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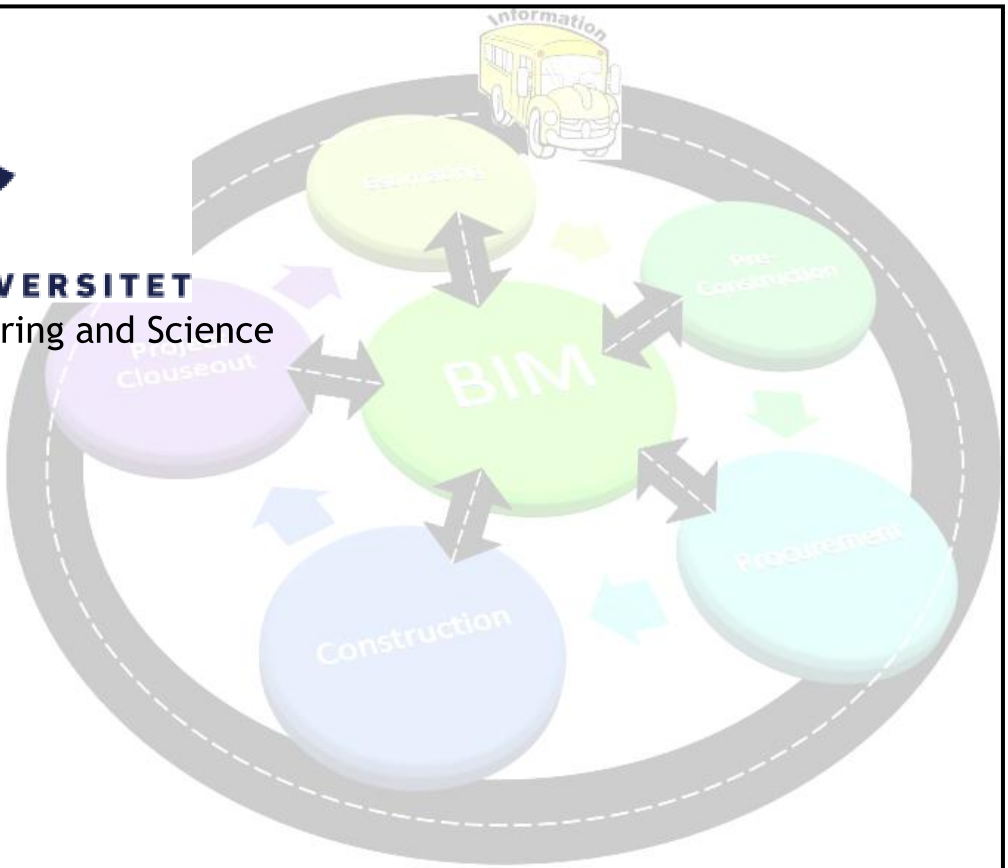

THEME:
FUTURE INFORMATION TECHNOLOGY AT THE CONTRUCTION SITE

TITLE:
BIM INSIDE THE CONTRACTORS ORGANIZATION: INFORMATION SHARING AND TRANSFERRING ALONG THE CONSTRUCTION STAGE. APPLICATION OF BIM IN INFRASTRUCTURE PROJECTS

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Master of Science Thesis in the Master Programme
Structural and Civil Engineering

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Synopsis:

This thesis focuses in the analysis of the technology at the construction site for information purpose. The study was based in the construction companies. The two main problems analyzed in this project are:

- Information sharing in the contractor's organization
- BIM in infrastructure projects

To support the study of the problems presented, are presented two theoretical chapters. One with the concepts for the project lifecycle. A second chapter with the state of art about BIM. The study have as base a real life project already executed. In the study are analyzed:

- the organizational processes
- the work processes
- the existing tools
- the need for new tools

Preface

The present document is written for the final master thesis, corresponding the 3rd and 4th semesters for the, Master in Civil and Structural Engineering at the Aalborg University in Aalborg.

This thesis under the title "BIM INSIDE THE CONTRACTORS ORGANIZATION: INFORMATION SHARING AND TRANSFERRING ALONG THE CONSTRUCTION STAGE. APPLICATION OF BIM IN INFRASTRUCTURE PROJECTS", has as main theme the topic "Future Information Technology at the Construction Site".

The idea for this project came from a project presented by the author's supervisor in the catalogue with the possible topics for the thesis. The great passion of the author for the topic lead to working on the idea.

Acknowledgements

The author would like to express his gratitude to all those who contributed to accomplish this work and assisted in this task. Many thanks for everything, without you all this would not have been possible.

