I) Columns**	**12 days**	**Mon 27/04/20**	**Tue 12/05/20 5:00**	
61		**5.2.1**	**3.2.1.1 Pillars**	**6 days**	**Mon 27/04/20**	**Mon 4/05/20 5:00**	
62		5.2.1.1	3.2.1.1.1 IPE330	6 days	Mon 27/04/20	Mon 4/05/20 5:00	
63		**5.2.2**	**3.2.2 Rectangular & square hollow sections**	**6 days**	**Tue 5/05/20 8:**	**Tue 12/05/20 5:00**	
64		5.2.2.1	3.2.2.1 TCAR200*6	6 days	Tue 5/05/20 8:	Tue 12/05/20 5:00	
65		**5.3**	**3.3.1(I) Beams**	**21 days**	**Wed 13/05/20**	**Wed 10/06/20 5:0**	
66		**5.3.1**	**3.3.1.1 Main Beams**	**9 days**	**Wed 13/05/20**	**Mon 25/05/20 5:0**	
67		5.3.1.1	3.3.1.1 Beam IPE360	9 days	Wed 13/05/20	Mon 25/05/20 5:0	
68		**5.3.2**	**3.3.2 Secondary Beams**	**12 days**	**Tue 26/05/20 8**	**Wed 10/06/20 5:0**	
69		5.3.2.1	3.3.2.1 Beams IPE200	6 days	Tue 26/05/20 8	Tue 2/06/20 5:00	
70		5.3.2.2	3.3.2.2 Beams HE260A	6 days	Wed 3/06/20 8	Wed 10/06/20 5:0	
71		**5.4**	**3.4(I) Framing**	**32 days**	**Thu 11/06/20 8**	**Fri 24/07/20 5:00**	
72		**5.4.1**	**3.4.1 rectangular hollow section (RHS)**	**5 days**	**Thu 11/06/20 8**	**Wed 17/06/20 5:0**	
73		5.4.1.1	3.4.1.1 300*100*8	5 days	Thu 11/06/20 8	Wed 17/06/20 5:0	
74		**5.4.2**	**3.4.2 Square hollow**	**5 days**	**Thu 18/06/20 8**	**Wed 24/06/20 5:0**	
75		5.4.2.1	3.4.2.1 800*80*3	5 days	Thu 18/06/20 8	Wed 24/06/20 5:0	
76		**5.4.3**	**3.4.3 Hollow circular**	**6 days**	**Thu 25/06/20 8**	**Thu 2/07/20 5:00**	
77		5.4.3.1	3.4.3.1 TRON70*2.5	6 days	Thu 25/06/20 8	Thu 2/07/20 5:00	
78		**5.4.4**	**3.4.4 Rectangular & square hollow sections**	**4 days**	**Fri 3/07/20 8:0**	**Wed 8/07/20 5:00**	
79		5.4.4.1	3.4.4.1 TCAR200*6	4 days	Fri 3/07/20 8:0	Wed 8/07/20 5:00	
80		**5.4.5**	**3.4.5 Profiles**	**5 days**	**Thu 9/07/20 8:**	**Wed 15/07/20 5:0**	
81		5.4.5.1	3.4.5.1 CAE50*3	5 days	Thu 9/07/20 8:	Wed 15/07/20 5:0	
82		**5.4.6**	**3.4.5 Circular Bars**	**7 days**	**Thu 16/07/20 8**	**Fri 24/07/20 5:00**	
83		5.4.6.1	3.4.5.1 16mm	3 days	Thu 16/07/20 8	Mon 20/07/20 5:0	
84		5.4.6.2	3.4.5.2 20mm	4 days	Tue 21/07/20 8	Fri 24/07/20 5:00	
85		**6**	**4.1(I) Electrical**	**35 days**	**Mon 22/06/20**	**Fri 7/08/20 5:00 P**	
86		6.1	4.1.1 Electrical Equipments	6 days	Mon 22/06/20	Mon 29/06/20 5:0	
87		6.2	4.1.2 Lighting Fixtures	8 days	Tue 30/06/20 8	Thu 9/07/20 5:00	
88		6.3	4.1.3 Cable Trays	9 days	Fri 10/07/20 8:	Wed 22/07/20 5:0	
89		6.4	4.1.4 Conduits	12 days	Thu 23/07/20 8	Fri 7/08/20 5:00 P	
90		7	**Stage 2 (5-10 Panels)**	0 days	Fri 7/08/20 8:0	Fri 7/08/20 8:00 A	
91		**8**	**3.1.1(II) Structure**	**183 days**	**Wed 5/02/20 8**	**Fri 16/10/20 5:00**	

Figure 36:Gantt chart scheme in Microsoft® Project

2.2.3 Interoperability between softwares

2.2.3.1 Gantt Chart Interoperability Analysis from Tekla Structures to CPM Software

Likewise, the other industries, timing, deadlines and task durations have vital importance also in AEC industry. This argument emphasizes the value of methods to set schedules, create timetables and time management. As mentioned before, Gantt Charts are one of the most used methods. In AEC industry, they are generally produced by Construction Project Management software or BIM software which are capable. More specifically, by combining Gantt Charts with 3D Models, a 4D Model can be obtained and used to visualize and manage construction steps properly. However, in the use of this solid method, there might be some challenges regarding interoperability, because of the possible workflow between stakeholders. Unless each stakeholder uses the same software, the conflicts can be expected in Gantt Chart interoperability from one software to another.

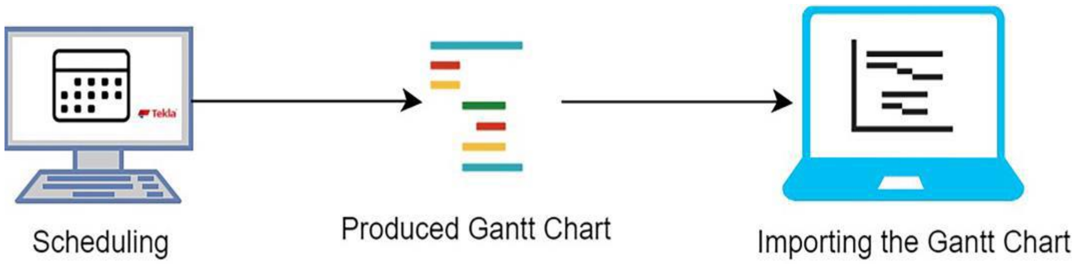


Figure 37: Gantt Chart Interoperability Analysis from CPM Software to Tekla Structures

In this part of the thesis, the interoperability analysis of produced Gantt Charts was presented to identify the possible incompatibilities between BIM software which can occur in exporting/importing Gantt Charts.
Incompatibilities of Gantt Chart interoperability can be defined as investigation of the differences in schedules (i.e. Gantt Charts) from one tool to another.
Considering the real applications, the criteria to study in the assessment of Gantt Chart exchange can be given as:

- Is the Gantt Chart exported completely?
- Is there any data-loss or change?
- How much the effect of these changes to the project management?

Starting point of this research was to produce a Gantt Chart in Tekla Structures to analyze the Gantt Chart interoperability. In Tekla Structures, the followed way of producing Gantt Chart is given in the Figure below.

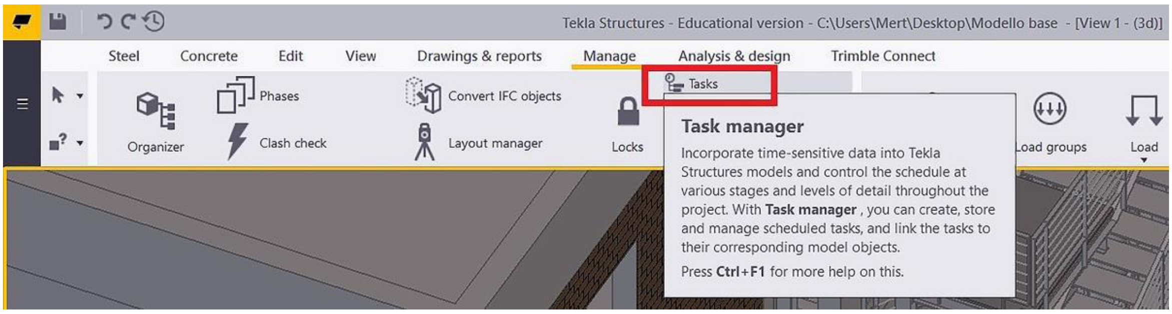
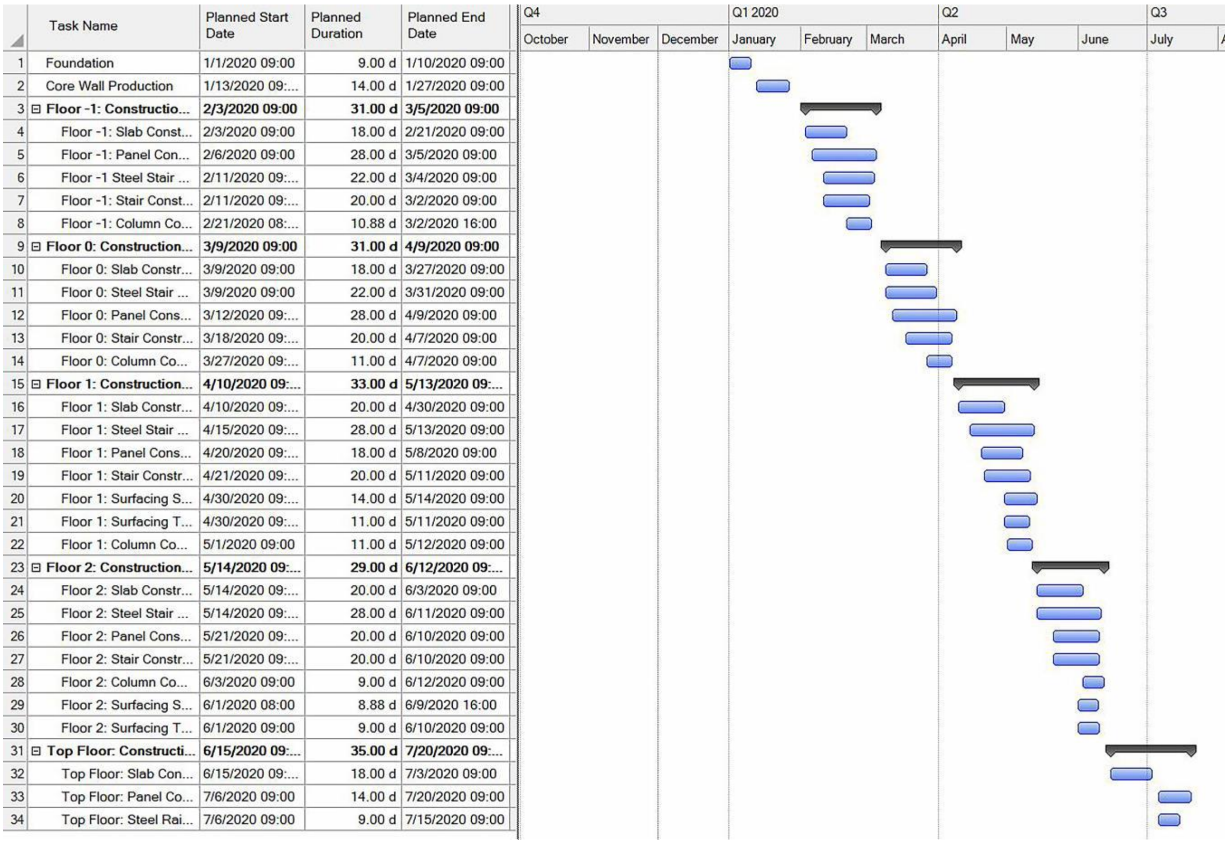


