



Universidade do Minho  
Escola de Engenharia

André Carvalho Lima

Upgrade of an industrial building:  
BIM model of the as-built situation  
and evaluation of modifications

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MSc Dissertation  
Integrated Master in Civil Engineering

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*“Deus quer, o Homem sonha,  
a obra nasce.”*

Translation:

*“God wants, man dreams,  
the work is born”*

Fernando Pessoa



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# ABSTRACT

Building stock in need for upgrading is increasing, particularly in developed countries. For that reason, the awareness of authorities and general public in regard to this problematic is rising, and relevant challenges are brought about to the Construction Industry, which has traditionally been mostly targeted in new constructions, rather than upgrading works.

In parallel, Building Information Modeling (BIM) is bringing relevant changes to the operation procedures and principles of Architecture, Engineering and Construction (AEC) industry. This methodology consists on a comprehensive approach to projects by integrating a set of collaborative technologies and policies that will help on several concerns, particularly construction management and data assessment. In spite of the great potential of BIM, many stakeholders in the AEC industry still struggle to implement such methodology framework, and it is necessary to bring about demonstration of feasibility, highlighting the associated benefits. This need is particularly important in the emerging market of upgrading constructions, particularly in markets such as that of Portugal.

Considering these facts, through BIM application in a real case study, the present work has the objective to show and explore some BIM potentialities in existing buildings. This work was done in a corporate environment, on a Portuguese construction company, owner of an unfinished existing building, where an economic viability study is being performed to its real estate promotion after its upgrading (including renovation and remodelling).

These objectives were achieved through the performance of the as-built BIM model, as well as another one corresponding to the reformulation. The dissertation includes explicit reference to the difficulties and challenges along the process, as well as a critical evaluation of the benefits that can be harvested in the scope of a construction company.

**Key-words:** *Building Information modelling (BIM); interventions in existing buildings, as-built BIM model; BIM in a construction company*





## RESUMO

É cada vez mais visível a necessidade de conservação do património edificado, principalmente nos países desenvolvidos. Por essa razão, nota-se uma crescente preocupação das autoridades e do público em geral, onde relevantes desafios têm sido levantados na Indústria da Construção, que tradicionalmente tem focado mais na construção de novos edifícios, e não na remodelação dos existentes.

Em paralelo, o Building Information Modeling (BIM) tem demonstrado mudanças relevantes nos processos de operações da indústria da Arquitetura, Engenharia e Construção (AEC). Esta metodologia consiste numa abordagem abrangente para projetos, integrando um conjunto de tecnologias e políticas colaborativas que permitem apoiar vários aspetos, particularmente a gestão do projeto de construção e o acesso aos seus dados. Apesar do grande potencial do BIM, muitas partes interessadas da AEC continuam a lutar para implementar tal metodologia de trabalho, sendo necessário a realização de demonstrações de viabilidade, destacando os benefícios associados. Esta necessidade é particularmente importante no mercado emergente da remodelação, particularmente em mercados como o atual de Portugal.

Tendo por base os aspetos referidos, através da aplicação a um caso concreto de estudo, o presente trabalho tem como objetivo genérico mostrar e explorar algumas das demais potencialidades do BIM em edifícios existentes. Este trabalho foi feito em ambiente empresarial, numa construtora Portuguesa, que possui um edifício existente inacabado, onde existe um estudo de viabilidade económico para promoção imobiliária após a sua alteração (incluindo renovação e remodelação).

Esses objetivos serão adquiridos através da realização do modelo BIM como construído bem como outro correspondente à sua reformulação. Esta dissertação inclui referências explícitas às dificuldades e desafios sentidos durante o processo, bem como uma avaliação crítica dos benefícios que podem ser colhidos no âmbito de uma empresa de construção.

**Palavras-chave:** *Building Information Modeling (BIM); intervenções em edifícios existentes; modelo BIM como construído; BIM numa empresa de construção.*



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# LIST OF SYMBOLS AND ABBREVIATIONS

- 2D – Bidimensional
- 3D – Tridimensional
- AEC – Architecture, Engineering and Construction
- AIA – American Institute of Architects
- BIM – Building Information Modeling
- CAD – Computer-aided Design
- COBie – Construction Operations Building Information Exchange
- COBIM – Common BIM Requirements
- ETICS – External Thermal Insulation Composite Systems
- FM – Facility Management
- GSA – General Services Administration
- HDR – High Dynamic Range
- HVAC – Heating, Ventilating and Air Conditioning
- ICT – Information and Communication Technology
- IFC – Industry Foundation Classes
- LCA – Life Cycle Assessment
- LOD – Level of Detail, Level of Development
- MEP – Mechanical, Electrical and Plumbing
- NBIMS – National BIM Standard
- NE – Northeast
- NSRRC – National Synchrotron Radiation Research Centre
- NW – Northwest
- OCCS – Overall Construction Classification System
- OM – Operation and Maintenance
- QTO – Quantity Take-Off
- SBM – Statsbygg Building Information Modelling Manual
- SE – Southeast
- SW – Southwest
- kg – kilogram
- m – Meter
- un – Units



# 1. INTRODUCTION

## 1.1. Subject Background

The recent world economic crises that strongly affected Europe and particularly Portugal has led to a strong reduction of public investment on construction, with a significant impact on the AEC industry.

In addition to the economic crisis, there is another quite relevant aspect that is causing the rate of new constructions to decline. It is related to the existing building stock in Europe that tends to be sufficient for the current needs of the population, leading to a saturation of the sales market (Ochoa & Capeluto, 2014).

Even with the economic crisis felt since the beginnings of the 21<sup>st</sup> century, during the past decades the main attention of the Portuguese AEC industry was focused on increasing the building stock with new buildings, while maintenance and repair of existing buildings has been relegated to secondary importance. The idea of conservation of the building stock basically did not exist and nowadays, there are cities which exhibit significant and relative widespread signs of building deterioration. Oporto, which is the second largest city in Portugal, is a good example of that, having many uninhabited buildings that have been neglected throughout the years (Martins, 2014).

Figure 1 shows the decreasing of the new buildings rate in Portugal. However, even with this decreasing the maintenance and rehabilitation were remained for a secondary importance.

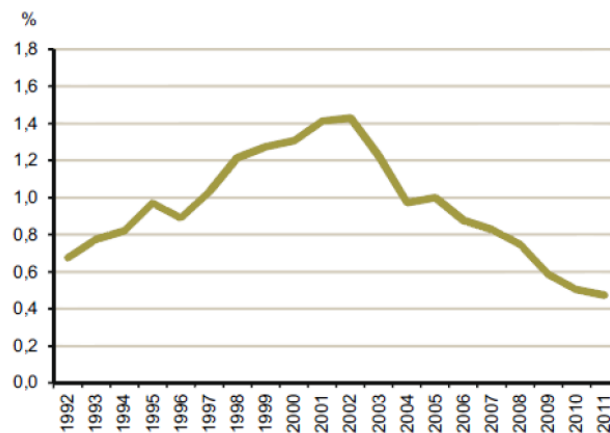


Figure 1 - Annual medium variation of the habitational buildings in Portugal (Martins, 2014)

On the other hand, there are having an increasing preoccupation with the world's environment and sustainability. A recent study in the United Kingdom has reached the conclusion that the national AEC industry was one of the most sectors that mostly influence the environment. In such particular case, governmental agents stated that sustainable practices should be adopted in short to medium term, by setting ambitious targets to 2020 and 2050 (Department of Energy & Climate Change, et al., 2015).

An example of sustainable practices that is increasingly appearing on AEC industry with a fast proliferation is the BIM which was chosen by the UK and some other countries to help them to reach its targets (McAuley, Hore, & West, 2012).

BIM, is considered to be much more than a new and improved CAD, and it is thought to be one of the most promising developments in the AEC industry. By the simulation of the construction project in an accurate and integral 3D virtual model which contains all the necessary information in the form of data repository, it will be possible to support the decision making of the stakeholders during the building's lifecycle (Caires, 2013).

## **1.2.Scope and objectives**

The main objective of this dissertation is to implement a BIM model of an existing industrial building and evaluate the process of renovation and remodelling of such building in BIM context. It is intended to uncover specific challenges that are placed in the application of BIM in the context of existing buildings, in particular concern to the practical challenges involved. The application of BIM methodology to an existent building that will need reformulation works has the main objectives of perform the BIM model of the as-built situation (except mechanical, electrical and plumbing (MEP) model) and the reformulation of the existing building situation with BIM methodology the following main topics are explored:

- Interoperability between BIM software;
- Quantity Take-Off (QTO);
- Construction planning;
- Classification systems;
- Use of temporary elements;
- Objects modelling;
- Study of deconstruction and removal interventions;
- Study of the different situations and renovating works.



In addition to that, there exist a secondary list of topics to the present dissertation that are expected to reach with this study:

- 3D Rendered model and movie for promotion;
- Project optimization;
- Construction time;
- Specialities match;
- Improvement of coordination.

The dissertation was conducted within a collaboration between the University of Minho and CASAIS, S.A., which is a Portuguese construction company who owns the partially built industrial facility that is object of study in this dissertation and intends to reformulate the building for selling/renting purposes. The availability of this real-life example in which the owner is directly involved brings a significantly important added value to the dissertation.

### 1.3. Chapter outline

This dissertation is organized in five chapters, where the first of which consists of this introduction.

The literature review presented in **Chapter 2** contextualizes BIM in existing buildings. To do this, it contains the definition of some interventions types in existing buildings, and also a brief explanation of the BIM concept. It also contains relevant information about field data capturing techniques and the main challenges and potentials of BIM in the context of existing buildings. In such concern, focus is given to what should be done before start before the modelling and to discuss some modelling strategies or challenges.

**Chapter 3** relates to the implementation of the as-built situation of the case study of an industrial building located in Vila do Conde, Portugal. After giving an overall presentation of the case, it will start explaining the modelling strategies, continuing with modelling challenges on the infrastructure, superstructure and architecture. After having the as-built model it was used to analyse some BIM potentialities as the construction planning and the quantity take-off and consequent comparison with CASAIS S.A. documentation. Lastly, a discussion of the modelling is held, with specific regard to the potential costs and revenues that BIM can represent in this context.

**Chapter 4** consists on the same case study but this time with the intention of studying and planning the interventions to be performed on the existing building. As Chapter 3, it starts with a presentation of the works pretended to do and the presentation of the modelling strategies. Considering this, it is possible to model/evaluate the intervention works that are intended and posterior utilization of BIM tools as mentioned.

To conclude, **Chapter 5** provides a summary of the main conclusions, together with some suggestions for possible extensions of the concluded work.

## 2. BUILDING INFORMATION MODELING IN EXISTING BUILDINGS

### 2.1. Intervention types in existing buildings

With respect to interventions in existing buildings, it is not possible to apply a term which represents every intervention that is possible to perform on it. Regarding the Refurbishment Manual, it is possible to divide it into some levels: (i) Reconstruction; (ii) Restoration; (iii) Deconstruction; (iv) Demolition; (v) Renovation; (vi) Repairs; (vii) Refurbishment; (viii) Conversion; (ix) Gutting (Giebler, et al., 2009).

On the research held, a wide variety of definitions of each term was found used to describe different interventions in existing buildings and different connections between them.

After the revision, it was made a systematization for this specific case study, and it was chosen to study the interventions which were thought to be the most appropriate for the scope of the present dissertation.

Figure 2 provides an outline of the types of intervention mentioned above, which will be object of further discussion in this document.

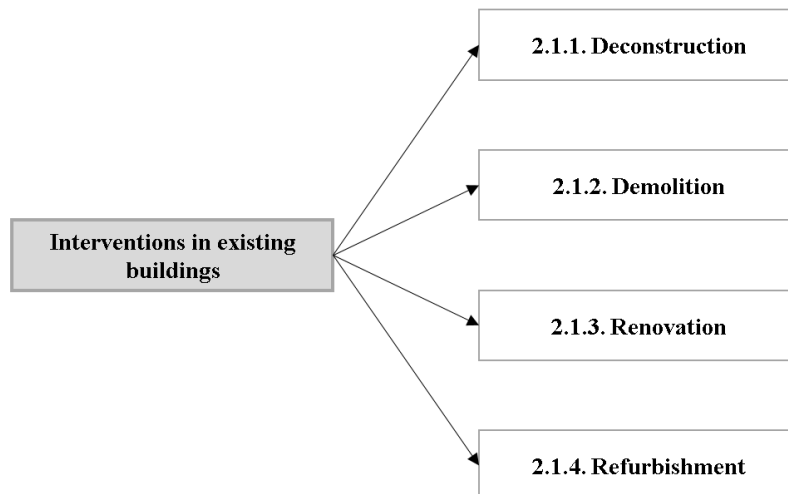


Figure 2 - Summary of chapter to be studied

#### 2.1.1. Deconstruction

The service of take apart and disassemble is considered to be deconstruction, as synonym of dismantling (Omniclass, 2015).

It is important to note that there are some differences between deconstruction and demolition, since the term demolition refers to an undifferentiated demolition, while the term deconstruction refers to a selective demolition, or partial/total dismantling of the building for material recovery.

During the research for this dissertation, a study on the removal and disposal of fenestration units in two separate buildings was found, belonging to the same period and built with similar construction materials. Demolition techniques were used for removing the fenestration units from one of the buildings that was undergoing refurbishment; while, disassembling techniques were used for dismantling similar units from another building that was being selectively deconstructed. The study concludes that the amount of energy consumed, time taken and waste generated, were far greater, and the revenues much lower, when conventional demolition techniques and tools were used (Elias-Ozkan, 2014).

Hence, with all the previous information, it is easy to conclude that on the necessity of fenestration disposal in building refurbishment projects, from the point of view of resource conservation (material, energy, time, and money) deconstruction was found to be more advantageous in the disposal of reusable building components.

It was also found during the literature review that a selective deconstruction allows for material reutilization and recycling, innovation and technology, construction sustainability, new market opportunity - used materials auctions, environment and economic benefits (Couto, Couto, & Teixeira, 2006). Another example, as shown in Figure 3, was the company ‘Hurricane Hauling and Demolition Inc.’, a based demolition and hauling company, that has begun a tear down project using selective deconstruction, saying that it is an environmentally friendly alternative to demolition that helps homeowners as well as the environment (Hurricane Hauling & Demolition, 2012).



*Figure 3 - Disassembling parts of a building (Hurricane Hauling & Demolition, 2012)*

### 2.1.2. Demolition

Demolition is an intervention in existing buildings that means to tear down or raze (Omniclass, 2012). This term demolition means a deconstruction type that is not controlled or planned which do not take into account waste or recycle management (Couto, Couto, & Teixeira, 2006).

There are different demolition ways and techniques to apply to buildings. They could base on simple processes, such as: by action of self-weight; by impact; by means of hydraulic machines; by means of pneumatic machines; by fracture of parts through expansive fluids; by elements fusion; by chemical processes (Vital, 2003).

Figure 4, shows that demolition is the phase of the building's life cycle that produces more waste compared to all other phases. This waste cause air and water pollution, occupies higher volume of landfill and, when poorly managed, may cause relevant risks to public health. In the European Union, the demolition contributed to 40 to 50% of the total construction waste, compared with a range of 10 to 20% for new buildings and 30 to 40 % for rehabilitation (Martins, 2014). With that, it is understandable that, in a sustainable vision, it is more consistent to choose rehabilitation rather than demolitions, or at least in total demolitions.



*Figure 4 - Building being demolished by pneumatic machine (Volvo, 2010)*

### 2.1.3. Renovation

Renovation is an upgrade intervention on existing buildings synonym for alteration, which could mean, for example, to make fresh or sound again as though new, clean up,

replace worn and broken parts in, repair or returning to a good state of repair (Omniclass, 2012).

Examples of general renovation interventions in existing buildings could be:

- Exterior and Interior paint (see Figure 5);
- Repair of wall cracking (see Figure 5)



Figure 5 - Before and after renovation (Lima & Rocha, 2015)

- Plumbing repair;
- Electricity repair;
- HVAC repair or maintenance;
- Installation of floors and tiling;
- Installation of plasterboard for ceilings, divisions or repairs.

In Figure 6, it is possible to see a renovation where it was necessary to renovate the structure of an existing pool because it showed up some cracks that were damaging the existent insulation causing losses of water.

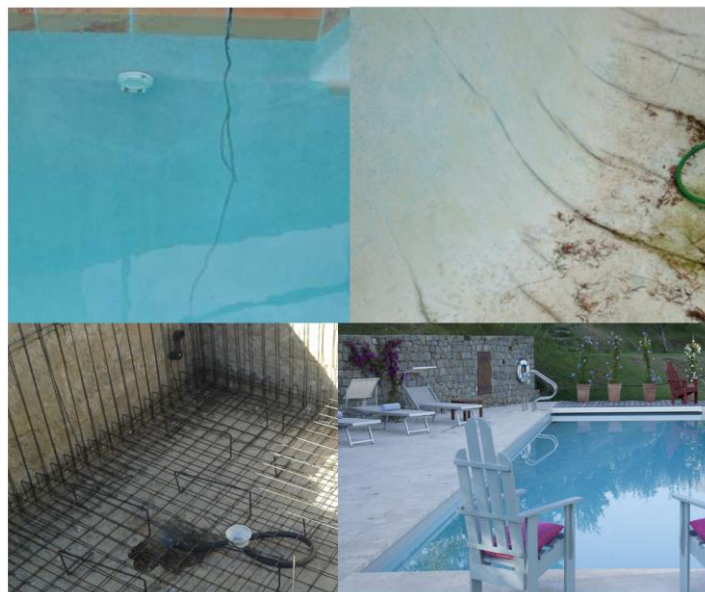


Figure 6 - Pool structural renovation - Process (Lima & Rocha, 2015)

### 2.1.4. Refurbishment

Refurbishment means providing something with a component or feature not fitted during manufacture or adding something that it did not have when first constructed (Giebeler, et al., 2009). Considering this, refurbishment as an upgrade intervention in existing buildings is to make over or rebuild providing benefits, which could also be named as remodelling (Omniclass, 2012).

Usually the refurbishment involves modifications to existing buildings that can improve energy efficiency or reduce the need for energy. This intervention, if well executed, can result in decreased operating costs, particularly in old buildings, as well as help existing buildings to come back to the market and stay attractive gaining advantage over other existing buildings which are not refurbished.

Despite all the types of refurbishment there are some which are thought to be more relevant for the present dissertation, which are the thermal intervention, and the structural intervention. Thermal interventions are mostly focused on reducing the need for heating/cooling buildings, and they are usually targeted at façades or ceilings. There are several thermal improvement alternatives such as:

- Modernization of façade without insulation application;
- External Thermal Insulation Composite Systems (ETICS) (see Figure 7);



Figure 7 - ETICS system (1-Brick or thermal block; 2-Adhesive; 3-Thermal Insulation; 4-Reinforcement-mesh embedding; 5-Reinforcement mesh; 6-Primer; 7-Rendering mortar) (L37, 2014)

- Interior or exterior insulation improvement (see Figure 8);



Figure 8 - Installation of insulation on ceiling during its renovation (Lima & Rocha, 2015)

- Vacuum insulation panels.

A structural refurbishment intervention in existing buildings could happen on the ceilings which are becoming old and deteriorated as it could be in Figure 9 the before and after structural refurbishment. This work has the structural refurbishment work providing a new structure to the ceiling and a thermal refurbishment work providing an insulation that did not exist before, as shown in Figure 8.



Figure 9 - Before and after refurbishment (Lima & Rocha, 2015)

Sometimes, it is difficult to assess whether it will be better to make renovation or proceed directly to the deconstruction of the building and consequently re-build a new construction, due to the high costs associated with a strong renewal of a very run-down building. However, in many cases the process of demolition and new construction turns out to be much more expensive, making the adoption of rehabilitation measures to be the



most frequently taken measures by the owners of existing buildings (Moreli, Harrestrup, & Svendsen, 2014).

Other structural refurbishment, which is normally used is the strengthening of the structure. It is performed when some elements of the structure have been damaged, but during the retrofit the overall behaviour of the structure should be considered. Some examples of structural retrofitting could be external reinforcement as shown in Figure 10, or post-tensioning using reinforcement material. (AboutCivil, 2014).

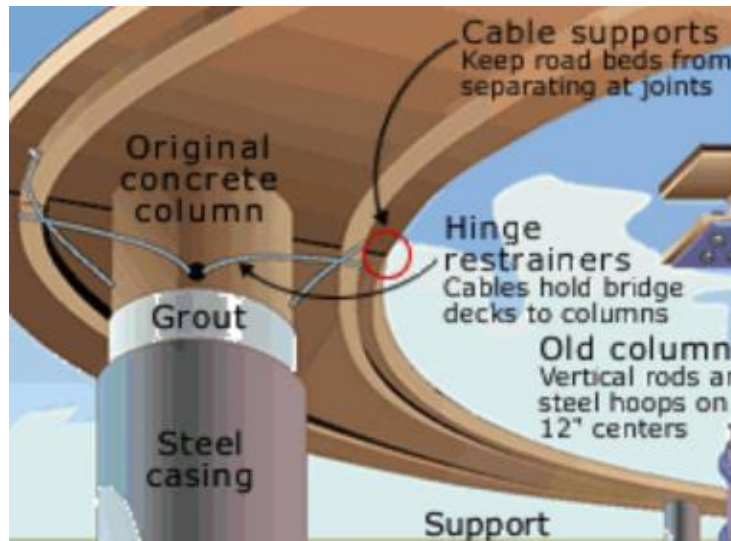


Figure 10 - Seismic refurbishment (AboutCivil, 2014)

Sometimes, it is difficult to assess whether it will be better to make renovation or proceed directly to the deconstruction of the building and consequently re-build a new construction, due to the high costs associated with a strong renewal of a very run-down building. However, in many cases the process of demolition and new construction turns out to be much more expensive, making the adoption of rehabilitation measures be the most frequently taken measures by the owners of existing buildings (Moreli, Harrestrup, & Svendsen, 2014).

## 2.2.BIM Concept

BIM consists on a set of interacting policies, processes and technologies generating a work methodology that is able to manage, from a virtual model, 3D sketch and project data, in a digital format throughout the building's life cycle, as shown in Figure 11 (Succar, 2009).

Nowadays, the continuous proliferation of BIM methodology in the AEC, is eminent as well as on the universities in an academic environment (Caires, 2013). Considering

this, it is clear that the concept is being more and more dominated by all the interested parties. Around the world, and particularly in Portugal, a remarked advance is visible over the past years. There are already some companies adopting/implementing BIM, as well as several scientific papers and master's thesis and even courses or training sessions to disseminate this methodology.

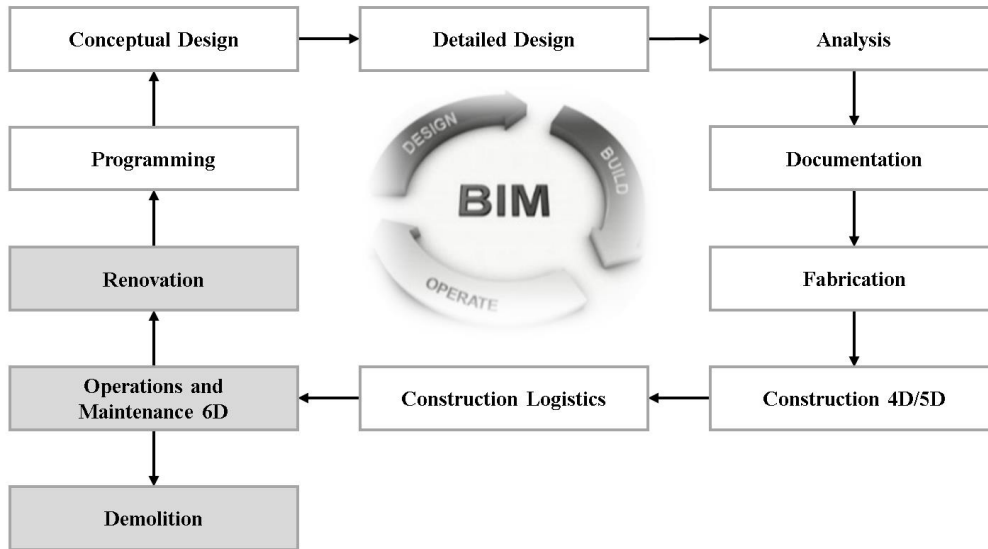


Figure 11 - BIM present in different building's life cycle phases - adapted (Green BIM Engineering, 2014)

BIM is based on the virtual construction of a building in a 3D digital model, known as a building information model, where simultaneous simulations associated with design and construction can be automatically generated by architects, engineers and contractors giving them more support in developing projects more efficiently.

BIM is able to provide a holistic and more interactive vision of the project, making the interdependencies that prevail between the various project specialties of a building explicit (architectural, structural, and MEP layouts) by technologically coupling the involved stake holder's designs (Caires, 2013) (see Figure 12).

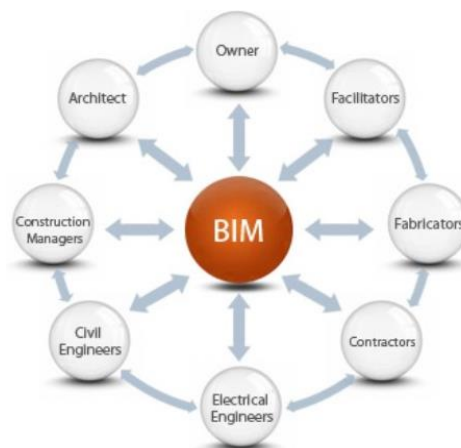


Figure 12 - Collaborative BIM methodology of sharing a virtual model (CONSTRUCTION, M. H., 2009)

BIM processes which have been studied until the present moment are more focused on new buildings (Volk, Stengel, & Schultmann, 2014).

## **2.3.Challenges of BIM in Existing Buildings**

Despite the initially main intention of BIM being from new buildings, there is an increasing request of development of BIM in existing buildings. Some studies show there are some obstacles on BIM implementation in existing buildings as well as high efforts to model/convert captured building data into semantic BIM objects, updating of information in BIM and handling of uncertain data, objects and relations in BIM occurring in existing buildings (Volk, Stengel, & Schultmann, 2014).

Considering that BIM is a quite complex methodology to study, there are several issues and challenges raised along its study and implementation, which necessarily have to be addressed. In the following chapters, an overall idea of barriers and challenges that have to be overcome during the execution of a BIM project for an existing building will be given.

### **2.3.1. Before the modelling starts**

#### **2.3.1.1. As-built model**

The term as-built represents exactly what it says; the as-built model is an exact representation of what is actually constructed in a given moment. In other words, it is a editable copy of the record BIM that is constantly updated to represent the current building and systems configuration (GSA, 2007).

As-built models could be treated as a digital asset of the building, which could be used throughout the building life cycle (Li, et al., 2013).

Recently, planning and handover processes have shifted from the usual design-bid-built to Integrated Project Delivery (IPD) in a collaborative atmosphere, considering the value of ‘as-built’ BIM information in retrofit and deconstruction intervention types in existing buildings (Volk, Stengel, & Schultmann, 2014) (see Figure 13).

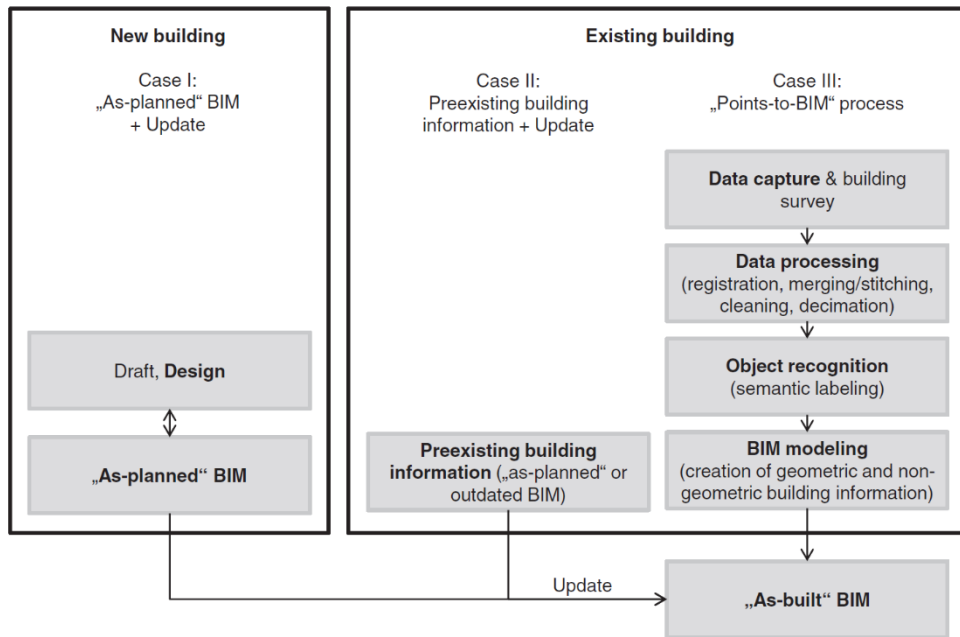


Figure 13 - BIM creation processes for new and existing buildings (Volk, Stengel, & Schultmann, 2014)

### 2.3.1.2. Regulation and standards

Many BIM regulation rules and standards exist, and are being developed nowadays. After some review, it was found that there is a generalized lack of information about BIM in the context of existing buildings. However, in the specific context of initial situation for BIM models, and also for as-built models (context of end of a construction), several regulations provide information, which is discussed in the following subchapters, organized according to the issuing country. Regulation and standards are more developed in Finland, The United States, Singapore, Norway and The United Kingdom. It was made a research through all of them and it was found some interesting information about existing buildings from all of them unless The United Kingdom and Singapore.

#### 2.3.1.2.1. Finland

The Finish BIM regulation named as Common BIM requirements 2012 (COBIM), is constituted by twelve documents, which have some information for existing buildings.

All BIM models required for the project must be supplemented in the construction stage to reflect modifications made so that they correspond with the end result as-built. The primary intended use of as-built models is related to the use, maintenance and repair of the building. An as-built model has information about maintenance and repairs, space and occupancy management and planning of later use and interventions of the building (COBIM, 2012a).

For existing buildings, the as-built model is divided in two important parts. One of them is the 'Site model' and the other one is the 'Inventory model'. The 'Site model' is the plot model and can also include boundary marks and location of other judicially or technically significant points, such as drains or cables. It is recommended to include areas external to the site like buildings and street areas nearby so that they can be processed as an entity by themselves. Regarding the 'Inventory model', it is the model of the existing building where it is advised to be careful with striving for high accuracy for this model. Very often old buildings are somewhat slanted, sloping, curved or otherwise imperfect in their geometry. This fact could bring many difficulties when doing an 'Inventory model' (COBIM, 2012b).

For the architects, if there is a previous 'Inventory model', it significantly facilitates their work in comparison with new buildings of the same size. On the other hand, if it is incomplete or does not exist at all, the modelling time required for a project like that can be many times higher than for a new building project. The guidelines for existing buildings are almost the same as in new buildings. However there are some differences whether working with inventory BIM, or with design coordination. If there is an 'Inventory BIM' it is ideal that it has been created using the same software that is used by the architect. This will minimize the problems caused during data exchange. The end result is further improved if the model has been prepared by, or under supervision of, the project architect. That way this is an opportunity to influence modelling methods, naming of model objects, modelling accuracy and the phasing of the work. If the architect uses a different software it will be necessary to re-model it, or in a worst-case scenario, to do a completely new model. Regarding the design coordination, if there is a valid 'Inventory BIM' in initial planning stage, it will facilitate BIM-based design coordination. With this, the architect can provide a BIM-based design to other disciplines at a rapid pace. Interventions in existing buildings often mean an increased amount of new HVAC and electrical installations. It reinforces the importance of collaboration, in which BIM provides an effective tool for use by the entire project team (COBIM, 2012c).

Regarding the structural designers, in intervention projects, the scope of modelling should always be agreed on project specific basis. The scope and accuracy of modelling is affected by possible inventory model and its suitability. When it is necessary, the structural designer may model the existing structures, in an initial phase, whether there is no previous model or there is a model with insufficient accuracy. After that, they need to model the structures of the new project (COBIM, 2012d).

In general, an as-built model of an existing building will significantly help in interventions that could be necessary when conducting every work inherent to these.

### **2.3.1.2.2. The United States**

For interventions in existing buildings, stakeholders and their roles need to be defined. The provision of easy and non-proprietary methods and roles of the different stakeholders is an important factor for developing standard data transfer models. Construction Operations Building Information Exchange (COBie) specification is one of the standards established by the National BIM Standard (NBIMS) committee (East E. W., 2007).

COBie helps to organize information about new and existing buildings. Also, it is general enough that it can be used to document both buildings and infrastructure assets. It is a mean of sharing structured information and it is simple enough that it can be transmitted by using a spreadsheet. Furthermore, the contracts of interventions in existing buildings are not based on BIM yet, because they have not been developed and standardized to this effect.

The requirements for the timing of COBie deliverables on typical facility acquisition projects are important. Participants in specific contracts should review individual contract requirements for any changes to these general requirements. COBie deliverables increase in content over time to reflect the increasing maturation of the design or completion of the construction project. Regarding specifically the as-built construction deliverable, the general contractor shall be the responsible for this and Beneficial Occupancy derivable. For projects that employ Third Party commissioning, the Commissioning Agent may assist the General Contractor to coordinate and validate the quality of the General Contractor deliverables at the Beneficial Occupancy and the As-Built Construction Deliverables. The As-Built Construction Deliverable will be provided as a single COBie file for each facility in the project (and site, if applicable) that reflects the as-built design documents delivered as fiscal completion of the project. This file shall update the Beneficial Occupancy Deliverable model to reflect any additions, updates, or deletions to the underlying buildings and associated COBie data. The complete set of commissioning information shall be provided with this deliverable. Information needed to operate and maintain the facility shall also be included in this COBie deliverable (East & Carrasquillo-Mangual, 2013).

COBie should facilitate extracting and transferring data from BIM to interventions in existing buildings. It includes specific information about rooms and zones, equipment and its location, submittals, instructions, tests, certificates, preventive maintenance and safety plans, troubleshooting plans, start-up procedures, shut-down procedures, and emergency plans as well as resource data for these activities (WBDG, 2010). However, since the majority of existing buildings are not being intervened with BIM yet, stakeholders collaboration might remain ineffective.

The U.S. General Services Administration (GSA) also are continuously developing a standard which is named by GSA Building Information Modeling Guide Series (GSA, 2007). GSA refers that the benefits of determining the spatial environment and as-built conditions have played a key role in reducing costs and delivering a higher quality engineering effort. GSA is divided in different guide series: (i) Overview, (ii) Spatial Program Validation, (iii) 3D Imaging, (iv) 4D phasing; (v) Energy Performance and Operations; (vi) Circulation and Security Validation; (vii) Building Elements; (viii) Facility management.

Regarding 4D Phasing, it says that on site, BIM models can be used for bi-weekly construction progress reviews and to compare as-built with as-planned schedules for management and claims purposes.

On Energy Performance and Operations guide it refers that for renovation and modernization works, one of the project challenges is to perform an accurate model of the as-built conditions.