To my supervisor, Kjeld Svidt, Professor at the Department of Civil Engineering from the Aalborg University at the Aalborg Campus, I owe my deepest gratitude. Early showed his availability, friendship and a great human and professional conduct and with whom I am delighted for this opportunity of working with. Throughout his patience, constant availability, and monitoring and also for all the motivation and encouragement, I want to leave here expressed my most sincere thanks and recognition. Without his support, the enthusiasm within our discussions during our meetings, the will to always want to help and being always a friend, this project would hardly be completed.

I would like to express my acknowledgment to all the professors I had the chance to meet and work with along this Master program. They played a very important role in my process of learning and growth professionally and as a person. Thank you all for your teachings.

To Aalborg University for all the availability of all the needed tools to complete this thesis. The possibility of having a study room and for the permission to stay within the premises, outside normal working hours.

To my family that was always present, even in spite of the distance that separates us, and supported me especially in the most difficult times. A special thanks to my parents for always helping me and never stop believing. To you I own everything I am and everything I have today.

To my friends, group mates and all of those which helped me during these two years. Thank you for your patience, without you fellows, this would have been an arduous and difficult path to tread.

I want to leave here also my most heartfelt tribute to my grandparents, who are no longer among us, but always supported me in life. This moment is dedicated to you and for you, wherever you are.

Reading Instructions

This thesis will be divided into main chapters, being identified with the number of the chapter followed by the chapter's name. The chapters will be aligned to the left of the page. Following is an example about how the chapter will be presented "1 Introduction". The main chapters might contain one or more sections. The sections will be presented by firstly the number of the chapter preceded by the number of the section and the section's in the following form, "1.3 Presenting the Problem". Into the sections, if containing subsections with several levels, these will be shown through firstly the chapter where they belong, then the section where they are inserted and after the level(s) of the section, e.g. "4.5.2 Project lifecycle", where the number two is the level of the subsection. For levels below the third one, the same rule will be applied. All the levels will have a level below the three will not appear in the index. In the beginning of a chapter, a short presentation will be made and a brief introduction to the content approached along the respective chapter.

When writing this project, work was done by searching information about the topic, eespecially for the theoretical part. Thus, along the theoretical chapters, references will be found. These references will be based in several sources taken from books, scientific papers, journals, internet websites. The references from books, scientific papers, journals and internet websites, will be done according to the Harvard Method, i.e., [Surname, year]. For references where two author are involved, the presentation will done similarly, but, with the first and the second author with "and" between them, [Surname1 and Surname2, year]. When the source will have more than two authors, the first author will be presented, preceded by the expression "et *al.*" and the year after ([Surname et *al.*, year]). There will be also situations where the source will be shown with the name and then the year between brackets, as the following example; Steven (2014). There will be also situations where an author is mentioned through other one. In this situation the reference will be me by presenting the referred author, with the word "in", preceding the author where the reference was found (Surname1, year1, in Surname2, year2). All the references mentioned above will appear in the bibliography chapter, located at the end of this document. The bibliography will be written as follows; for the books, scientific papers, journals, internet websites, written in the following way: authors, date, title, version, publisher and year of publication. For the internet websites sources, the shown by following author(s), date, title, Internet source, year of revision and date of download.

Along the present document there will be, pictures, charts and photos. The captions these elements will, be shown under the it, and enumerates according firstly, the chapter preceded for the position in the chapter. For example, the third figure in the chapter five will be presented as Figure 5.3. When the figures will be referred along the text, they will appear, using the previous example, as "Figure 5.3". For tables, the captions will be shown above the table, following the same rule for the figures. For example, the second table in chapter three, will be presented as Table 3.2, being referred along the text in the same way. For both figures and tables, the source(s) will be written together with the caption, the same way as mentioned in the previous paragraph. For tables, figures or charts originally made for this document, as for photos belonging the author, no source will be added. All the figures, charts, pictures and tables will be first appear referred into the text, being only shown after its first mention in the text.

The attachments will be presented in the end of this work being designated by Appendix. The Appendix will have the designation A, and will be split into five groups. To distinguish the groups, after the name of the appendix, will be added the number of the group. So, the for the group number three, the appendix will have the designation Appendix A.3. Inside these appendixes are placed the respective information. This information will be differentiated by a letter followed by a parentheses and then, the name of the information. For example, for a 3D model of a doghouse will be c) Doghouse 3D model. The letter has the meaning of the position of the information.

As mentioned previously in the preface, once for ethical and deontological reasons, there will be some anonymous references, mentions and postings. When those references will be referring to a company, this will be denominated by "Company" proceeded by a number, as for example "Company 12". For projects references, the same procedure will be used, but here, instead of a number, a letter will be used after the word "Project" i. e. "Project D".