Figure 38: Tekla Structures Task Manager for Producing Gantt Charts

In Tekla Structures, there are a lot of “Task List Items” to produce Gantt Chart, such that: “Task Name”, “Task Type”, “Planned Start Date”, “Planned Duration”, “Planned End Date”, “Actual Start Date”, “Actual End Date”, “Quantity”, “Contractor”, “Percentage Complete”, “Milestone Task”, etc. However, for this study, necessary fields to add information were: “Task Name”, “Planned Start Date”, “Planned Duration” and “Planned End Date”.

The assigned values for chosen fields: “Task Names” were decided according to the designed elements and “Start”/“End” dates were designated in a generic way. The Gantt Chart produced in Tekla Structures contains assigned various structural elements to main tasks and subtasks according to a logical sequence.

The produced Gantt Chart in Tekla Structures for the assessment was given in the following Figure:



	Task Name	Planned Start Date	Planned Duration	Planned End Date
1	Foundation	1/1/2020 09:00	9.00 d	1/10/2020 09:00
2	Core Wall Production	1/13/2020 09:...	14.00 d	1/27/2020 09:00
3	⊟ **Floor -1: Constructio...**	**2/3/2020 09:00**	**31.00 d**	**3/5/2020 09:00**
4	Floor -1: Slab Const...	2/3/2020 09:00	18.00 d	2/21/2020 09:00
5	Floor -1: Panel Con...	2/6/2020 09:00	28.00 d	3/5/2020 09:00
6	Floor -1 Steel Stair ...	2/11/2020 09:...	22.00 d	3/4/2020 09:00
7	Floor -1: Stair Const...	2/11/2020 09:...	20.00 d	3/2/2020 09:00
8	Floor -1: Column Co...	2/21/2020 08:...	10.88 d	3/2/2020 16:00
9	⊟ **Floor 0: Construction...**	**3/9/2020 09:00**	**31.00 d**	**4/9/2020 09:00**
10	Floor 0: Slab Constr...	3/9/2020 09:00	18.00 d	3/27/2020 09:00
11	Floor 0: Steel Stair ...	3/9/2020 09:00	22.00 d	3/31/2020 09:00
12	Floor 0: Panel Cons...	3/12/2020 09:...	28.00 d	4/9/2020 09:00
13	Floor 0: Stair Constr...	3/18/2020 09:...	20.00 d	4/7/2020 09:00
14	Floor 0: Column Co...	3/27/2020 09:...	11.00 d	4/7/2020 09:00
15	⊟ **Floor 1: Construction...**	**4/10/2020 09:...**	**33.00 d**	**5/13/2020 09:...**
16	Floor 1: Slab Constr...	4/10/2020 09:...	20.00 d	4/30/2020 09:00
17	Floor 1: Steel Stair ...	4/15/2020 09:...	28.00 d	5/13/2020 09:00
18	Floor 1: Panel Cons...	4/20/2020 09:...	18.00 d	5/8/2020 09:00
19	Floor 1: Stair Constr...	4/21/2020 09:...	20.00 d	5/11/2020 09:00
20	Floor 1: Surfacing S...	4/30/2020 09:...	14.00 d	5/14/2020 09:00
21	Floor 1: Surfacing T...	4/30/2020 09:...	11.00 d	5/11/2020 09:00
22	Floor 1: Column Co...	5/1/2020 09:00	11.00 d	5/12/2020 09:00
23	⊟ **Floor 2: Construction...**	**5/14/2020 09:...**	**29.00 d**	**6/12/2020 09:...**
24	Floor 2: Slab Constr...	5/14/2020 09:...	20.00 d	6/3/2020 09:00
25	Floor 2: Steel Stair ...	5/14/2020 09:...	28.00 d	6/11/2020 09:00
26	Floor 2: Panel Cons...	5/21/2020 09:...	20.00 d	6/10/2020 09:00
27	Floor 2: Stair Constr...	5/21/2020 09:...	20.00 d	6/10/2020 09:00
28	Floor 2: Column Co...	6/3/2020 09:00	9.00 d	6/12/2020 09:00
29	Floor 2: Surfacing S...	6/1/2020 08:00	8.88 d	6/9/2020 16:00
30	Floor 2: Surfacing T...	6/1/2020 09:00	9.00 d	6/10/2020 09:00
31	⊟ **Top Floor: Constructi...**	**6/15/2020 09:...**	**35.00 d**	**7/20/2020 09:...**
32	Top Floor: Slab Con...	6/15/2020 09:...	18.00 d	7/3/2020 09:00
33	Top Floor: Panel Co...	7/6/2020 09:00	14.00 d	7/20/2020 09:00
34	Top Floor: Steel Rai...	7/6/2020 09:00	9.00 d	7/15/2020 09:00

Figure 39: Gantt Chart Produced In Tekla Structures

After this step, it was necessary to export this produced Gantt Chart for exchange purposes in XML format.

2.2.3.2 Gantt Chart Interoperability Analysis from Tekla Structures to Microsoft Project 2016

In this part of the thesis, it was presented how the time information exchanged from Tekla Structures to MS Project 2016 by use of Gantt Chart. This specific case can be the representation of a workflow between a designer or an owner who uses Tekla Structures and a planning engineer, construction/project manager or a consultant who uses Microsoft Project 2016. The workflow was given in the Figure below:

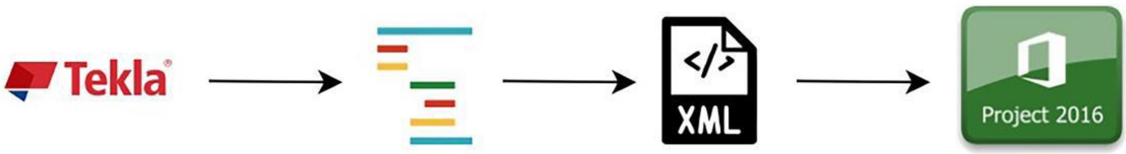
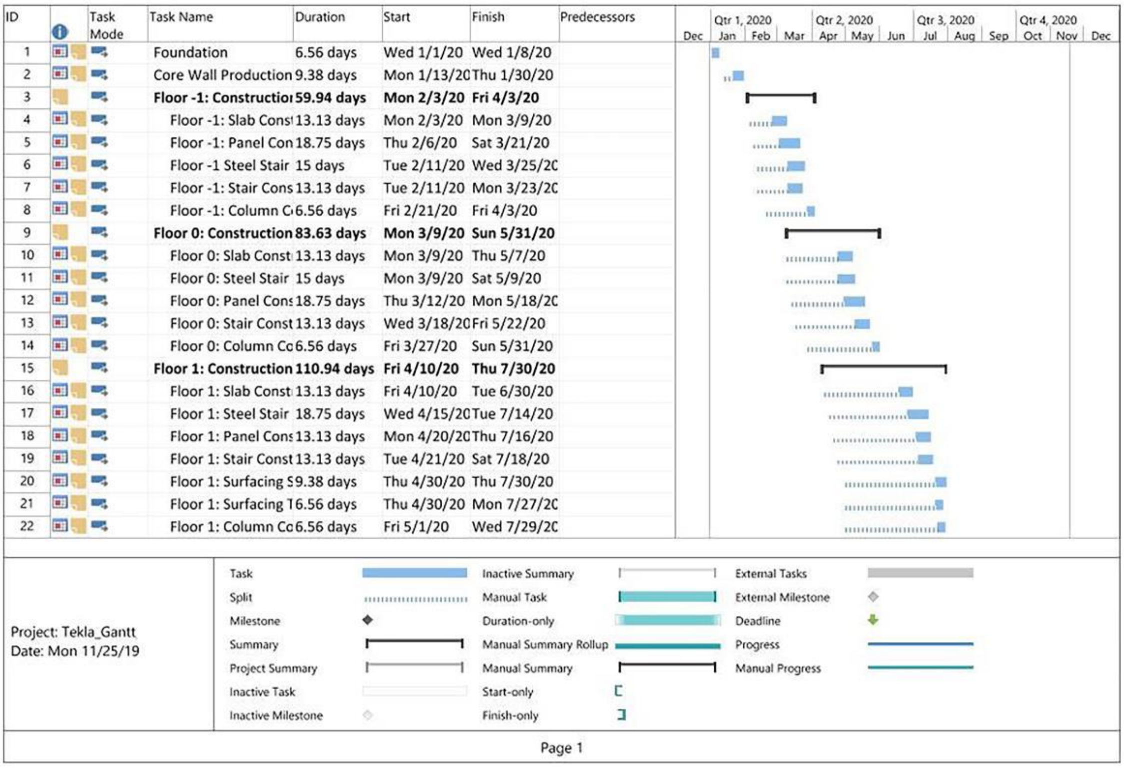