Regarding existing buildings, GSA recommends 3D Laser Scanning technology to perform as-built and as-constructed information to have improvements in quality, accuracy, coordination and efficiency.

Lastly, regarding the facility management it says that maintenance data will create greater efficiencies, because having an accurate as-built information model will reduce costs and time required for renovations, increasing customer satisfaction and optimizing operations and maintenance of building systems to reduce energy usage. To perform this models is important to identify 'core' information that shall be required in every as-built BIM submission. Furthermore, it says that BIM models represent as-built conditions, including architectural supplemental instructions, change notices, and field changes and include the minimum attributes required by GSA.

### **2.3.1.2.3. Norway**

Statsbygg Building Information Modelling Manual, SBM, contain generic requirements for BIM in projects and at facilities. Its purpose is to describe requirements in respect of BIM in the open Industry Foundation Classes (IFC) format where the main targets audiences are design teams, client project and facility managers and domain practitioners involved in BIM processes (SBM1.2, 2011).

Regarding the scope of the present dissertation, SBM only defines some aspects of building survey in pre-design stage. Indeed, it merely defines that the building survey can be conducted by using traditional geometrical measuring of points and corner points, using photogrammetry, 3D Laser Scans, or a technical condition survey.

### **2.3.1.3. Classification systems**

The activities conducted throughout the life cycle of any facility generate an enormous quantity of data that needs to be stored, retrieved, communicated, and used by all parties involved. Advances in technology have increased the opportunities for gathering, providing access to, exchanging, and archiving all of this information which ought to be made available and how quickly that access should be provided.

Continuing advances in 'smart building technologies', 'BIM technologies', and construction practices have not only increased the amount and detail of data generated and exchanged, but have also further raised expectations about its use and value as an asset. This increase in the amount and types of information generated, and the AEC industry's subsequent reliance on it, demands an organizational standard that can address the full scope of this information throughout a facility's life cycle. This organizational standard will enable and add certainty to information communicated between parties separated by miles, countries or continents.

There are various classification systems that are mainly used in different parts of the world. The most widespread are the Omniclass (Omniclass, 2015), Talo2000 (Rakennustieto, 2015) and Unifomat II (Unifomat II).

The Building 2000 Project Classification, also known as Talo2000, cover building elements, building services elements, structural parts, property management and user tasks. In addition to that, project estimating and accounting related to new construction or renovation, as well as in price setting, the classification also covers projects provisions.



Originally Unifomat was developed specifically for design phases estimates. Unifomat II is applicable to all phases of a building's life cycle. An important phase which it is referred that Unifomat classifies is the 'Scope of work definition for building renovations and retrofits'. Generally it serves to classify building specifications, cost estimating, and cost analysis. It is subdivided by six major groups which are: substructure; shell, interiors; services; equipment and furnishings; and finally special construction and demolition. For each of this major group elements it exists a second level grouping elements and a third one to individual elements.

Regarding Omniclass, also known as Overall Construction Classification System, OCCS, is organized based on the segregation of information types to be classified into a set of discrete, coordinated tables. Its names are: construction entities by function, construction entities by form, spaces by function, spaces by form, elements, work results, products, phases, services, disciplines, organizational roles, tools, information, materials and properties. Furthermore, every tables has four levels of stratifications and usually also have synonyms and definitions to try to better understand the difference between each item. Is considered the evolution of Unifomat and some others classification systems because it served as legacy source from which several Omniclass tables content and organization have been drawn and adapted (Omniclass, 2006a).

As Omniclass came from Unifomat it is possible to see some linearity between them. In addition to that, Omniclass shows up with more potentials because it is extremely more stratified showing more divisions on individual elements.

#### **2.3.1.4. Level of Development (LOD)**

Depending on the required level of accuracy, the clarification of necessary source data may also require the expertise of designers specialised in particular fields and other consultants (COBIM, 2012b).

BIM features require a certain precision and richness in information and timeliness of underlying data through which the models could respond correctly to the proposed requirements. A concept often used to define BIM wealth of information objects is called the level of detail or development also defined by LOD. Depending of the BIM regulation standards of different countries, it exists different ways of definition LOD. After some research it was found BIMFORUM document 'Level of Development Specification' made in 2011, from the American Institute of Architects (AIA), which defines every data that all objects are required to have to reach a certain LOD. On Table 1 it is possible to

see to see a resume of LOD. The LOD defines the geometric and non-geometric information that a component should contain. Usually it is referred to as a point in time, a life cycle phase or contractual responsibilities. For example, to be able to perform analysis or plan features, LOD of attributes and relationships of objects must be set, such as information on durations, dependencies or precedence (Jaehoon, et al., 2014).

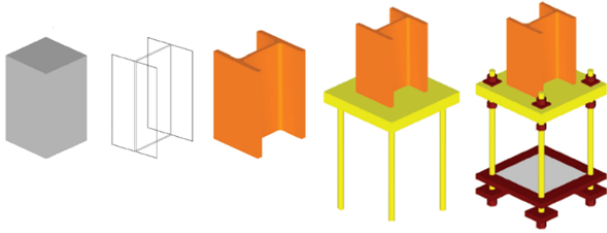
Levels of Detail	Levels of Development
<p>Approximate geometry, precise geometry, fabrication level/construction documentation;</p> <p>Conceptual, approximate geometry, precise geometry, fabrication, as-built;</p> <p>As-designed/as-planned, as-built, as-used;</p> <p>Schematic design, detailed design, level of fabrication (shop model);</p>	<p>LOD 100, LOD 200, LOD 300, LOD 400, LOD 500</p> 

Table 1 - Levels of Detail/Levels of Development - adapted (Volk, Stengel, & Schultmann, 2014; BIMFORUM, 2013)

LOD 500 is the final level of development that represent the project as-built. It is a LOD appropriated for operational and maintenance aspects. From Table 1 it is possible to understand the holistic and realistic definition that an as-built model need, regarding the figure of LOD 500, to be exactly how is it constructed in reality. However, the effort to reach this LOD, sometimes could be extremely high where this development may not be necessary regarding the functions that are wanted to be performed from the as-built model.

### 2.3.1.5. Utilization of classes of objects

Objects are fundamental to build a BIM model. These should be representative of the reality, have the necessary information to the model construction, and have three-dimensional expression and also information.

Regarding the information, objects and families should have the necessary information for everyone that will use it.

Nowadays it is possible to obtain objects from own software libraries, online libraries and self-developed. Before starting the model it is important to know what type of information is necessary to include on each object and what purpose is wanted for the model in the future to evaluate which level of development is necessary with the objects.

Free online libraries are continuously increasing market and construction products companies are increasing their interest on providing its product models to the public. Some examples of free online libraries are:

- RevitCity (Revit City, 2015);
- Bradleycorp (Bradley, 2015);
- BIMObject (BIMObject, 2015);
- Bimetica (Bimetica, 2015).

Some years ago, it was completely impossible to have this work facilitation. It was necessary to model every object that was needed. However, nowadays, there has been an increasing manufacturer's preoccupation about having their products modelled to use in BIM.

The intention of this is that in a short period of time, the modelling will be simplified because the majority of the objects will be modelled and it will be almost like a copy paste, because the turnover of the use of certain objects enables the designer to have more productivity in a short time.

### **2.3.2. Data capturing techniques**

In an attempt to model an existing building, two different cases could happen. The first case applies to constructions where there is some pre-existing BIM information, which culminates in carrying out the validation and update of information. The second consists of a process through which one has to start by making the capture and the research of the building, as to process such information into a BIM model. Each of these provide a different modelling effort. However, in existing buildings, the lack of information and the construction of pre-existing BIM information lead to application of the second case in most situations.

There are several techniques of data capturing and building surveying, that can be subdivided into two large groups: (i) non-contact techniques and (ii) contact techniques. For this dissertation, some methods of (i) and (ii) are discussed in detail due to their affinity with the topic and methods applied. The methods are summarized in Figure 14, and include laser scanning, evaluating pre-existing information (e.g. drawings) and manual measuring methods.

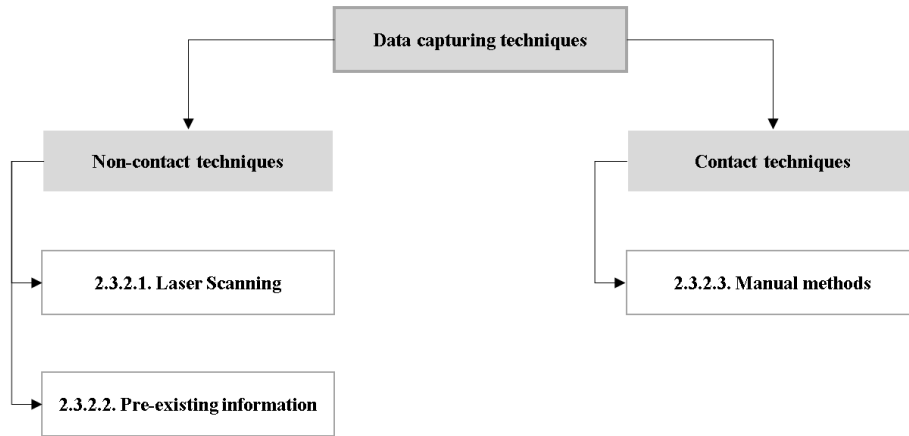


Figure 14 - Data capturing techniques to be studied - Adapted (Volk, Stengel, & Schultmann, 2014)

Depending on the Level of Development, LOD, the best data capturing and building surveying techniques to be used is evaluated.

In order to perform a comprehensive audit on existing buildings, the mentioned data capturing techniques might be combined with other methods of non-destructive testing to analyse materials and properties. Possible methods could include material- or texture-based recognition and structure recognition beyond surface through ground penetrating radars (see Figure 15), radiography, magnetic particle inspection, sonars or electromagnetic waves (see Figure 16) or tags installed during retrofits (Volk, Stengel, & Schultmann, 2014).



Figure 15 - Ground penetrating radar (GPRS, 2015)

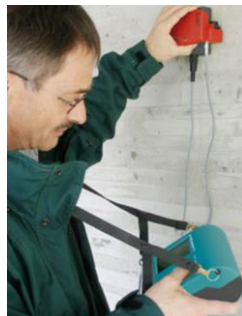


Figure 16 - Covermeter + Profometer (CAPCO, 2015)

In the following sub-chapters, based on the research, some data capturing and building surveying techniques, which are thought to be more important and current on

upgrading services in construction industry, regarding the scope of the present dissertation will be examined.

### **2.3.2.1. Laser scanning**

Laser Scanning method, being classified as a non-contact technique, belongs to the Range-based Techniques Group.

Laser Scanning is nothing more than a generation of 3D point clouds, which is usually obtained through a 3D reconstruction method, which takes its data. Regardless of the data source, the core of 3D reconstruction process consists of a registration procedure aiming to bring different sets of data into the same coordinate system. Scan Stations need to be moved around the scene to ensure a good coverage, hence, rigid deformations, such as translations and rotations, must be considered. Comparing with other techniques Laser Scanning is less involved and less error-prone. However, in this case, appearance cues might not be available, and the registration procedure relies mostly on geometric information (Pătrăucean, et al., 2015).

The measurement accuracy of the point cloud data has a crucial influence on the accuracy of the as-built modelling process. So, after the generation of 3D point clouds, it is extremely advised to do a 3D point cloud pre-processing. Pre-processing the input data is advised to remove outliers, reduce noise, and compensate for missing data, and has become a prerequisite to model an existing building (Pătrăucean, et al., 2015).

In practice, Laser Scanning is widely employed because it is fast, simple to use, and yet highly accurate. However, it has some disadvantages, related to the cost and fragility of the equipment, as other difficulties inherent to the scanning of reflective, transparent or dark surfaces. Regarding these facts, sometimes, manual techniques are adopted because with them it is possible to collect most of the special components and others.

In addition to the previous related disadvantages, there are some other critical difficulties (Jaehoon, et al., 2014):

- The complex design of indoor structures;
- Obstacles which make the scanning difficult;
- Necessity of time-consuming manual operation;
- Huge data sizes;
- Possible system slow-down or failure.

That is why there has been some research on image-based techniques, where it is believed that photogrammetry and videogrammetry are seen as better or complementary methods of range-based techniques.

However, Laser Scanning stations continue to be under constant development and research. And despite all the applications of this instrument, Laser Scanning stations are a solution whether you need a detailed representation of an existing façade, a 2D floor plan or 3D data for integration into BIM, real-time planning of architecture and building projects with fast and accurate *delivery* (Leica, 2015).

In Figure 17 it is possible to see an example of a scan station. Leica is one of some companies which work on geosystems and sell Scan Stations. They research on this field and try to improve data capturing and building surveying techniques with their technological knowledge. One of their last releases was the Scan Station P30 & P40.



Figure 17 - Leica Scan Station P30 & P40 (Leica, 2015)

This station provides high performance under harsh conditions together with highest quality 3D data and HDR imaging at an extremely fast scan rate of 1 mio points per second at ranges of up to 270 m. Unsurpassed range and angular accuracy paired with low range noise and survey-grade dual-axis compensation from the foundation for highly detailed 3D colour point clouds mapped in realistic clarity. In addition to that, the extremely durable new laser scanners perform even under the toughest environmental conditions, such as extreme temperatures ranging from -20°C to +50°C and comply with the IP54 rating for dust and water resistance. Furthermore, this system provides a portfolio as an integrated part of a complete scanning solution including hardware, software, service, training and support, 3D laser scanner data that can be processed in the industry's

leading 3D point cloud software suite, which could be Leica Cyclone stand-alone software, Leica CloudWorx plug-in tools for CAD systems and the free Leica TruView.

As it was mentioned before, there are different companies working in this industry providing Scan Stations with different characteristics and prices. A previous study should be done on of which brand could provide the best Scan Station for the type and use of scan that you want to do. For example, the INOVx RealityLinx Model, Polyworks Modeler, Geomagic Design X (Rapidform XOR2), RiSCANPro commercial software's, which provide Laser Scanning systems, only have CAD integration and not BIM integration (Volk, Stengel, & Schultmann, 2014).

COBIM show the use of laser scanning in special cases such as historic building documentation, where measurements can be done at an even greater level of accuracy and where measurements points are for example in intervals of 1 mm. However, the work load related to the measurements is in this case considerably higher. Figure 18 shows an excerpt of a laser scanning point cloud of a historic building attached with photographed colour data (COBIM, 2012b).



*Figure 18 - Room in the Museum Centre of Turkey (COBIM, 2012b)*

Sometimes, there are some difficulties in scanning some special objects, such as roofs, and the measures of which could be complemented by other survey methods such as videogrammetry or photogrammetry, for example.

#### **2.3.2.2. Pre-existing information**

The modelling of existing building is done based on measurements, inventories and investigations performed on site. This information is supplemented with existing drawings and other documents (COBIM, 2012b).

Pre-existing information is a method of data capture and building surveying, which is classified as a non-contact techniques group. Pre-existing information, could be photos, 2D or 3D CAD detailed drawing documents (see Figures 19 and 20), etc.

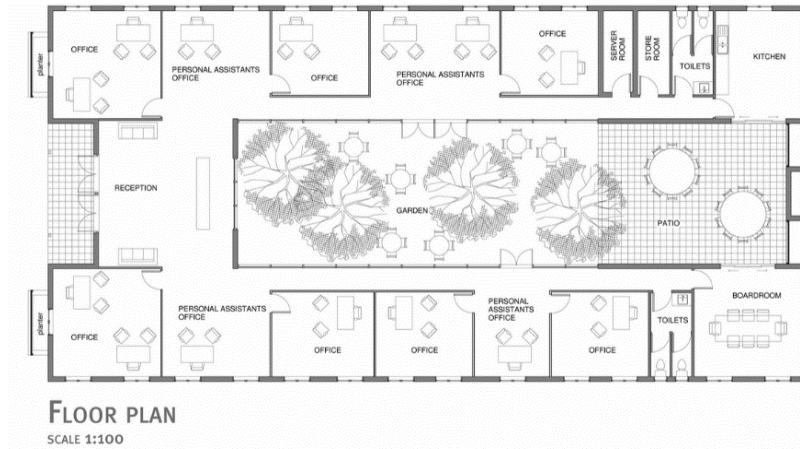


Figure 19 - 2D CAD Floor Plan (FASTAANYTIMELOCK, 2015)

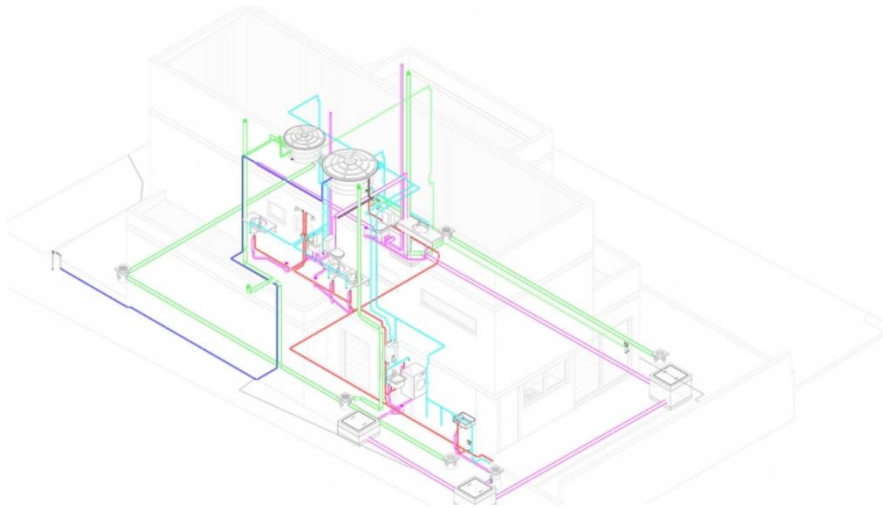


Figure 20 - 3D CAD MEP Installation (Arqbox, 2015)

Normally, this methodology of using pre-existing information assists in gathering additional information such as components, dimensions, materials, textures, functions, connections, positions or maintenance periods (Volk, Stengel, & Schultmann, 2014).

When it is necessary to do an as-built model, having this pre-existing information could provide several benefits comparatively to the traditional measures techniques. It will be much faster and easier to have an accurate model. However, it would be necessary to check if the pre-existing information is in agreement with the existent building, because, for example, during the execution of 2D or 3D CAD detailed drawings, the risk of making simple errors is extremely high. Thus, it could be concluded that the best way



to do an 'as-built' model is with all the presented techniques which complement each other, and with that, it will be possible to do an even more accurate model.

### **2.3.2.3. Traditional methods**

Traditional measure methods can have either contact or non-contact techniques. On contact techniques there are the manual techniques and on non-contact techniques, the range-based techniques are traditionally used. These manual techniques capture mostly spatial and other component-related information (Volk, Stengel, & Schultmann, 2014).

The traditional measurement tools for as-built data acquisition are (Jaehoon, et al., 2014; Volk, Stengel, & Schultmann, 2014):

- Laser distance meters;
- Digital cameras;
- Measuring tapes;
- Calipers.

In these ways of data capturing and building surveying, the dimensions of all building elements, for example walls, windows, and doors, are manually measured and documented. Such manual field surveying is rather labour-intensive, time-consuming and error-prone work. Additionally, as data sets are often interpreted manually, they are not integrated electronically into the project design and schedule (Jaehoon, et al., 2014).

It is true that construction specifications for a project serve as a major knowledge source for identifying inspection goals. These specifications describe the quality requirements for the construction project and, as such, state allowable performance tolerances for the constructed products. This information can be directly translated into inspection goals. However, this is too tedious to be done manually due to the large number of construction projects. Therefore, there is a need to automate this process as much as possible (Akinci, et al., 2006).

## **2.4. BIM Potentialities in existing buildings**

The literature review conducted in the scope of this dissertation has revealed publications that deal with the potentialities of BIM in the context of existing buildings. However, only few of such potentialities are already being explored in practice (Volk, Stengel, & Schultmann, 2014).

Some examples of the BIM functionalities that are currently being explored in existing buildings are: clash detection or spatial program validation, with which it is possible to perform a BIM quality assessment (Eastman & Sacks, 2011). Other functionalities involve cost estimations (NIBS, 2012); daylight analyses (EETD, 2013); data management, documentation, visualization (GitHub, 2013); energy/thermal analysis and control, carbon foot printing (EnergyPlus, 2013); life cycle assessment (LCA) (Autodesk, 2011); sustainability, monitoring, performance measurement (through sensors) (Autodesk, 2013); operation and maintenance (OM); facility management (FM) (Sabol, 2008); quantity take-off, scheduling (Vico Office Suite, 2013); structural analysis (Liberty Industrial, 2012); and subcontractor and supplier integration or prefabrication (e.g. of steel, precast components, fenestration, glass fabrication) (Eastman & Sacks, 2011).

During the research for this section, it was found difficulties on finding specific studies that would be helpful as examples for this dissertation due to its specific scope of deconstruction and upgrade of an existing building. However, the following paragraphs are dedicated to brief outlines some studies applied in real contexts of BIM applications trying to show some benefits of this methodology in existing buildings.

An example of that was a study of a BIM-based system created for demolition and renovation waste estimation and planning, made in Hong Kong, that was presented with an example scenario with a 47-floor residential building to test this system (Cheng & Ma, 2013). A BIM based system was developed for estimation and planning of deconstruction and renovation waste. With the multi-disciplinary information that a BIM model can contain, the system created extract material and volume information and integrated the information for detailed waste estimation and planning. Another important functionality of this system was the improved capacity for evaluation of pick-up truck requirements and waste disposal solutions according to the charging fee for different waste facilities. It was developed a system that could estimate the stockpile from waste came from an intervention on an existing building.

Another example was a study made to find the benefits of building information modelling in the project lifecycle in Asia (Li, et al., 2013). The study involved the study of five distinct large-scale public and financial for which BIM models had been prepared for the design, construction and operational phases. Different uses of BIM are compared and contrasted in the context of separate backgrounds. The following enumeration of the five cases provides a brief specific description of each of the case studies.

1) One of the case studies was the Chong Qing International Circus City which has a complex geometry, as shown in Figure 21.

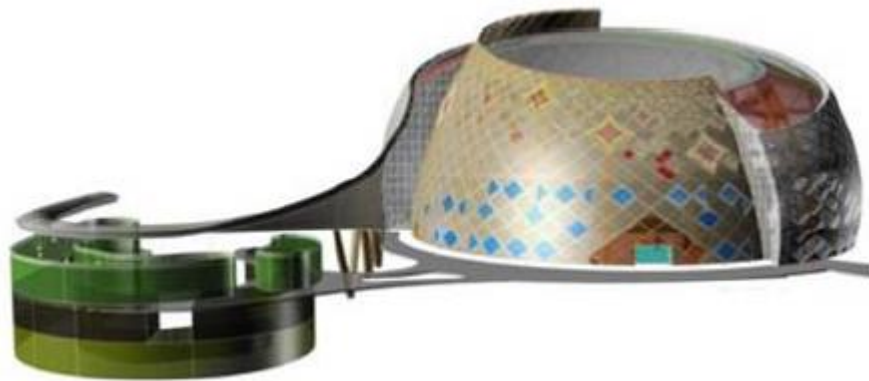


Figure 21 - Chong Qing International Circus City (Li, et al., 2013)

The strategy adopted was to model the structure, architecture and MEP with Autodesk Revit software and perform a parametrized model of the curtain wall in CATIA software due to its complexity. It was performed calculation of quantities and costs, calculation of material consumption and budget the building structure, facility, and MEP qualitatively and quantificational; and finally conduct corporation with sub-contractors based on the 3D model.

2) Other was the Wuhanm New City International Expo Centre where the strategy was to create a BIM construction plan according to the BIM regulation of planning. The BIM model was created based on the construction plan and the properties were embedded into the BIM model based on the operational phase (see Figure 22).

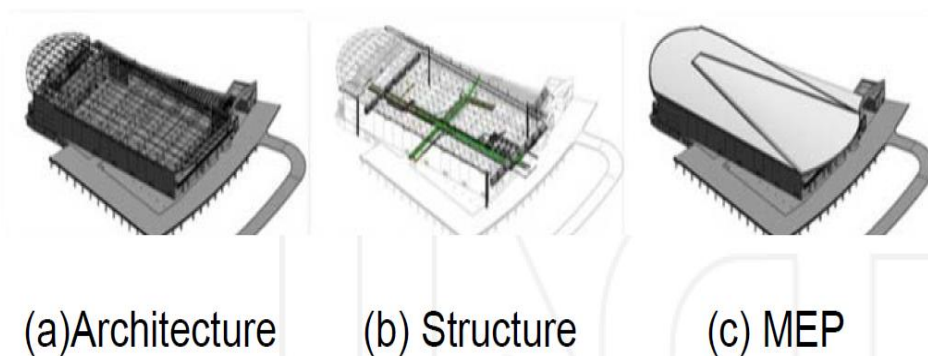


Figure 22 - Architectural, Structural and MEP models of Wuhan New City International Expo Centre (Li, et al., 2013)

After performing this model, it was easily concluded that it facilitates the rescue of equipment in emergencies, investment for exhibitions and access to information via a central database. An operational management module based on this model provides support for emergencies and digital expos. Operational safety and security was improved

and the public were able to learn about the project, increasing the overall value of the project.

3) The BIM model of Chengdu Financial City had a strategy based on the creation of the infrastructure and MEP model. After that it was performed a clash detection, construction plan and a BIM model for facility management in operational phase.

With BIM it was possible to correspond to different regulations of merchants and to arrange various functions for each part of the city, avoiding vacancy and waste of funds.

4) Shangai Disaster Control Centre is one of the most important systems of the State Grid Corporation and an equipment information monitoring and dynamic data display and warning were performed with BIM methodology to enable the real-time monitoring of facility status. Thus, the user can be warned of issues quickly. It also permitted positioning and navigation in a BIM database and with the assistance of BIM.

5) Lastly, the national Synchrotron Radiation Research Centre, NSRRC, where it was needed to apply BIM methodology in the context of Facilities Management, within a strategy of BIM-enabled maintenance schedule and warnings, space allocation and modification and asset management. It was possible to monitor the real-time status of facilities and to manage the maintenance schedule efficiently with automatic notification, ensuring a good working environment for all the facilities and avoids ageing materials causing damage to facilities.

### 3. CASE STUDY: BIM MODEL OF ITARION BUILDING

#### 3.1. Background and presentation

##### Introduction

The Itarion building, owned by Qimonda, was initially targeted to be a production block for electronic components. It is located in Vila do Conde, Portugal, next to the existing complex of buildings of Qimonda as shown in Figure 23.

It is important to refer that the author of the architectural project was the company ‘Pitágoras - Arquitetura e Engenharia integradas’ atelier and the author of the structural project was Rui Oliveira engineer.

The plan size of this new building is approximately 170m by 72.5m, and its longest façades are orientated to Southwest (SW) and Northeast (NE) respectively.

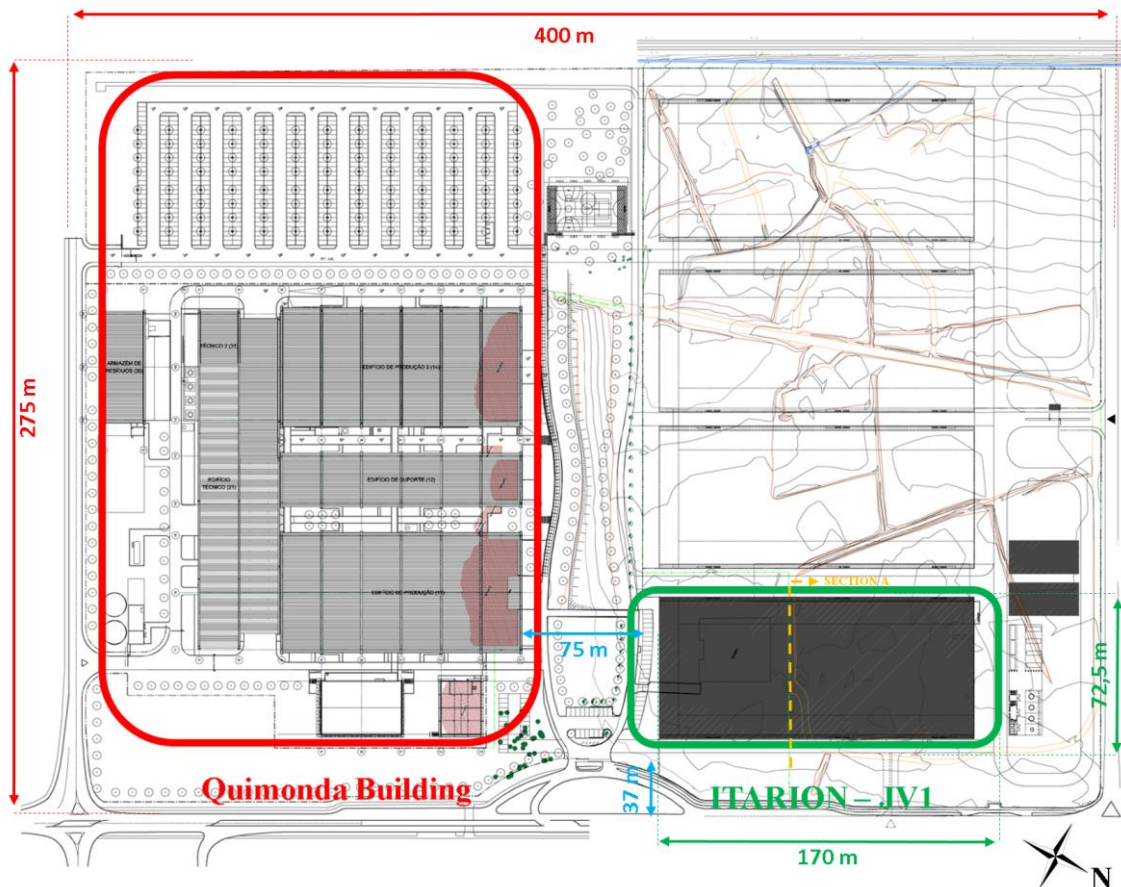


Figure 23 - Overall plan

##### Description of the Building and Layout

In Figure 24, section A, it is possible that the building is composed by three main levels: level 1, level 2 and roof level.

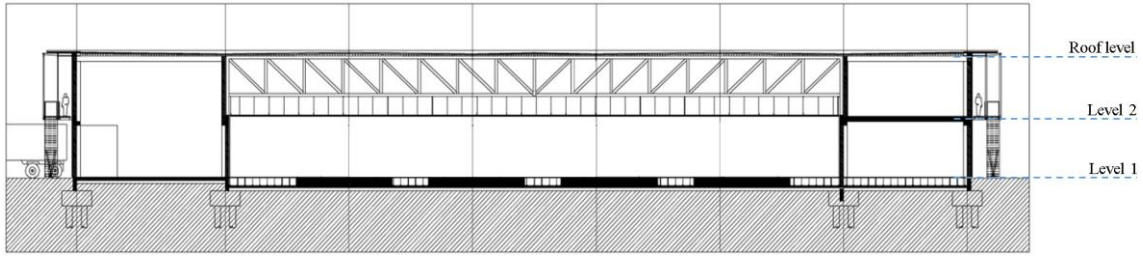


Figure 24 - Section A

The plan of level 1 which can be seen in Figure 25 allows understanding the basic layout of the building, which has three main parts: (i) the office areas situated on the Southeast (SE) façade; (ii) the storage and logistic areas in both NE and SW façades; (iii) the production zone is located in the core of the building, occupying most of its area (160m by 50m with total free height of 4.5m).

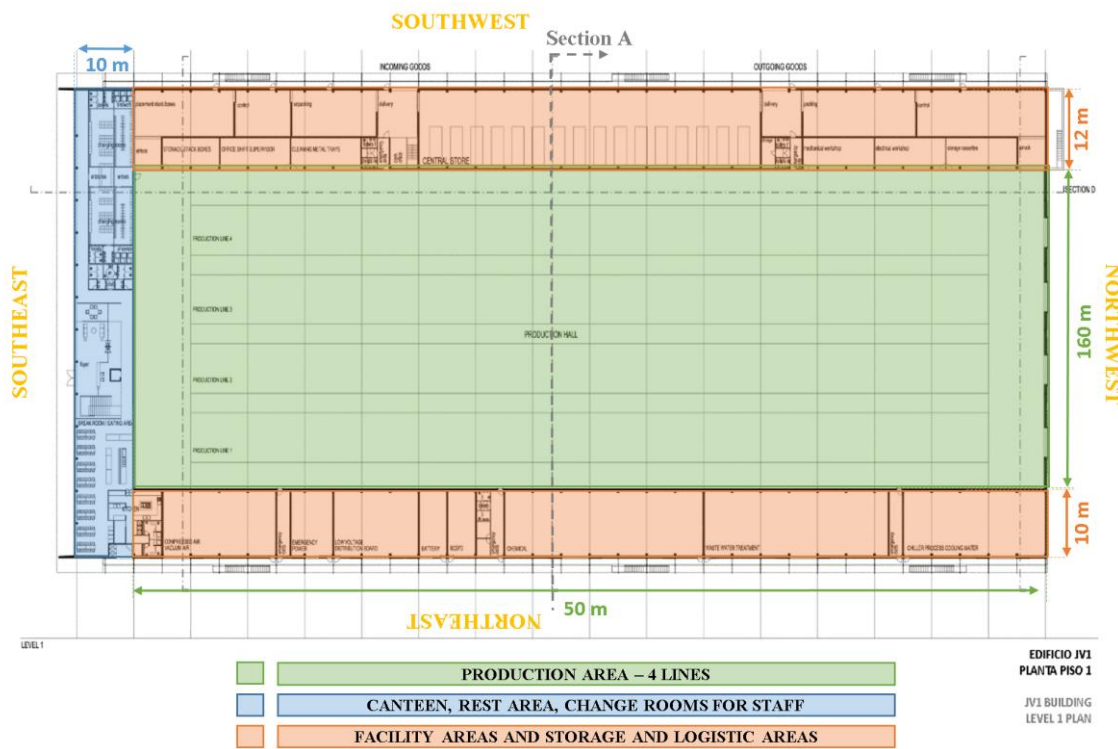


Figure 25 - Level 1 plan JV1 Building

This core area is surrounded by two storey bodies, along all of its length with 10 and 12m widths and one on their SE side, a 10m width component.

Figures 25 and 26 shows the lateral bodies with 10 and 12m widths, will respectively accommodate facility areas and storage and logistics areas. On SE side, a 10m wide two storey area for offices and other services that assist production - canteen, rest area and change rooms for production staff on the first floor, leaving the second floor exclusively for offices, an area that will extend to occupy the leftover area of the second floor of the body that contains storage and primary product treatment.