Author's Statements

The author would like to make some explanations and statements related to what will be presented in this thesis. Due to the context and content of this, examples where products, such as software, materials, brands, suppliers and other similar, will be presented. Along these mentioned presentations, comparisons, choices exemplifications, evaluations, classifications, as well as the mention for alternative solutions might be included. But, although all the actions mentioned, these should be seen as mere examples and explanations and not as a standard choices, depreciations, publicity or advertisements to some specific brand, material, manufacturer. The author would like to express that it is not his intention to show any kind of preference for any type of product, brand or supplier. The author wants also to apologise for some errors in the translation for the technical words for the electrical and mechanical parts will be presented. Also, some of the documents will be presented into the Annexes, due to their size, and since are presented more to serve as examples, not many careful was taken when translating them.

Abstract

Construction companies are facing nowadays several problems. The lack of projects for construct is one of the problems in the construction sector. With the problem of existing less projects, come high competition between national and international companies for awarding the projects. This competition, leads in many cases to prices given just to award the project. As a consequence many losses occur from this works, which lead to more problems into the company. But, most of the losses occur due the lack of communication and organization inside the organization. There is no collaboration between the teams and the departments. The work processes are done as if the departments were different organizations.

A new approach is emerging in the construction sector, Building Modelling Information (BIM). BIM is praised as been a collaborative tool. However, BIM is still trying to have its affirmation into the construction sector. BIM has revolutionized the design process of the projects with its Parametric Building Design technology. The objects have the capacity to carry information, the models can be visualized in 3D. With BIM, the construction process can be simulated, by adding the time a the costs to the 3D models. A visualization close to the reality can be achieved through these simulations. Many projects were already made by using BIM to support the design, construction and facility management processes along its lifecycle. However very few or none infrastructure projects where yet analysed.

The present work intends to study the information process within construction companies. The idea of this study is to analyse the collaborative feature of BIM to help in the information sharing. Based on the project lifecycle, the construction stage is analysed for information sharing and transference. Since this is a new approach which is starting to be implemented, the organizational and works processes are further studied. When studying BIM, some of the existing tools are analysed. At the same time, based on an infrastructure project, the application of BIM in these type of projects is studied.

Thus, the present work is organized into six chapters. The first chapter, the Introduction, presents the structure of this thesis, the initial ideas and impressions, the problem and the scope of the project. In chapter two is presented the methodology used for doing this work. The third chapter have a approaches the topic of construction management and project management. In this chapter are defined the concepts which are used for analysing the problem. Chapter number four contains the state of art. BIM topic is developed in this chapter by presenting what is it. Also, what has been done so far with BIM and it's level of development are shown here. BIM's history is presented, together with some case studies. The fifth chapter is where the problems are analysed. The current situation, the needs and the possible future solutions are presented in this chapter. Chapter six contains the discussions about the most relevant problems and respective conclusions. This chapter also contains the future perspectives, with some suggestions for future works and research.

Keywords

BIM (Building Information Modelling); Contractor; Construction Management; Costs Control; Information Sharing; Project Management; Scheduling

Abstrakt

Konstruktions firmaer står med udfordrende problemer nu til dags. Mangel på projekter for konstruktioner er en af problemerne i konstruktions-sektoren. Med problemet om manglende projekter, er der høj konkurrence mellen natioanle of internationale firmaer til at vidergive disse projekter. Denne konkurrence, betyder at i mange tilfælde til priser givet blot at tildele projektet. Som en konksekvens af dette er der mange mangler, som udspejler sig i flere problemer i det pågældende firma. Men de fleste mangler forekommer på grund af manglende kommunikation og organisation i selve firmaet. Der er ingen samarbejde mellem holdene og afdelingerne. Arbejdet er udført på sådan en måde, at afdelingerne var seperate firmaer i selve firmaet.

En ny tilgang er på vej i konstruktions-sektoren, Building Modelling Information (BIM). BIM er rost til at være et samarbejdende-værktøj. BIM prøver stadigvæk at etablere sig i konstruktions-sektoren. BIM har revolutioneret design processen af projekter med dens "Parametric Building Design technology". Objekterne har kapaciteten til at lagre informationer, således at modellerne kan blive visualiseret i 3D. Med BIM, så kan konstruktions processen bliver simlueret, ved at tilføje tiden og prisen i 3D-modellerne. En visualitation tæt på virkeligheden kan opnås gennem disse simluationer. Mange projekter var allerede lavet med hjælp af BIM som en support til design-, konstruktion- og facilitet processerne igennem dens livsstil. Men meget få, eller næsten ingen, infrastruktur projekter er blevet analyseret.