Figure 40: Gantt Chart Transfer from Tekla Structures to MS Project 2016

The produced Gantt Charts imported into Microsoft Project 2016 and the output obtained was given in the following Figure:



ID	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Foundation	6.56 days	Wed 1/1/20	Wed 1/8/20	
2		Core Wall Production	9.38 days	Mon 1/13/20	Thu 1/30/20	
3		**Floor -1: Constructio**	**59.94 days**	**Mon 2/3/20**	**Fri 4/3/20**	
4		Floor -1: Slab Cons	13.13 days	Mon 2/3/20	Mon 3/9/20	
5		Floor -1: Panel Con	18.75 days	Thu 2/6/20	Sat 3/21/20	
6		Floor -1 Steel Stair	15 days	Tue 2/11/20	Wed 3/25/2C	
7		Floor -1: Stair Cons	13.13 days	Tue 2/11/20	Mon 3/23/2C	
8		Floor -1: Column C	6.56 days	Fri 2/21/20	Fri 4/3/20	
9		**Floor 0: Construction**	**83.63 days**	**Mon 3/9/20**	**Sun 5/31/20**	
10		Floor 0: Slab Const	13.13 days	Mon 3/9/20	Thu 5/7/20	
11		Floor 0: Steel Stair	15 days	Mon 3/9/20	Sat 5/9/20	
12		Floor 0: Panel Cons	18.75 days	Thu 3/12/20	Mon 5/18/2C	
13		Floor 0: Stair Const	13.13 days	Wed 3/18/20	Fri 5/22/20	
14		Floor 0: Column Co	6.56 days	Fri 3/27/20	Sun 5/31/20	
15		**Floor 1: Construction**	**110.94 days**	**Fri 4/10/20**	**Thu 7/30/20**	
16		Floor 1: Slab Const	13.13 days	Fri 4/10/20	Tue 6/30/20	
17		Floor 1: Steel Stair	18.75 days	Wed 4/15/20	Tue 7/14/20	
18		Floor 1: Panel Cons	13.13 days	Mon 4/20/20	Thu 7/16/20	
19		Floor 1: Stair Const	13.13 days	Tue 4/21/20	Sat 7/18/20	
20		Floor 1: Surfacing S	9.38 days	Thu 4/30/20	Thu 7/30/20	
21		Floor 1: Surfacing T	6.56 days	Thu 4/30/20	Mon 7/27/2C	
22		Floor 1: Column Co	6.56 days	Fri 5/1/20	Wed 7/29/2C	

Figure 41: Gantt Chart Output of MS Project 2016 After Import Process1

Figure 42: Gantt Chart Output of MS Project 2016 After Import Process2

A comparison was performed to see if the input information “Task Name”, “Start Date”, “Task Duration” and “End Date” were changed/lost or not.

The interoperability condition results of Gantt Chart produced in Tekla Structures and the output of the MS Project 2016 can be seen from the Table below.

Compared Input (Tekla Structures➔MS Project 2016)	**Interoperability Condition**
Task Name	✓: *Good Interoperability*
Planned Start Date	✓: *Good Interoperability*
Task Duration	☒: *Medium Interoperability*
Planned End Date	☒: *Medium Interoperability*
Legend: ✓: ***Good Interoperability***: The input information successfully imported. ☒: ***Medium Interoperability:*** The input information imported with small differences, not completely different than initial one. Slight adjustments are necessary. ✘: ***Poor Interoperability***: The input data is completely different or totally lost and meaningless for use.	

Consequently, in the analysis results regarding “Task Name” and “Planned Start Date” outputs were correctly exchanged from Tekla Structures to MS Project 2016. However, “Task Duration” and logically “Planned End Date” inputs were not properly transferred. In “Task Duration”, there were slight changes in the assigned values of each task. The reason for this can be the incompatibilities of two software groups while taking into consideration of the Non-Working Days or Working Hours.

As a result, integration of these two software packages can be successfully used if the users make minor adjustments in the outputs.

2.2.3.3 Gantt Chart Interoperability Analysis from Microsoft Project 2016 to Navisworks

The previous methods used for interoperability were having some problems. Now we are using this 3rd method which is also used in our thesis as a main part.
About the import files in Navisworks were made some interoperability tests, aimed to understand the difference between three kind of files: .rvt, .nwc, .ifc, and of course the best way to obtain a fair import into the simulation software.

- .rvt the normal Revit file extension was the first attempt, following the previous scheme, the five .rvt files were imported into Autodesk Navisworks, where there were some leak, basically about the structural connections previously shaped in Advance Steel, that was the only weakness, because otherwise is the faster way to export and all other elements were imported in Naviswork fairly.

- .IFC files, are the common standard kind of files for interoperability, works well between Revit and Navisworks, there's some imprecisions in some elements shape, once are open in Navisworks, imprecisions that could be easily fixed changing some value in .IFC exportation panel, the following scheme represent the one more step compared to the previous, that consist in the exportation from .rvt to .IFC.

- .nwc, (temporary trade specific file), is the Navisworks format that can be exported directly from Revit, using a tool specially present in Revit, after the previous tests with .IFC and .rvt files this is the one which gives best results, exporting the whole model without leak or geometric errors, settings were managed to have a correct exportation especially for what concern structural connections, due to a improvable interoperability between Revit and Advance Steel.
- The scheme structure is the same to the previous, there's always one more step converting .rvt files in .nwc, before connection wit the .mpp time schedule in Autodesk Navisworks.

These 3 files are the main part to perform the interoperability between all three-software used but the approach discussed in this section includes use of CSV import. For this purpose, conversion from XML to CSV file format was needed by Microsoft Project 2016. This option can be useful when stakeholders do not have older versions of Microsoft Project 2016. The Gantt

Chart XML file produced in Microsoft Project 2016 and Gantt Chart output was also presented in Figure 43. Even though the results found in that stage was not perfect, Gantt Chart analysis by use of CSV import via MS Project 2016 to Navisworks was performed to identify the changes and lost data in the Gantt Chart.

Afterwards, the XML file shown in Figure was saved as CSV file by Microsoft Project 2016. Lastly, this obtained CSV file was imported into Navisworks using the command specified as "CSV Import".

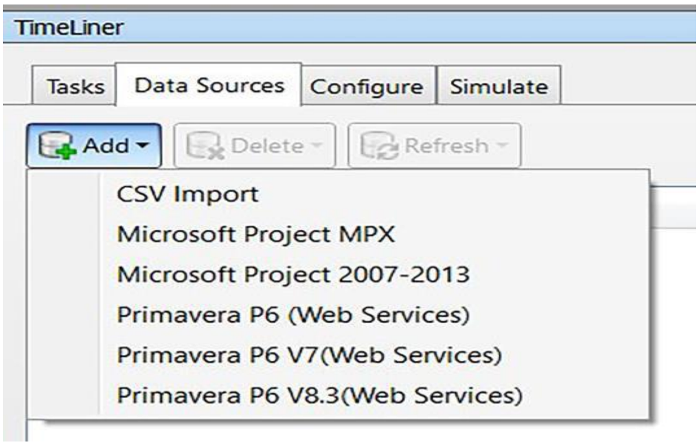


Figure 43: Data Import Methods in Navisworks

The workflow can be seen from the Figure below for better understanding of the concept:

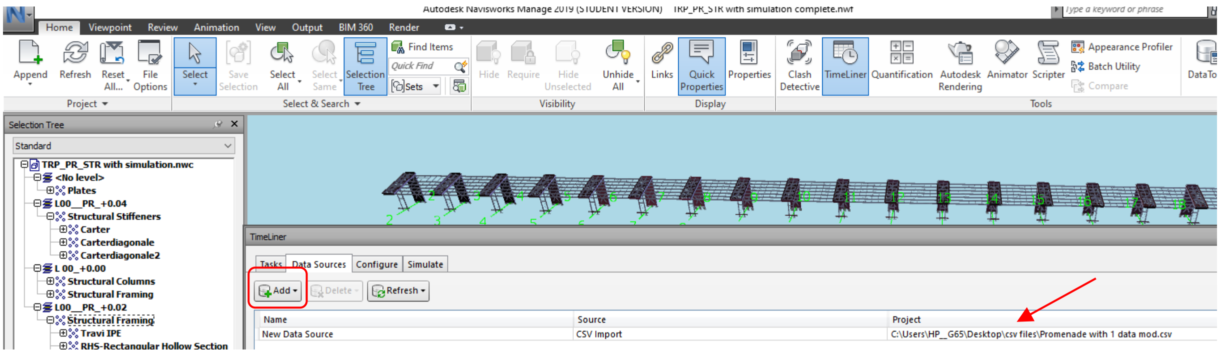


Figure 44: Data Source Adding in Navisworks

After performing CSV import and using "Rebuild Task Hierarchy" command the added data would be seen in Tasks tab. In the Figure 2-39, the Gantt Chart output of Navisworks can be seen:

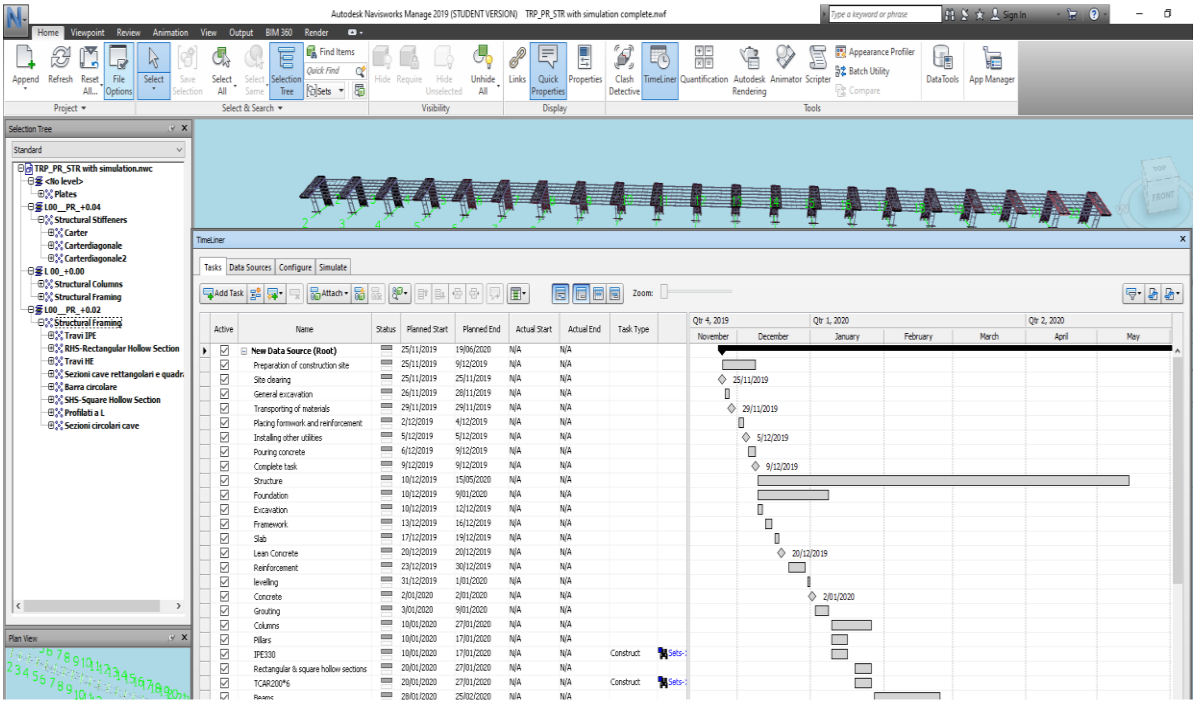


Figure 45: Gantt Chart Output of MS Navisworks After Import Process via MS Project 2016

2.2.4 4D PROCESS AND 4D SIMULATION

2.2.4.1 4D structural Information Model

The 4D structural information model is a sub-BIM that consists of three main parts of information: basic information, 4D information, and structural information. Basic information presents the fundamental 3D geometric information. 4D information and structural information then embody and enrich the basic information for different objectives and applications. The contents of each part are introduced as follows.

1. *Basic information*: So as to meet the needs of basic BIM applications, basic information includes the kernel content of information, particularly 3D geometric information.

2. 4D information: Besides basic information introduced in the earlier section, 4D information also includes some other information like resources, site layout, construction activities, schedules, processes, etc.

3. Structural information: This includes structural element types, profiles (including area, centroid, inertia moment, etc.), local axes, materials, loading conditions, etc., so that computer programs can automatically build up a structural analysis model.

4D structural information model provides a universal source of data, ensuring that the integrated application can share all related information. It focuses on storage and provision of information while the analytical model focuses on structural calculation according to certain analytical methods after acquisition of information.

4D management includes schedule, resource, and site layout management. They are self-modifying with the progress of the real- time control. Specifically, 1) modification of construction schedule dominates the change in structural systems; and 2) with 4D resource management, relevant material data, as well as time-dependent loads can be obtained, to determine the resistance of structural elements and construction load effects.

4D structural analysis consists of four aspects, i.e.,

1. the structural system, the resistance of each element, and the load effect can be automatically determined according to design codes and stochastic simulation;

2. then the structural safety performance indicators, such as stresses, strains, and displacements, can be calculated at any time point;

3. based on the abovementioned indicators, fuzzy analysis or other evaluation methods can be applied to evaluate the overall safety performance of the structure;

4. if site-measured data can be obtained, dynamic prediction models can be applied to adjust the evaluation.

To build up the 4D structural information model Enrich the 4D model by appending project properties (e.g., resources, budget quota, and site layout, extend structural information by linking elements to material properties, control parameters for meshing, activity-based loads, etc.; and establish the 4D structural information model by organic and automatic integration of the abovementioned information

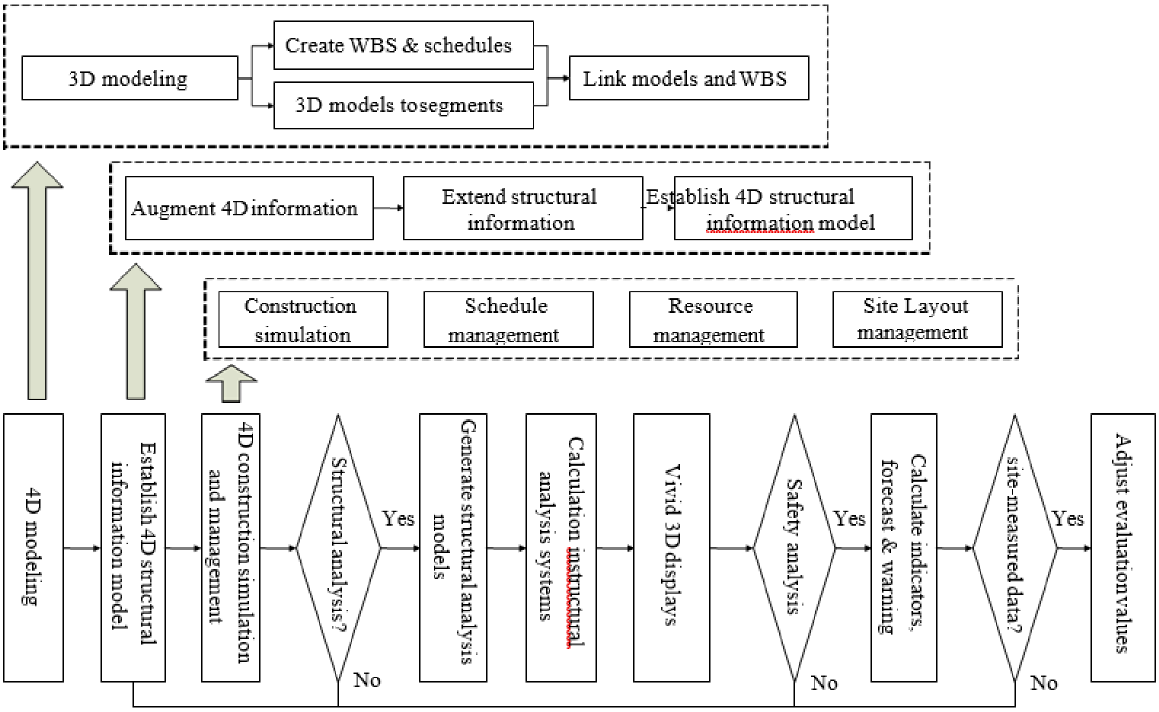


Figure 46: Flowchart of 4D structural information model-based analysis approach

2.2.4.2 4D Simulation using Navisworks Timeliner

According to different time intervals (days, weeks, or months) and schedules (planned schedule or actual schedule), the construction process can be sequence- or reverse-simulated. Through 4D schedule management, construction schemes can be modified and controlled. Furthermore, schedule tracing and analysis are available by comparing planned and actual schedule data. By setting up several sets of resource stencil, construction quantities, resource requirements, and estimated cost can be computed automatically and precisely by 4D resource management. The 4D site management function can assist managers in accomplishing efficient site space utilization by linking 3D facility entities to the construction schedule, which is similar to other structural elements.

We can create 4D simulation of construction operations and workplans using our Revit model in combination with Navisworks manage.
The steps involved including export of our Revit model in a format that Navisworks can import creating a schedule of tasks that will be required in construction process.
In this thesis, we have already created a task schedule with Microsoft project 2016 as mentioned previously, which contains expected start and end dates.
Navisworks can import data from Microsoft project as it is also discussed above in detail.

Then we pull those two pieces together which are Revit model “Promenade” with the task timeline in the Navisworks manage application as shown in figure.