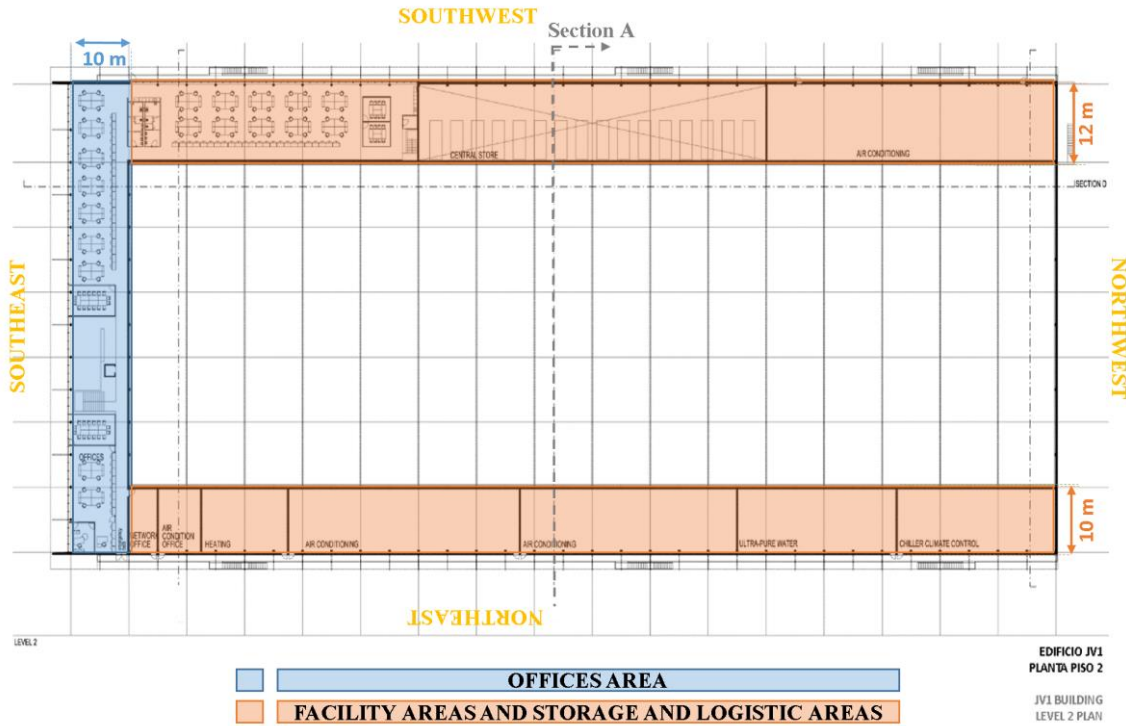


Figure 26 - Level 2 plan JV1 Building

### Materials and Finishes

In terms of structural system, the building comprises both reinforced concrete (columns, waffle slabs), mixed steel/concrete slabs and steel beams/trusses.

The infrastructure is completely composed of concrete material and in Figure 27 it is possible to see the plan of the infrastructure, where is identified two buried zones to -4.5m level.

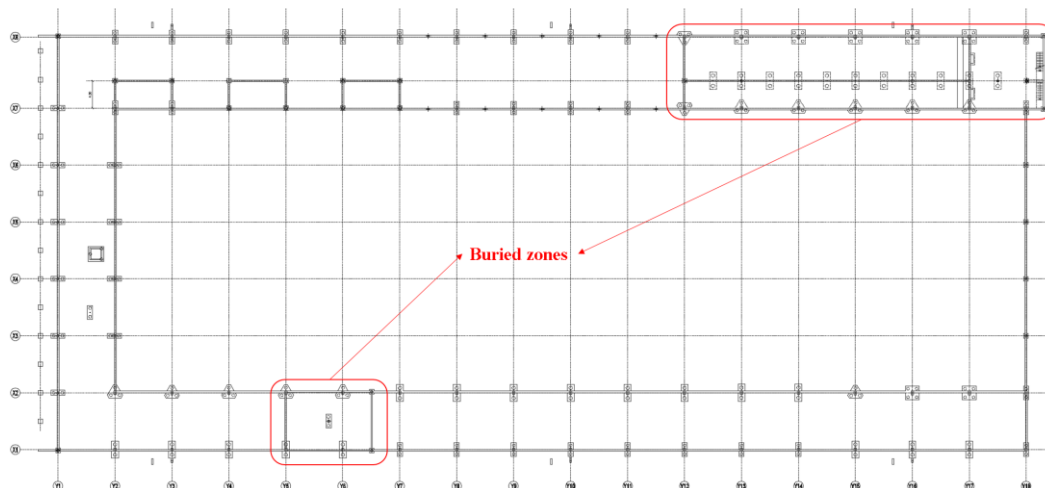


Figure 27 - Infrastructure plan

In Figure 28 is possible to see a general overview of the infrastructure elements. It contains views from the different foundation piles and measures from foundation beams and foundations lintels.

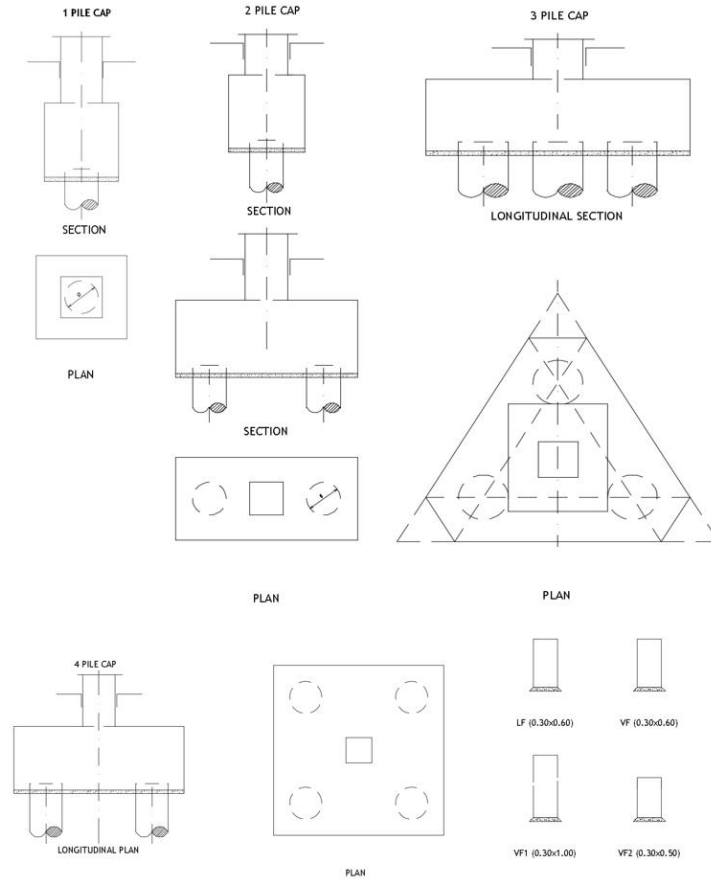


Figure 28 - Pile caps, foundation beans and foundation lintels

In Table 2 it is possible to see a resume of all the dimension of the foundation piles caps. The number 500 or 600 means the pile diameter in mm and every of them have 12m height.

Designation	Equal parts	Dimensions		
		Lenght	Width	Height
ME600-1	23	0.9	0.9	0.90
ME500-2	45	2.4	0.9	1.10
ME600-2	21	2.8	1.00	1.30
ME500-3	10	4.09	1.00	1.25
ME500-4	4	2.4	2.40	1.30

Table 2 - Pile caps dimensions

The superstructure can be seen in Figures 29, 30 and 31.



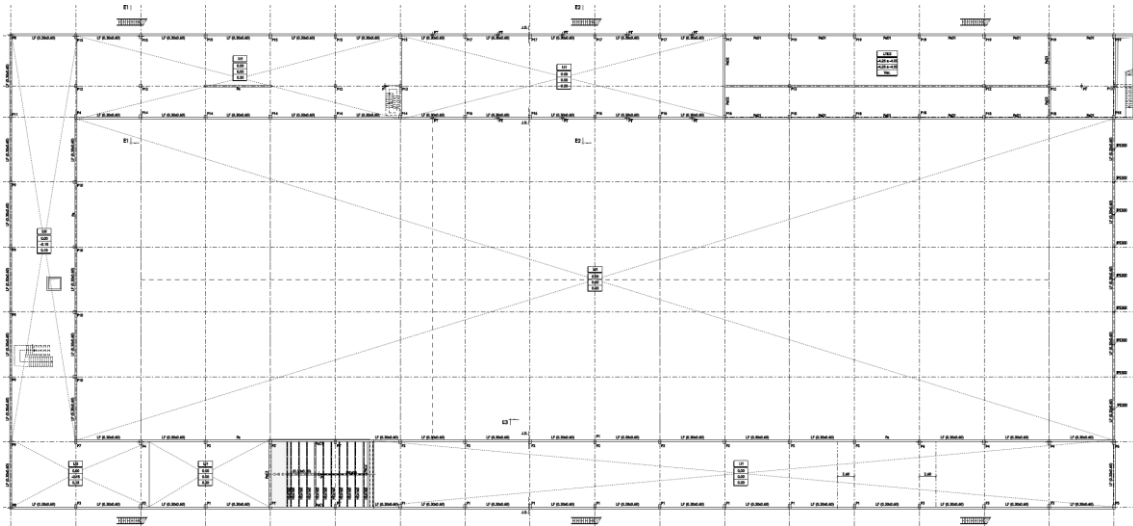


Figure 29 - Level 1 structural plan

In Figures 30 and 31 it is possible to see some zones with little squares. It represent waffle slabs.

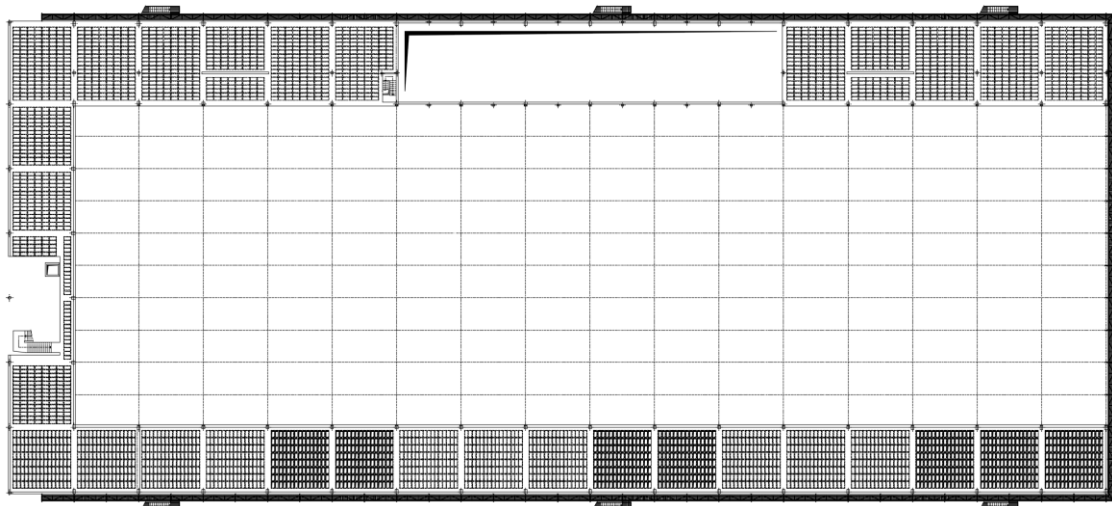


Figure 30 - Level 2 structural plan

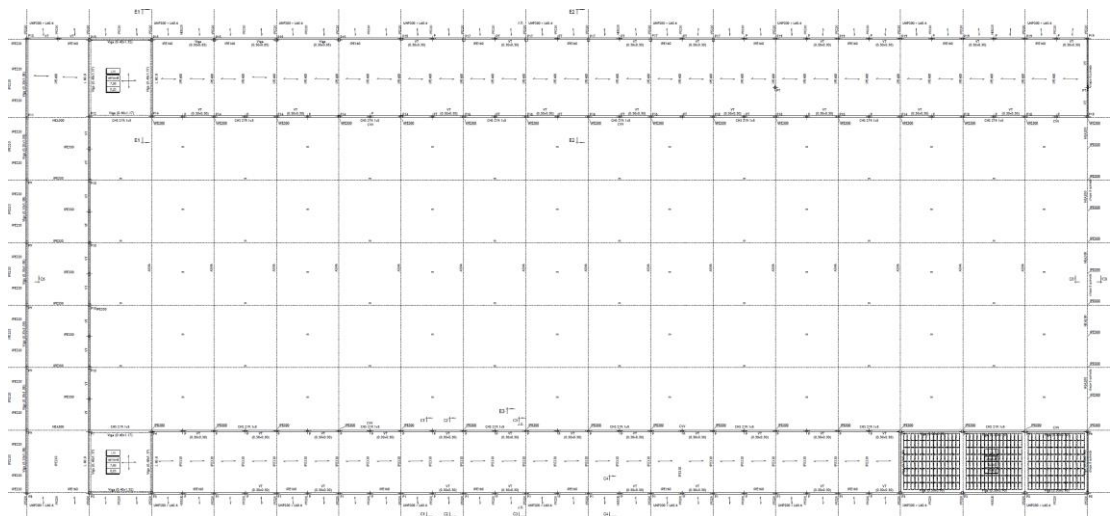


Figure 31 - Roof structural plan

In Figure 32 is possible to view a 3D CAD drawing from Rui Oliveira engineer which represents all the steel structure.

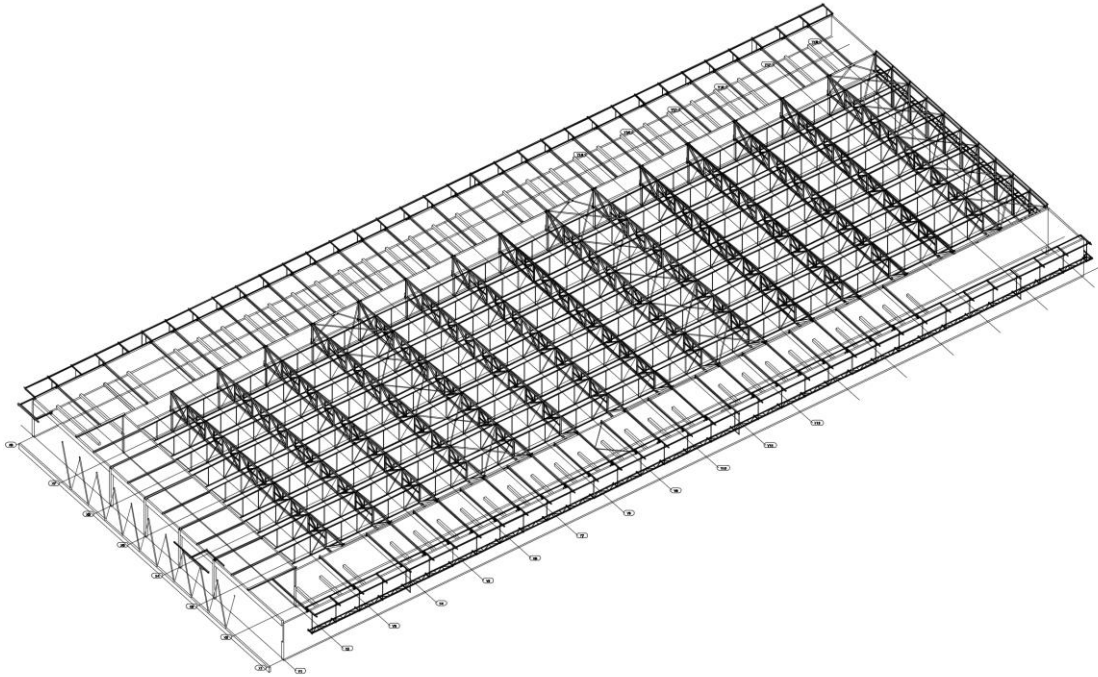


Figure 32 - Steel structure project

The roof cover was made using a lightweight deck solution as shown in Figures 33 and 34 - corrugated metal sheeting, thermal insulation and waterproofing membranes.

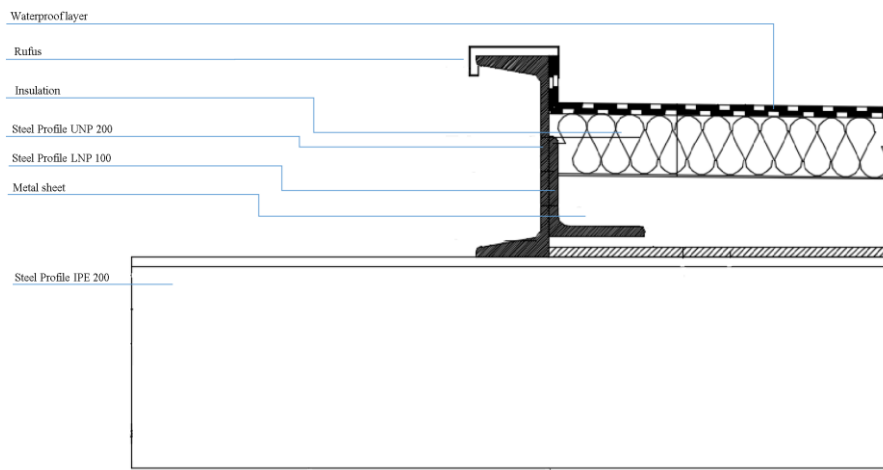


Figure 33 - Roof cover detail

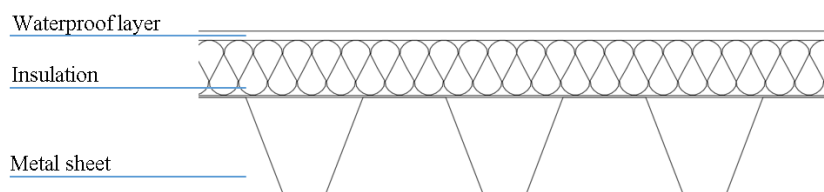


Figure 34 - Roof cover detail - section view

The exterior walls, shown in Figure 35 were made using a traditional ventilated system with thermal bricks, insulation and exterior covering.

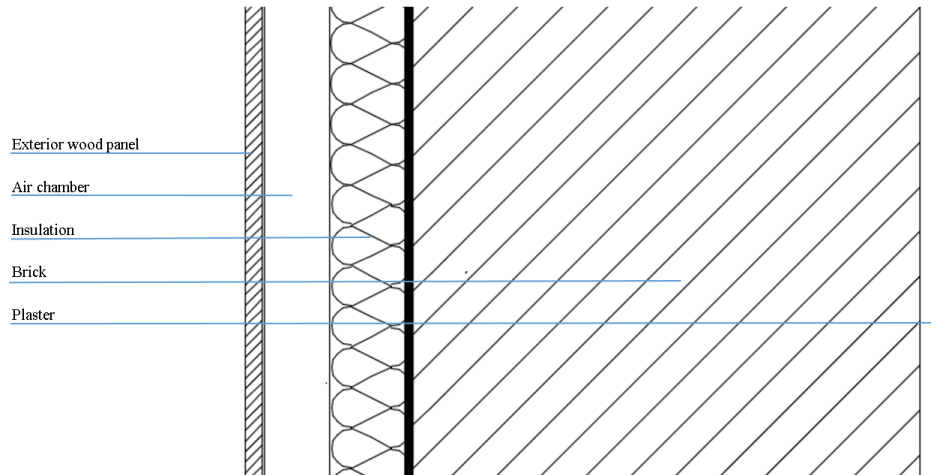


Figure 35 - Exterior wall detail

Figure 36 shows exterior galleries and staircases using steel structures and pavements.

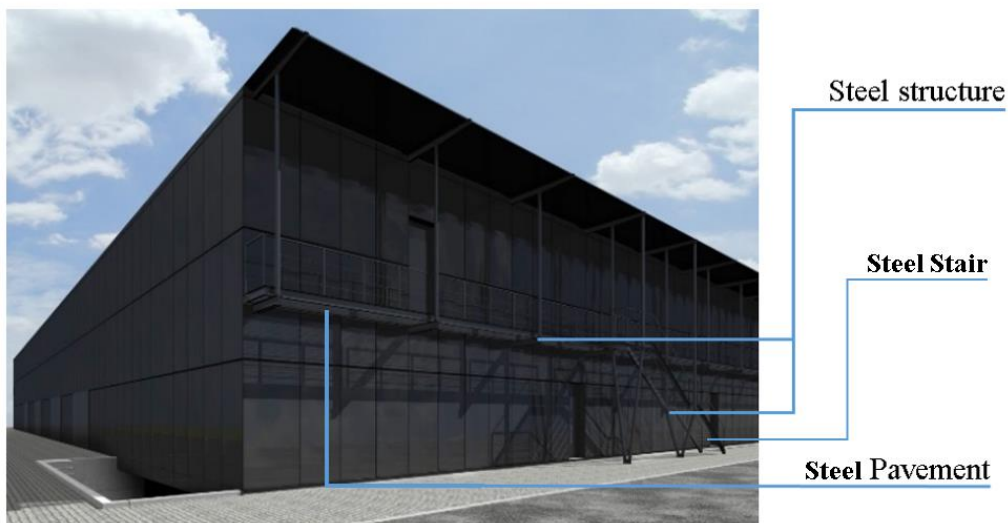


Figure 36 - Exterior finishes

The interior walls were made using plasterboards in social areas and offices, and brick walls in all other areas. The technical areas were plastered with masonry.

The ceilings were made in plaster boards in social and Office areas and modular in the production zones;

In Figure 37 it is possible to see two curtain walls as other steel structure elements.

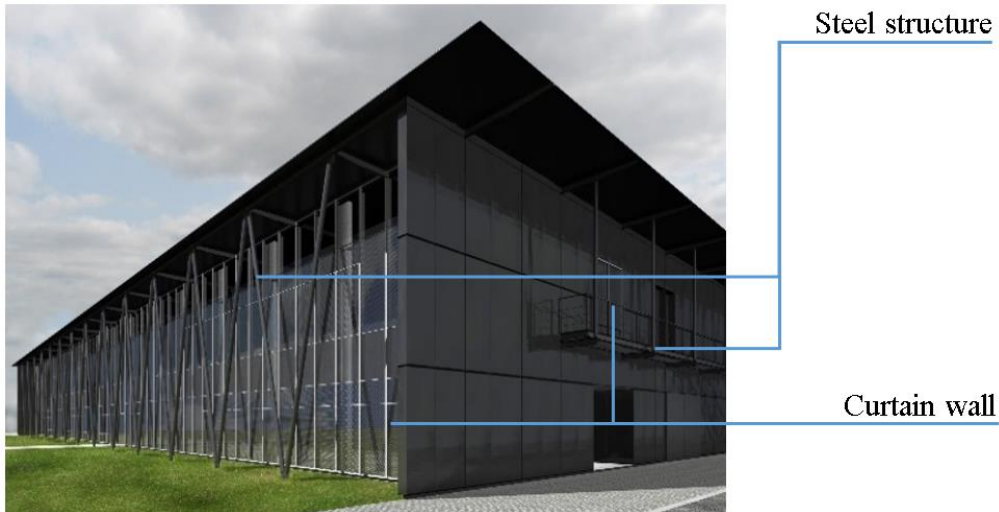


Figure 37 - Curtain walls

CAS AIS, S.A. won the bid for the construction of this building, and started the construction in 2008. However, due to the insolvency of Quimonda in this year, the construction was halted. At such time, the building partially constructed with all the structures, buried networks and some finishes done. Considering this, the land and the current construction were passed on to CAS AIS, S.A. as a method used to pay off some of Quimonta debts. The building is not finished yet and it is also not currently in use.

### 3.2. Information gathering and systematization

To gather all the information necessary to perform the as-built model it was made some data capture through different methods.

Regarding the pre-existing information, CAS AIS, S.A. have all architectural and structural drawings and documents that were made for this entire building.

After having a general view from the building with the existent documentation, it was made two visits to the existent building. The first one to take photos and to have a general view of the building to start the modelling (see Figures 38 and 39).



Figure 38 - Itarion photo - Back Façade



*Figure 39 - Itarion photo - Production Zone*

And the last one was made after three weeks of modelling where it was reached a level where it was necessary to confirm some measures as well as to confirm if some parts were built or not. On this last visit, it was used a traditional tape and a laser distance meter.

In addition to that, during all the dissertation, it was possible to meet some people involved on its construction as well as with people that are intervenient on Itarion reformulation planning. For example, some conversations were made with the quantifications team, the planning department director, the technical department director, and the architect who is working on ITARION reformulation.

It was also possible to collect the existent 3D model from the company which executed the steel structures.

### **3.3. Modelling strategies**

#### **3.3.1. Software choice**

There is a wide variety of BIM enabled software and the success of BIM implementation often lies on the correct choice of BIM software to be used, which must be in accordance with the intended objectives for BIM modelling. After some research it was found that Tekla Structures, Bentley AECOSIM, Autodesk Revit, Archicad were some of the ones that had the necessary BIM capacities, while having deep market penetration worldwide.

Before choosing a specific software it was need to systemize the BIM uses that are wanted to perform with the model.

Regarding the planning it was wanted a software which permit the existing conditions modelling and the creation of construction phases. Regarding the construction, it was

considered important to have 3D coordination with 3D control and planning. Furthermore, it was also wanted to extract quantities from the model.

It was necessary a modelling software that permit the interoperability with quantification and 4D planning specific software. As it was also wanted to perform a final promotional movie of the building, the software had the necessity to have interoperability with specific visualization software, for example Lumion 3D.

After some research it was found that Autodesk Revit was one of the most used ones that permit to perform almost all of the BIM uses referred, unless the 4D planning. However, it exists from the same company, the Autodesk Navisworks, which is used mostly for planning, quantification and clash detection. Using software from the same company was thought to be a good choice since they should interoperable well between them.

As it was already referred, MEP model is not an objective for this dissertation. However, it is known that in Revit it is possible to perform it.

In addition to that, as this dissertation was made in a corporate environment, in CASAIS, S.A., Autodesk Revit was selected as the basic modelling platform because this was the one that the company has licence and would use in case of implementation. So, for this reason, it was better to use this software to improve the company knowledge on it. The same decision was also made for the planning software. It was chosen to use Autodesk Navisworks due to its easy interoperability with Revit and due to the fact that CASAIS, S.A. already has one license of it.

It was also read that these Autodesk software allows for easy and quick learning due to its interactive interface and this would be a crucial aspect to the amount of work that was defined for the present dissertation.

Lastly, it is also important to refer that it will also be used Tekla Structures to interoperate with models between different software for specific reasons that will be explained in detail during this chapter.

### **3.3.2. Adoption of classification systems and LOD definition**

Regarding the adoption of a classification system, it was tried to find which one fits better for the scope of this dissertation and has also a higher level of stratification, avoiding ambiguity in classification of the different objects, specifically for a construction project, that would be the one that fits better on a construction company. Regarding the

revision of the literature it was found interesting to use Omniclass classification system not only because it seemed to correspond to the first requirements, but also that Revit has a specific parameter for each object that has an automatic Omniclass classification.

Omniclass has different tables for different purposes. It was decided to classify the elements with Omniclass Table 23 - Products, where it is possible to see the respective classification in Table 3.

Regarding the classification in Revit, it supplies a specific field for the Omniclass number and the related OmniClass title for each family category. However, it has not reached full elements classification because system families as floors and walls do not yet offer an option for assessing those OmniClass values, neither rooms nor spaces.

Because of that, and after discussing with Portugal Autodesk representative, it was recommended and chosen to classify the model with a shared parameter that exist on every objects and system families called 'Keynote'.

Considering this situation, some improvements in Revit are to be expected on this field of information in regard to optimize its classification. For example in an ideal perspective, the automatic classification of entire model regarding a specific classification system, or even with the option to choose which system would be preferred.

Regarding the LOD definition, in one of the first meetings held for this dissertation it was necessary to define a minimum Level of Development intended for the as-built model. Regarding all levels presented in Chapter 2, it was found that LOD 300 is usually used because it has the necessary detail to perform the potentialities needed or expected for this model. A higher LOD would result on extremely effort increasing which is not necessary for the specified BIM uses. These higher LOD are more often required for FM BIM uses when is needed for example the description of the item, manufacturer, model number, supplier and date purchased.

LOD 300 will have the necessary detail to perform 3D visualization and coordination, quantifications and planning.

Table 4 shows the LOD of the different objects present in the model, and as it is possible to observe, some objects have a higher LOD than 300. It happens because it was not modelled every objects. Some objects were obtained from online libraries and imported from other software.

Classification ITARION_Omniclass_Table23					
OmniClass Number	Level 1 Title	Level 2 Title	Level 3 Title	Level 4 Title	Level 5 Title
<b>Structural and Exterior Enclosure Products</b>					
<b>Foundations</b>					
23-13 29 11		<b>Foundation Piles</b>		Foundation Pile Components	
23-13 29 11 11 21				Driven Piles	Pile Caps
23-13 29 11 13 13					Concrete Filled Steel Driven Piles
<b>Envelope Enclosure Products</b>					
<b>Glazed Facade and Roof Structures</b>					
23-13 33 27 11				Curtain Walls	
<b>Framing Products</b>					
<b>Structural Frames</b>					
				Column Slab Frames	
23-13 35 11 13 11					Columns
23-13 35 11 13 13					Beams
<b>Structural Walls</b>					
23-13 35 21 11				Concrete Structural Walls	
23-13 35 21 13				Masonry Structural Walls	
<b>Structural Floors and Flat Roofs</b>					
				Structural Floor Decks	
23-13 35 23 11 11					Concrete Structural Floor Decks
23-13 35 23 11 13					Metal Structural Floor Decks
				Structural Roof Decks	
23-13 35 23 13 13					Metal Structural Roof Decks
23-13 35 23 15				Structural Grating Floors	
<b>Interior and Finish Products</b>					
<b>Multi-Function Interior Coverings, Claddings, Linings</b>					
23-15 13 23				<b>Interior Plasters</b>	
<b>Openings, Passages, and Protection Products</b>					
<b>Doors</b>					
				<b>Metal Doors</b>	
23-17 11 13 11				Hollow Metal Doors	
				<b>All Glass Doors</b>	
23-17 11 23 11				Swinging All Glass Doors	
23-17 23 17				<b>Stairs</b>	
				Stair Component Products	
23-17 23 17 11 17					Stair Railings
<b>Interior Window Treatment</b>					
23-17 21 13 15				Window Interior Shutters	

Table 3 - Omniclass Classification









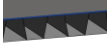

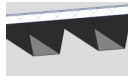






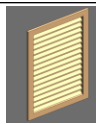
Classification LOD ITARION							
Omniclass Number	Level 1 Title	Level 2 Title	Level 3 Title	Level 4 Title	LOD	Image	
23-13 29 11 11 21	Substructure	Foundations	<b>Standard Foundations</b>				
			Column Foundations & Pile Caps	300			
23-13 29 11 13 13			<b>Special Foundations</b>				
			Pile Foundations		300		
23-13 35 11 13 13	Shell	Superstructure	<b>Floor Construction</b>				
			Floor Structural Frame (Concrete)	300			
23-13 35 19			Floor Structural Frame (Steel Framing Columns)	400			
23-13 35 19			Floor Structural Frame (Steel Framing Beams)	400			
23-13 35 19			Floor Structural Frame (Steel Framing Bracing Rods)	400			
23-13 35 23 11 13			Floor Decks, Slabs, and Toppings (Metal Floor Deck)	300			
23-13 35 23 11 11			Floor Decks, Slabs, and Toppings (Concrete)	300			
23-13 35 23 11 13			<b>Roof Construction</b>				
			Roof Decks, Slabs, and Sheathing (Metal)	300			
23-17 23 17					<b>Stairs</b>		
	Stair Construction	300					
23-17 23 17 11 17	Stair Railings	300					
23-13 35 21 13	Exterior Vertical Enclosures	<b>Exterior Walls</b>					
		Exterior Wall Construction	350				
23-17 11 23 11		<b>Exterior Doors and Grilles</b>					
	Exterior Entrance Doors	350					
23-17 11 13 11	Exterior Entrance Doors	350					
23-15 13 23	Interiors	Interior Construction	<b>Interior Partitions</b>				
			Interior Fixed Partitions	350			
23-17 21 13 15			<b>Interior Windows</b>				
	Interior Fixed Windows	350					

Table 4 - LOD Classification

### 3.3.3. Utilization of objects/families

The majority of the objects and families used were from the original Revit library, unless the steel structure that was imported from another model and software, as it will be explained on the follow subchapters. In addition to that, a list of the objects that were modelled or adapted in place or even obtained from online libraries is shown in Table 5.





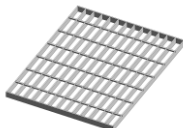
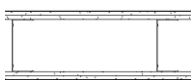
Name	Figure	Source
Triangular' Foundation pile		Adapted from Revit Library
Lightweight Slab		Modeled in place in Revit
Cover Roof Deck		
Steel Railling		
Metal Door		RevitCity
Interior window		
Welded Grating		
Plasterboard wall		bimobject®

Table 5 - Source of some objects used on BIM model

During the modelling and utilization of certain objects it was found some difficulties not only on its modelling but also on its use on BIM potentialities as the quantification works.

On the final as-built model it will not appear the lightweight slabs on the project due to different reasons. Modelling this object is a really complex task which involves many effort because this object needs to be modelled in the correct way so that extracting information from it. Figures 40 and 41 show its measures and forms of the interior space of the lightweight slab present on the project and on the local, and an attempt was made to model it on Revit, and it was created starting with a cubic solid where it was removed an interior part as shown in Figure 42. As result it was reached a good model in terms of visualization comparing with the real slab.



Figure 40 - Ferca recoverable plastic model

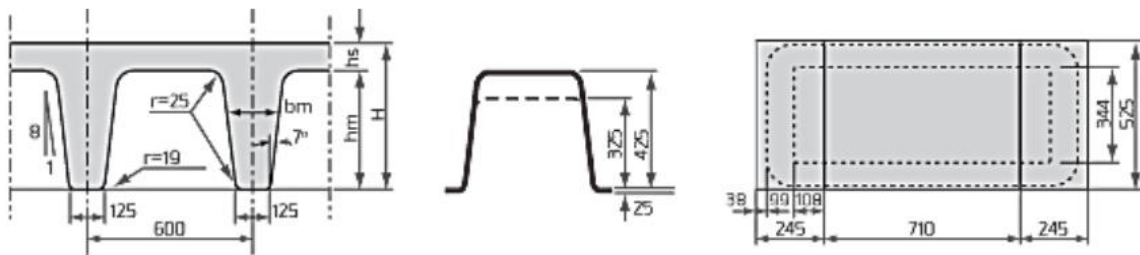


Figure 41 - Ferca Recoverable Plastic Model

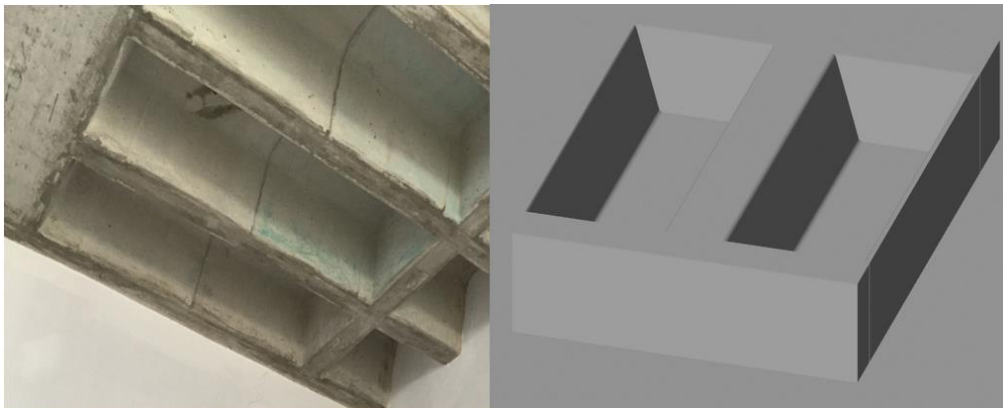
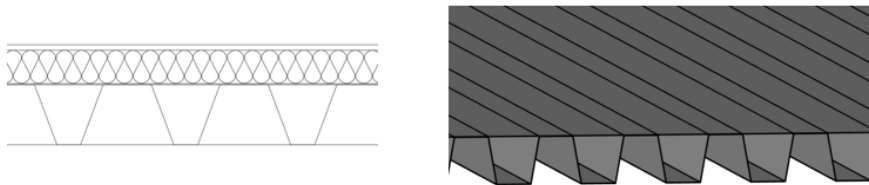


Figure 42 - Lightweight Slab of Itarion building

However, it was known that it has a limited use because it would be difficult to have the information necessary from this, as the quantification of concrete volume. As the modelling of specific elements was not the principal scopes of the present dissertation, it was decided to not lose many time to further study this specific part. As solution for the as-built model it was used a normal slab with an equivalent height that is used by the technical teams of measuring which will provide an equivalent quantification.