Dette projekt har intentionerne at studere informations processen inden for konsuktrions firmaer. Ideen er at analysere samarbejds-funktionen af BIM som en hjælp til informations deling. Baseret på projektets livstid, konstruktionen stadiet er analyseret til informations deling og viderføring. Da dette er en ny tilgang som er i gang med at blive implementeret, organisation- og arbejdsprocessen er ydermere studeret. Under analysen af BIM, er nogle af de eksisterende værktøjer gennemgået. På samme tid, baseret på et infrastrukturelt projekt, er benyttelsen af BIM også studeret.

Derfor, vil dette projekt blive delt op i 6 kapitler. Det første kapitel, Intruduktionen, vil præsentere strukturen af dette afgangsprojekt, de første ideer, indtrykket, problemet og formålet med dette projekt. I kapitel to er metoden præsenteret for dette projekt. Det tredje kapitel indeholder en tilgang til emnerne af konstruktions-ledelse og projekt-ledelse. Kapite fire indeholder State of Art. BIM emner er udarbejdet i dette kapitel. I dette kapitel vil det præsenteres hvad der er blevet lavet hidtil med BIM og til hvilken grad dette er udviklet. BIM's histore er præsenteret, sammen med nogle studie cases. Det femte kapitel er hvor problemerne er analyseret. Den nuværende situation, behovet og fremtidige løsninger er præsenteret i dette kapitel. Kapitel seks indeholder en diskussion af de mest

relevante problemer og de respektive løsninger. Dette kapitel indeholder også fremtidige perspektiver, med nogle forslag om fremtidig arbejdsmuligheder og forskning.

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Acronyms

AAU - Aalborg University;
ABM - Activity-Based Methods;
AEC - Architect Engineering and Construction;
ARC - Applied Research of Cambridge;
BIM - Build Information Modelling;
BOQ - Bill of Quantities;
CAD - Computer Aided Design;
CM@R - Construction Management at Risk;
CPM - Critical Path Method;
DB - Design-Build;
DBB - Design-Build-Bid;
GMP - Guaranteed Maximum Price;
ICE - Institution of Civil Engineers;
IPD - Integrated Project Delivery;
IT - Informatics Technologies;
IT - Information Technology;
LBM - Location-Based Methods;
LBS - Location Breakdown Structure;
LBS - Location-Based Scheduling
LNEC - Laboratório Nacional de Engenharia Civil (National Laboratory for Civil Engineering);
LOB - Line of Balance;
LSM - Linear Scheduling Method;
NIBS - National Institute of Building Sciences;
OS - Operative Systems;
PBD - Parametric Building Design;
PERT - Performance Evaluation and Review Technique;
SHE - Safety, Health and Environment;
SMEs - Small and Medium-Sized Enterprises;
SOH - Sydney Opera House;
UK - United Kingdom;
USA - United States of America;
WBS - Work Breakdown Structure;

1 Introduction

This chapter has the purpose for introducing this thesis, as well as the content which will be part of it. Firstly will be presented the current climate for the construction sector, by guiding the reader to an introduction to the problem and scope of this work. Then through the sections that follow, it will be presented how the document is organized and structured, followed by the initial ideas and impressions about the topic. After that, the problem will be introduced and the scope of the project will be presented. Finally, the assumptions and considerations used for the purpose of this thesis will be presented.

Presently the world in general faces an economical crisis. This crisis is affecting almost all the sectors in our society and countries. The construction sector is not an exception, being in most countries, the first sector where difficulties arise and which suffers the consequences. It is known that the construction sector has a great influence into the economy of a country. This is easy to understand, since with this sector many others can benefit in a direct or indirect way. The construction sector, beside having a great contribution for the development of a country, provides employment, a circulation of money in a country and thus leading to a movement in the economy. As for example, brings life to the catering sector, transportation sector and many others, directly or indirectly.

Beside the crises, there is also another factor to be taken into account. This is the global evolution, but with special attention to IT technology evolution. It is of great importance to keep actualized, to keep up to date and always looking to pioneer cutting edge technology and methods. By researching a little it is possible to find companies that were once major world powerful companies, and are nowadays closing and falling on bankrupt. Some reasons for this can come up to mind, being immediately the first one the actual crisis. But, it is also true that companies which were losing market, have strengthened their position and are in the present with a good ranking. It comes out from this that, some of those major companies just did not adapted to the technology evolution and stood still in time, while other followed this evolution and even managed to bring and create something new.

In the construction sector, the story is not different. The evolution must be followed and one should not be afraid to try and seek for new solutions. Presently, due to the crisis countries are facing, owners, architects/engineering design companies and construction contractors are facing serious problems within the projects. The competition is bigger, the deadlines are getting shorter, the complexity and demands of the projects are getting higher. The costs and prices are getting higher and consequently the profit margins are decreasing and the quality demands are increasing as well. For these reasons, the need for the design companies, as well as for the contractors to get the projects its becoming bigger. But on the other side, the economical resources from the owners are also tight and despite this, the maintenance costs are not decreasing, which is an aggravating factor. Through this panorama, it becomes very important to make fast decisions, based on a higher level of certainty, by decreasing the costs and the time. It is in this context that this project is focused, on studying the capacities of BIM and how can this bring some fresh air to the construction sector.