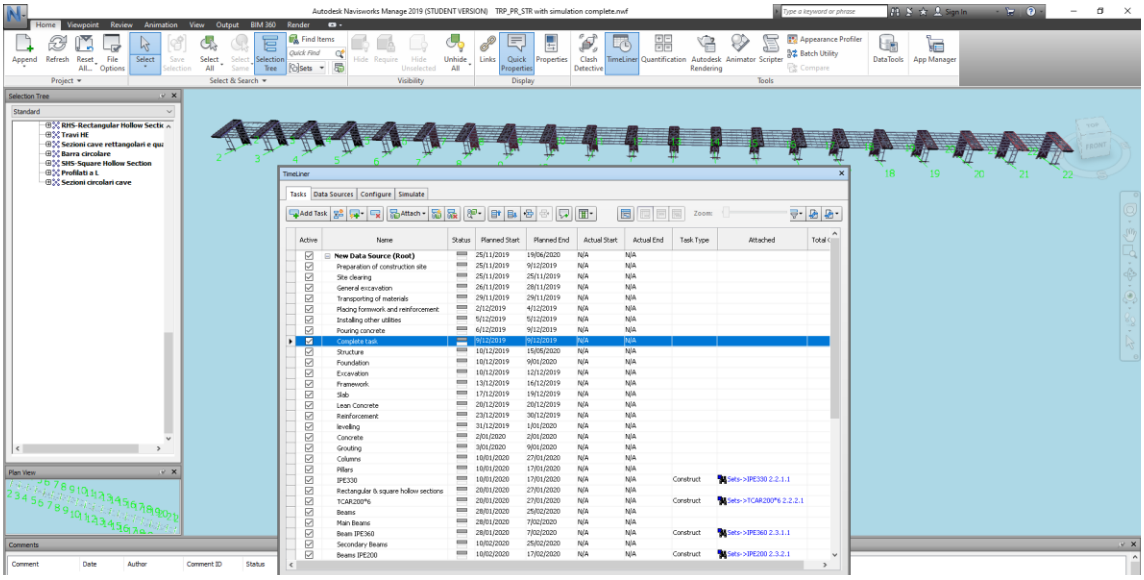


Figure 47: Task timeline in Navisworks

The key to creating a 4D simulation of the construction process is linking the elements/families in the Promenade model with these tasks. we can do that by attaching the individual elements/families or sets of elements to each of the task in the timeline.

Creating the sets will be the key to working effectively with Navisworks manage software. There are several ways to create sets in Navisworks manage timeline. The way which we have used in this thesis is by find items.

We have already mentioned above that how we can import task schedule from Microsoft project into Navisworks. Now the main part is to link these task elements to each of the building model by creating number of sets inside Navisworks.

The series of search sets will help us map the promenade elements/families using the 4D-task-ID that we have entered in Revit model (detailed mentioned in coding section above) to each of these tasks.

To create the search sets, click Find items- enter criteria that we want to match. In our case, go to the Element-4Dtask id-2.2.1.1 (wbs code provided in Revit model) as shown in the figure.

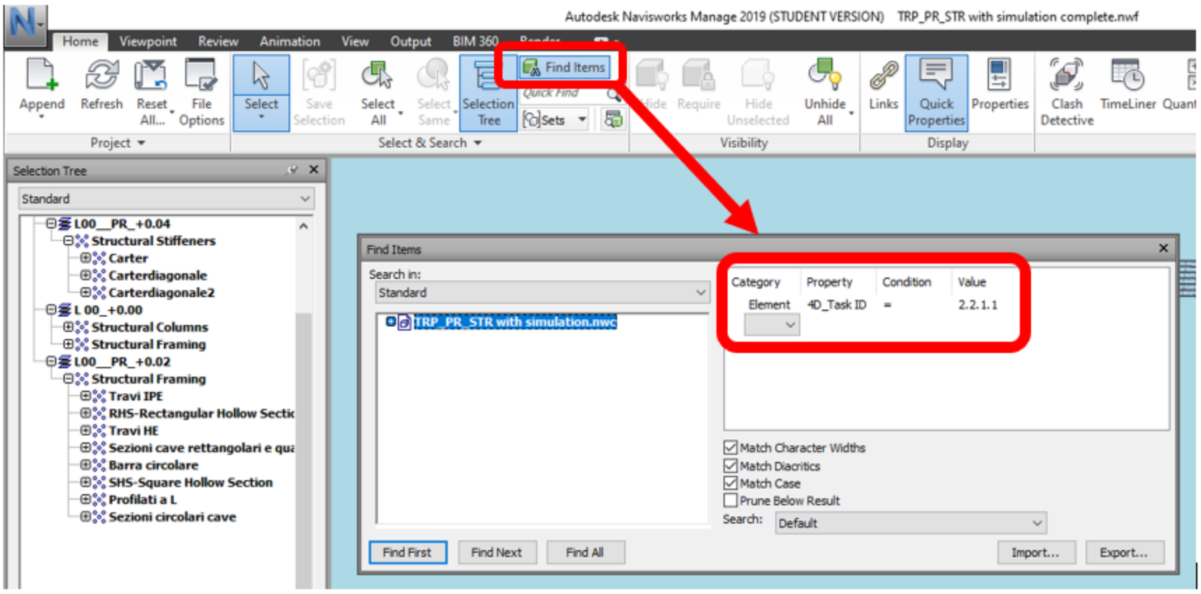


Figure 48: Process of creating the search sets

After that, if you will click on "find all" tab in Navisworks, you will see that which elements in the model are matched, in the example given above, we have selected "Pilastro IPE330", as shown in the figure

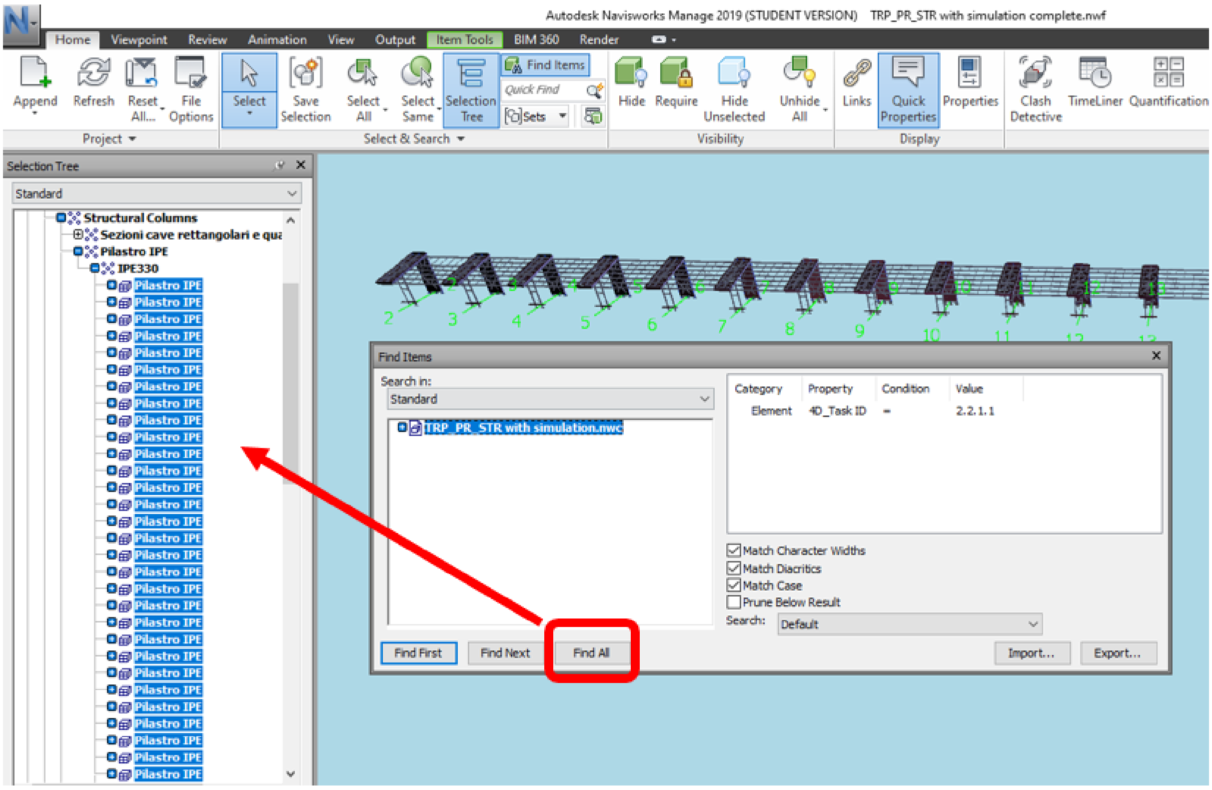


Figure 49: Process of finding all items of same category to provide coding

If the selected items are not visible, the click on “hide unselected” tab to show all the selected items. As we can see in the figure above that the selected items are not visible in the model so we will use that command. As shown in the figure.