Just for information, during the research it was found that parametric objects with non-linear forms, should be modelled on specific software to this end. An example of that is Autodesk Dynamo software which is specialized in parametric objects which are exportable to Revit (Autodesk, 2014). Parametric objects have great potential because they are built in a way that it is possible to automatically change its dimensions and characteristics according to the alteration of introduced values on the model conception.

Other limited situation was the ribbed plate cover, which was modelled in place in Revit software (see Figure 43), but due to the fact that the object was not parameterized and due to its trapezoidal profile, it was known that it would bring difficulties on the quantification works. When it was tried to quantify its superficial area, it did not happen because the trapezoidal form was creating difficulties on reading the object. Here, as on the lightweight slabs, was chosen to continue with the modelling as it was not the main objective of the present dissertation. Considering this, this time not as the previous case, it was chosen to let the cover with that configuration for visualization and do not perform evaluation of quantification for this part.



*Figure 43 - CAD drawing and BIM model*

### **3.4. Infrastructure modelling**

Firstly, regarding the site model, there was access to the CAD drawing with every elevations. However, it was the elevations that existed before the construction started. After the first visit of the local, it was saw that the land surrounding is completely plan, 20 cm lower than the level 1 concrete finish layer. Considering this, it was simplified and for the as-built model it was not modelled any site model.

Regarding the localization of the model, due to the BIM uses defined for the as-built model, it was not necessary geo-referring the model. However, to facilitate the future models importation and exportation it was defined a specific survey point and project base point in Revit as shown in Figure 44. Normally it is chosen a strategic point which is easily identified in structural and architectural plans.

On this specific case it was made the simplification to consider the same point as survey point and project base point as the (0, 0, 0) coordinates point.

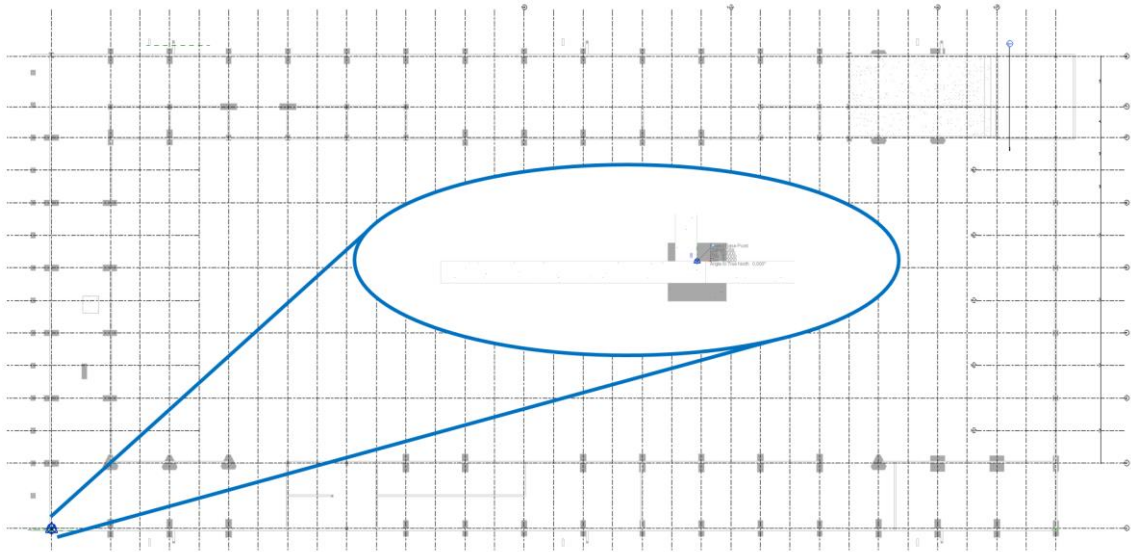


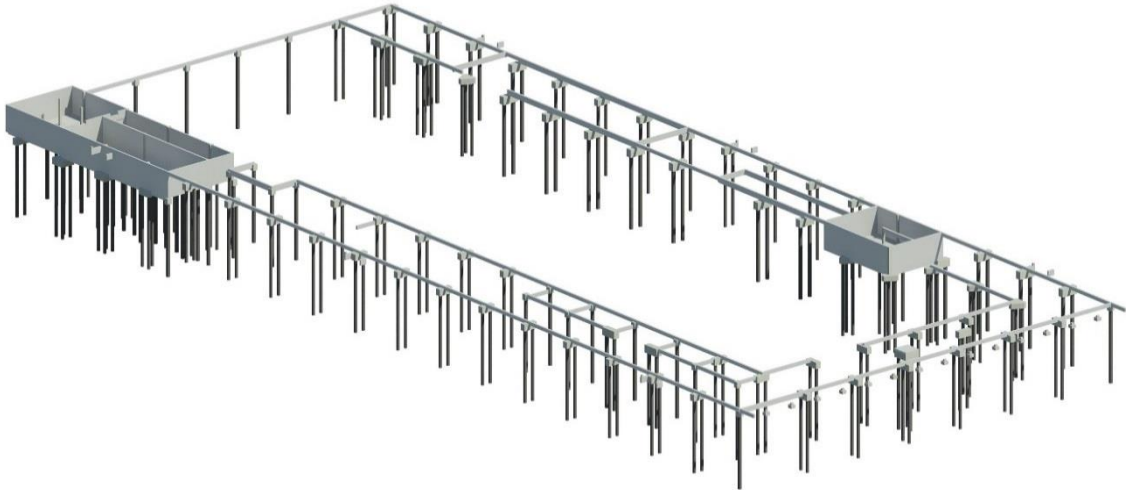
Figure 44 - Survey point and Project base point

After the research and execution of some necessary objects as explained before, modelling the infrastructure was the next step.

All structural elements below the ground level were modelled including all the foundation piles, beams, columns and the elements necessary to do the -1 level as the slabs and structural walls. As strategy method used for every as-built modelling, was the importation of the structural and architectural CAD drawings to Revit, which facilitate the localization of every objects.

Regarding the foundation piles present on the project, as shown in Figure 28 and Table 2, it was used a parametrized foundation pile existent in Revit library that made it easier to put on the model. It was only necessary to adapt the triangular one which Revit did not contain the exact configuration.

In the Figure 45 it is possible to see a representation of the infrastructure modelled in Revit.



*Figure 45 - Infrastructure Representation*

### **3.5. Superstructure modelling**

On the superstructure there is a slight difference from the infrastructure. It is a mixed structure with components in concrete and others in steel. Considering this, it was decided to subdivide the superstructure into two models. One is the structural concrete model and the other one is the steel structure model.

#### **3.5.1. Concrete structure**

With the elements used to do the infrastructure, it was already possible to also model the structural concrete part of the superstructure. It contains all the concrete columns, slabs and stairs as it was designed and built. From Revit libraries were used customized columns and beams which are parametric, permitting to create every necessary measures. Regarding the slabs it was made a simplification that already was mentioned before about the waffle slabs. It was substituted from normal structural floor system families in Revit.

There, everything that is above the ground to perform the level 1 and 2 was modelled and created. Regarding the stairs, it was modelled as it was designed and built as it can be seen in Figures 46, 47 and 48. It was modelled with the specific Revit stairs command and it was designed by component where it is possible to put every measures of the stairs. It is not an easy modelling process, but once it is get some experience, it was reached some acceptable results.

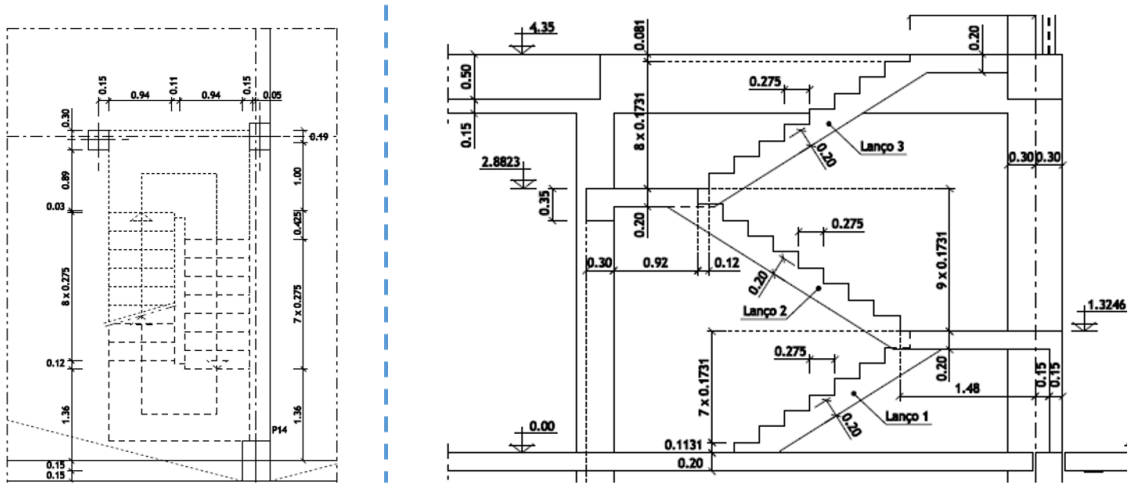


Figure 46 - Stair plan

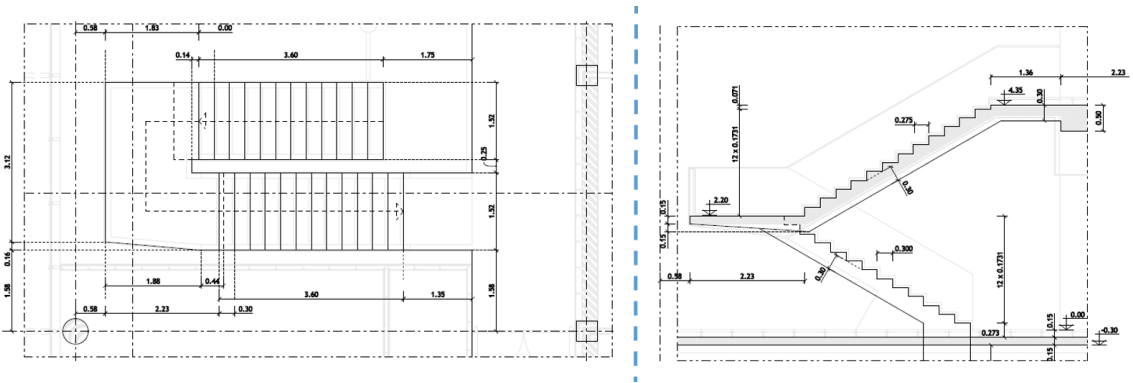


Figure 47 - Master stair plan

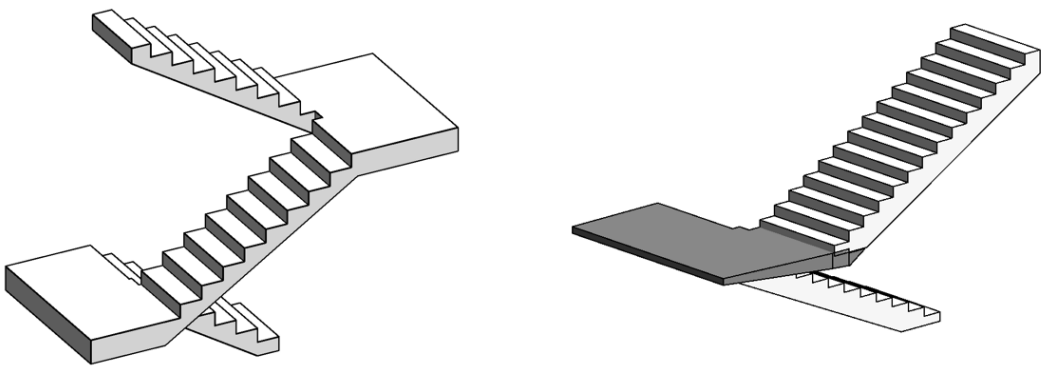
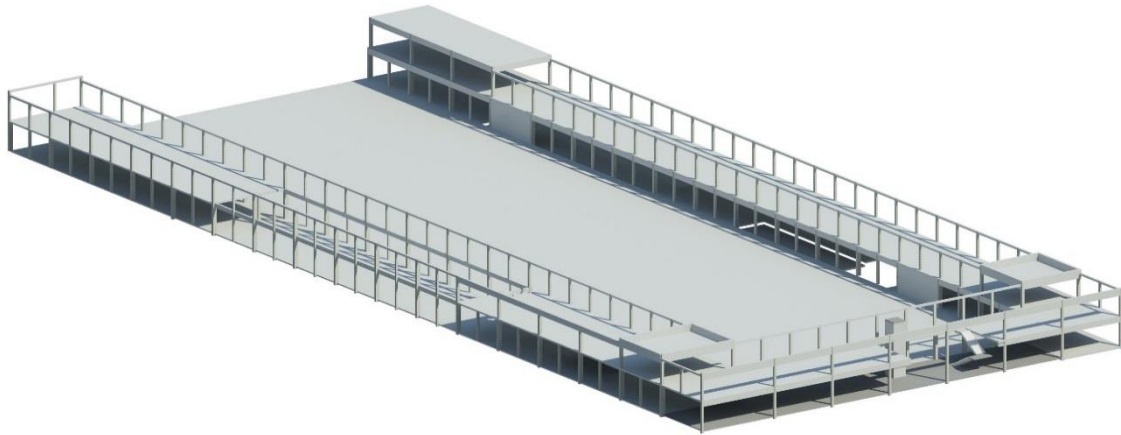


Figure 48 - Stairs models

In Figure 49 it is possible to see a representation of the concrete superstructure modelled in Revit.



*Figure 49 - Superstructure Representation - Concrete part*

### **3.5.2. Steel structure**

In this sub model of the superstructure, there was a difference from all other models. This steel structure was applied by a Portuguese company sub-contracted by CASAIS, S.A., whose name is Martifer Group, because they are experts in steel structures. It was known that they have worked for a long time with the software Tekla Structures and they make the model on this software to improve the coordination and production of the same project. The base model created to the execution of the steel structure was kindly provided by Martifer Group. Tekla models are a folder which contains every information of the model divided by some specific subfolders. The model was sent on its habitual folder and as it was modelled in 2008, it is estimated that was used Tekla Structures version 14. Nowadays, it was already released the version 21.

The interoperability between Tekla Structures and Autodesk Revit has two possibilities to interact between them. It could be by '.ifc' exporting and importing system or it is possible to use a direct API that makes the software interoperable. As it was wanted the collaboration between the model present in Tekla and the ones created in Revit, it is recommended by Tekla to use the first method which is the most common one (Tekla Structures, 2015).

In Figure 50 it is possible to see Martifer model opened on Tekla Structures and it is also possible to see some concrete parts that certainly served as a guide to model the steel structure.



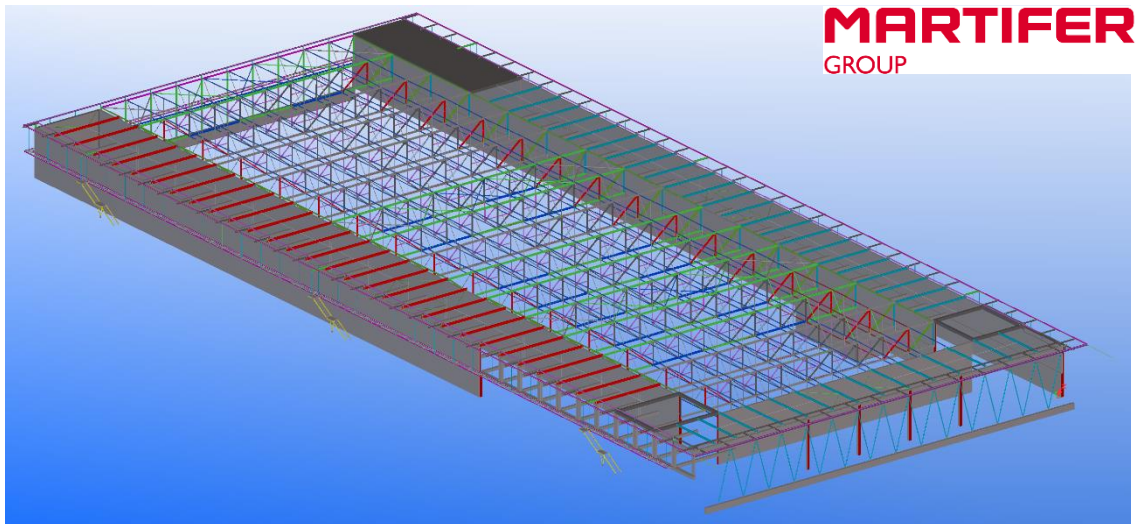
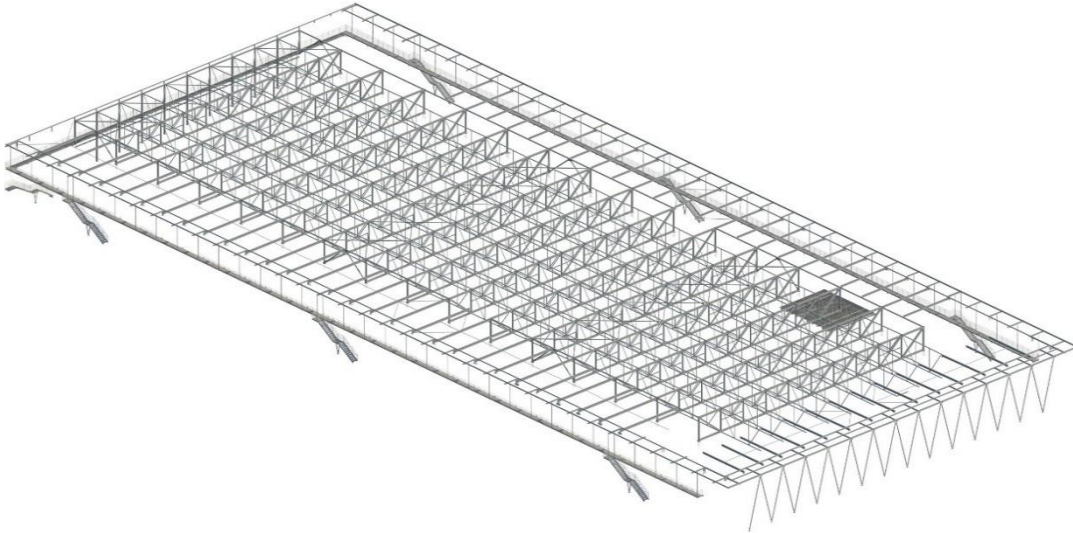


Figure 50 - Superstructure image from Tekla environment - Steel structure model

These concrete parts were removed, as they had already been modelled and the IFC method of exchanging information was used to interoperate between the two platforms. Having this model in an IFC file, it was possible to save it on Revit as a Revit model. However, as the Tekla Structures model was made in 2008, there were some difficulties to realize this process. However, after this experience, if the process is done with caution since the beginning it will work perfectly. There is a necessity to select well every objects that are wanted to export, to choose the IFC version that is wanted to use, the specific information that is wanted to transfer and which use is pretended for the model to be exported (visualization or geometry modifications for example).

Regarding the positioning of the model it happened some problems. During the research it was found that Revit only permit to link IFC files since 2015 version, which was the one used. Despite this big update regarding the last versions, it is not yet possible to snap precisely the parts or objects from a IFC link, turning it impossible to adjust perfectly the IFC link with Revit model. However, it was concluded that if the steel structure in Tekla software would have the same survey point and project base point it, when exporting to IFC and linking it to Revit, it would position the models in the same reference. Unfortunately, it did not worked on this case and the solution found was to try to position it manually as accurately as it would possible to see. It was made a verification and the difference is less than one millimetre, so it was considered to be good positioned.

In Figure 51 it is possible to see that after some effort and some alternative solutions it was possible to have a relatively good model in Revit.



*Figure 51 - Superstructure representation from Revit environment - Steel structure part*

Despite the good visualization quality and precision of every elements that the model has on Revit environment after the importing works, it was found that the interoperability between all the software used was not the best. It failed because, although it was transferred all the information fields existent on Tekla model, IFC organized it on a way that Revit would not be able to read. Example of that, was the field of information which quantify the weight of which element, turning impossible the quantification on the software that was initially used for it, the Navisworks. It is thought that another reason to this, is that the model has several years and is from an old Tekla Structures version. However, it was found that it would be possible to quantify it on Revit, because there is the possibility to choose what specific existent field of information is wanted to include on the quantification works, despite it does not assume that this field is the elements weight.

However, there are other limitation that is the organization of the model. On Revit, during the modelling, all the objects were modelled by levels and subcategories giving organization to the model. When the steel structure model was imported to Revit it was everything mixed which is not organized for example by plates, bolts, beams and columns. Furthermore, it was not linking the objects to the Revit levels and subcategories, turning impossible to choose in an automatic way (for example bolts), which create several difficulties to quantify the steel structure as it contains more than 3000 different parts. It would only possible to quantify it clicking on each objects piece by piece which are wanted to quantify.



finished (see Figures 54 and 55), just to identify how many walls will be needed to remove, because all of them are deteriorated. Considering this, it would be possible to help on the deconstruction intervention with the quantity of material to be disassembled, for example.

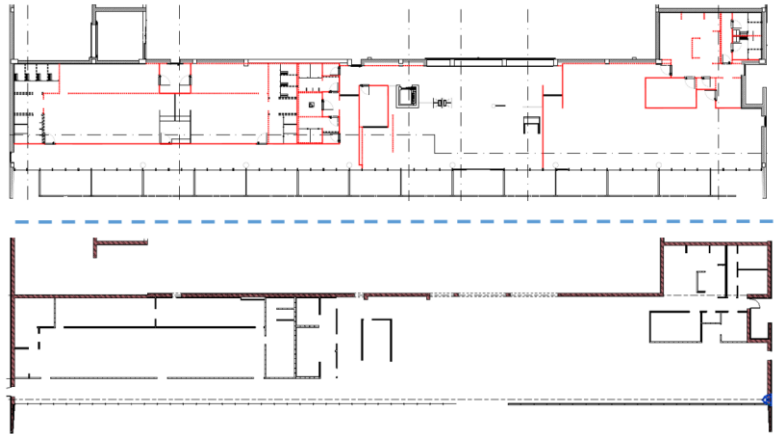


Figure 54 - Level 1 Plasterboard wall modelled compared with initial project

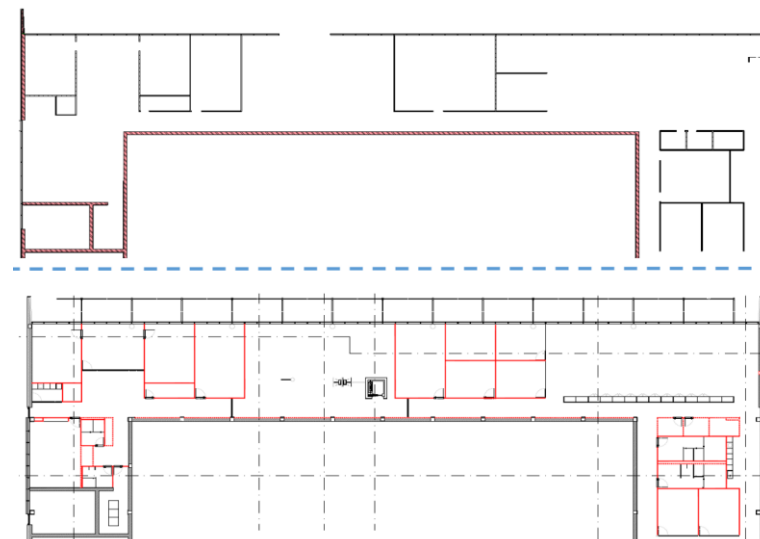


Figure 55 - Level 2 Plasterboards modelled compared with initial project

As shown in Figure 56, it was used the Knauf plasterboard walls, which were the ones applied, that were obtained from BIMObject online library.

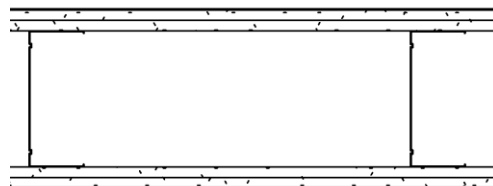
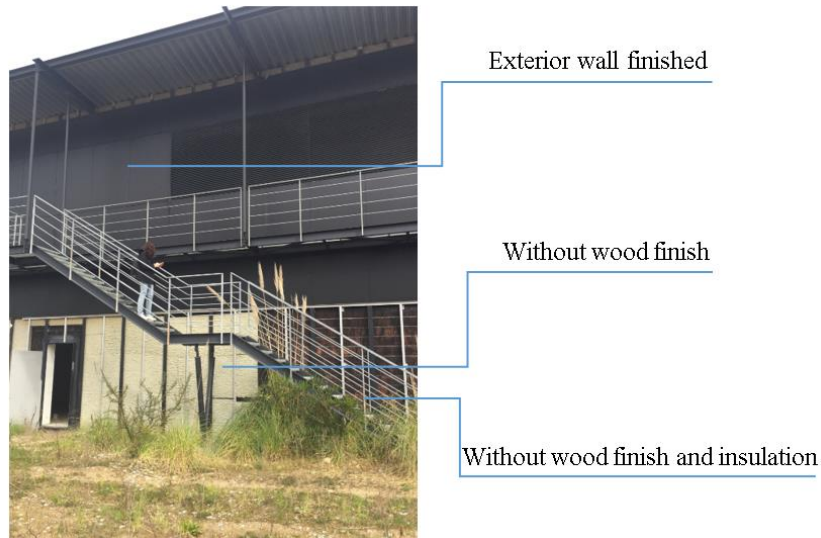


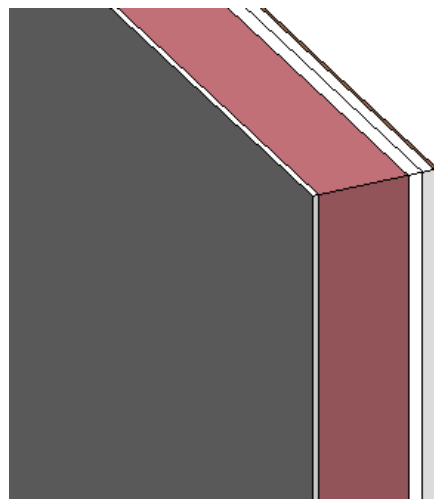
Figure 56 - Knauf plasterboard wall (BIMObject, 2015)

Another problem compared with the plasterboard, which can be seen in Figure 57, walls were the exterior façades. Some of them only had the brick, others the brick and the insulation, and others everything including the final material in wood.



*Figure 57 - Existent parts of the exterior façade*

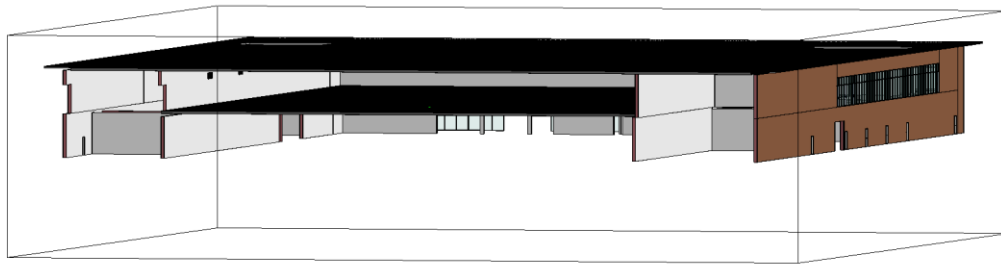
To do an accurate as-built model of these walls on its current situation, would result in an extreme effort of modelling with many visits to the local to count every single element that is placed or not. Considering this, and as the plasterboard walls situation is concerned, it was decided to model every existent exterior wall with insulation and with the wood finish, with Revit wall system families as can be seen in Figure 58 and compared with the initially designed in Figure 36. Another reason was the LOD 300 initially defined that do not require more detail.



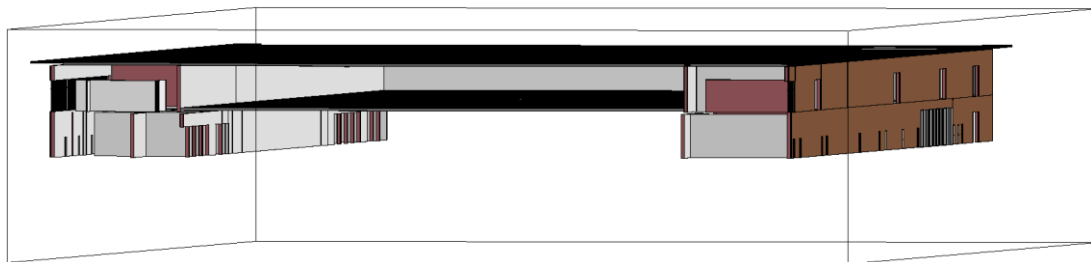
*Figure 58 - Exterior with every layers initially designed*

In Figures 59 and 60, from the SE and NW side respectively, it is possible to see the central production zone surrounded from both sides for the two story bodies which were to accommodate facility areas and storage logistics.

It is also possible to see, on both these figures, the ceiling that divides the production zone from the steel structure that sustain every production zone.



*Figure 59 - Architecture view on the SE direction*



*Figure 60 - Architecture view on the NW direction*

As it can be seen in Figure 61, a final architectural model representation was reached. Here it is possible to see the curtain wall from the SE and SW side.

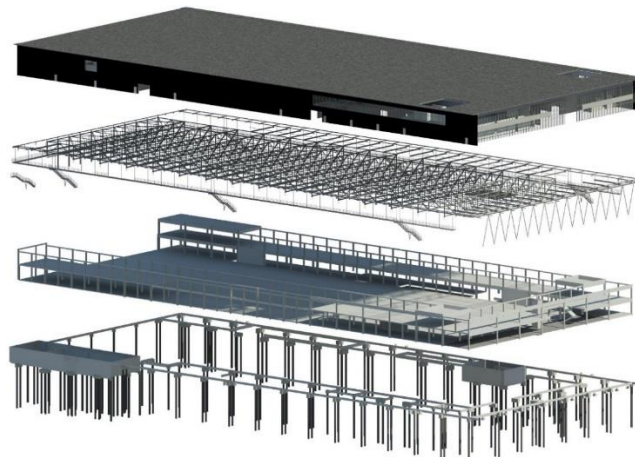


*Figure 61 - Architectural Representation*

### 3.7. The use of BIM models

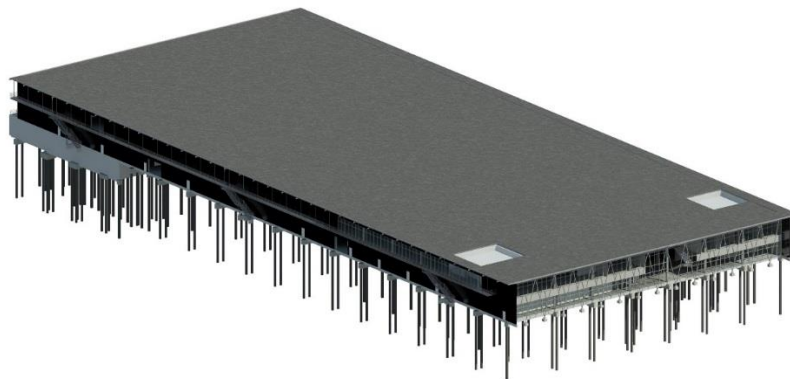
#### 3.7.1. Final as-built model

Regarding the clash control of the as-built model it was not performed for some reasons. Firstly, as the MEP model was not modelled and it is known that the main clashes appear between the MEP model and the other specialities. On the other hand, the as-built was not modelled exactly by separated models from different specialities. As it was only one person doing the modelling, it was decided to use only one model and everything was checked during the modelling and confirmed with the existing building situation, so it was decided to not perform a clash detection here as a continuous quality control was made during the modelling. However, after the as built model performed, it was divided the different specialities in different models to better understand each speciality, as it can be seen in Figure 62.



*Figure 62 - Mounting every models*

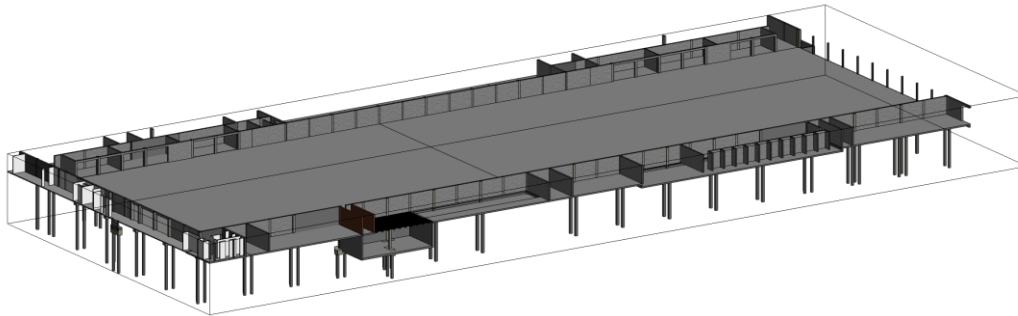
With the combination of the four models created, it was possible to perform a full representation of the as-built model, as it can be verified in Figure 63.