Beside the crises and the present situation in the world, another crucial feature should be taken into account. The communication, the information and knowledge sharing and the documents transference between the parties involved in the project. This nowadays, due to the scenario the construction sector is facing, plays an even more important and crucial role. Particularly in the transition phases of the project, this may reveal to be determinant in the performance of the company throughout the entire construction process and in the performance of the team in the construction site. Thus, it is important having correct, complete and organized easy reading information transferred and transported along the entire construction stage. This enables making easier the communication, working processes and performance of the team(s) in the construction site, offices as well as between these two "sectors" of the project.

1.1 Initial Ideas and impressions

BIM is an approach staring to get more adepts in the construction sector. In some countries, BIM is seen as a wager for the future, as an alternative to boost the economical situation and the construction sector.

Many studies were recently developed, as it is possible to be seen in the literature. But all this advances and studies, as well as the literature from books are mostly, if not all, related with BIM used in the construction of building.

For infrastructure projects, the information available is almost reduced to the books related to the software that use BIM in these type of construction projects, such for example Autodesk Civil 3D and Novapoint. Will not probably be too much risky saying that, this availability may be only for the more popular and known software.

The information inside an organization may the one of the main keys for the success. The lack of information between the contractor's participant involved in the project is barrier for the success of the project.

Many times the same work as to be redone due to the lack of information shared. This happens eespecially when the contractor awards the project for constructing. The communication and collaboration between the team responsible for estimating the project and the one who will be responsible for the construction is poor or nonexistent. The information shared is also of poor quality.

Many times there are no flow on the information, being used in the construction of the project what comes from the owner. In the end of the construction process, no information is left or created. The majority of the work developed along the construction of the project is lost. Again no experience, knowledge and data from the construction site is passed for the next projects. The leaning process has to start from the beginning. Time is lost and wasted on searching and reconstruction the information for the new project.

1.2 Presenting the Problems

The problems studied in this thesis are the communication inside contractors organizations and application of BIM in projects for infrastructure. The basis for these problems relies on using BIM inside the construction companies. The analysis will be done by using as support a project of water supply pipelines. This will be done by using the existent experience and knowledge for building projects, studying and learning about the process and possible software. Then, based on the experience and knowledge acquired though the literature, the infrastructure projects .

The first problem, is the communication sharing and transferring inside the contractors construction companies. This is a problem, probably involving the great majority of the companies.

There is a lack of collaboration and sharing of information between the departments involved in the project. The main problem relies in the estimating department and the construction department. These two departments should work in collaboration between them, by sharing experiences, knowledge and information. But instead, usually the project is estimated for tendering, and the process is closed. Then, between the tendering process and the construction process exists always a big gap in the time between these two phases.

The software used in the estimating department is usually different from the software used in the construction department. For instance, when estimating the project, software as Candy (www.constructioncomputersoftware.com) is used. This enables a high detail level of estimating. Thus, in the construction site, the monitoring and control of the variables considered when estimating is done "manually" by using for instance Microsoft Excel. Even estimating software can import information into Excel files format, there is always losses of information. The, the enquiries for prices done through the estimating process are usually not shared and many other information which is lost or not shared. The same can be said about the construction department. When building information, this is usually done in a very confusing way. When closing the project usually no information is kept, or if kept in a very unorganized way. This leads to losses of information and no experience is shared.

The second problem, is related with BIM in infrastructure projects. There seems not the be much work developed about this topic. Infrastructure projects are projects very sensitive to all the external factors. So, dealing with the management for the resources and productivity of the project should be done carefully. These are the main responsible "elements" for the derailing of these type of projects. The capacity of BIM for simulating possible scenarios may bring a great help in the managing the resources and productivity. How can BIM be applied into infrastructures projects, since these are quite different from the building construction projects.

1.3 Scope of the Project

The main goal of this project, is in the application of BIM inside the contractors organization. The purpose of this study is to see how BIM can be used by the contractors during the construction stage. This main goal is split into two focus. One of these focus is to study how

BIM can be used inside the contractor for minimizing the losses of information between the departments, and the to increase the profit. The other focus is in how can BIM be used for the contractors in infrastructure projects.

In the first problem, the aim is to study how can the information be shared and transferred by the departments of a company, across the construction stage. To see how the available tools can help in this process and which may be needed to improve or change. The purpose is also to study the structure and organization of the companies before and after implementing BIM.