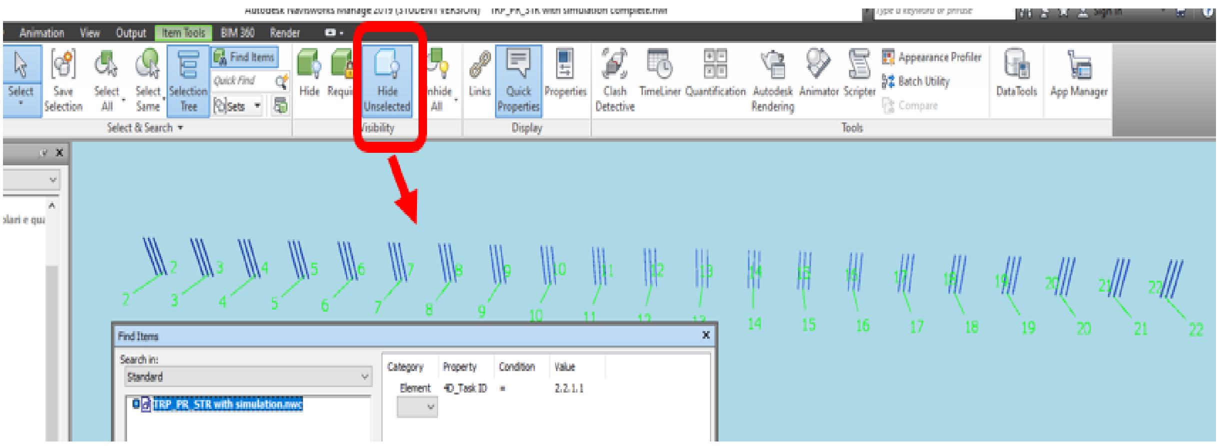


Figure 50: selected items visibility process

The next is to create sets. To do that, we will click on “sets” tab- Add current search/save search (by right click of the mouse), which we have created as mentioned.

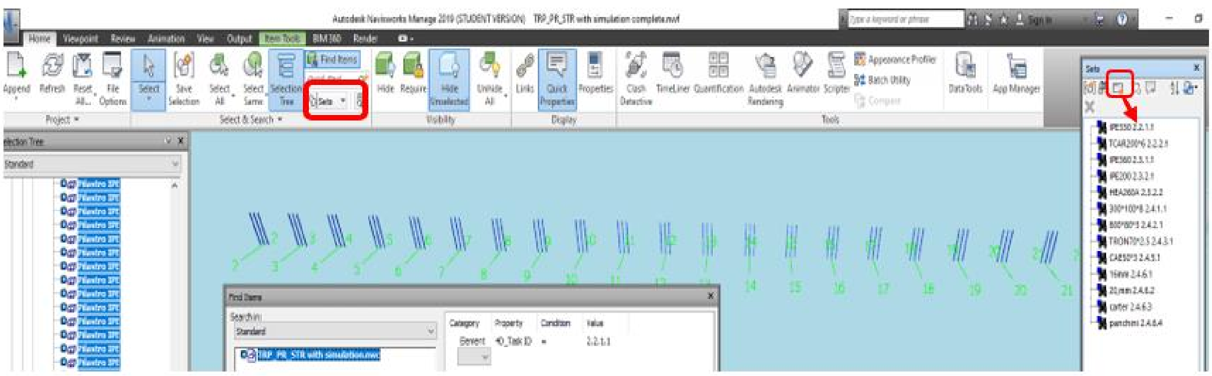


Figure 51: creating sets into Navisworks

To make the mapping automatic, we want to have one for one match between the names of the sets and the task id that we are matching them against. So, by repeating the method given of searching sets above, we will create all the sets.

After completing the search sets, return to the Navisworks timeline and select “rules tab”. The timeliner rules window that will map timeliner task to specific item, selection sets or layers within the model.

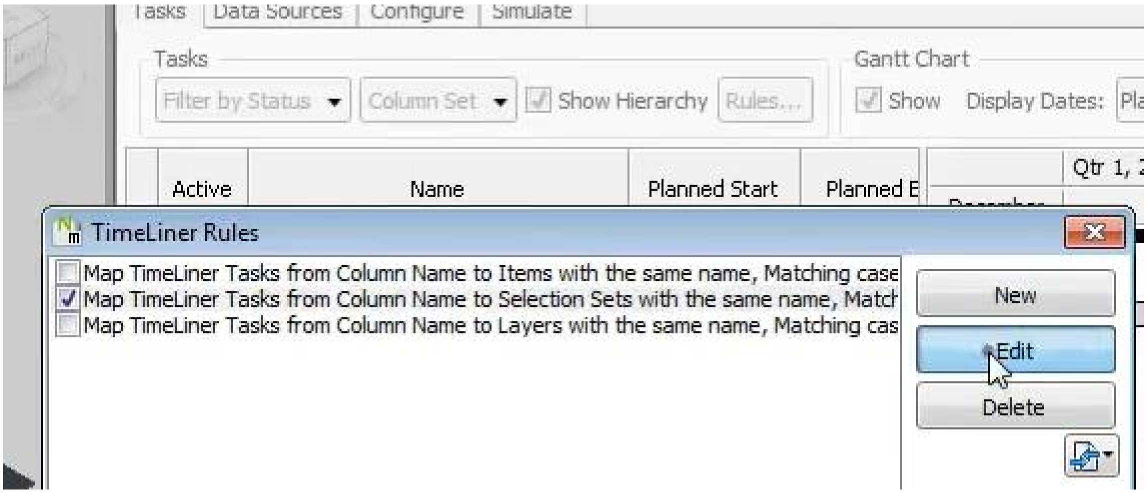


Figure 52: Mapping between the sets and task id1

After choosing the edit option as shown in figure, choose for mapping the "user1" columns which contains the "4D task id" to "selection sets" with the same name and then click the apply rules button, as shown in the figure.

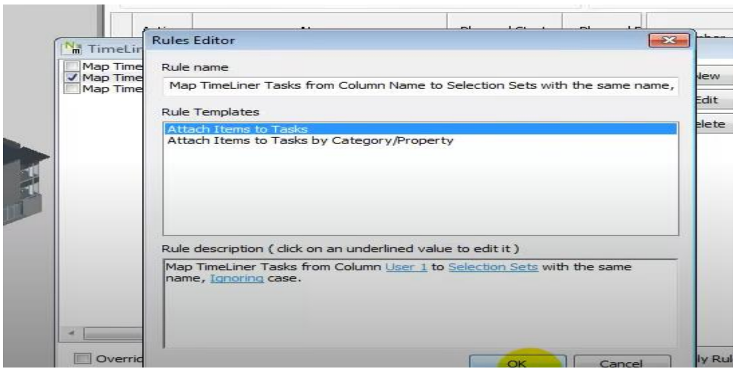


Figure 53: Mapping between the sets and task id2

After completing the rules section, return to the timeline and we will see that each of the different task in the timeline now have the search set associated with them that will automatically pull elements from the "promenade model".

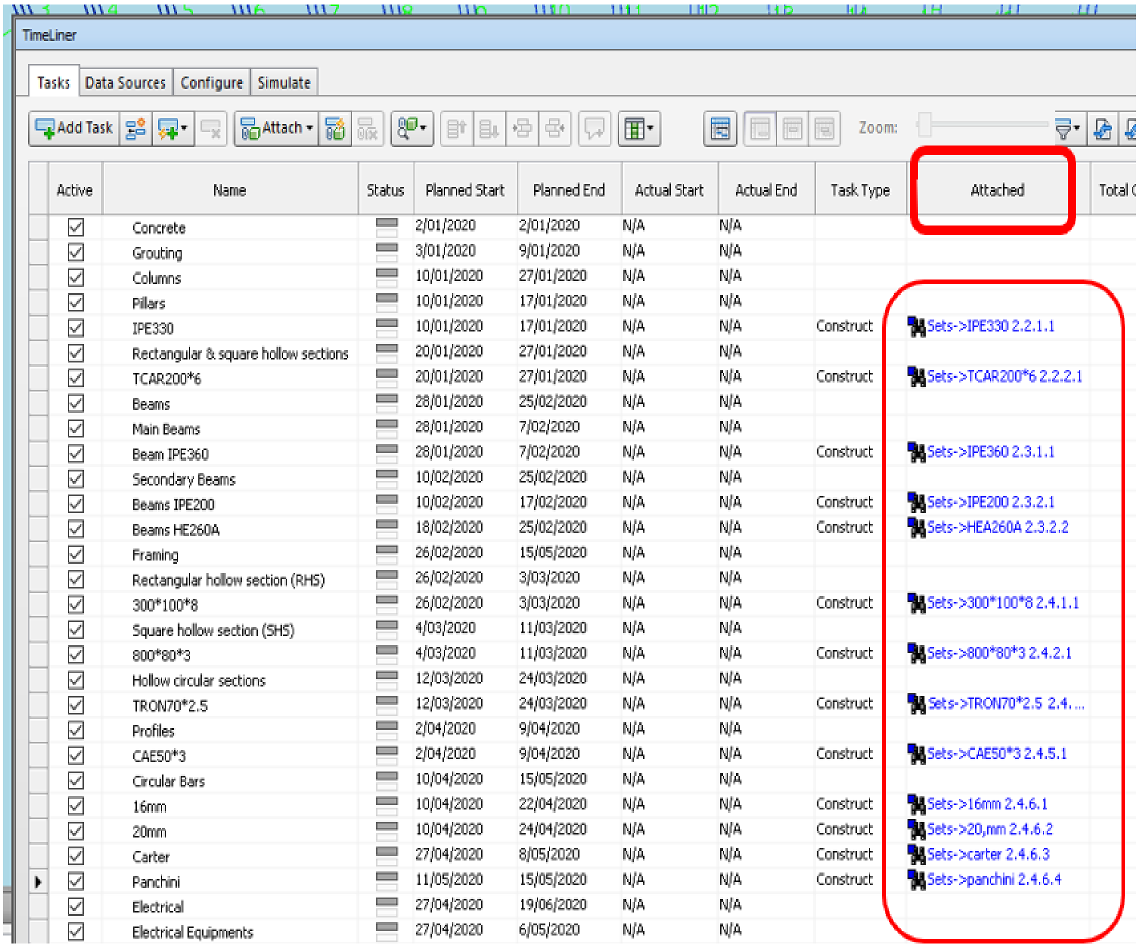


Figure 54: Associating search sets of task ids in timeline

2.2.4.3 Simulation settings and Running 4D simulation

After attaching the model elements to specific tasks in timeliner, we can perform the simulation. Set up the simulation by looking at the options available under the "simulate tab" and start with the "setting tab" that is available for customizing the simulation.as shown in the figure.