*Figure 63 - As-built model representation*

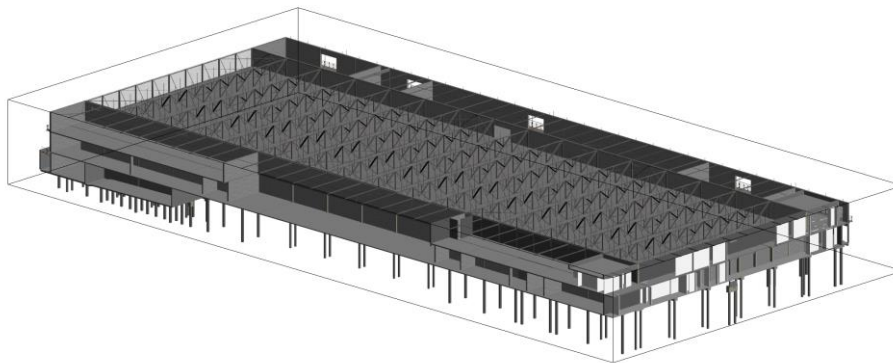
In Figures 64 and 65 it is possible to see some cuts on the model to better understand how the building is inside. It is easily understandable the different spaces at different levels with the help of this 3D model.

In Figure 64 it is possible to see the first floor of the entire building with the central production zone, surrounded for both larger sides by the facility areas and storage logistics, and on the SE zone from the top, it is possible to see the offices area.



*Figure 64 - Some details from the level 1*

In Figure 65 it is possible to see the second floor of the entire building with the upper zone of the central production zone with the respective ceiling of separation and all the steel structure that supports all this zone and permits that the production zone does not have any column.



*Figure 65 - Details from the level 2*

In Figure 66 it is possible to see a cover detailing which is comparable with Figure 33.



*Figure 66 - BIM Model cover detail*



In the follow figures, it will be made a comparison between the CAD drawings and BIM model views.

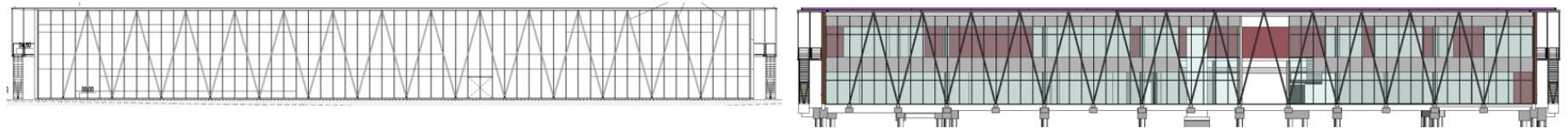


Figure 67 - Structural and architectural SE façade (CAD: left, BIM: right)

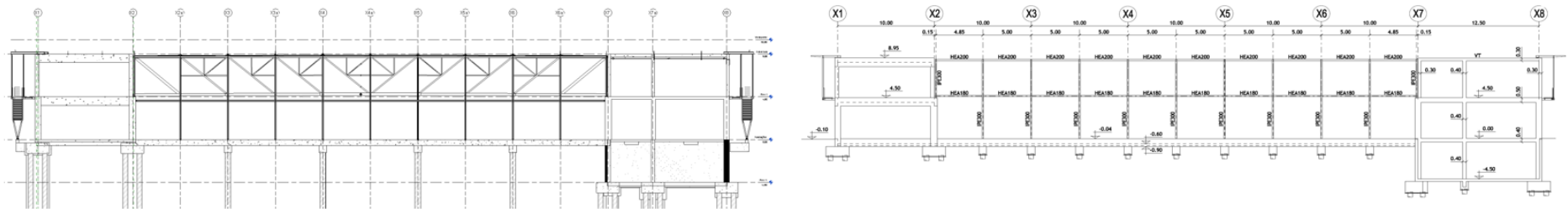


Figure 68 - Structural NW Façade (CAD: right, BIM: left)



Figure 69 - Structural and architectural SW façade (CAD: up, BIM: down)

### **3.7.2. Comparative analysis with traditional approach**

Another important aspect in the construction sector is material quantification. Quantifying a project represents one of the most important and detailed tasks on the construction activity. This task is essential whether for estimating construction costs or to its planning. During this dissertation it was clearly visible that this is one of the most important aspects when budgeting a project for tender. The quantification is one of the crucial parts of this process, because a single error could result in a loss of thousands or even millions of euros. More than half of the time of the execution of this dissertation was spent in the CASAIS S.A. Technical Department where this type of work is done. There are six people every day measuring projects to do quantification sheets. With the extremely difficult deadlines and constant new projects coming to measure, this work is becoming an impossible mission to accomplish on time with the necessary accuracy. Only people with years of experience could do this type of work to get some acceptable results. And even these experts may make mistakes due to the nature of this task, which together with all the pressure and tiredness make budget errors almost inevitable.

This fact is one of the main intentions of this dissertation. If modelling a project and getting its quantifications could carry less effort and be more accurate, rather than doing it manually with the traditional CAD drawings, it would be a great advantage to the company and a serious motive to implement this new methodology.

After some research on their archives it was possible to have access to all their quantifications works done for this project. CASAIS, S.A. follow the national measuring guides (Fonseca, 2010) and normally these quantifications are separated by phases or specialities works.

It starts with the foundation piles which is divided by the drilling, the concrete and the rebar measures. After that first phase, there is the stability phase with earth works, blind concrete, structural concrete formwork, steel structure, and finally the rebar quantification. Lastly, there is the finishes quantification. These tables are normally organized on Microsoft Excel as it can be seen in Table 6.

CAS AIS		Mobile: +351 253 305 400 - Fax: +351 253 305 499 - casais@casaisinvest.pt - www.casais-sa.pt						
Identity: ITARION SOLAR, LDA		Date: 18-02-2009						
Building: Fábrica ITS1 em Vila do Conde		Page:						
Article	Designation	unit	equal parts	Measures				
				Dimensions			Quantity	
				Lenght	Width	Height	Parcial	
6	Concrete in infrastructures							
6.1	C30/37, XA1 in file caps of foundation piles ITS1	m3		318.35				288.24
	ME500-1	9		0.80	0.80	0.90		5.18
	ME600-1	23		0.90	0.90	0.90		16.77
	ME500-2	45		2.40	0.90	1.10		106.92
	ME600-2	21		2.80	1.00	1.30		76.44
	ME500-3	10		4.09	1.00	1.25		51.13
	ME500-4	4		2.40	2.40	1.30		29.95
	MNu1	1		2.20	2.10	0.40		1.85
6.2	C30/37, XA1 in foundations ITS1	m3		5.40				5.92
	S1	14		0.80	0.80	0.60		5.38
	S2	6		1.00	0.30	0.30		0.54
6.3	C25/30, XC2 in foundation beams ITS1	m3		100.00				149.85
	LF1	45		9.60	0.30	0.60		77.76
	LF1	2		4.67	0.30	0.60		1.68
	LF1	1		9.30	0.30	0.60		1.67
	LF1	2		9.50	0.30	0.60		3.42
	LF1	1		60.00	0.30	0.60		10.80
	LF1	2		4.55	0.30	0.60		1.64
	LF1	1		49.40	0.35	0.60		10.37
	LF1*	1		12.50	0.30	0.80		3.00
	LF2	9		9.60	0.30	0.93		24.11
	LF3	2		3.30	0.30	0.60		1.19
	VF1	2		3.10	0.30	0.60		1.12
	VF1	3		9.20	0.30	0.60		4.97
	VF1	2		8.20	0.30	0.60		2.95
	VF1	2		3.85	0.30	0.60		1.39
	VF1	4		3.95	0.30	0.60		2.84
	VF2	6		1.05	0.30	0.50		0.95

Table 6 - Part of CAS AIS, S.A. stability quantities sheet

As it was also pretended to perform a study of construction planning with the as-built model, it was decided to perform the quantification work in Autodesk Navisworks software. Figure 70 shows that having a building information model and with the help of it, it was possible to import the model there and to do a quantification system by organizing the model in sets. Quantifications, would also be possible to perform in Revit software, however, it was decided to perform the quantifications on this chapter in Navisworks and on chapter 4, it will be done in Revit to see the potentials from both software.

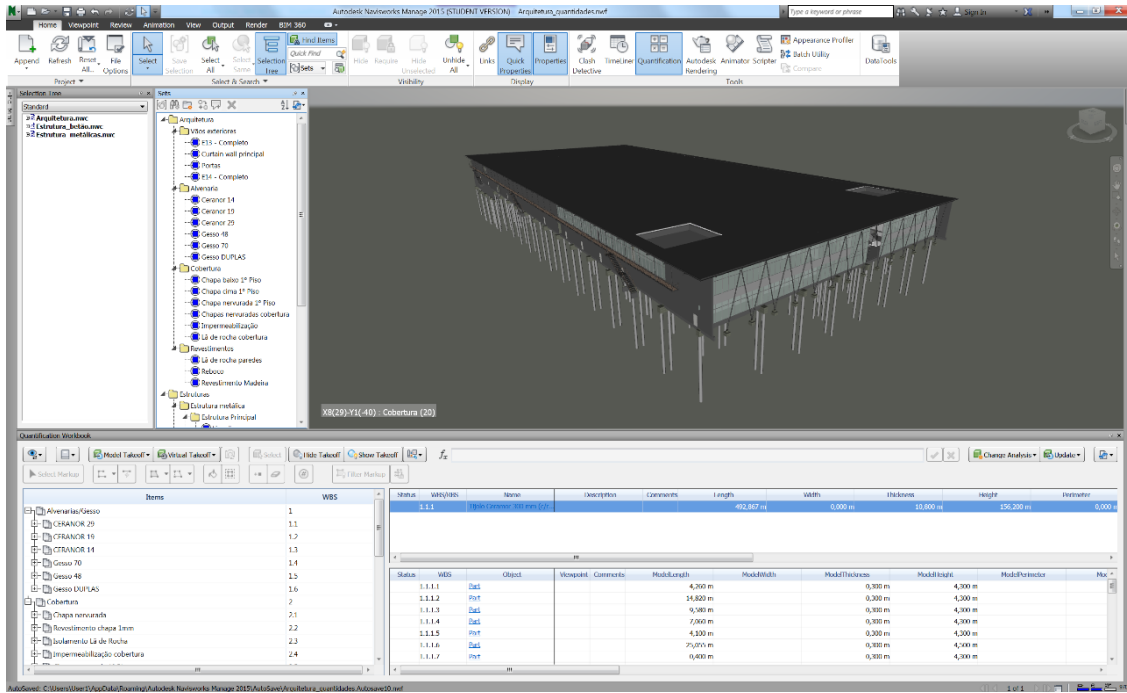


Figure 70 - As-built model and quantification workout in Navisworks software

As a result, after exporting this to an Excel sheet, it is possible to have several different and customized quantification sheets. In Table 7 is possible to see a resumed example with linearity and organization. To see a full example it would be possible to see it in APPENDIX 1.

Names	ModelLength (m)	ModelWidth (m)	ModelThickness (m)	ModelHeight (m)	ModelPerimeter (m)	ModelArea (m <sup>2</sup> )	ModelVolume (m <sup>3</sup> )
<b>Concrete Infrastructures</b>							
Pile caps of fo	133.1	243.7	124.6			648.6	280.1
ME500-1	5.6	5.6	7.0			15.7	4.5
ME500-2	40.5	108.0	49.5			260.6	106.9
ME500-3	23.0	26.5	9.0			76.6	36.7
ME500-4	23.0	26.5	9.0			76.6	36.7
ME600-1	18.4	18.4	23.0			51.5	14.7
ME600-2	20.0	56.0	26.0			154.8	72.8
MNu1	2.6	2.7	1.1			12.9	7.7
Foundation be	903.2	1.9		18.5		881.9	170.5
LF (0.30x0.6)	629.7					485.1	81.3
LF (0.30x0.7)	7.5					7.4	1.5
LF (0.30x0.8)	12.5					13.6	2.9
LF (0.30x0.9)	109.1					136.9	21.5
LF (0.40x0.9)	11.9					17.9	4.3
LF1 (0.35x0)	50.3					46.4	8.2
Betao - 250	51.5	1.0		3.4		30.8	7.6
Betao - 300	30.6	0.9		15.1		143.8	43.1
Burried walls	190.3	3.5	2.0	61.8	254.6	1507.7	438.4
Foundations	17.6	11.2	7.0			20.7	6.3
S1	11.2	11.2	7.0			20.2	4.5
S2	6.4					9.5	1.8
<b>Concrete in su</b>	<b>2709.3</b>	<b>3.7</b>	<b>0.3</b>	<b>56.3</b>	<b>4.4</b>	<b>2572.5</b>	<b>518.7</b>

Table 7 - Example of a table resulted from Navisworks

As far as it is concerned, it is easy to conclude that there are several potentialities to the construction sector. However, there have been several difficulties to reach accurate

results with every modelled object. During the dissertation, it was explained that happened some problems with the modelling of specific objects, and it consequently was decided to not proceed with the quantification of these elements.

In addition to the previous points, it was impossible to compare other quantities because the building is unfinished, and the as-built model only has what was constructed. Considering this, it is impossible to compare the plasterboard walls, some insulation and interior works as well as some finishes.

With the intention of doing a comparative analysis with the traditional methods to see the accuracy of the model, it was decided to compare only the elements that allow to do this and where it was thought the modelling was reliable. Normally the quantifications are organized by construction phases as it could be seen in Figure 71.

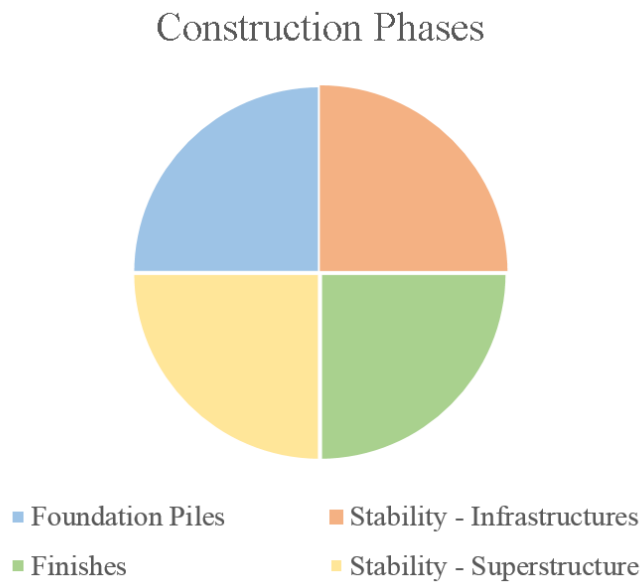


Figure 71 - Different phases of construction

In Table 8 it is possible to see the elements that were quantified with the respective separation by phases.

Descriptive	CASAIS, S.A. Quantification	Model Quantification	Units	Difference
Piles	568.84	564.55	m <sup>3</sup>	0.75%
Level -1 walls and slabs	440.5	438.44	m <sup>3</sup>	0.47%
Pile caps	288.24	280.11	m <sup>3</sup>	2.82%
Foundations	5.92	6.25	m <sup>3</sup>	5.28%
Columns	191.56	194.82	m <sup>3</sup>	1.67%
Beams	277.89	268.44	m <sup>3</sup>	3.40%
Masonry works	7433.07	7719.82	m <sup>2</sup>	3.71%
Imm cover sheet flooring	8039.53	7987.76	m <sup>2</sup>	0.64%

Table 8 - Comparative analysis between CASAIS, S.A. vs. Model Quantification

As it could be observed there are some satisfactory values when these quantities are compared, which means that both quantifications should be well done.

It is possible to see that the difference does not over pass much the 5%. It happened only in one case, in foundations, but considering the extremely lower quantity of concrete of this part, it is understandable that a difference of 0.33 m<sup>3</sup> will result on a difference higher than 5%.

The conclusion to be drawn from this work is that if there is an absolute certainty that the model is well executed without any errors, it surely will give more accurate values than a manual measure.

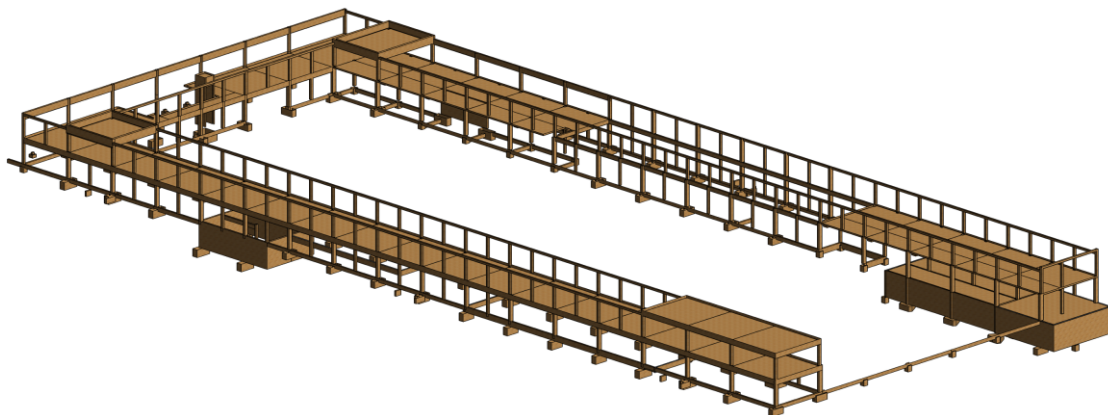
Other important thing is that in case of alteration of the project, in BIM methodology, as an integrated platform, will automatically recalculate the quantifications, contrarily with the traditional measure that if the project suffer any alteration, it is necessary to perform the quantification again.

### **3.7.3. Temporary elements - formwork**

During the execution of the thesis, and finished the as-built model, it was found interesting to try to see some other BIM potentialities even if it was not initially planned and also if it does not fit exactly for existing buildings.

It was thought that it could be a good work to try to model the formwork used to build the existent building and quantify it to see what would be the potentialities of performing this work on BIM software instead of a usually manual method used in CASAIS, S.A. and in the most of the AEC companies.

Initially it was modelled in Revit every formwork which would be necessary for all the construction phases as it could be seen in Figure 72.



*Figure 72 - Formwork model*

It was taken into account some detailed aspects as the beam-column connections to try to have a perfect quantification as it could be seen in Figure 73.



Figure 73 - Formwork detail

In Table 9 it is possible to see a partial part from the CASAIS, S.A. formwork quantification sheet, which gives a total of 12562.23 m<sup>2</sup> of formwork.

CAS AIS		Mobile: +351 253 305 400 - Fax: +351 253 305 499 - casais@casaisinvest.pt - www.casais-sa.pt					
Identity: ITARION SOLAR, LDA		Date: 18-02-2009					
Building: Fábrica ITS1 em Vila do Conde		Page:					
Article	Designation	unit	Measures				
			Dimensions			Quantity	
			Length	Width	Height	Parcial	Total
8	Formwork						<b>12,562.23</b>
8.1	Formwork for concrete superficies types A1						
8.1.1	caps of foundation piles ITS1	m2	788.44				787.30
8.1.2	foundations ITS1	m2	26.90				31.02
8.1.3	foundation beams ITS1	m2	672.00				989.13
8.1.4	Burried slabs and deposit walls ITS1	m2	2,392.00				1,709.60
8.2	Formwork for concrete superficies types A2						
8.2.1	walls ITS1	m2	739.10				672.88
8.2.2	columns ITS1	m2	1,430.00				1,745.22
8.2.3	beams ITS1	m2	1,716.00				1,958.75
8.2.4	slabs ITS1	m2	968.00				
8.2.5	lightweight slabs ITS1	m2	3,933.00				3,925.53
8.2.6	stairs slabs ITS1	m2	66.40				58.65
8.2.7	small foundations ITS1	m2	1.50				1.32
8.2.8	other foundations and steel parts ITS1	m2	9.40				19.02

Table 9 - Resume of formwork CAS AIS, S.A. quantification sheet

Exporting the model to Navisworks software, it was possible to quantify the formwork by level as it could be seen in Table 10, giving a total of 12750.15 m<sup>2</sup> of formwork representing an excellent result comparing with CASAIS, S.A. only with a difference smaller than 1.5% between them. It is thought to be a very relevant work because it is possible to see the formwork which is being quantified on a 3D model. Comparing with the traditional way of measure this works on CAD drawings, it will avoid many errors as forgetfulness of some elements quantification or double counting of some works.

Names	ModelLength (m)	ModelWidth (m)	ModelThickness (m)	ModelHeight (m)	ModelPerimeter (m)	ModelArea (m <sup>2</sup> )	ModelVolume (m <sup>3</sup> )
<b>Formworks</b>	<b>6632.5</b>	<b>71.5</b>	<b>7.2</b>	<b>5979.6</b>	<b>4683.1</b>	<b>12570.2</b>	<b>387.5</b>
Cover	1711.8	3.1	3.4	85.5	1767.5	1671.5	41.8
Foundations	3035.4	44.6	0.1	3499.3	184.1	5073.8	195.7
Level 2	1595.0	19.8	3.6	2138.5	2731.5	5325.0	133.0
Level -1	290.3	4.0		256.3		679.8	17.0

Table 10 - Formwork quantification extracted from Navisworks

Other potential that this work will provide is for the construction planning. During this study it would be possible to represent the formwork elements as temporary elements helping on the preparation of these tasks.

#### 3.7.4. Construction planning (4D)

The construction planning, also called BIM 4D, represents the association of the variable time, materialized in construction activities to elements of a 3D smart model. Regarding this, in general, the BIM 4D is intended to graphically simulate the construction operations sequence with 3D visualizations, to obtain more holistic representations of the project development and to make this process more accessible to all the construction stakeholders, regardless of their level of knowledge and experience.

The planning of a construction is crucial for its success. With good planning it is possible to do a good coordination of every aspect during the construction of the building, with the strong possibility of saving money because there in time and cost optimization. It is made traditionally with the Microsoft Project software, which is currently the most used to do the construction plannings (see Figure 74).



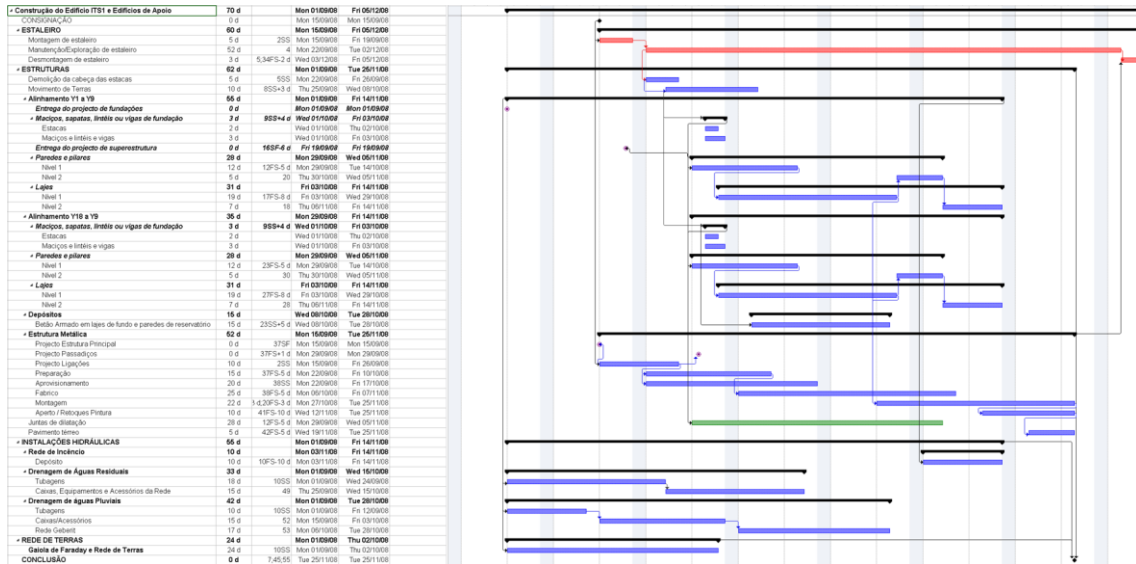


Figure 74 - CASAIS, S.A. Stability Microsoft Project File

CASAIS, S.A. provided their planning documents and two different ones were found. One was the stability planning and the other one was the finishes' planning, whose due to its complexity and many works/activities that were not modelled and due to the specified LOD, these plannings were readjusted to provide an easier methodology of work on the software. In Figure 75 it is possible to see the adapted stability planning.

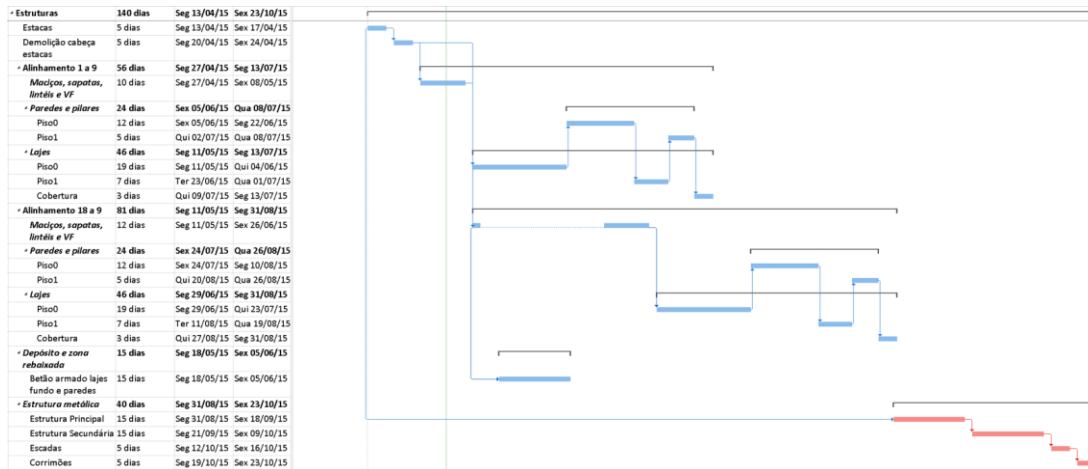


Figure 75 - Stability Microsoft Project file adapted

Having a building information model, could add some advantages to this traditional process. There are two different processes to build 4D models. The first one is the construction of 4D resources in 3D BIM tools. The other one is to export from the 3D BIM tool used to a 4D tool and also import the respective chronogram. Most of the BIM tools do not have 'time' capacities and require 4D specific modules or supplements to be able to add data. Due to these limitations, various suppliers started to develop specialized 4D production model tools from 3D models. As it was started to design with Autodesk

software it was decided to continue with this supplier. With the help of Autodesk Navisworks software, it is possible to import the model, as well as the Microsoft Project files from the construction.

After that, as can be seen in Figure 76, with the association of each object to each activity defined on the Microsoft Project file, it is possible to perform a video of the construction with its respective timeline.

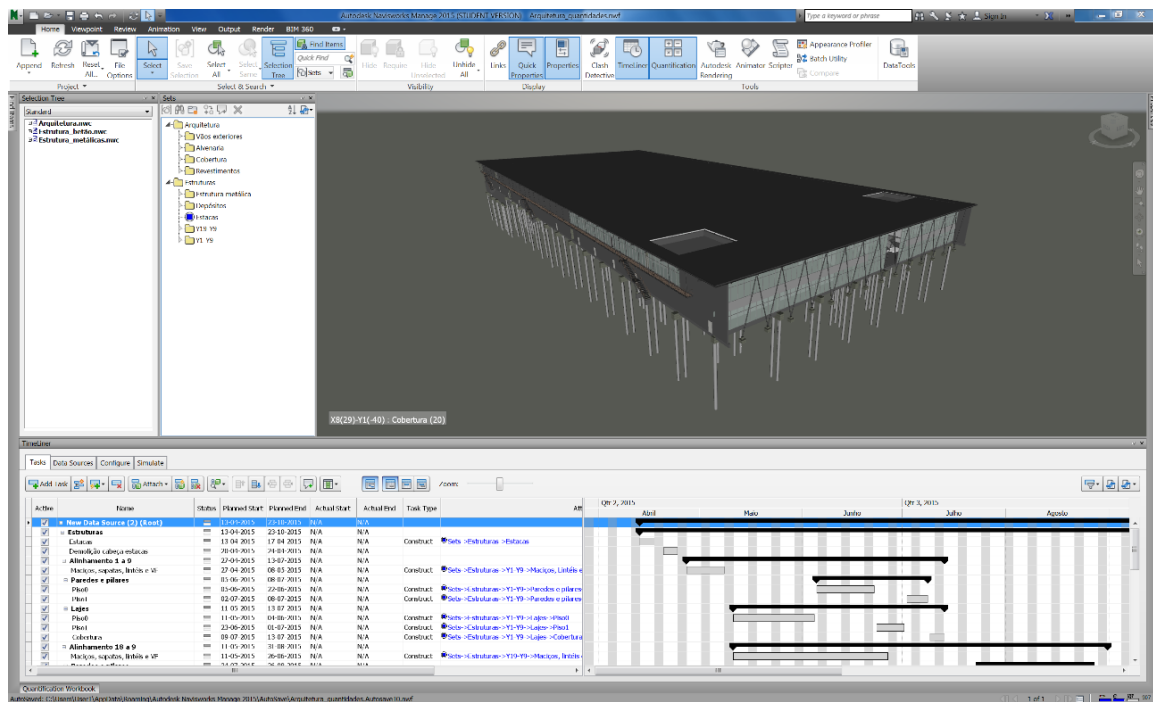


Figure 76 - As-built model and timeline workout in Navisworks software

This is a considerable and rather beneficial step to the construction. With this holistic visualization it will be possible to optimize many processes and coordinate much better the construction and the warehouse organization as the temporary elements. In addition to that, as it was referred it will be possible to perform a sequential construction representation of the phases accompanied with the timeline enabling the visualization of the evolution of the works with the time, also with the possibility to add different types of construction.

After discussing with the planning director from CASAIS, S.A., it was possible to understand that a usual problem of the traditional way of planning, just with the Gantt chart, is the coherence invisibility between the diverse activities linkage and its successors. Something that is totally visible when using BIM and it avoid the error as some cheated plannings to win bids that are not credible when analysed on its feasibility. Using BIM, it is possible to have a holistic view of the planning where it is easier to check every works that were bid and will be performed.

BIM 4D could be utilized by designers, engineers and technical directions of work teams to essentially analyse and visualize projects when making decisions, on the viability analysis of the project and on its construction operations, to develop estimates and manage resources and to communicate and collaborate with clients and other stakeholders.

Regarding the evaluation of 4D BIM specialized tools, there are some important aspects to evaluate before choosing the software to be used:

- Capacity of BIM importation - what geometry, BIM formats or data types of objects which are possible to import. In some cases, tools only import geometry, names and little else;
- Capacity of the chronogram importation - what chronogram format types it is possible to import;
- Reorganization - it is necessary to have tools that support an easy reorganization of some component data of the model;
- Temporary components - normally it is necessary to introduce (and remove) temporary components, for example, excavation areas, scaffolding, warehouse areas, cranes, etc. To ideally turn the 4D tool into a library which permits the users to quickly add these components;
- Data introduction - after conversation with a construction director, it was found that the objects performance rates and the variables of labour are important for a construction planning;
- Analysis capacity - specific analysis as space-time conflict analysis, to identify the activities that happen in the same space;
- Concrete pours - fast, easy and accurate concrete pour creation.

Considering this, it is understandable that a previous study should be performed about what the best software would be for the specific functions that would be needed for the intended work.

### **3.8. Modelling time**

The time of model a BIM project is extremely important to know if this methodology could provide an increase of efficiency on AEC industry or not. Software estimation involves working out the effort required for completing the software development work. The effort is usually worked out in terms of man-days.

In Figure 77 it is possible to see the learning curve, which adds expertise as one learns a subject with time, shows that initially the rate of learning is slow, then there is a very fast learning and finally as expertise has been gained, the rate of new learning drops.

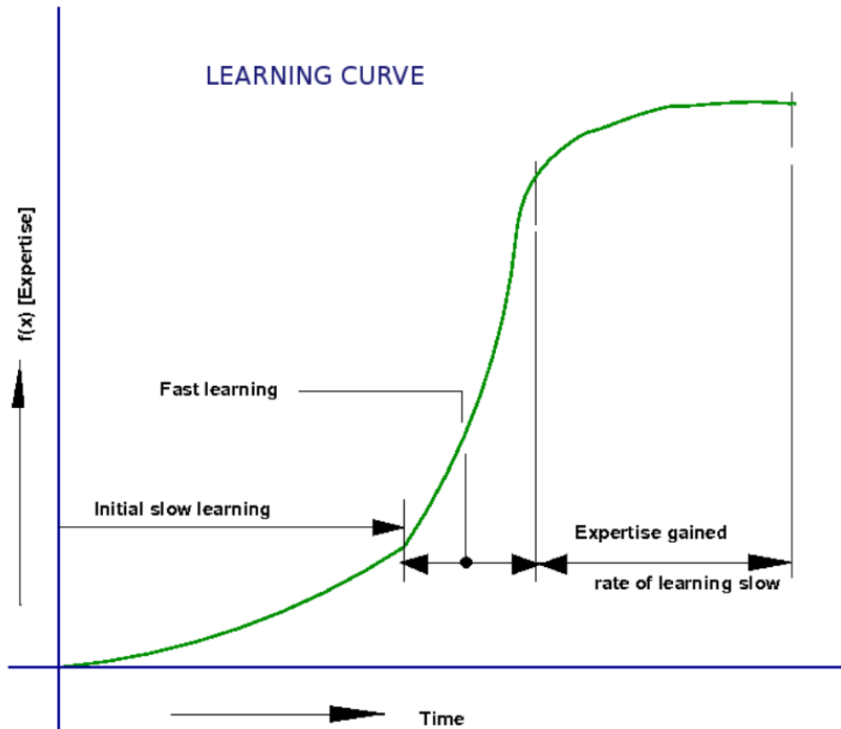


Figure 77 - Software learning curve (Softprayog, 2015)

Without any previous experience on BIM software, it was necessary to see and read many videos, tutorials, training books and textbooks.

Some of the best tutorials seen were Lynda tutorials (Lynda, 2015). It was seen the ‘Up and Running with Revit’ and ‘Navisworks Essential Training’.

Regarding textbooks, CASAIS, S.A. has a Revit 2015 book very useful explaining every Revit functionalities (Garcia, 2015). In addition to that, CASAIS, S.A. already had a training in Revit before and they provided me its training book which has a general overview of Revit software with a lot of details with practical examples.

It was also joined an international Facebook group with many users that helped every time (Revit Architecture, 2015).

Some exercises were made as well as to get in touch with the software.

All this learning process took more or less one week to gain capacities to start the modelling. Starting the model, the continuous occurrence of doubts made it necessary to continuously study about the software used.

Since the first meeting with all the responsible persons of this dissertation up until a regularized version of the model, the task took roughly thirty days, including all the initial learning phase. It is seen as a good result regarding all the barriers that were overcome and the fact that there was only one modeller.

An aspect that should be mentioned, is that after some capabilities were reached, it was understandable that at this point in time, maybe the model or a specific part of the model should be done in a different way which would facilitate and improve the model. However, due to a restricted timeline it would be impossible to restart the model each time something new was learned and also a new way to model certain elements was discovered.

After this experience, it is predicted that an even more accurate as-built model could be done in a relatively shorter time. This reduction of time is also possible when a company, reaches a point that has expertise labour, the necessary maturity on BIM methodology and everything ready to start a model like libraries and every processes well defined. Considering that it was not modelled the steel structure it is understandable that with maturity, the time consuming could be much lesser than the dissertation time. As it could be seen in Figure 78 and admitting that it would take 9 days to perform the steel structure considering the learning curve, it will give a total of 32 days. Comparing this value with the total of the future provision, it is possible to reach approximately a 47% reduction of time.