The application of BIM in infrastructure projects, intends to study how BIM can be useful in these type of projects. The information available about BIM in infrastructure projects is very limited or even inexistent. This work intends to make some sort of a first approach to the topic about BIM in infrastructure projects. The goal here, is to see the capabilities for some of the existing software, and how can be used in these type of projects. In addition, focus will be given to the needs for new tools or some adaptations for the already existing ones.

2 Methodology

This chapter, will present the methodology used along project. How the work was developed and the steps followed along all the stages of the project will be stated in the methodology.

2.1 Introduction

For the realization of the present thesis, were followed three main steps. In a brief presentation, the methodology can be divided as follows:

- Bibliographic research and study;
- Software analysis and study;
- Analysis and discussions.

In Figure 2.1 is presented a scheme, which describes the steps followed along this thesis. Due to the small size, Figure 2.1 can be found in the Appendix A.1 a), for a better visualization. In a short presentation for the steps, mentioned above, the bibliography research consisted in the process for acquiring knowledge and a theoretical background support.

Along the software analysis, the idea was to learn the concepts about the software. How to use it, which information the software contains, how can this information be collected. So, this step consisted in the process for acquiring knowledge about some of the BIM software.

In the analysis and discussions, was made the analysis to the problems for this thesis. This process was based on the knowledge acquired from the bibliographic research and software analysis.

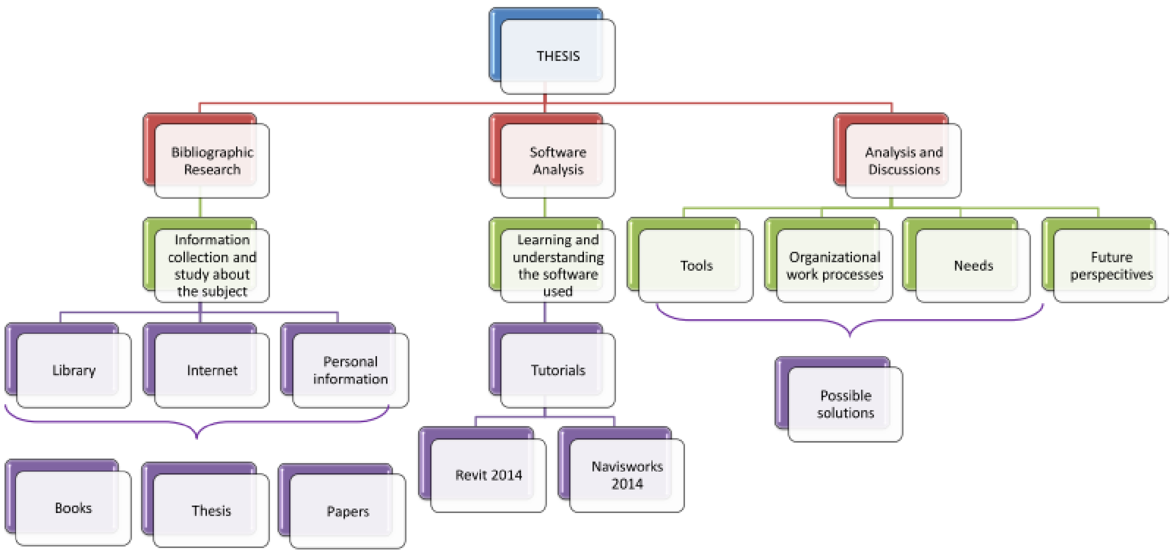

Figure 2.1- Scheme for the applied methodology.

2.2 Bibliographic research and study

The topic BIM was something totally new for the author when this project began. The author felt the need for searching and learning about BIM, to see what was already done and how is the present situation. At this point of the work, the author made an exhaustive research for the available information about BIM topic. Also, the author found important to study and present a theoretical approach about construction management and project management.

The idea was, later on when analysing the problems, to use the theory and concepts from construction and project management as a foundation for BIM. Gathering these two theoretical approaches to proceed to the analysis of the problem and search for the goals. The author made use from all the available resources he could find.

Along the bibliographic research and study, there were three main sources used for information collecting and knowledge acquirement. Those where:

- The Aalborg University (AAU) Library;
- The internet;
- Author's documentation.

From the AAU library, were used books mainly about construction management and project management. Some books about the history and the first steps of BIM were collected from the AAU library. The author also made use of scientific papers and journals about some more specific topics. Thesis from other authors which already worked or are working with BIM and information in the construction section were used as well.

The author made use, of his personal books, thesis and papers collected posterior to this work. The information collect from these last two documents was about BIM. From the books, the author also made use for the topic related with the construction and project management. To cover his needs, the author also acquired some books related with BIM during the realization of this work. The author's supervisor gave a precious help by showing some good books about the topic, and sharing his books and information.