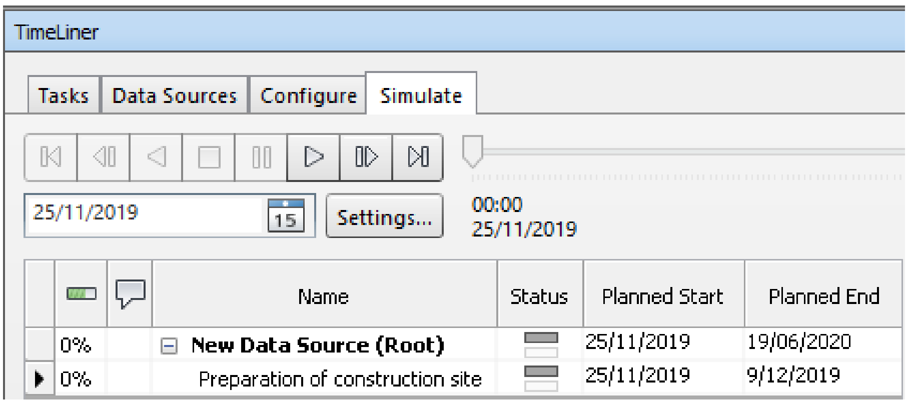


Figure 55: Setup for simulation1

The important setting is to check the “interval size” that will determine the incremental displayed as we step go through the simulation.
In our thesis, we have used 1 “interval size” with each day and the “playback duration” is 15 seconds, as shown in the figure.

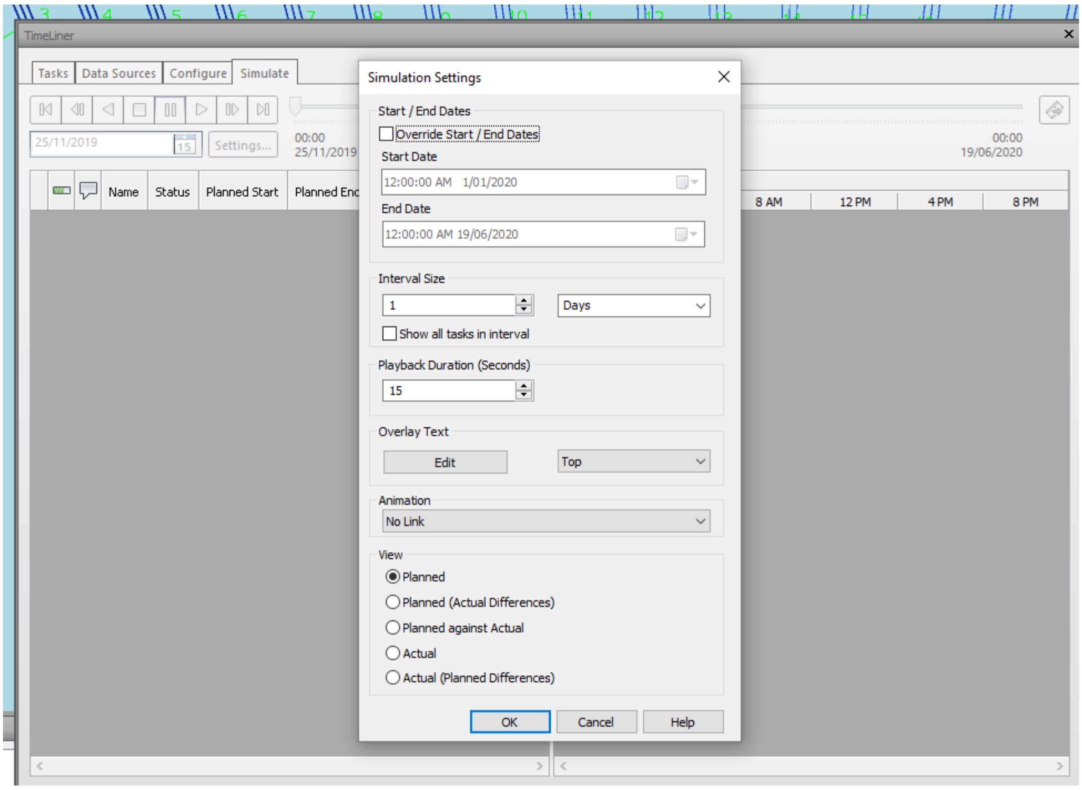


Figure 56: Setup for simulation2

But we can change that setting according to the requirement and need. If you want to look the detail of the sequence, then we should select the “playback duration” as minimum as we can.

After completing these steps, we are ready to run the simulation. To do that, click the paly button and simulation is ready to run.

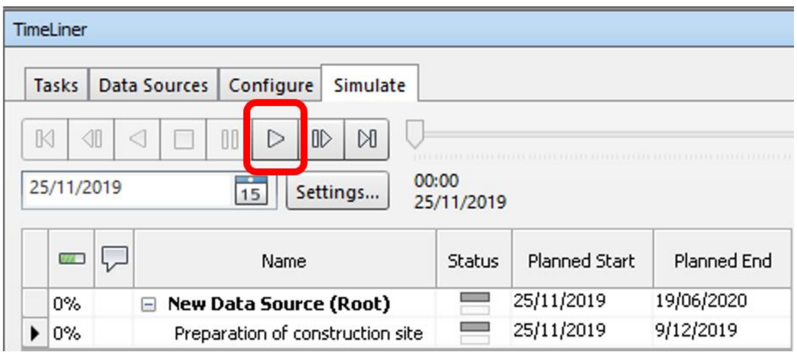


Figure 57: Setup for simulation3

2.2.5 5D Resources using Dynamo

5D BIM is an advanced technology in the AEC industry, which can be used for managing time, cost, and resources; it can even handle the logistical site plan. 5D BIM can help quantity surveyors review alternative designs during the early stage of the project as a decision-making tool, since the 5D BIM can quickly extract approximated quantity from different 3D BIM models and then add the 4D schedule to finalize the 5D cost budget.

However, the development of 5D BIM is hampered, by many reasons, such as the high initial implementation costs but low accuracy. Moreover, the current 5D BIM software and applications cannot fulfil the subcontractors' requirements which are focused on detailed works, such as external cladding. They are appropriate for the rough cost estimation of a large scope, which is satisfied with the requirements from project planners and head contractors. The quantity take-off of current major 5D BIM applications or software is approximate quantity instead of exact quantity due to the Level of Development (LOD) limitation.

Dynamo is more appropriate for the detailed quantity take-off, such as three-dimensional printing (3DP) elements. 3DP is used to print precise and complex elements.

As a useful information platform, 5D BIM is not only utilized during the project construction process but also during the entire life cycle. For example, BIM can share and update the drawings and specifications easily in the cloud database, and then 5D BIM can generate more consistent and accurate cost estimation. BIM platform provides a smooth flow of information sharing among stakeholders to transfer the information quicker and easier among multidiscipline to reduce errors or unnecessary works. Additionally, 5D BIM can show a clear budget and construction progresses to participants. Moreover, 5D BIM is time efficient for alternative design analysis and decisions at the early stage. 5D BIM often conducted the cost management and cost analysis in other software or application. 5D BIM can better monitor the project costs not only in the short term but also in the long term by including related information and resources.

We have used **Dynamo script** within Revit plugin to calculate the cost estimation process (5D) and to design a script for all the layers' quantity take-off from one multilayer wall at the same time, to detect the meticulous differences among the layers. Furthermore, this script can be used to extract the detailed quantities from the Revit elements.

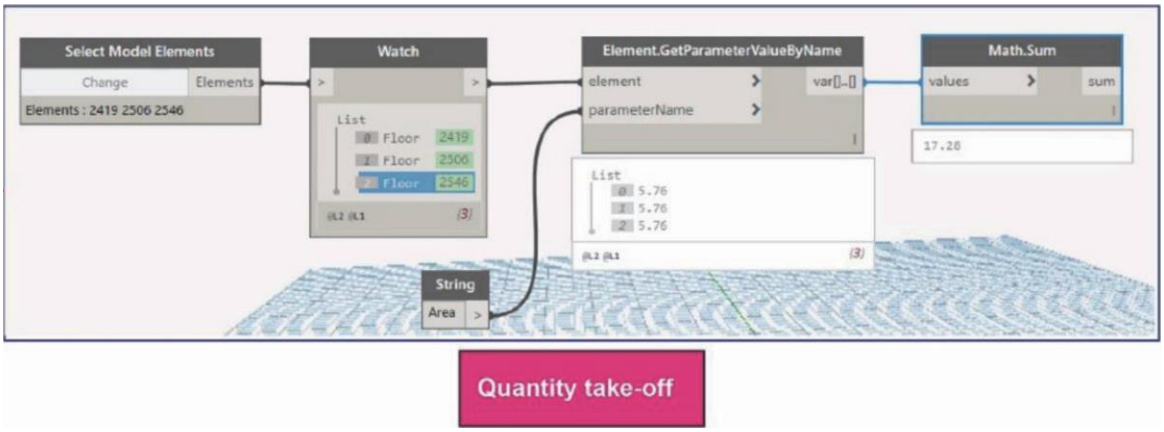


Figure 58: Dynamo-extension in the Revit for detailed quantity take-off.