<b>Work designation</b>	<b>During dissertation (days)</b>	<b>Post-dissertation (days)</b>
<b>Foundation piles</b>	<b>2</b>	<b>0.25</b>
<b>Concrete Infrastructure</b>	<b>3</b>	<b>0.75</b>
<b>Concrete Superstructure</b>	<b>5</b>	<b>1</b>
<b>Formwork</b>	<b>3</b>	<b>2</b>
<b>Steel Structure</b>	<b>9</b>	<b>6</b>
<b>Finishes</b>	<b>10</b>	<b>7</b>
<b>TOTAL</b>	<b>32</b>	<b>17</b>

Table 11 - Modelling time

As this dissertation was done in a construction corporate environment in technical department, an interesting analysis could be made by trying to compare the time of modelling to perform the quantifications works with the traditional methods and see what are the expected time consuming for each. However, it is extremely important to refer that after model the entire construction it will provide several potentialities that are not only related with quantifications, as it was tried to show during the present dissertation. Quantifications are only one of the several potentialities that a BIM model could provide.

It is clearly known that the model will be an enormous value for every life cycles phases of the building to be constructed.

On traditional methods the time is used to measure the CAD drawings and on BIM methodology it is mainly used to model because the quantifications are almost automatically extracted.

Figure 78 shows a resume of the dissertation consuming times and an estimation for the same work, but this time with BIM maturity.

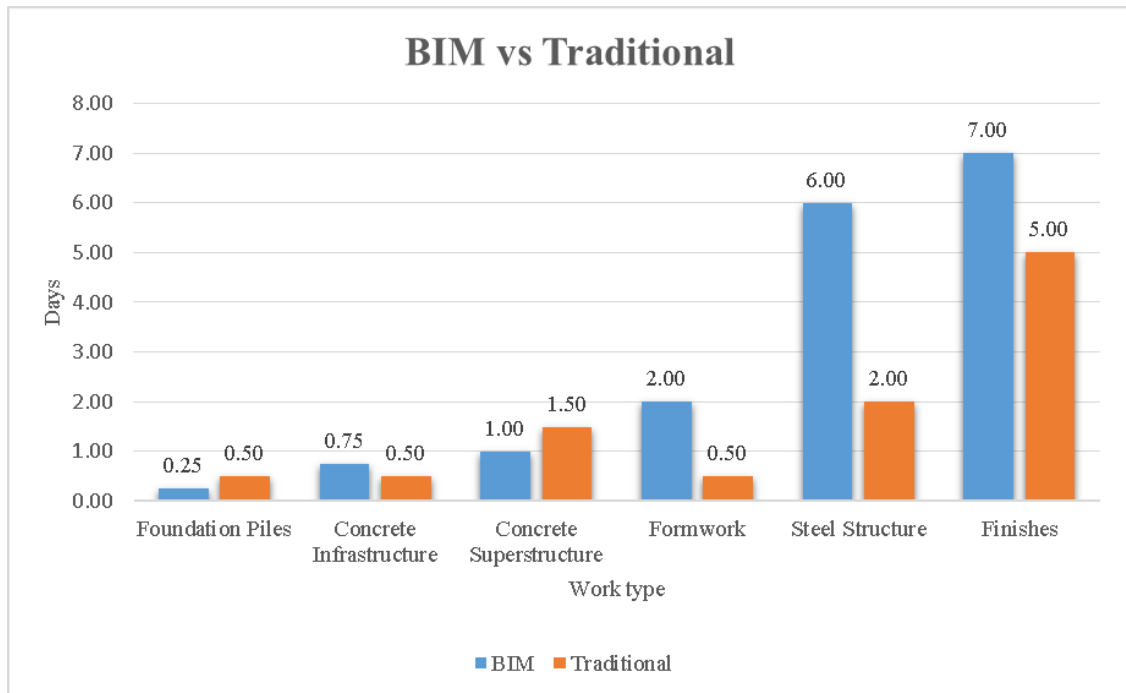


Figure 78 - Times consuming estimation (one person)

Figure 79 it is shown a cumulative graph with an estimation of time consuming labour for both methods for the different works performed. It was considered only one person working either for traditional method or BIM modelling.

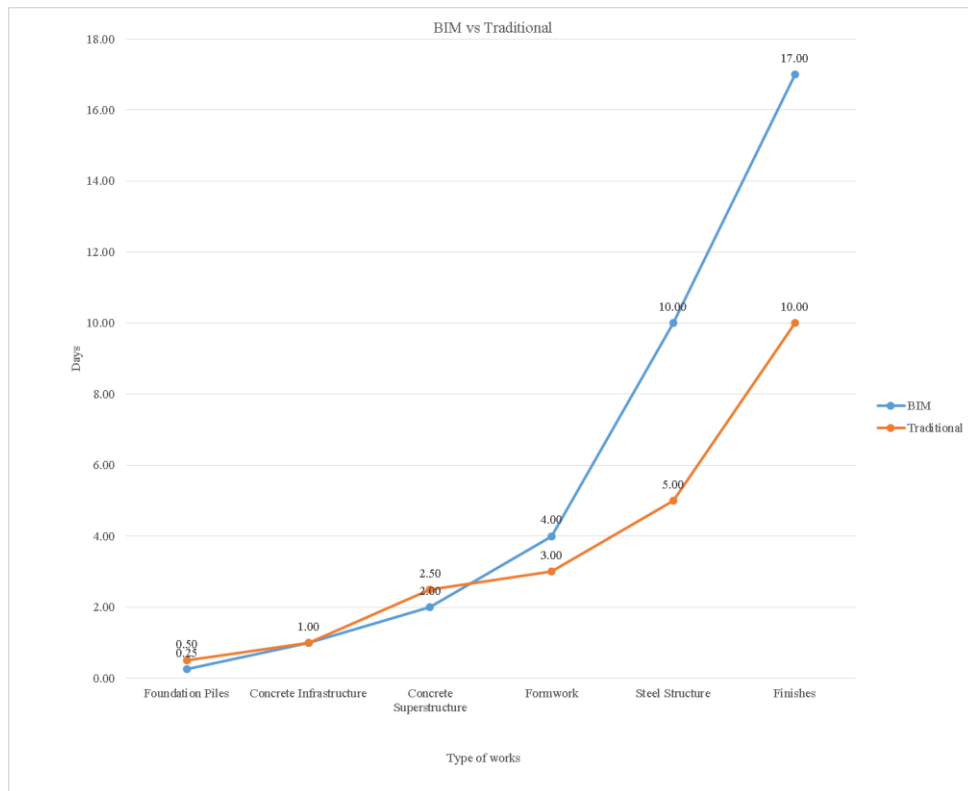


Figure 79 - BIM vs Traditional method

Doing the totals, BIM methodology has 17 days consuming, and the traditional method has 10 days. So it is easily calculated that BIM methodology has sensitively more 60% of time consuming comparing with the traditional method to get quantifications.

If it is being considered to implement BIM in a construction company, it is clearly understandable that when budgeting a construction it will be necessary to model the entire project and consequently it will increase budgeting costs. However, in bid phases it will possible to perform 4D BIM potentialities and win competitiveness in face of strong competition. And in case of winning the project, it will provide several benefits, as well as improve productivity and save costs.

This type of analysis is very important to justify to the company direction BIM methodology implementation, as it means a significant investment in software, hardware, consulting services, training and expertise labour.





## **4. CASE STUDY: INTERVENTIONS IN ITARION BUILDING WITH BIM**

### **4.1. Background and presentation**

The present chapter presents the application of BIM in the scope of the refurbishment of the ITARION building. The application had the objective of optimizing construction schedules, clash control and specialities coordination.

The refurbishment process had already been preliminary planned before the beginning of this dissertation. The corresponding drawings were the basis for the modifications to the BIM model presented in the previous chapter. Figure 80 shows the plan of level 1 after refurbishment, in which the intention of transforming the building into a logistics centre can be observed. The building will be divided into eight 20m wide warehouses. The warehouses are located in the former production area, which solely has 4.5m of free height in the current situation. Therefore, as the height of 4.5m is insufficient for storage purposes in pallet racking systems, the refurbishment process will involve the deconstruction of the current ceiling at, as to allow the increase of free height in each warehouse to 8m (thus allowing pallet racking systems with 7-8m height). The division of the warehouses coincides with the structural trusses above the production area, and thus no intervention on the trusses themselves is necessary, except for the suppression of some bracings and purlins.

The plan of level 1 shown in Figure 80 further allows the identification of docking areas at the SW façade of the refurbished building. Each warehouse will allow two trucks to be docked simultaneously, being serviced by cargo elevators. The front of the building (SE façade) shall include shop window displays and entrance for the general public.

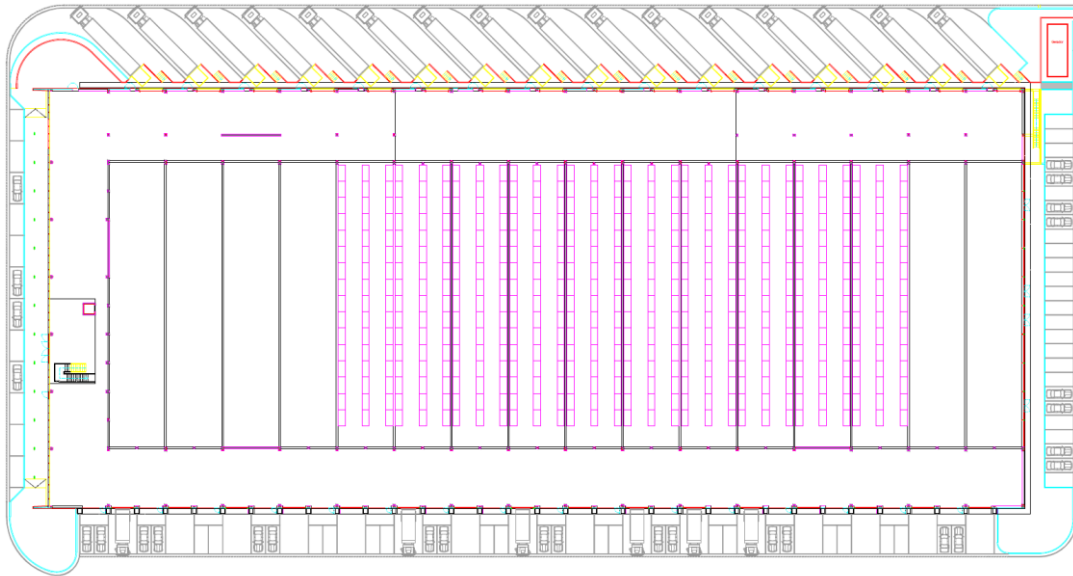


Figure 80 - Plan of Level 1 after the refurbishment process.

Figure 81 shows level 2 that will continue to have a ‘U’ shape level which will be accessible and will have the offices area. The previous central production zone, will be the new storage area.

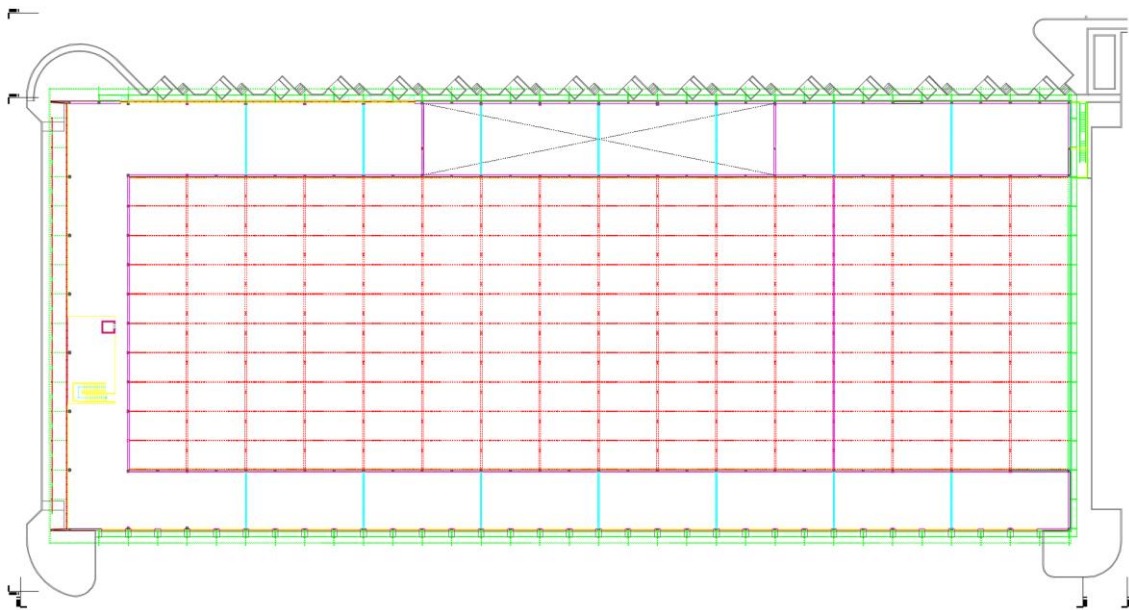


Figure 81 - Plan of Level 2 after the refurbishment process.

## 4.2. Modelling strategies

In general, the modelling strategies were the same as the ones presented in chapter 3. This sub-chapter presents the new objects that were obtained from online libraries, as well as the classification of the new modelled elements and their LOD.

In specific regard to objects obtained from online libraries, highlight is given to Table 122, which includes the new steel gates and the racks to apply in the refurbishment process. These objects were found to be satisfactory in terms of the contained information and their graphic representation. Regarding the objects obtained by RevitCity, they all are performed by different users who publish their works facilitating other ones on the modelling time consuming. Normally these objects have only its geometrical information without any other important data as the manufacturer or classification systems. Otherwise, objects provided by BIMObject are from manufacturers and it have every information necessary about the specific product. Given the graphic complexity of these objects themselves, there was a significant saving of modelling time associated to the adoption of pre-modelled objects.

In concern to the LOD modelling strategy, Table 133 summarizes the intended/modelled LOD of the new objects added to the BIM model.

Regarding all that was said in chapter 3 about Adoption of Classification Systems, it was done again for the elements modelled to the refurbishment intervention to be done on ITARION building as shown in Table 144. As it could be seen, new level of stratification was necessary to create two types of Metal Doors to give the possibility to identify two different types of steel doors that will be applied during the refurbishment.




Name	Figure	Source
Steel Gate		
Rack		

Table 12 - Source of some objects used on BIM model




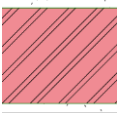


<b>Classification LOD ITARION - Refurbishment</b>						
Omiclass Number	Level 1 Title	Level 2 Title	Level 3 Title	Level 4 Title	LOD	Image
23-13 33 27 11		Exterior Vertical Enclosures	<b>Exterior Walls</b>			
			Exterior Wall Construction	350		
			<b>Exterior Doors and Grilles</b>			
23-17 11 23 11			Exterior Entrance Doors	350		
23-17 11 19 13			Exterior Entrance Doors	300		
23-15 13 23	Interiors	Interior Construction	<b>Interior Partitions</b>			
			Interior Fixed Partition	350		
23-21 11 11 17	Equipment & Furnishings	Furnishings	<b>Fixed Furnishings</b>			
			Fixed Art	300		
23-11 21 13 13	Building Sitework	Site Improvements	<b>Roadways</b>		300	

Table 13 - Refurbishment elements - LOD classification.

<b>ITARION Refurbishment Elements Classifications_Omniclass_Table23</b>					
<b>OmniClass Number</b>	<b>Level 1 Title</b>	<b>Level 2 Title</b>	<b>Level 3 Title</b>	<b>Level 4 Title</b>	<b>Level 5 Title</b>
<b>Site Products</b>					
<b>Pavements</b>					
<b>Roadways</b>					
23-11 21 13 13				Roadway Surfacing	
<b>Structural and Exterior Enclosure Products</b>					
<b>Envelope Enclosure Products</b>					
<b>Glazed Facade and Roof Structures</b>					
23-13 33 27 11				Curtain Walls	
<b>Framing Products</b>					
<b>Structural Walls</b>					
23-13 35 21 11				Concrete Structural Walls	
23-13 35 21 13				Masonry Structural Walls	
<b>Openings, Passages, and Protection Products</b>					
<b>Doors</b>					
<b>Metal Doors</b>					
23-17 11 13 15.1				Steel Doors (Type 1)	
23-17 11 13 15.2				Steel Doors (Type 2)	
<b>Composite Doors</b>					
23-17 11 19 13				Sliding Composite Doors	
<b>Furnishings, Fixtures and Equipment Products</b>					
<b>Commercial Furniture</b>					
<b>Commercial Storage Units</b>					
23-21 11 11 17				Comercial Storage Racking	
<b>Conveying Systems and Material Handling Products</b>					
<b>Vertical Transportation Equipment</b>					
<b>Elevators</b>					
<b>Traction Elevators</b>					
23-23 11 11 11 11					Freight Traction Elevators
23-23 11 11 11 13					Passenger Traction Elevators

Table 14 - Refurbishment objects Omniclass classification

### 4.3. Deconstruction intervention

Before doing the works of renovation and refurbishment, it will be necessary to deconstruct some parts of the existent building. The process will involve the disassembling of several parts in order to attempt reuse whenever possible, or alternatively to make their recycling. To execute that deconstruction with this objective, the plan will be to disassemble the maximum objects that have to be deconstructed instead of demolishing them.

Regarding deconstruction works, it was considered the yellow colour to represent the parts that will be deconstructed to provide the constructors with a holistic view of the works that have to be carried out. The representation of the parts to be deconstructed in the scope of the ITARION building is shown in Figure 82.

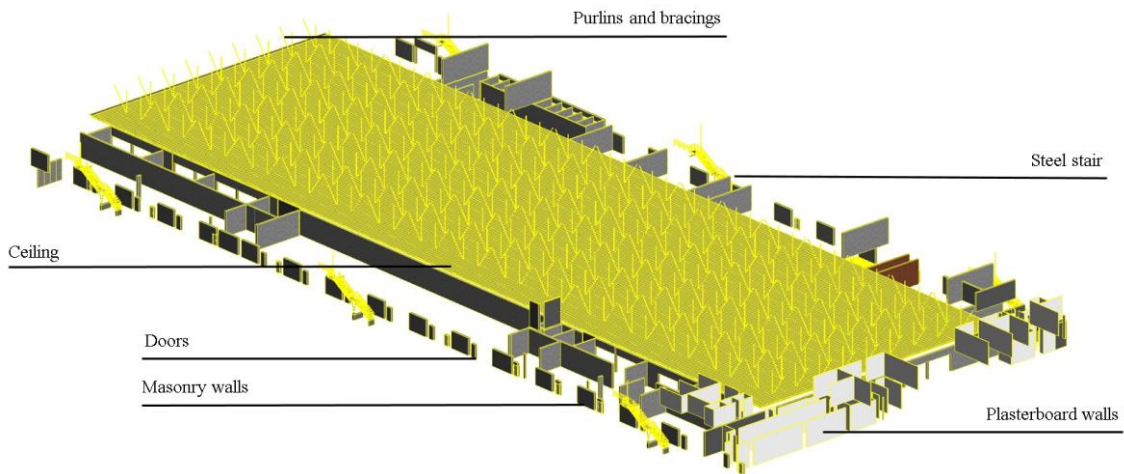


Figure 82 - Deconstruction works shown in yellow colour

As shown in the figure above, the deconstruction works are:

- Removal of the ceiling in the production zone at 4.5m height (see Figure 83);
- Removal of steel purlins and bracings (see Figure 83);

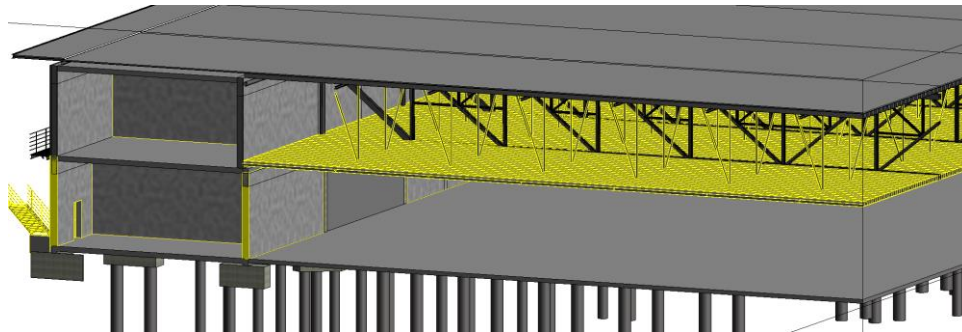


Figure 83 - Production zone intervention detail

- Removal of all existent plasterboard walls;

- Removal of almost every non-structural masonry wall partitions of the building;
- Removal of doors;
- One interior stair demolition;
- Removal of the external stairs and some railings;

#### 4.4. Upgrade intervention

In terms of modelling, after describing/marketing the deconstruction works, the upgrading intervention was carried out. This intervention will be constituted of both types presented in chapter 2: renovation and refurbishment works.

It was considered the red colour to represent the parts that will be constructed during the upgrade intervention to provide the constructors with a holistic view of the works that has to be carried out (see Figure 84).

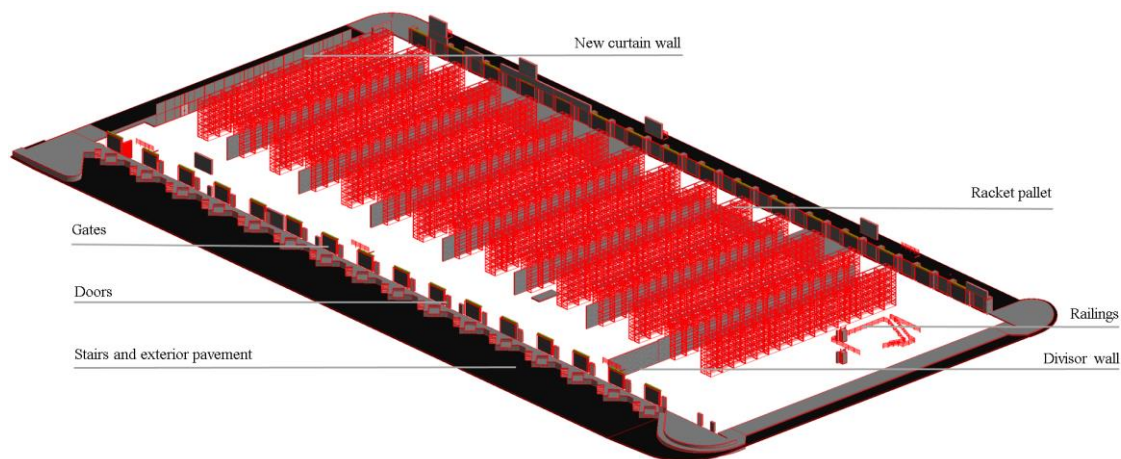
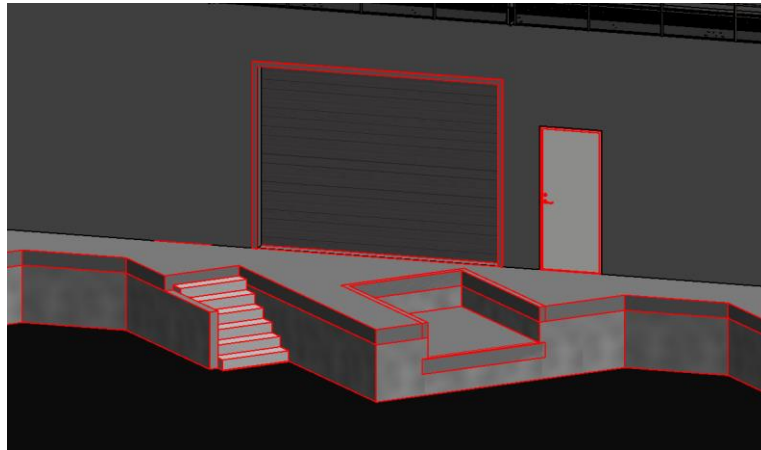


Figure 84 - Red parts - Upgrade works

As shown in the figure above, the refurbishment works are:

- Installation of industrial racking pallets;
- Installation of exterior gates (see Figure 85);
- Installation of new exterior doors (see Figure 85);
- Installation of curtain walls and doors;
- Installation of an elevator;
- Installation of some railings;
- Construction of divisor walls between each warehouse;
- Installation of a mechanic elevator on the back of the building for loading and unloading;
- Construction of the outdoor pavement in tar (see Figure 85);

- Exterior finishes in masonry (Figure 85).



*Figure 85 - Upgrade detail*

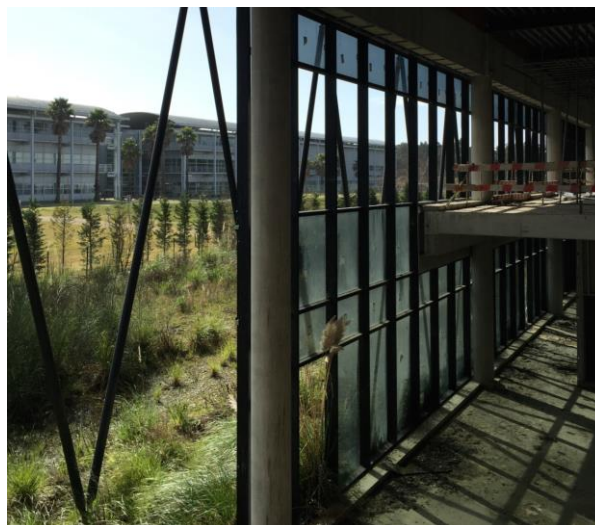
It will also be necessary to carry out some renovation works like:

- Renovate some concrete surfaces which are becoming deteriorated;
- Renovate some steel structures which are in risk of breaking for example the exterior walkways (see Figure 86);



*Figure 86 - Walkway needing renovation*

- Renovate the existent curtain walls on the SE side of the building (see Figure 87);



*Figure 87 - Unfinished curtain wall*

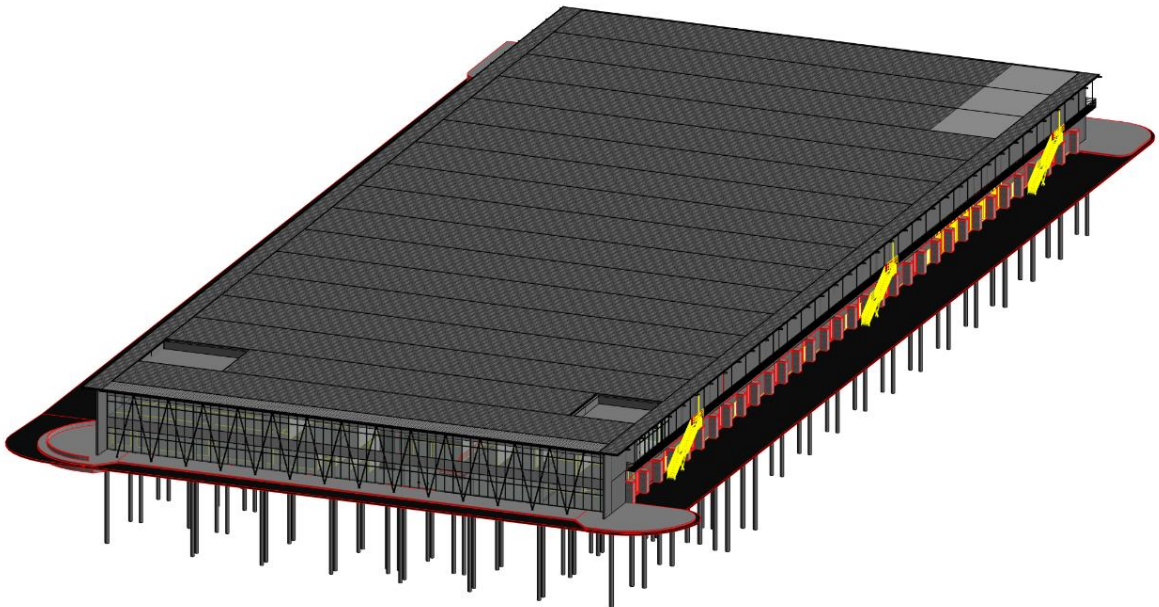


- Renovate the exterior façades, changing the deteriorated insulation and finishes and placement of new ones (see Figure 57).

Regarding the modelling of these renovation elements, it was modelled as it is in good condition. For these reason there will be some difficulties in quantify the renovation works. However, it was made a simplification of not modelling this which agrees with the LOD determined for the BIM model.

#### 4.5.Final model

In Figure 88, it is possible to see the final model with the yellow and red works to be carried out.



*Figure 88 - Yellow and Red works*

Figure 89 show the plan views of the intervention at both levels 1 and 2.

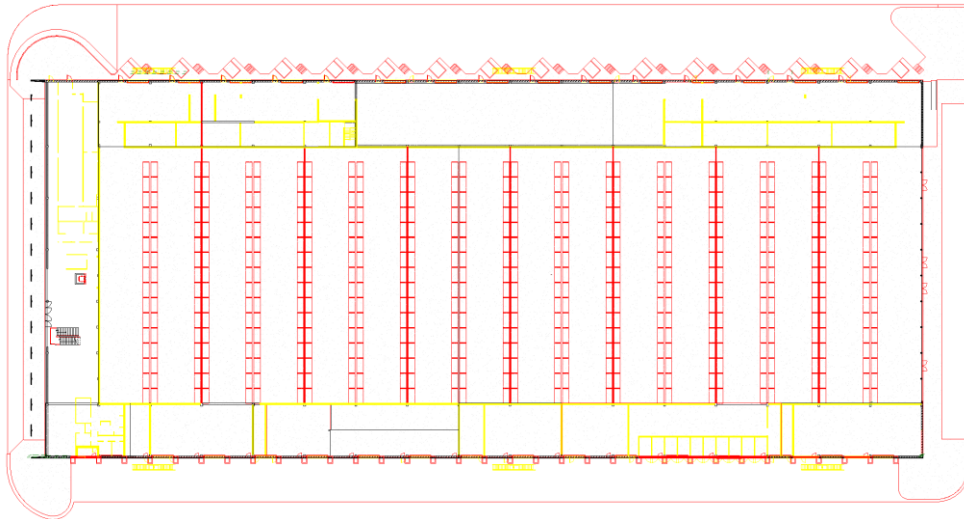


Figure 89 - Alterations plan - Level 1

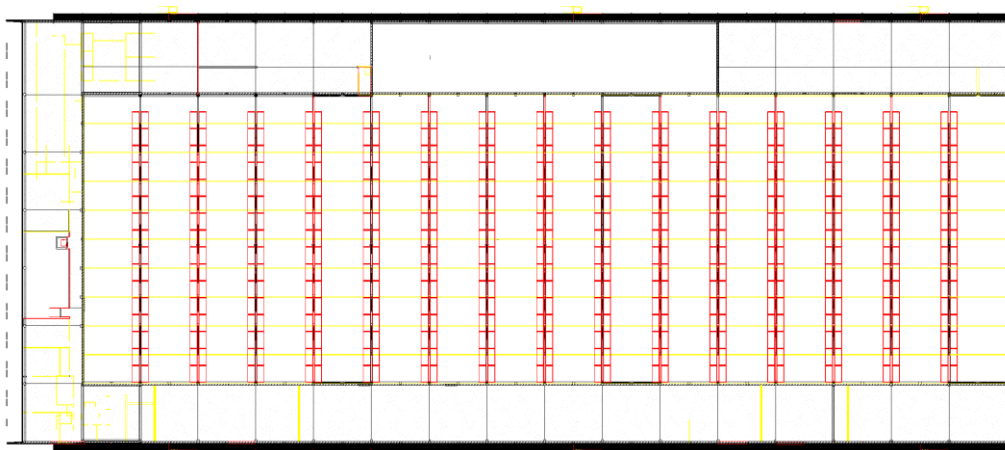


Figure 90 - Alterations plan - Level 2

Figure 91 shows a 3D view of the ITARION building after the upgrading intervention.

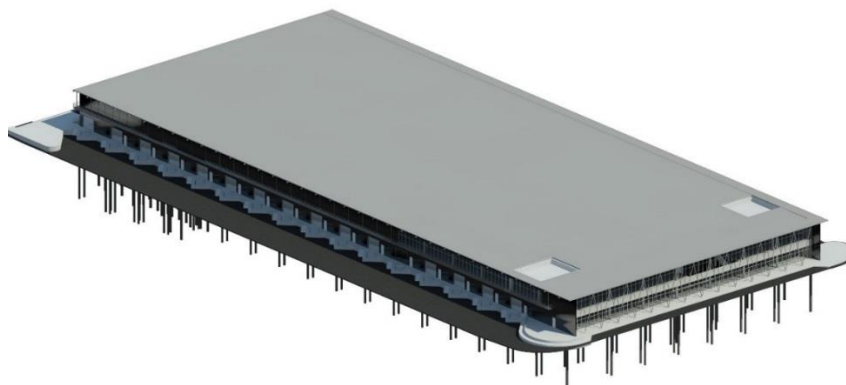
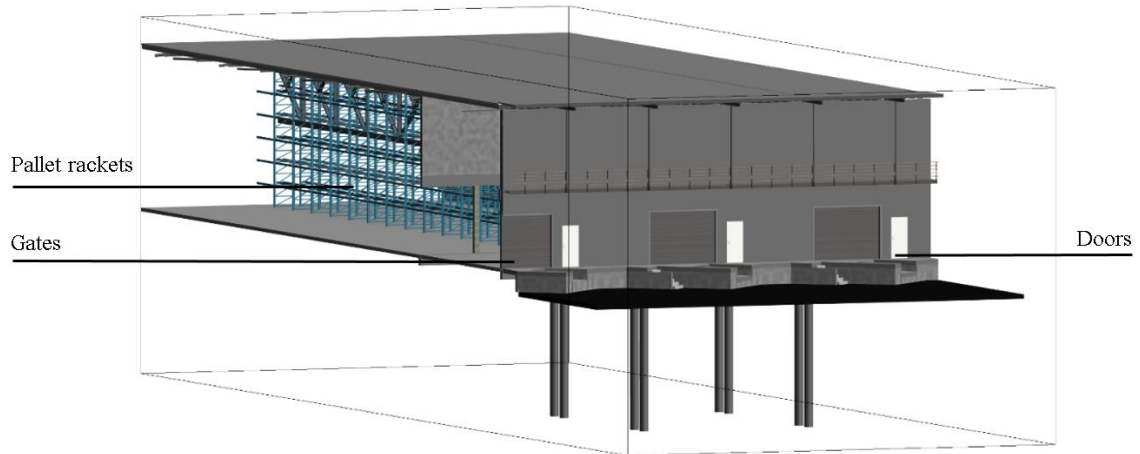
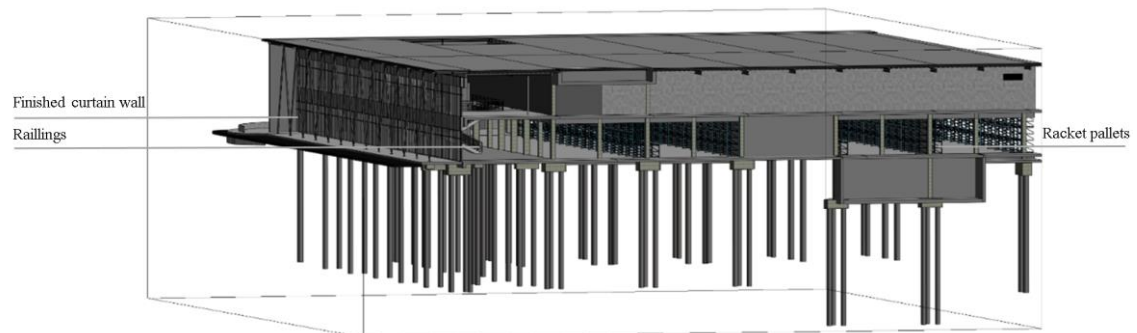


Figure 91 - Final View of the Upgrading Works

In Figure 92, it is possible to see some cutaways of the model to better understand the interventions works that are intended to perform. It is possible to see all the doors and gates that were planned to be removed and the new ones for placement, the steel structure demolished, the new racket pallets system and the finished curtain wall.