The internet was used to complement the information needed for proceeding with the work. From the internet were also collect books, scientific papers and thesis from other authors.

Beside the purpose of acquiring knowledge about the main topic of the thesis, the information collected was used for building the theoretical chapters. These chapters are the "Construction Management and Project Management" and "State of Art". These two chapters provided the foundation for the study presented in this thesis.

2.3 Software analysis and study

For the realization of this project, the author needed to learn about some software which uses BIM. In a first step there was a theoretical research about what is BIM, how it is being applied. Information about BIM's level of developed and available software were also made.

The software analysis was somehow a big challenge. All the used software was completely new for the author. So, along the software analysis and study stage, was made a process for knowledge and understanding about the available software and its capacities. The author made use of tutorials for learning how to work and deal with the software. The resources used for the learning process were video tutorials, books, forums about the software and some other experiences shared in internet. The author made use Revit, Navisworks, all of them from 2014 version.

The purpose for this learning process, was to be able to build the models. Learning how the software works and to help in understanding the information contained on it. This would give the possibility to the author for analysing the problems proposed for the realization of this thesis.

2.4 Analysis and discussions

To analyse the problems, the author used a project which was already familiar with. This analysis and discussions, were based on the experience gained when reading the literature, working with the software and from the discussions with the supervisor along this period.

To meet the goals proposed for this thesis, the tools were studied. Since BIM is still a new approach in the construction sector, in this study were also analysed the work process inside the contractors organizations. The needs for adaptations, tools and procedures were studied and analysed. Finally into the future perspectives were left some suggestions for the future.

3 Construction Management and Project Management

In this chapter, the main concepts related with the project management and construction management within the construction stage will be defined. The participants involved in a construction project will be introduced together with the roles they play along the project lifecycle. Further on, it will be presented how the construction companies can be constituted, by showing their organizational structure. In the end, the project process and developments will be shown, by stating the considerations and simplifications taken in this thesis. The construction sectors, the project lifecycle as well as the phases of the project during the construction stage will be introduced as well.

3.1 Introduction

This chapter as the main purpose to introduce the reader with the concepts, considerations and simplifications that will be present along this thesis. The author's perspective and opinion about the concepts will be also presented when discussing some of the topics. In a first approach, the project management and construction management will be introduced, by showing their concepts, definitions and how they will be considered along the present document. This will allow to have a clear understanding about the meaning of the concept for project management and construction management when being used in this work.

With the introduction of BIM in the construction sector, some changes and adaptations inside the companies organization will be required. This means the emergence of new participants and stakeholders and thus, the possible need of creating a new department. In this chapter, the more classical model will be treated. So, firstly it will be presented the participants and stakeholders with the roles they play in the entire project lifecycle. Secondly, more focused into the construction process, it will be shown how the contractors companies can be structured and organized. The idea is to, later on, make the bridge between the old concept and the new concept, when introducing BIM. Also when dealing with the problem of information sharing and transferring, this organization may reveal to be very important.

In the end of the chapter, will be presented the construction sectors, by defining the inherent concepts to these sectors. The project lifecycle will be shown, and here the stages that will be considered in this thesis will be defined. Also the projects delivery methods and the project types will be introduced, because these will play a very important role along the project lifecycle. Finally, the phases which are part of the construction stage will be exposed.

The chapter will be structured by six sections. These are: Construction Management and Project Management Concepts, Project stakeholders and intervenients, Construction Companies - Structure and Organization, Projects, Processes and Developments. The sixth section will be the Summary, where an overview with the highlights for the content of this chapter will be done.

3.2 Construction Management and Project Management Concepts

This section has the goal of presenting the concepts for construction management and project management. These concepts are very commonly used within the construction industry to refer to some stakeholders who play a specific role(s) during the project lifecycle. The project manager concept has a more wide range of application, like into the contractors, architecture and engineering companies, inside the project owner bodies, as among all the other parties active in a construction project. Yet, the concept construction manager has a more restrict range. Along the literature when searching for project manager and construction manager and the related tasks, project management and construction management respectively, these concepts have their definitions for what they mean very well defined. However, analysing the roles and tasks along the construction process, in many references these differences become tenuous, not being possible to distinguish where one ends and the other starts.

3.2.1 Project manager and project management

The following definitions for management, construction manager, project manager and project management can be found in Davies and Jokiniemi (2008);

- management: "a body of people forming the administrative leadership of a company or business";
- construction manager: "a contractor's employee responsible for managing and supervising work on a large site or several small ones; a senior site manager";
- project manager: "client's representative; a professional person or body whose task is to run construction projects for a client";
- project management: "management; the profession of running construction projects on behalf of a third party".