This figure is only a simple script to show the area quantity extracted from the existing model.

The Dynamo for element quantity take-off programming consists of six stages:

1. Select the ‘Select Model Elements’ node from the Dynamo library and select the target element in the 3D model.

2. Select the ‘Watch’ node to list the detail code of each item.

3. Connect the ‘Watch’ node to the ‘Element. Get Parameter Value by Name’ node. The results listed below are the area (parameter name) of each visible element.

4. In this scenario, the value or the outcome of the parameter name is area.

5. Select the ‘Math Sum’ node to calculate the total area of the 3D model.

This programming is also suitable for the users to gain other material information, such as the type of material.

This figure shows the example of one quantity which is used in our model as “barra circolare 16mm”.

The process adopted for this quantity take-off programming consist of following:

1. Open your model in Revit and click on dynamo plugin
2. Select the “family types” or simply you can write down in search bar
3. Select “All elements of family type” to connect all the similar family used in Revit model
4. Select “solid elements” to convert these selected items into list”
5. Select “volume” to calculate the total volume or if the diameter is given then simply

calculate the area and the volume

6. Select the “list.map” to put the quantities into map and sum all these values by selecting “sum”
7. To calculate the price simply select “number” and price has already been selected from piedmonte price list for that item
8. Select “multiply” to get the final price value.

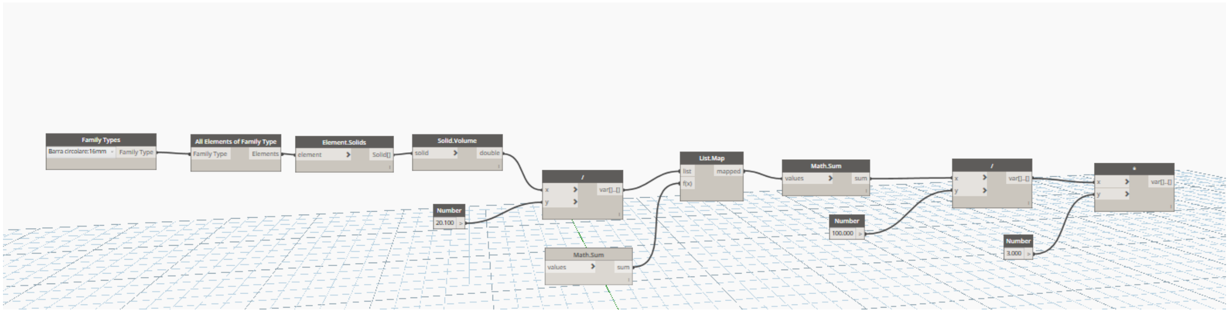


Figure 59: Quantity take off in Dynamo for “barra circolare 16mm”

This same process is adopted in calculating all other quantities but there was some problem with calculating the column section because of the shape as column used in this model is “I” shaped so to overcome that problem ,simple excel sheet has been used.

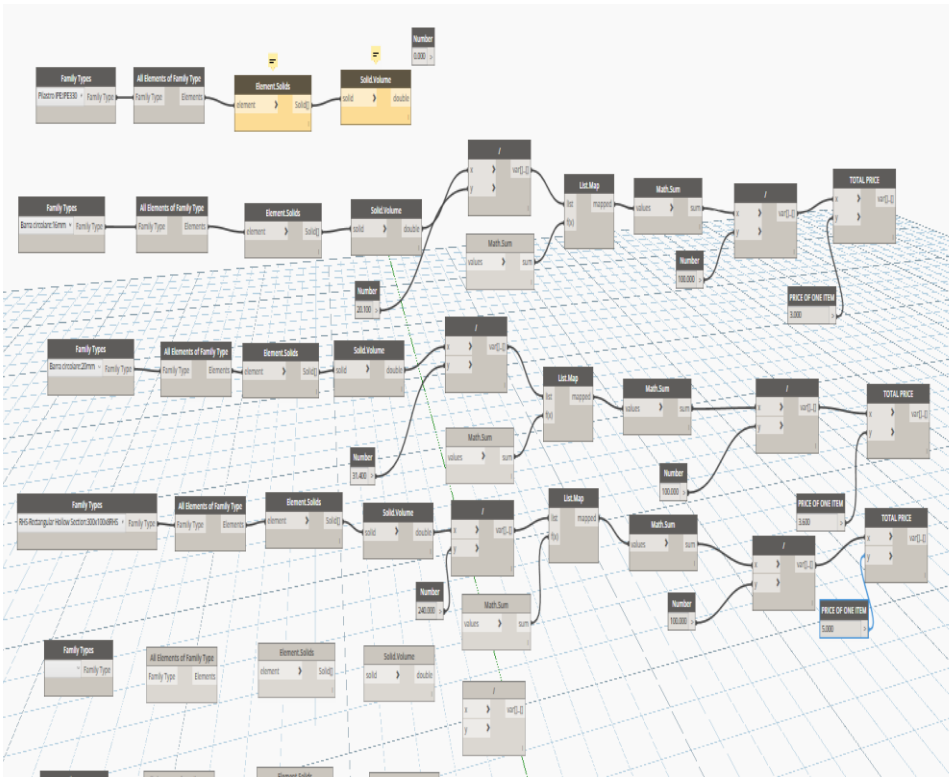


Figure 60: Quantity take off scheme of entire project in dynamo

As you can see in the figure above that there is some problem calculating the area and volume of “pilastro IPE330” because it contains, I shaped figure column so the easy way to do it on excel sheet.

3 Conclusion and future developments

3.1 Conclusion

This study presented a BIM-based concept for construction projects to investigate how BIM processes impact project management. For this reason, an already built 3D model in Revit 2019 named Promenade has taken as a case study. The case study demonstrates how BIM allows effective sharing of a 3D model of a project that includes necessary semantic data for all processes that were investigated within the scope of the study. However, it should be noted that generation of the model with all the required information presents challenges for inexperienced users. It can be clearly said that once the model is complete with all details about the model, creating Floor Plans; Ceiling Plans, 3D Views, Perspectives, Elevations, Sections, Renders, Schedules and Quantities can be generated automatically. Furthermore, the ability to detect clashes, errors or defects of the project in the early design stages, before construction, helps managers avoid unnecessary costs.

The focus in this case study was on construction management of 3D model built in Revit 2019 named Promenade. So, the thesis is particularly divided into four categories.

1. Provide workbreakdown structure **codes** inside Revit 3D model which can help us calculating the quantities in 4D software and used throughout thesis for also calculating the cost estimation of these families because by creating these codes by using shared parameters and project parameters inside Revit will help us detecting these quantities in BIM software like Navisworks and also Dynamo.

2. Creating the **work breakdown structure** of the entire project which is the main part because workbreakdown structure is a tool use to make the work more manageable approachable.it single handedly integrates scope, cost schedule baseline are in alignment so we have broken down the entire project into manageable chunks of work which can easily be supervised and estimated.

3. 4D process which includes the time scheduling of the entire project which was done by using Microsoft project 2016 which includes the time management process of the entire project by having estimated start time and estimated finish time along with work breakdown structure codes to specifically identify each of the family/element used in the model and also create Gantt chart to visualize the activities starting and ending linkage and if two or more activities are starting together or either finishing together. And for 4D simulation, Navisworks manage 2019 software has been used.

4. The final part of thesis which includes 5D BIM quantity takeoff to calculate the cost estimation of the entire project. **Dynamo software** has been used to calculate the quantities take off which is plug-in inside Revit 2019.

3.2 Future developments

The construction industry is deeply changing in the lasts years, and BIM methodology is a fundamental part of this process, leading to a more automatized industry managed by BIM softwares.

This thesis represents an attempt to deepen these aspects, trying to use BIM to reach others goal further the normal BIM modelling.

This point is occupying a central spot in the speech about construction industry and BIM, the necessity to understand which LOD is required to any task and find a way to calculate an average LOD value in models composed by different detail degree. The project management that represent a large part of this thesis becomes a fundamental tool in construction industry, but also in other industry fields. In this thesis was treated beginning from the project tasks decomposition made in the WBS code, that was made by myself after analysing the most common standards codification currently used, where was found a multitude of classification, and a future improvement is to create a common code to be used worldwide putting in contact all the various classifications.

Surely a future development is to apply also the other parts of the activity code to all elements in the project assuring firstly a more detailed plan considering any single element with its positioning attribute, that wasn't useful in such a small project, but become necessary in larger size building, then the last code part applied to have a direct connection with the cost source and finalized to obtain a cost survey.

Another future development is the adoption of 5D BIM, for instance, software securing, training investment, and low time efficiency, lacking standards of software compatibility. The other limitation of 5D BIM is the low LOD, which cannot extract the detailed data from the 3D model for cost estimation. The BIM models are not designed for the quantity take-off or the cost estimation, so some details will not be shown in the models, it is tough to extract the detailed quantity from elements for quantity estimation. 5D BIM provides timely communication but cannot guarantee the quality of the communication. At the end of 2016, Software Advice (UK) analyzed and reported that 50% of the investigated small and medium enterprises still conduct the cost estimation manually [16]. There are many limitations of CUBIT adoption in New Zealand and Australia, such as low accuracy of quantity take-off or detailed quantity missing. CUBIT Build soft is developed by MiTek (an Australian company) and used in Australia, New Zealand, the United Kingdom, and Ireland. So, the industry believes BIM needs a process change approach than information drive approach.

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