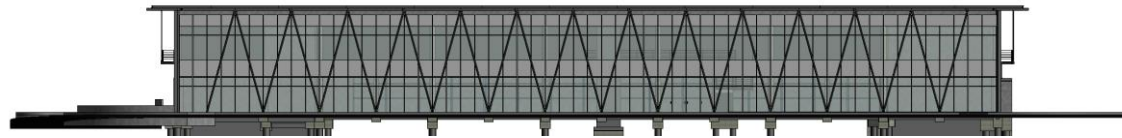


*Figure 92 - Some details of the final model*



*Figure 93 - Other details of the final model*

In the follow images it is possible to see all new elevations from the SE, NW, NE and SW views.



*Figure 94 - New SE view*



*Figure 95 - New NW view*



*Figure 96 - New NE view*



*Figure 97 - New SW view*

In Figure 98 it is possible to see the new level 1 plan compared with the actual CASAIS, S.A. proposal.

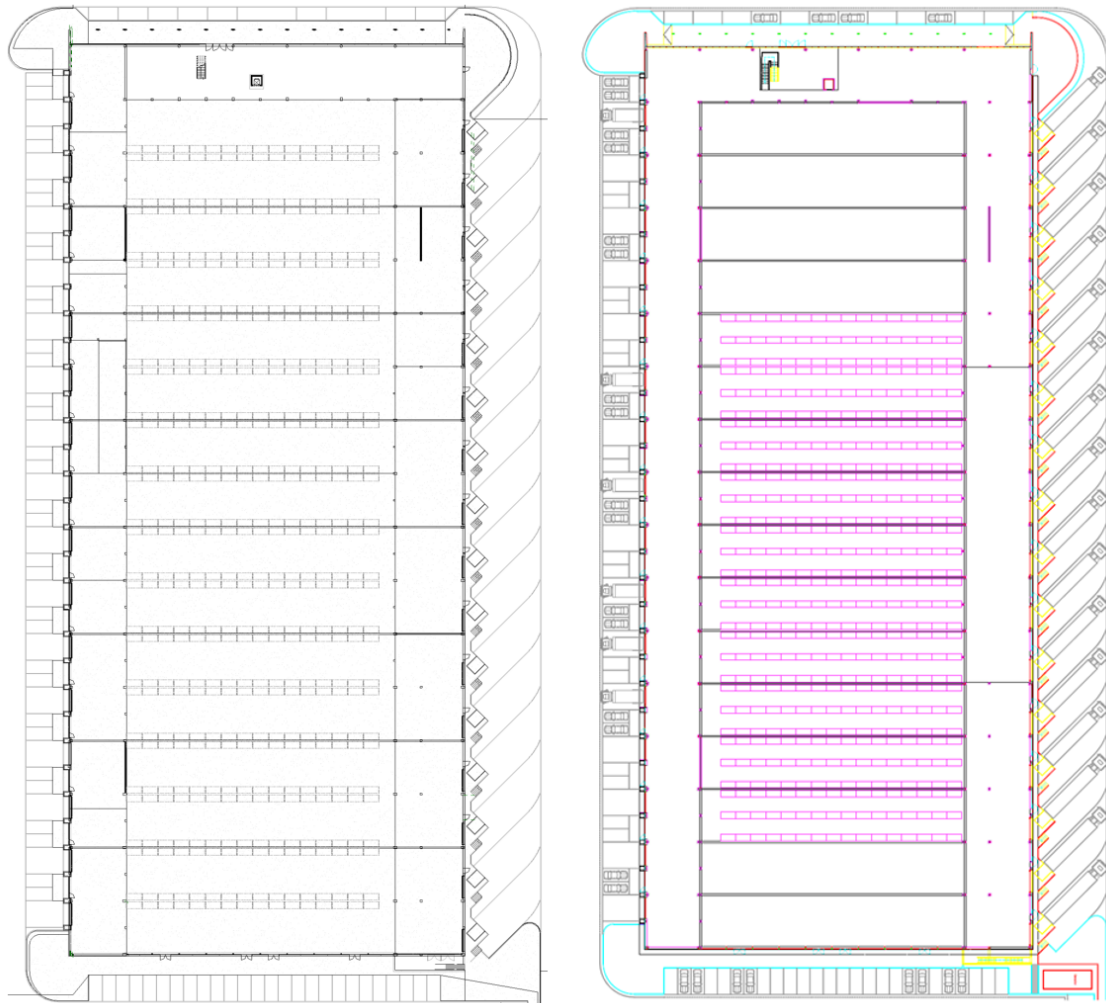


Figure 98 - Level 1 plan (BIM-left; CAD-right)

It is remarked that the model after upgrading was totally made by marking the elements for deconstruction and the new constructions in the model of the initial situation (described in Chapter 3). The modelling process involved the definition of two different project phases associated to each element: Initial project (as-built situation) and Final project (after deconstruction and upgrade works) as it is possible to see in Figure 99.

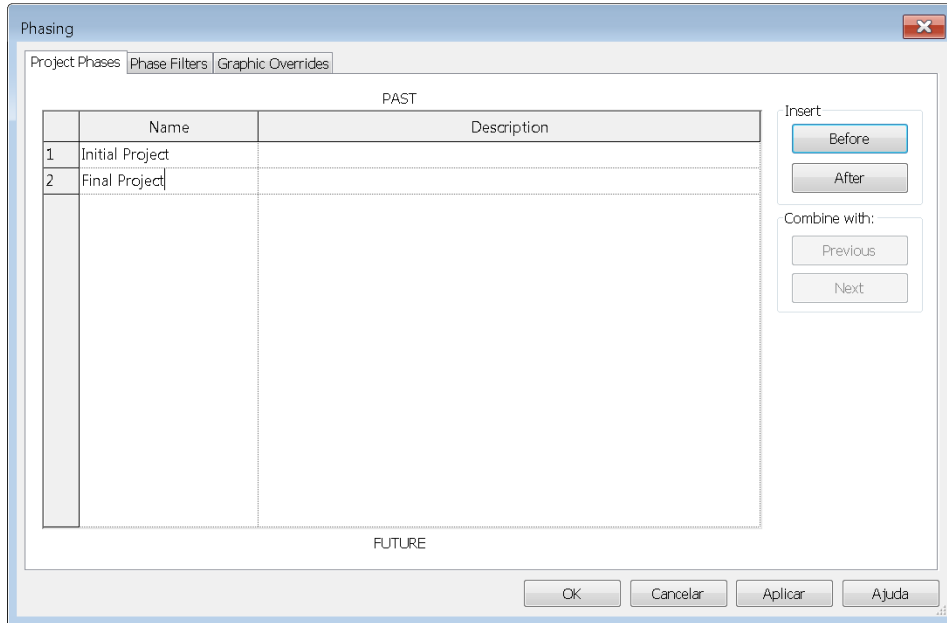


Figure 99 - Project phases Revit

It is therefore possible to filter information (or views) regarding the several phases of the project, including the initial stage, the stage after deconstruction works and the final stage after the new construction works are finalized. For further detail and to perform some of the previous views it was created different filters: overview of the alterations with or without the existing model; deconstruction works without the existing model; upgrade works without the existing model as can be seen in Figure 100, by changing the fields ‘Overridden’, ‘By Category’ and ‘Not displayed’.

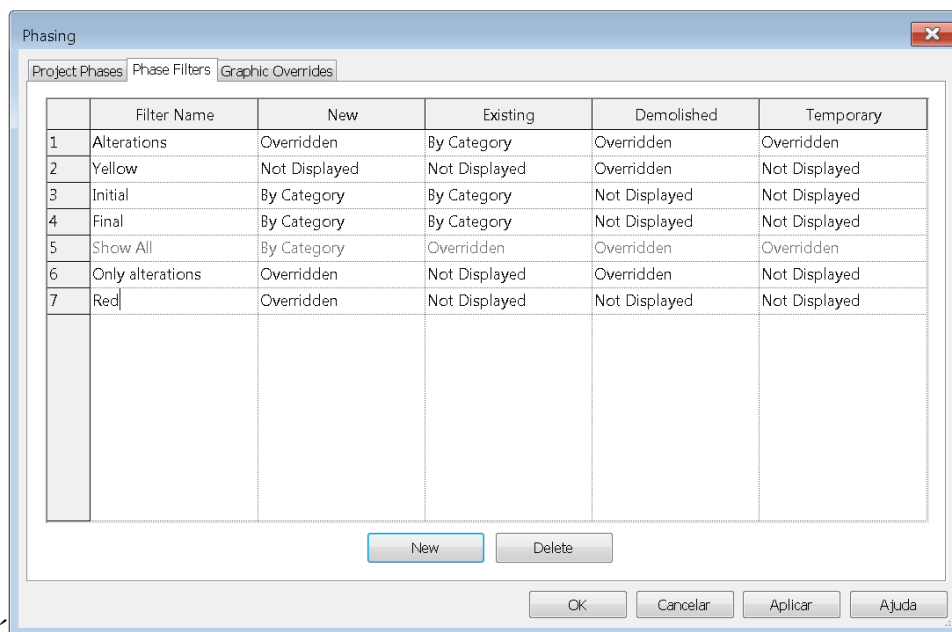


Figure 100 - Phase filters Revit

Considering this, it will possible to create different views and floor plans to show and better understand every works that will be performed as shown in Figure 101.

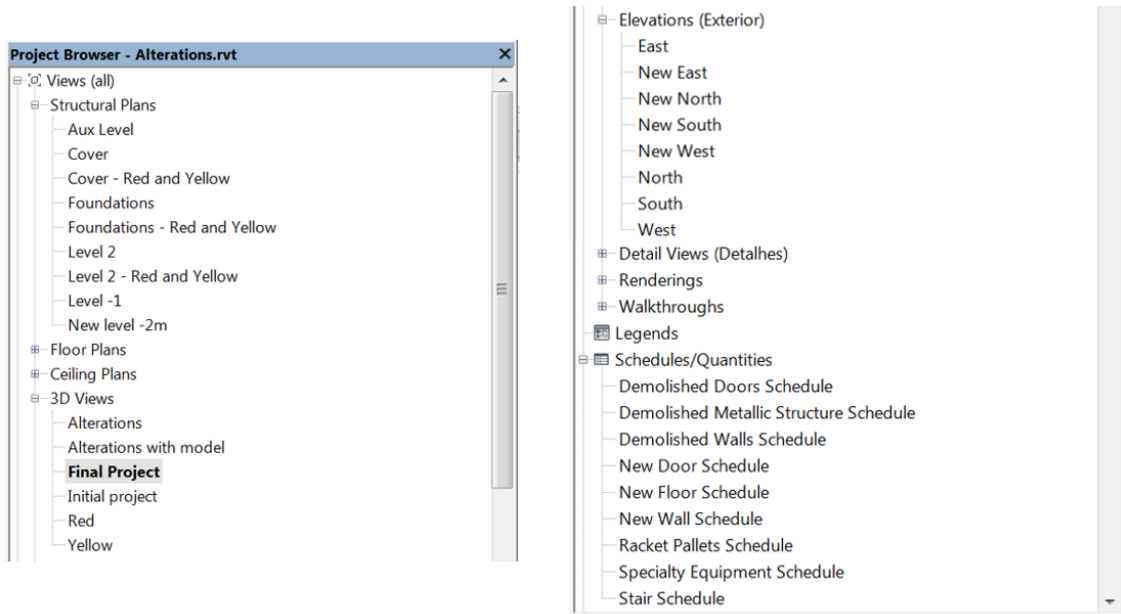


Figure 101 - Project Browser Revit

Figure 102 exemplify it by showing different views in different phases with different filters.

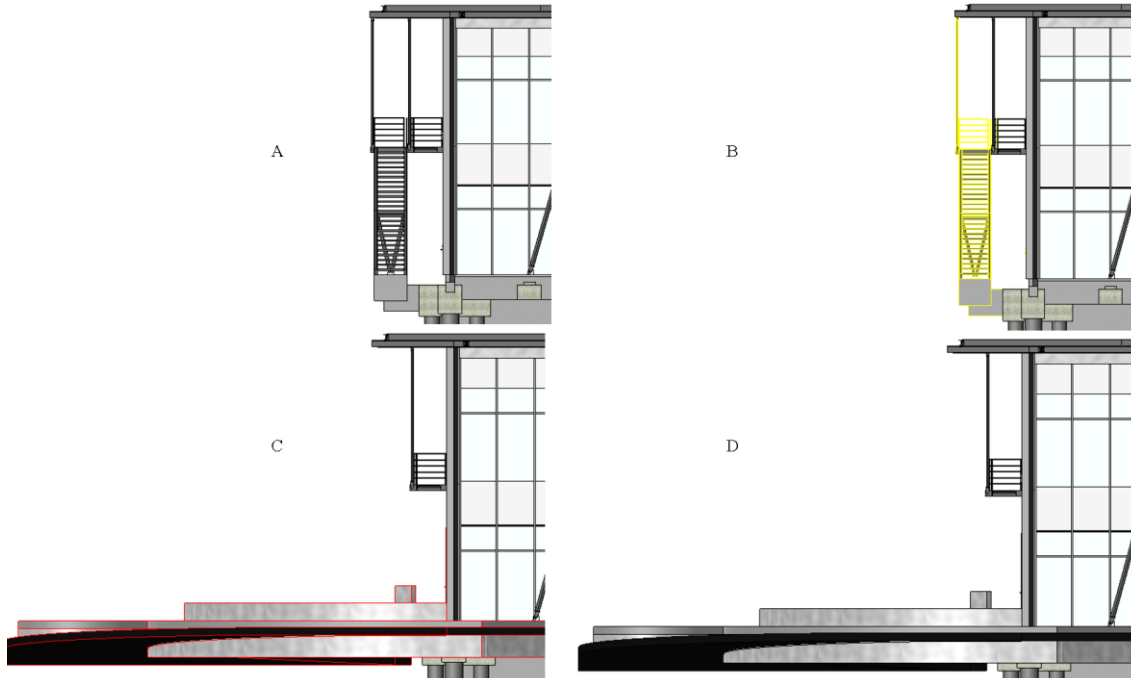


Figure 102 - Project phases and filters (A-initial project, B-initial project with deconstruction works signaled; C-final project with upgrade works signaled; D-final project)

## 4.6. Utilization of BIM tools

### 4.6.1. Clash detection

In order to ensure a correct coordination of the upgrading interventions, clash detection operations were performed through the use of Autodesk Navisworks.

The first thing to do was to import the different models in their native format to Navisworks. The as-built model was added without the items that will be deconstructed and another model with the upgrading items to be constructed. As MEP elements were not modelled, the coordination checking solely includes the architectural and structural models.

After performing the clash test, 461 clashes were found. However, an adequate analysis of the clash report allows understanding that many of the clashes actually corresponding to modelling simplifications, which are not a problem by themselves. In the particular case of this model, most of the reported clashes were related to structural connections between the steel or concrete parts (see Figure 103), inducing the clash detection algorithms to consider it as a collision.

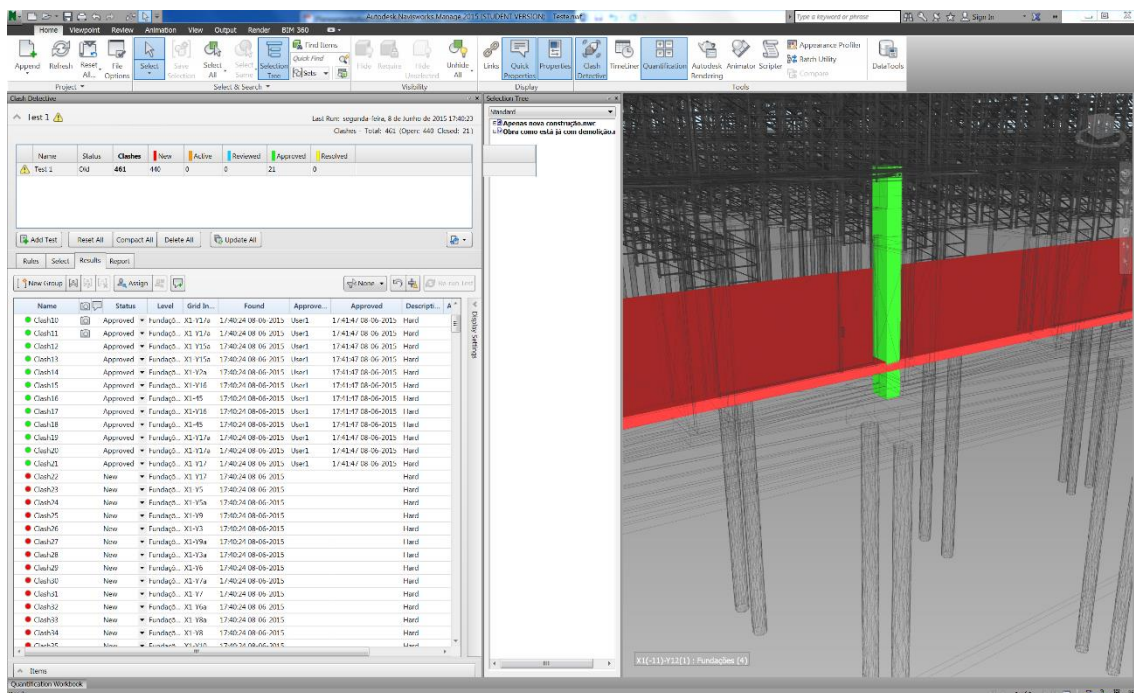
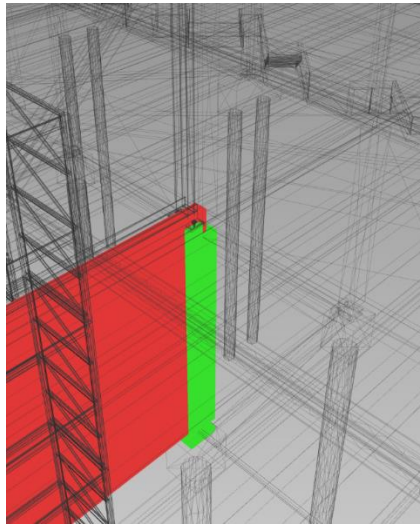


Figure 103 - Clash detection test

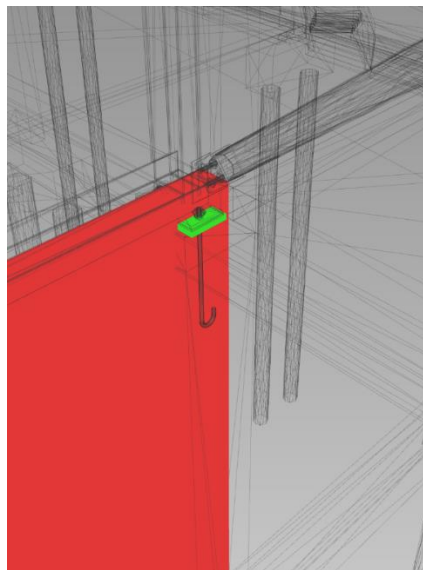
Considering this, it was possible to disregard clashes that do not actually represent real problems and solve the ones that need to be remodeled or adjusted. For example in Figures 104 and 105, it is possible to see that a wall was modeled for the upgrading



intervention (in red) that intersected with an existing column and some steel components (in green) that are on the top of this column. After this test, it was possible to readjust these little aspects on the modelling software and solve them.



*Figure 104 - Collision between wall and column*



*Figure 105 - Collision between wall and steel element*

#### **4.6.2. Quantity take-off (QTO)**

As mentioned previously, quantification is extremely important for constructions being one of the most crucial aspects during the budgeting of a construction.

In chapter 3 an analysis was made between CASAIS, S.A. quantities maps versus quantities maps obtained from the as-built BIM model. In this subchapter the quantity take-off of the deconstruction works and the refurbishment works will be made. However, no comparison is made in regard to the traditional QTO methods, as the quantification was not yet made on behalf of the construction company.

On this chapter, instead of the previous one, the quantifications will be performed on Revit because it is known that it will be possible to quantify the steel structure that will be deconstructed, which was not possible in Navisworks, due to the referred problems of exchanging information with the model from Tekla Structures software. Regarding the rest of the quantification, both software are equal in terms of quantification giving exactly the same values.

As it could be seen in Figure 101, it was prepared the schedules/quantities on Revit to perform it.

#### 4.6.2.1. Deconstruction quantities

Regarding the deconstruction, the quantity take-off of some existent doors, walls and steel structure was performed.

Having started off with the doors it was evidently possible to choose which parameter that was required to show on the different columns of the quantification sheet. For this object, it was agreed that it would be interesting to see the following parameters:

- Keynote (field of Omniclass classification);
- Family;
- Family and Types;
- Phase Created;;
- Level.

After choosing these parameters, it was possible to choose some specific settings as filters, different ways of sorting/grouping and some different formatting types. Considering this, it was possible to perform a clear sheet with all the necessary information (see Table 155).

Deconstruction Doors Schedule					
Keynote	Family	Family and Type	Phase Created	Phase Demolished	Level
<b>Metallic Venezian Door</b>					
23-17 21 13 15	Porta Veneziana M	Porta Veneziana Me	Project	New Project	Foundatios
Metallic Venezian Door: 19					
<b>Swedoor_JW_Function_Bering_single_outswing</b>					
23-17 11 13 11	Swedoor_JW_Fun	Swedoor_JW_Funct	Project	New Project	Foudnations
Swedoor_JW_Function_Bering_single_outswing: 23					
<b>Grand total: 42</b>					

Table 15 - Deconstruction Doors Schedule

Regarding the steel structure to deconstruct, some improvements were found on Revit quantifications comparatively with Navisworks. In chapter 3 it was said that it was not

possible to quantify the steel structure because this model came from an older version from Tekla Structures software. Some incompatibilities were found because of the fields where the information was being transferred from. On Revit it was possible to add these specific fields, for example the weight of the different parts of the structure, to the columns of the sheet as it can be seen in Table 166. There is only an example of one plate that will have to be removed. The rest of the sheet is in APPENDIX 2. Regarding this table it was agreed that the most important fields to be presented were:

- Type;
- Object Type Override;
- Assembly Mark;
- Assembly Weight;
- Grade;
- Part Marks;
- Phase created;
- Phase Demolished.

Deconstruction Metallic Structure Schedule							
Type	Object Type Override	Assembly mark (Tekla Common)	AssemblyWeight (Tekla Quantity)	Grade(Tekla Common)	Part mark (Tekla Common)	Phase Created	Phase Demolished
<b>PLATE</b>							
<b>CHP15*107.1</b>							
PLATE	CHP15*107.1	A43BR1	61,46 kg	S275JR	A43PL4	Project	New Project
PLATE	CHP15*107.1	A43BR2	61,46 kg	S275JR	A43PL4	Project	New Project
PLATE	CHP15*107.1	A43BR3	60,15 kg	S275JR	A43PL4	Project	New Project
PLATE	CHP15*107.1	A43BR4	60,15 kg	S275JR	A43PL4	Project	New Project
<b>CHP15*107.1: 12</b>			<b>243,23 kg</b>				

Table 16 - Deconstruction Steel Structure Schedule

This is a tool with huge potential because it will be possible to program how many trucks will be necessary to remove all the deconstruction parts from the place and estimate costs for this. Comparing this Quantification performed in Revit against the other one made in Navisworks, it is possible to see that in Revit it was possible to quantify the weight of the steel structure to be deconstructed. It was possible because Revit gives the possibility to choose each parameter that it is wished to put on the quantifications sheets. Navisworks, with the information exchange, lost some information. On this case it will not be shown the complete table in appendix because it has several pages. However, the grand total of pieces to be deconstructed is 1274 and the weight of them is 484406,41 Kg.

The last element that was performed for deconstruction schedules were the walls. Many walls need to be removed, so it will be interesting to know the quantities of walls to be removed to help with the budgeting works. During the study of quantifications in Revit, as it can be seen in Table 177, it is also possible to order the elements as it is thought to be the best way to sort the elements. In this case it was decided to sort the walls regarding its Omniclass classification number. There is great potential in objects classifications where it will be possible to quantify with a structural organization that is internationally recognized.

For this schedule it was decided to perform the table with the following parameters:

- Keynote;
- Area;
- Type;
- Base Constraint;
- Family;
- Family and Type;
- Function;
- Length;
- Phase Created;
- Phase Demolished;
- Structural Material;
- Volume;
- Width.

Deconstruction Walls Schedule												
Keynote	Area	Type	Base Constraint	Family	Family and Type	Function	Length	Phase Created	Phase Demolished	Structural Material	Volume	Width
23-17-21-13-15												
Knauf Danogips E MR 450 160/160 AA/AA M0												
Foundations												
23-17-21-13-15	30,57 m²	Knauf Danogips E MR 450 160/160 AA/AA M0	Foundations	Basic Wall	Basic Wall: Knauf Danogips E MR 450 160/160 AA/AA M0	Interior	7,74	Project	New Project	Knauf Danogips - Vacant	6,42 m³	0,21
23-17-21-13-15	8,80 m²	Knauf Danogips E MR 450 160/160 AA/AA M0	Foundations	Basic Wall	Basic Wall: Knauf Danogips E MR 450 160/160 AA/AA M0	Interior	2,37	Project	New Project	Knauf Danogips - Vacant	1,85 m³	0,21
23-17-21-13-15	8,80 m²	Knauf Danogips E MR 450 160/160 AA/AA M0	Foundations	Basic Wall	Basic Wall: Knauf Danogips E MR 450 160/160 AA/AA M0	Interior	2,31	Project	New Project	Knauf Danogips - Vacant	1,85 m³	0,21
Foundations: 3 48,17 m²												
Knauf Danogips E 48,17 m²												
23-17-21-13-15-3 48,17 m²												

Table 17 - Deconstruction Walls Schedule

In the previous table a parameter was chosen that will definitely help with the deconstruction works. There is the possibility of seeing a parameter which is the volume that calculates the exact volume of the total walls to be deconstructed. If there is the possibility of deconstructing the walls instead of demolishing them, it is known how much volume will be necessary to carry the walls to another place and every measure that the truck will need to have for this work. This is an extremely powerful tool that will help perform a deconstruction execution plan.

#### 4.6.2.2. Upgrading quantities

In this second part of quantifications, the new parts to be constructed during the upgrading works were quantified. The same process that was shown before was followed as it could be seen in Table 188.

Racket Pallets Schedule				
Family	Family and Type	Level	Phase Createdse Demoli	Type
Pallet_Racking_-Victor_85	Pallet_Racking_-Victor_8578: 900 x 3600mm Racking		Novo projeto	None 900 x 3600mm Racking
<b>Grand total: 1440</b>				

Table 18 - Upgrading Racket Pallets Scheduling

In this subchapter the new doors, floors, walls, pallets and stairs to be constructed were quantified. As it has the same aspect of the previous tables shown, it has been placed in APPENDIX 2 for illustrative purposes.

#### 4.6.2.3. Work and quantities map preparation

In the two preceding sub-sections, the QTO of the interventions have been described.

In a construction company, receiving a project to bid, firstly it is necessary to measure every works to do on technical department and after that it is necessary to send to other department to bid, the commercial department. The document sent to the commercial department has to be a clear description of the works and they have to be organized by a structure developed by the company which could be seen on some CASAIS, S.A. quantification sheets showed before.

Regarding BIM methodology, there are some processes that could be optimized and better organized. As it was explained before, it is possible to extract the quantities with a column with the classification system used on this dissertation. It will provide organization and a complete and integral sheet with every works.

Unfortunately, regarding the classification systems, there are not yet classification for interventions in existing buildings as the deconstruction, refurbishment and renovation works. For example, when classifying a door with its OmniClass number it will not possible to understand if it belongs to a deconstruction, renovation, or refurbishment. However, as the objects were classified during the modelling, it was used to better organize the tables, but this classification does not distinguish each intervention will be made as deconstruction, renovation or refurbishment. That was the reason to perform three different tables: Removal and deconstruction works (Table 199); Refurbishment works (Table 2020); and Renovation works (Table 2121).


 <b>CASAIS</b>		Mobile: (+351) 253 305 400 Fax: (+351) 253 305 499 Web - Site: www.casais.pt	
<b>Identity:</b>	<b>André Lima</b>	<b>Date:</b>	July 2015
<b>Building:</b>	<b>ITARION Interventions</b>	<b>Page:</b>	
<b>Omniclass Number</b>	<b>Designation</b>	<b>unit</b>	<b>quantity</b>
<b>REMOVAL AND DECONSTRUCTION WORKS</b>			
<b>23-13 00 00 Structural and Exterior Enclosure Products</b>			
23-13 35 19	Steel purlins and bracings	kg	486406.41
23-13 35 19	Steel Stairs	un	6
23-13 35 23	Structural Floors and Flat Roofs		
<b>23-13 35 23 11 Structural Floor Decks</b>			
23-13 35 23 11 13	Production zone ceiling	m2	8000
<b>23-15 00 00 Interior and Finish Products</b>			
23-15 13 23	Plasterboard walls	m2	1084.3
23-15 13 23	Masonry walls	m2	3227.66
<b>23-17 00 00 Openings, Passages, and Protection Products</b>			
23-17 11 13	Metal Doors		
<b>23-17 11 13 15.1</b>	<b>Steel Doors (Type 1)</b>	<b>un</b>	<b>23</b>
<b>23-17 11 13 15.2</b>	<b>Steel Doors (Type 2)</b>	<b>un</b>	<b>19</b>
23-17 23 17	Stair	un	1
<b>23-17 23 17 11 Stair Component Products</b>			
23-17 23 17 11 17	Raillings	un	6

Table 19 - Removal and deconstruction works list


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<b>Building:</b>	<b>ITARION Interventions</b>	<b>Page:</b>	
<b>Omniclass Number</b>	<b>Designation</b>	<b>unit</b>	<b>quantity</b>
<b>NEW CONSTRUCTION</b>			
<b>23-11 00 00 Site Products</b>			
23-11 21 13	Roadways		
<b>23-11 21 13 13</b>	<b>Outdoor pavement in tar</b>	<b>m2</b>	<b>3922.13</b>
<b>23-13 00 00 Structural and Exterior Enclosure Products</b>			
23-13 33 27	Glazed Facade and Roof Structures		
<b>23-13 33 27 11</b>	<b>Curtain wall North Side</b>	<b>m2</b>	<b>426.21</b>
23-13 35 23	Structural Floors and Flat Roofs		
<b>23-13 35 23 11</b>	<b>Structural Floor Decks</b>		
23-13 35 23 11 11	Exterior and Finish interior pavements	<b>m2</b>	<b>2250.28</b>
<b>23-15 00 00 Interior and Finish Products</b>			
23-15 13 23	Divisor walls between each warehouse	<b>m2</b>	<b>2521.13</b>
<b>23-17 00 00 Openings, Passages, and Protection Products</b>			
23-17 11 13	Metal Doors		
<b>23-17 11 13 15.1</b>	<b>Steel Doors (Type 1)</b>	<b>un</b>	<b>29</b>
<b>23-17 11 13 15.2</b>	<b>Steel Doors (Type 2)</b>	<b>un</b>	<b>16</b>
23-17 11 19	Composite Doors		
<b>23-17 11 19 13</b>	<b>Exterior gates</b>	<b>un</b>	<b>32</b>
23-17 23 17	Stair	<b>un</b>	<b>16</b>
<b>23-17 23 17 11</b>	<b>Stair Component Products</b>		
23-17 23 17 11 17	Raillings	<b>un</b>	<b>7</b>
<b>23-21 00 00 Furnishings, Fixtures and Equipment Products</b>			
23-21 11 11	Commercial Storage Units		
<b>23-21 11 11 17</b>	<b>Racking pallets</b>	<b>un</b>	<b>1440</b>
<b>23-23 00 00 Conveying Systems and Material Handling Products</b>			
23-23 11 00	Vertical Transportation Equipment		
<b>23-23 11 11 11</b>	<b>Traction Elevators</b>		
23-23 11 11 11 11	Freight Traction Elevators	<b>un</b>	<b>16</b>
23-23 11 11 11 13	Passenger Traction Elevators	<b>un</b>	<b>1</b>

Table 20 - New construction works list

As it can be observed in Table 21, the Omniclass classification system was not used due to the aspects referred previously, and it was only classified by articles and order of works. For example the renovation of the exterior steel walkways it is known that some extension need to be repaired but this is a quantification that is impossible to be precisely. However, an estimation was made.


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<b>Building:</b>	<b>ITARION Interventions</b>	<b>Page:</b>	
<b>Article</b>	<b>Designation</b>	<b>unit</b>	<b>quantity</b>
<b>RENOVATION (estimation)</b>			
✓ 1.	Steel structures (walkways)	m2	195
✓ 2.	Curtain wall (south)	m2	404.06
✓ 3.	Exterior façades	m2	2849.8

Table 21 - Renovation works

After this work it was found that Omniclass has some limitations on classifying the specific works presented for the necessary interventions. For this reason it is thought that it would be better for construction companies to accordingly adapt their already developed traditional classification system and made the necessary alterations to use it in BIM methodology. It will facilitate the comprehension of the system as it is already known in the company, preventing a complete adoption of a new classification system and its implementation drawbacks.

#### 4.6.3. Construction planning (4D)

As there is not any planning for the intervention works in CAS AIS, S.A., as they are still on the designing phase, a planning was prepared including the operations of deconstruction works as well as the new construction. It was decided to use Microsoft Project instead of prepare it directly in Navisworks, because it is a specific software to perform chart diagrams and as mentioned before it was understandable full interoperability between these two software.



As it was shown in chapter 3 in ‘Construction Planning (4D)’, it was possible to associate each activity to each modelled object. After that, an extremely potential tool could be executed, which consists of a sequential construction representation of the works that are being held with a timeline showing the course of time and the works evolution. This is a great step in construction that will immensely help companies. As mentioned before, there is a possibility of assigning different colours to different activities. For this case, the deconstruction works will appear in yellow and the new construction works will appear in red which is normally used by the architects for this type of works.

Another aspect of the 4D BIM is the preparation of works which means an important preoccupation to construction companies. It was to be well planned to try to optimize time and processes during construction to increase productivity. Normally, in the traditional method, it is performed a CAD drawing with some details of the construction site organization. As it can be seen in Figures 106 and 107, with BIM it will be possible to have a 3D visualization of these works as well as extracting automatically the necessary plans. Normally, identifying the different zones and plan the construction site by the traditional method it is a really fast process to perform. However, with the BIM model finished, it is also extremely easy to identify different areas and to add specific temporary elements for construction and better understand the construction environment.

In addition to that it would be possible to add this to a 3D sequential construction representation of the works to be performed and detect if it is the best construction site planning. It was concluded in CASAIS, S.A. that with BIM it will be possible to have a holistic vision of the building site before starting the construction itself which will help to prevent some disorder or access difficulties that usually happen with the traditional methods.

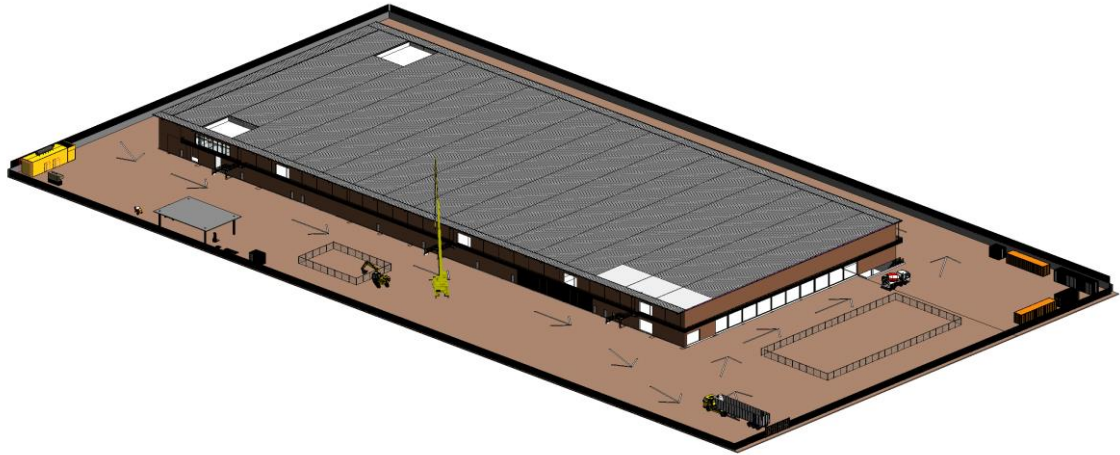


Figure 106 - 3D view of the construction site planning

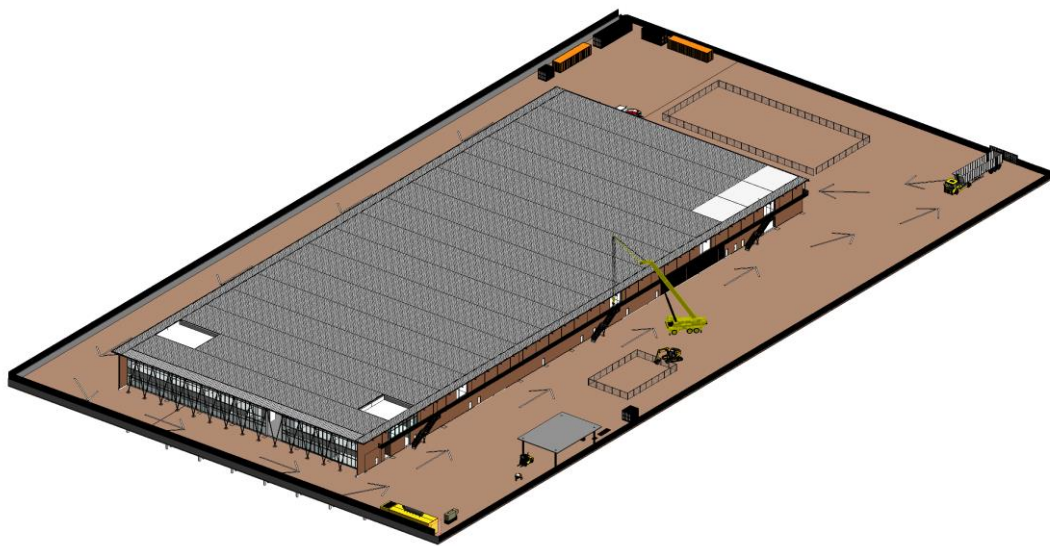


Figure 107 - Other 3D view of the construction site planning

All the machines, containers, fences, gates that could be seen in the above figures were obtained from RevitCity online library.

In Figure 108 it is possible to see an automatically extracted plan drawing with every details and information considering the construction site planning. It is possible to see a table with the designation of each element and its number with respective association to the figure; small 3D to help the visualization; every signposting necessary to put in the construction site; and general construction information on the label of the sheet.

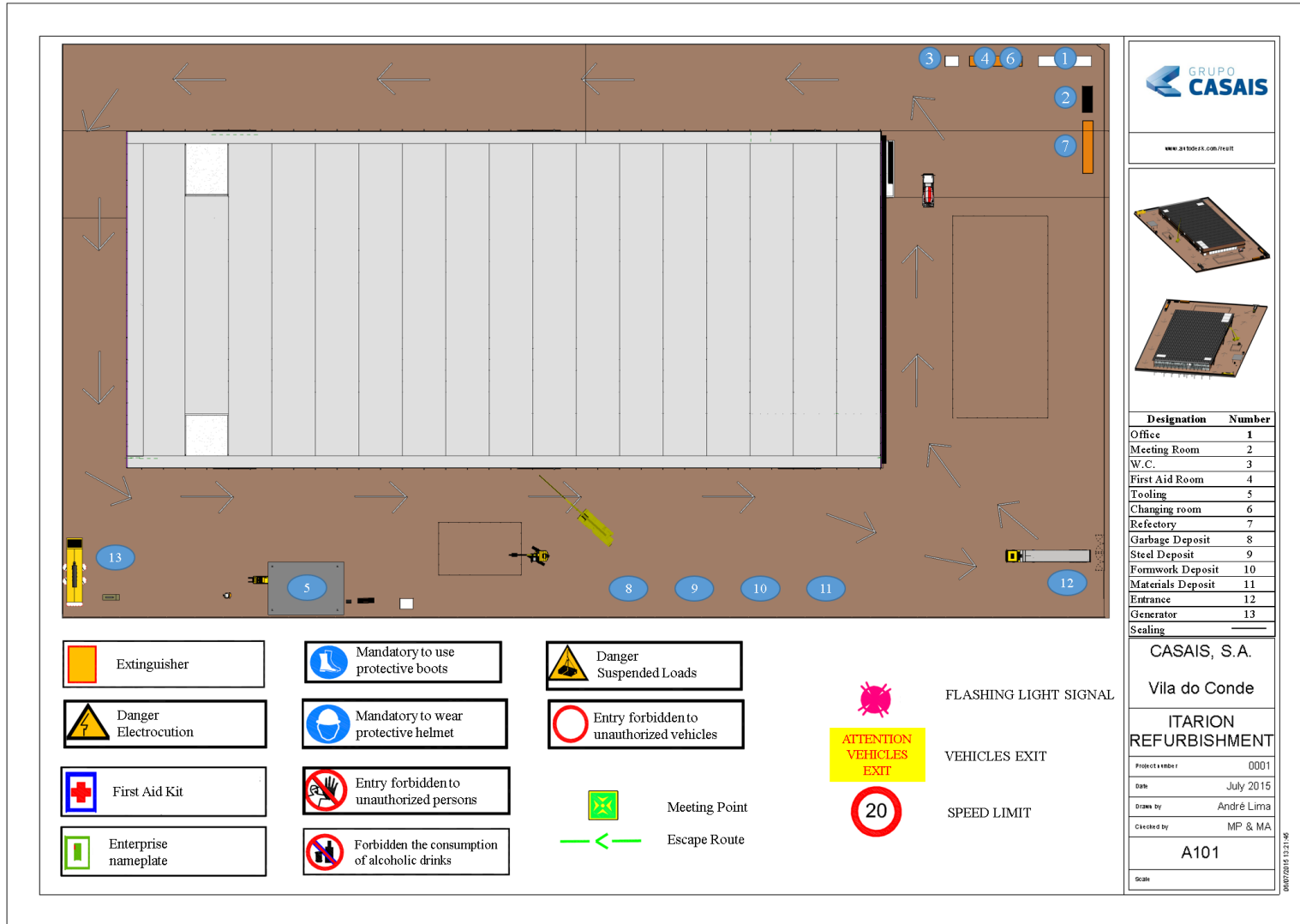


Figure 108 - Sheet extracted from Revit



## 5. CONCLUSIONS AND FUTURE DEVELOPMENTS

### 5.1. General considerations

In a global way, this dissertation has attained its initial objectives: an overview and experimentation of BIM capabilities and uses, with particular focus on upgrading interventions in existing buildings. The dissertation was developed within a collaboration between the University of Minho and the construction company CASAIS SA. Therefore, the approaches and methods were frequently dictated by the exploratory interest of the company, as to maximize the useful outcome of the work in what concerns industrial application.

With this dissertation it was possible to go a bit further beyond the BIM 3D, where some aspects of 3D modelling could be seen, some studies about classifications systems, LOD definitions and quantifications, and also the benefits of BIM 4D where construction planning with the inclusion of temporary elements was studied.

During the dissertation references were made about the limitations that were found during all the work and different types could be defined. Sometimes software limitations were found, others could be a lack of knowledge and some others could also be a lack of information.

- In what concerns software limitations, it is not possible to do much more unless starting to program or wait for a better version in the future which will solve the current lack of potentialities.

- Talking about knowledge limitations, it was felt that there are people and companies that are already working in a very high BIM maturity environment which are able to perform a lot of BIM specific potentialities. However, specific information with tutorials is hard to find on the internet. Most of the times is only possible to find basic information and tutorials about software for example. In addition to that, to perform certain BIM potentialities it is necessary maturity as it was referred before. Only sometime after BIM implementation it would be possible to have the necessary skill to perform specific potentialities also with less time consuming. It is known that are some companies that already implemented BIM that still to perform some traditional works to check and confirm if it is everything going in a good way. Maybe it is happening because they do not have yet the necessary BIM maturity to perform fully reliable BIM works.

- Lastly, the informational limitations, mean that at this moment, in certain aspects, BIM is still in development and some functionalities cannot be performed at least for now.

However, a general overview could be made by systematising some important aspects and recommendations were achieved during the execution of the dissertation:

- Regarding the classification systems, it was reviewed some of the most known systems and it was tried to apply on the present dissertation. It was found some difficulties on doing a direct application for this specific case and that is why it is recommended to adopt existent classifications systems but adapt it to better fit in the different AEC companies. It would be extremely difficult to find an existent classification system which fits perfectly on a specific AEC company.

- Due to the lack of information for existing buildings, it was difficult to percept which LOD would be the necessary to perform the works pretended in terms of deconstruction, renovation and refurbishment.

- An as-built model was reached with some simplifications as for example the exterior walls, plasterboard walls, some damaged objects etc. It is necessary to understand exactly which uses are pretended from the BIM model before the modelling starts. This will help to understand which level of accuracy is necessary to perform the works initially pretended.

- As mentioned in Chapter 2, it is being seen an increasing manufacturer's preoccupation on having their own products modelled in BIM available on free online libraries. It is recommended to use these objects because they are normally made by professionals with the necessary and accurate information needed for a BIM model, making the modelling easier to perform.

- It was used the data capturing techniques mentioned in Chapter 2 except the laser scanning because sufficient pre-existing information was given. However, it is advisable to use that even for a quality control checker of the as-built model modelled. In cases without sufficient pre-existing information it is extremely recommended to use as an important to tool to perform an accurate as-built model.

- In QTO it is also advisable to know before the modelling starts which elements are wanted to extract its quantification. Considering this, it will be possible to know before the modelling start how it will be necessary to model the objects to extract this

information. Otherwise, it could take to the re-modelling of certain objects that were not modelled to QTO as it was found on this dissertation. In some complex object geometries it is advised to use specific parametric software.

- Lastly, considering BIM 4D, the present works done on this dissertation about this matter were relatively easy and fast to perform comparing with the traditional methods. However, it could be thought that it is not a great step for construction planning because there are not many potentialities regarding the traditional methods. Despite the presented potentialities, BIM 4D could bring some other interesting potentialities regarding the line of balance and the comparison of the percentage of completion planned with actual values for each task will help a lot the construction works.

Generally, it is thought that a good work was done where any AEC company could have the opportunity to better understand this emergent methodology and to find some advantages of BIM either for new or existing buildings. Regarding Imocasais department, which is the CASAIS, S.A. department that is developing the new study of ITARION building, it was received a good feedback of BIM methodology. It was referred that it would be a great help to them to this reformulation in a 3D environment and have the possibility to see the alterations in a real perspective instead the traditional 2D CAD drawings. Generally, BIM was considered as a creative and innovative tool as an evolutionary process for the architectural project.

Furthermore, during the realization of the present thesis it was possible to show the work in progress to different people from AEC companies, from the university or even in workshops and trainings where some good feedback was received about its viability.

## 5.2.Future developments

Regarding the future of BIM in existing buildings it is thought that further development in diverse fields is needed:

- Functionally, as it was found in literature and referred on this dissertation, there are several potentialities with the utilization of BIM in existing buildings. But as it was also found, for example, COBie excludes information for elements for refurbishment or deconstruction planning. It will also be necessary to develop LOD for deconstruction related functionalities to know exactly what information the objects should have. In addition to that, further developments are required on the attribute and integration of techniques as, for example, semantic reasoning, that is essential to give attributes without being ambiguous, providing a better data capture and processing. This will help the interoperability between BIM and advanced functionalities and facilitate BIM implementation in existing buildings.

- The interoperability is one of the biggest obstacles between new and existing buildings. There has been a continuous development on universal structures of information but redirected to new buildings. During the literature review it was found that for deconstruction processes there is no information exchange. Unfortunately, due to the long life cycle of buildings and infra-structure, challenges arise from interoperability together with the rapid development of BIM models, the BIM expert functionalities and the continuous model maintenance during building's life cycle.

- Due to the fact of not having appropriate contractual documentation for deconstruction interventions, the different surveying and capture techniques used could differ from one to the other. The LOD and the technique used will influence all that comes next regarding the BIM creation and its effort. Although there is no information about LOD for deconstruction interventions, it is only known that is a time consuming process regarding the data capturing, processing and creation process. Furthermore and as explained before, it would be better to include other tests like material or texture bases recognition and non-destructive tests to improve the capturing and surveying. Resulting of the research made it was found that some of the most important challenges at this moment are effort reduction (automation) of capturing, processing, recognizing and 'as-built' BIM creation anew; capturing and integrating semantic information into BIM; as well as addressing technique-specific restrictions such as environmental influences in



field operation or post-processing of concealed, distorted, structural or semantic building information.

- With the spread of BIM in AEC industry, traditional processes and stipulations are adapted at different speed and scope to digitally supported collaboration through BIM. Unfortunately, only some countries are under political pressure which represents a boost to organization and legal BIM frameworks. In addition to that, resistance and lack of training is a fact to deal with. However, some collaboration systems are being improved and developed, so it is expected to have some new capacities to facilitate the process of collaboration.

- As far as it is understood, BIM implementation requires profound process changes, whose has great implications on contractual relationships in AEC industry. Institutions and professional associations in leading countries provide contract templates and legal advice for stakeholders in new buildings. Regarding existing buildings, there is a necessity to adapt the legal frameworks.

- Lastly, these companies that are more focused on more advanced life cycle activities like FM, Deconstruction and Upgrading will have to have an interdisciplinary education to implement BIM in existing buildings.

These items are thought to be the most important to start to implement BIM in existing buildings. However, as it was also said during the dissertation, as long as issues regarding new buildings are not fully studied and defined, it will not be possible to start with this even more meticulous process on existing buildings.



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# APPENDIX 1

Designation	ModelLength	ModelWidth	ModelThickness	ModelHeight	ModelPerimeter	ModelArea	ModelVolume
<b>Walls</b>							
<b>CERANOR 14</b>							
Brick Ceramor 140 mm (EXTERIOR/EXTERIOR)	1.71		0.14	4.50		6.83	0.96
Brick Ceramor 140 mm (masonry 1 faces)	5.76		0.42	13.50		25.88	3.62
<b>CERANOR 19</b>							
Brick Ceramor 190 mm (masonry 2 faces)	95.91		3.80	86.20		413.14	78.50
Brick Ceramor 200 mm (masonry 1 face)	4.60		0.20	4.30		19.78	3.96
Brick Ceramor 200 mm (c/masonry 2 face)	10.00		0.20	4.30		43.00	8.60
Brick Ceramor 200 mm (S/masonry interior/EXTERIOR)	5.15		0.20	18.00		46.31	4.63
Brick Ceramor 200 mm (S/masonry interior/EXTERIOR) 2	3.69		0.30	54.00		23.36	1.17
<b>CERANOR 29</b>							
Brick Ceramor 290 mm (c/masonry 2 faces) 2	4.60		0.29	4.50		20.70	6.00
Brick Ceramor 300 mm	20.63		1.50	21.50		88.70	26.61
Brick Ceramor 300 mm (c/masonry 2 faces) (1)	492.87		10.80	156.20		1945.56	583.67
Brick Ceramor 300 mm (c/masonry 2 faces) (2)	313.23		2.10	30.20		1383.34	415.00
Brick Ceramor 300 mm (c/masonry interior) (1)	59.24		3.90	56.30		256.19	76.86
Brick Ceramor 300 mm (c/masonry interior) (2)	128.68		1.80	25.70		568.24	170.47
Brick Ceramor 300 mm (c/masonry interior) (3)	72.50		0.30	0.40		29.00	8.70
Brick Ceramor 300 mm (c/masonry interior/EXTERIOR) (1)	358.49		2.40	36.00		1432.20	429.66
Brick Ceramor 300 mm (c/masonry interior/EXTERIOR) (2)	302.23		2.40	36.44		1294.55	388.36
Brick Ceramor 300 mm (c/masonry interior/EXTERIOR) (3)	61.61		0.60	2.90		89.34	26.80
Brick Ceramor 300 mm (S/masonry interior/EXTERIOR)	8.31		0.90	12.90		33.71	10.11
<b>Gesso 48</b>							
Knauf Danogips E MR 450 45/45 -AA M0	65.08		0.64	120.00		260.33	6.10
<b>Gesso 70</b>							
Knauf Danogips E MR 450 70/70 -AA M0	18.25		0.17	16.00		73.01	2.27
Knauf Danogips E MR 450 70/70 A/A M0	260.03		1.79	240.00		1040.11	32.98
Knauf Danogips E MR 450 70/70 AA/AA M0 (1)	272.92		1.88	262.30		832.41	20.05
Knauf Danogips E MR 450 70/70 AA/AA M0 (2)	586.43		6.42	1214.50		2617.58	63.00
<b>Gesso DUPLAS</b>							
Knauf Danogips E MR 450 160/160 AA/AA M0	60.12		0.71	84.00		240.46	10.17
<b>Roof cover</b>							
Nervured plate							45.64
Nervured plate 1 Level							28.89
Cover insulation			0.20			13186.30	131.86
Insulation			0.18			1214.09	85.24
Sheet finish 1mm			0.01			7987.76	79.88
Insulation and Mansonry	796.81		1.48	156.29		3216.01	158.23
<b>Walls finish</b>							
<b>Wood finish</b>							
Front wall s/ Brick	50.30		0.01	5.05		252.57	2.53
Brick Ceramor 140 mm (EXTERIOR/EXTERIOR)	1.71		0.01	4.50		6.83	0.07
Brick Ceramor 200 mm (S/masonry interior/EXTERIOR)	5.42		0.02	18.00		48.81	0.49
Brick Ceramor 200 mm (S/masonry interior/EXTERIOR) 2	5.95		0.04	36.00		53.37	0.53
Brick Ceramor 300 mm (c/masonry interior/EXTERIOR) (1)	359.98		0.08	36.00		1440.07	14.40
Brick Ceramor 300 mm (c/masonry interior/EXTERIOR) (2)	303.18		0.08	36.44		1300.39	13.00
Brick Ceramor 300 mm (c/masonry interior/EXTERIOR) (3)	61.61		0.02	2.90		89.34	0.89
<b>Serralharias/Vidros</b>							
<b>open E1</b>							
Curtain Panels							
System panels							
Glass		332.36	5.54	336.88		404.08	8.08
Curtain Wall Mullions							
Rectangular Mullion							
50 x 150mm	643.00		70.50			132.13	4.82
Beam	56.37		7.05			101.37	12.39
Beam 2	64.87		8.10			81.61	9.58
<b>open E13</b>							
50 x 150mm	269.29		30.30			55.37	2.02
Curtain Wall Sgl Glass		1.13	0.00	2.14		2.40	0.03
M_Curtain Wall Sgl Glass		3.62	0.00	6.40		7.74	0.10
Glass		91.41	1.52	107.46		129.29	2.59
<b>open E14</b>							
50 x 150mm	60.69		6.30			12.45	0.46
Curtain Wall Sgl Glass		1.13	0.00	2.14		2.40	0.03
Vidro		21.04	0.30	21.07		29.73	0.59
<b>open E2</b>							
Swedoor_JW_Function_Bering_single_outswing		22.50	0.00	45.12		112.64	3.30
<b>open E5</b>							
ITARION		2.27	0.00	7.24		18.20	0.21
<b>open E6</b>							
ITARION		2.27	0.00	7.24		18.20	0.21
<b>open E7</b>							
ITARION		18.16	0.00	57.92		145.60	1.72





<b>brick Ceramor 300 mm (c/masonry interior)</b>										
<b>Foundations</b>										
21-03 10 10 10	54,96 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	12,99 Project	New Project	brick furado (red)	17,59 m³	0,32
21-03 10 10 10	0,17 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	0,21 Project	New Project	brick furado (red)	0,06 m³	0,32
21-03 10 10 10	0,01 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	0,22 Project	New Project	brick furado (red)	0,00 m³	0,32
21-03 10 10 10	2,72 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	0,47 Project	New Project	brick furado (red)	0,87 m³	0,32
21-03 10 10 10	1,28 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	0,47 Project	New Project	brick furado (red)	0,41 m³	0,32
21-03 10 10 10	20,30 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	4,89 Project	New Project	brick furado (red)	6,49 m³	0,32
21-03 10 10 10	42,83 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	10,34 Project	New Project	brick furado (red)	13,70 m³	0,32
21-03 10 10 10	42,92 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	10,35 Project	New Project	brick furado (red)	13,72 m³	0,32
21-03 10 10 10	12,92 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	2,76 Project	New Project	brick furado (red)	4,13 m³	0,32
21-03 10 10 10	19,18 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	4,46 Project	New Project	brick furado (red)	6,14 m³	0,32
21-03 10 10 10	13,29 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	2,85 Project	New Project	brick furado (red)	4,25 m³	0,32
21-03 10 10 10	21,67 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	5,2 Project	New Project	brick furado (red)	6,92 m³	0,32
21-03 10 10 10	23,15 m²	brick Ceramor 300 mm (c/masonry interior)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	5,15 Project	New Project	brick furado (red)	7,41 m³	0,32
Foundations: 13	255,39 m²									
<b>Level 1</b>										
21-03 10 10 10	26,60 m²	brick Ceramor 300 mm (c/masonry interior)	Level 1	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	8,31 Project	New Project	brick furado (red)	8,51 m³	0,32
21-03 10 10 10	45,47 m²	brick Ceramor 300 mm (c/masonry interior)	Level 1	Basic Wall Basic Wall: brick Ceramor 300 mm (c/masonry interior)	Interior	10,04 Project	New Project	brick furado (red)	13,91 m³	0,32
Level 1: 2	70,07 m²									
brick Ceramor 300 325,47 m²										
21-03 10 10 10: 43.823,31 m²										
<b>Knauf Danogips E MR 450 70/70 -/AA M0</b>										
<b>Foundations</b>										
24,69 m²	Knauf Danogips E MR 450 70/70 -/AA M0	Foundations	Basic Wall Basic Wall: Knauf Danogips E MR 450 70/70 -/AA M0	Interior	6,21 Project	New Project	Knauf Danogips - Vacant	2,35 m³	0,1	
Foundations: 1	24,69 m²									
Knauf Danogips E 24,69 m²										
<b>brick Ceramor 140 mm (EXTERIOR/EXTERIOR)</b>										
<b>Foundations</b>										
6,79 m²	brick Ceramor 140 mm (EXTERIOR/EXTERIOR)	Foundations	Basic Wall Basic Wall: brick Ceramor 140 mm (EXTERIOR/EXTERIOR)	Interior	1,71 Project	New Project	brick furado (red)	2,30 m³	0,34	
Foundations: 1	6,79 m²									
brick Ceramor 140 6,79 m²										
<b>brick Ceramor 140 mm (masonry 1 faces)</b>										
<b>Level 1</b>										
15,38 m²	brick Ceramor 140 mm (masonry 1 faces)	Level 1	Basic Wall Basic Wall: brick Ceramor 140 mm (masonry 1 faces)	Interior	3,58 Project	New Project	brick furado (red)	2,45 m³	0,16	
9,27 m²	brick Ceramor 140 mm (masonry 1 faces)	Level 1	Basic Wall Basic Wall: brick Ceramor 140 mm (masonry 1 faces)	Interior	2,31 Project	New Project	brick furado (red)	1,48 m³	0,16	
1,09 m²	brick Ceramor 140 mm (masonry 1 faces)	Level 1	Basic Wall Basic Wall: brick Ceramor 140 mm (masonry 1 faces)	Interior	0,16 Project	New Project	brick furado (red)	0,17 m³	0,16	
Level 1: 3	25,74 m²									
brick Ceramor 140 25,74 m²										
<b>brick Ceramor 200 mm (masonry 1 face)</b>										
<b>Foundations</b>										
19,55 m²	brick Ceramor 200 mm (masonry 1 face)	Foundations	Basic Wall Basic Wall: brick Ceramor 200 mm (masonry 1 face)	Interior	4,92 Project	New Project	brick furado (red)	4,30 m³	0,22	
Foundations: 1	19,55 m²									
brick Ceramor 200 19,55 m²										
<b>brick Ceramor 200 mm (masonry 2 face)</b>										
<b>Foundations</b>										
42,83 m²	brick Ceramor 200 mm (masonry 2 face)	Foundations	Basic Wall Basic Wall: brick Ceramor 200 mm (masonry 2 face)	Interior	10,34 Project	New Project	brick furado (red)	10,28 m³	0,24	
Foundations: 1	42,83 m²									
brick Ceramor 200 42,83 m²										
<b>brick Ceramor 300 mm</b>										
<b>Foundations</b>										
1,19 m²	brick Ceramor 300 mm	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm	Interior	0,49 Project	New Project	brick burro vermelho	0,36 m³	0,3	
0,61 m²	brick Ceramor 300 mm	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm	Interior	0,14 Project	New Project	brick burro vermelho	0,18 m³	0,3	
41,71 m²	brick Ceramor 300 mm	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm	Interior	9,85 Project	New Project	brick burro vermelho	12,51 m³	0,3	
42,83 m²	brick Ceramor 300 mm	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm	Interior	10,34 Project	New Project	brick burro vermelho	12,85 m³	0,3	
Foundations: 4	86,34 m²									
brick Ceramor 300 86,34 m²										
<b>brick Ceramor 300 mm (S/masonry interior/EXTERIOR)</b>										
<b>Foundations</b>										
9,42 m²	brick Ceramor 300 mm (S/masonry interior/EXTERIOR)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (S/masonry interior/EXTERIOR)	Interior	1,99 Project	New Project	brick furado (red)	3,76 m³	0,4	
16,27 m²	brick Ceramor 300 mm (S/masonry interior/EXTERIOR)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (S/masonry interior/EXTERIOR)	Interior	4,38 Project	New Project	brick furado (red)	6,50 m³	0,4	
8,60 m²	brick Ceramor 300 mm (S/masonry interior/EXTERIOR)	Foundations	Basic Wall Basic Wall: brick Ceramor 300 mm (S/masonry interior/EXTERIOR)	Interior	2,03 Project	New Project	brick furado (red)	3,43 m³	0,4	
Foundations: 3	34,28 m²									
brick Ceramor 300 34,28 m²										
14	240,22 m²									
<b>Grand total: 195 4.311,96 m²</b>										

<b>New Door Schedule</b>				
Family	Family and Type	Phase Created	Phase Demolished	Level
<b>M_Curtain Wall Sgl Glass: M_Curtain Wall Sgl Glass</b>				
M_Curtain Wall	S_M_Curtain Wall Sgl Glass: I	new project	None	Foundations
M_Curtain Wall Sgl Glass: M_Curtain Wall Sgl Glass: 25				
<b>Venezian door Metálica: ITARION 1.25</b>				
Venezian door	Me Venezian door Metálica: IT	new project	None	Level -1
Venezian door steel: ITARION 1.25: 4				
<b>Steel_roller_Shutter_door_8580: Roller Shutter Door</b>				
Steel_roller_Shutt	Steel_roller_Shutter_door_8	new project	None	Foundations
Steel_roller_Shutter_door_8580: Roller Shutter Door: 16				
<b>Steel_roller_Shutter_door_8580: Roller Shutter Door 3000</b>				
Steel_roller_Shutt	Steel_roller_Shutter_door_8	new project	None	Foundations
Steel_roller_Shutter_door_8580: Roller Shutter Door 3000: 16				
<b>Swedoor_JW_Function_Bering_single_outswing: ITARION</b>				
Swedoor_JW_Fun	Swedoor_JW_Function_Ber	new project	None	Foundations
Swedoor_JW_Function_Bering_single_outswing: ITARION: 16				
<b>Grand total: 77</b>				

New Stair Schedule											
Actual Number of Riser	Actual Rise	Actual Tread	Base Level	Function	Keynote	Landing Type	Minimum Phase	Createc Phase	Demolished	Run Type	Top Level
7	0,17	0,28	New architecture	Exterior	21-02	10 80 10	300 mm	0,21	New Project	None	40 mm Pi Foundations
<b>Grand total: 16</b>											

New Wall Schedule											
Type	Area	Base Constraint	Family	Family ar	Function	Phase	Createc Phase	Demolished	Structural Materia	Volume	Width
<b>Concrete - 300 mm</b>											
<b>Foundations</b>											
Concrete - 300 mm	1,90 m <sup>2</sup>	Foundations	Basic Wa	Basic Wa	Retaining	New Project	None		Concrete	0,57 m <sup>3</sup>	0,3
Foundations: 2	1,90 m <sup>2</sup>									0,57 m <sup>3</sup>	
<b>Level 1</b>											
Concrete - 300 mm	0,90 m <sup>2</sup>	Level 1	Basic Wa	Basic Wa	Retaining	New Project	None		Concrete	0,27 m <sup>3</sup>	0,3
Level 1: 2	0,90 m <sup>2</sup>									0,27 m <sup>3</sup>	
Concrete - 300 mm	2,80 m <sup>2</sup>									0,84 m <sup>3</sup>	
<b>Curtain wall base</b>											
<b>Foundations</b>											
Parede cortina base	426,21 m <sup>2</sup>	Foundations	Curtain W	Curtain W	Exterior	New Project	None			0,00 m <sup>3</sup>	
Foundations: 18	426,21 m <sup>2</sup>									0,00 m <sup>3</sup>	
Parede cortina base	426,21 m <sup>2</sup>									0,00 m <sup>3</sup>	
<b>Brick Ceramor 10 mm (masonry 2 faces)</b>											
<b>New Architecture</b>											
Brick Ceramor 10 r	44,07 m <sup>2</sup>	New Architecture	Basic Wa	Basic Wa	Interior	New Project	None		Brick (red)	4,41 m <sup>3</sup>	0,1
New Architecture: 44,07 m <sup>2</sup>										4,41 m <sup>3</sup>	
<b>Foundations</b>											
Brick Ceramor 10 r	70,14 m <sup>2</sup>	Foundations	Basic Wa	Basic Wa	Interior	New Project	None		Brick (red)	7,01 m <sup>3</sup>	0,1
Foundations: 48	70,14 m <sup>2</sup>									7,01 m <sup>3</sup>	
Brick Ceramor 10 r	114,21 m <sup>2</sup>									11,42 m <sup>3</sup>	
<b>Brick Ceramor 15 mm (masonry 2 faces)</b>											
<b>New Architecture</b>											
Brick Ceramor 15 r	209,08 m <sup>2</sup>	New Architecture	Basic Wa	Basic Wa	Interior	New Project	None		Brick (red)	30,66 m <sup>3</sup>	0,15
New Architecture: 209,08 m <sup>2</sup>										30,66 m <sup>3</sup>	
<b>Foundations</b>											
Brick Ceramor 15 r	437,48 m <sup>2</sup>	Foundations	Basic Wa	Basic Wa	Interior	New Project	None		Brick (red)	65,56 m <sup>3</sup>	0,15
Foundations: 137	437,48 m <sup>2</sup>									65,56 m <sup>3</sup>	
Brick Ceramor 15 r	646,56 m <sup>2</sup>									96,22 m <sup>3</sup>	
<b>Brick Ceramor 200 mm (masonry 2 face)</b>											
<b>Foundations</b>											
Brick Ceramor 200 r	1.619,41 m <sup>2</sup>	Foundations	Basic Wa	Basic Wa	Interior	New Project	None		Brick (red)	388,66 m <sup>3</sup>	0,24
Foundations: 7	1.619,41 m <sup>2</sup>									388,66 m <sup>3</sup>	
Brick Ceramor 200 r	1.619,41 m <sup>2</sup>									388,66 m <sup>3</sup>	
<b>Brick Ceramor 240 mm (masonry 2 face)</b>											
<b>Foundations</b>											
Brick Ceramor 240 r	56,25 m <sup>2</sup>	Foundations	Basic Wa	Basic Wa	Interior	New Project	None		Brick (red)	13,50 m <sup>3</sup>	0,24
Foundations: 1	56,25 m <sup>2</sup>									13,50 m <sup>3</sup>	
Brick Ceramor 240 r	56,25 m <sup>2</sup>									13,50 m <sup>3</sup>	
<b>Brick Ceramor 300 mm (w/masonry interior/EXTERIOR)</b>											
<b>Foundations</b>											
Brick Ceramor 300 r	81,89 m <sup>2</sup>	Foundations	Basic Wa	Basic Wa	Interior	New Project	None		Brick (red)	34,33 m <sup>3</sup>	0,42
Foundations: 6	81,89 m <sup>2</sup>									34,33 m <sup>3</sup>	
Brick Ceramor 300 r	81,89 m <sup>2</sup>									34,33 m <sup>3</sup>	
<b>Grand total: 339 2.947,34 m<sup>2</sup></b>											
										<b>544,97 m<sup>3</sup></b>	