If analysing the literature related only with the topic project management, the concept can be found very well defined and explained. For Meredith and Mantel Jr. (2009) the project "manager is expected to coordinate and integrate all activities needed to reach the project's goals". Heerkens (2002) presents the following definition given by the Project Management Institute "... the application of knowledge, skills, tools and techniques to project activities to meet project requirements". According to PMI (2004), "project management is accomplished through the application and integration of the project management processes of initiating, planning, executing, monitoring and controlling, and closing".

So, after all, who is the project manager, what does he/she do, what are the tasks? Meredith and Mantel Jr. (2009) see the project manager as "the major resource input to the project compared to the team, the capital, the materials, and any other inputs". The "project manager has the task of identifying resources, and organizing them effectively and efficiently" (Johnson and Jenkins, 2003). The project manager "must oversee many functional areas, each with its own specialists".

To the project manager, according to Meredith and Mantel Jr. (2009), it is required to be responsible for:

- "The client and the environment";
- "Identify and correct problems at an early date";
- "Make timely decisions about trade-offs between conflicting project goals";
- "Ensure that managers of the separate tasks that comprise the project do not optimize the performance of their individual tasks at the expense of the total project".

Meredith and Mantel Jr. (2009) also present a chart (shown in Figure 3.1)for tasks and responsibilities, where it is represented the range of involvement for the project manager. From Figure 3.1 can be seen that, the project manager is not only responsible with the project itslef, but also the all the variables involved in the project. The project manager, beside being responsible for the costs, scheduling and process of the project, also needs to deal with the other departments which are correlated with the project.

Figure 3.1 - Project manager tasks and responsibilities chart (Meredith and Mantel Jr., 2009).

So, resuming what is project management by using the statement from Johnson and Jenkins (2003), project management is the "planning and controlling for everything involved into the projects".

Getting now into the literature about the topic project management in construction, the definitions and tasks are similar to those shown previously. Bennett (2003) mentions the concepts for project manager and construction manager when presenting the delivery methods (presented further in 3.5.3). Yet, the presentation is more intending to set the role they play through the entire process of the project on the owner's side. Bennett (2003) distinguishes two types of construction managers. In one type, the construction manager "acts as an extension of the owner's staff and assumes little risk". On the other type "occupies a contractual position between the owner and the execution contractors" by "replacing the general contractor". The project manager is presented by Bennett (2003) as the responsible person to whom the owner delivers "the entire project". Again, from the descriptions shown above, it can be said that, the construction manager is the one responsible for the tasks and procedures directly related with the construction part of the project. Thus, the project manager is the responsible for the overall view and for the entire project.

Walker (2002), for instance states that "project management is about the total process, not just about releasing a specification about time, cost and quantity." For Walker (2002), the meaning for the title of project manager is for "managing the project as a whole" by "managing the project for the client" where the "objective of the project manager must be achievement of the client's objectives". Yet Walker (2002) refers to the project manager, as "a member of the client's organization" that "seek to resolve conflict in the process in the interests of the client." Somehow, the perspective from Walker (2002) related with the project manager role is slightly different from those mentioned before. The concepts shown before were not making any distinction to the side of the project manager. Walker (2002) refers to the project manager as the responsible for the total project, but only on the owner side. According to Walker (2002), the person designated by the construction company as "project manager", is more considered as construction manager, due to his/her role be not being focused solely into the client's objectives.

3.2.2 Construction manager and construction management

Analysing now the concept of construction manager, it was seen above that, for Walker (2002), this is the responsible for the project, but from the contractor side. But, Walker (2002) in his book makes an approach to the topic of management in the construction, more focused in the owner/client. So, now it will be done the analysis for some of the literature, but more focused into the management in the construction within the contractor side. If looking to the definition given by Patrick (2004), in Jackson (2010), construction management is seen as the process that "entails the planning, scheduling, evaluation and controlling of the construction tasks or activities to accomplish specific objectives by effectively allocating and utilizing appropriate labour, material and time resources in a manner that minimizes costs and maximizes costumer/owner satisfaction." In the same line of ideas, Halpin and Woodhead (1998) presents the project manager's role as "to efficiently and economically apply the required resources to realized a constructed facility of acceptable quality within the time frame and budgeted cost specified". According to Halpin and Woodhead (1998), the construction manager has the duty of building the facility(ies) according to the project, with the provided resources (labour, equipment and material). The perspective of construction manager by Jackson (2010) is a little wider by considering as construction management, all the tasks involved in the project, else then only the "cost, time quality and safety" management in the construction site. So, for Jackson (2010) it is part of the construction management "package" the estimating; "administering the project"; "managing job site and construction operations"; "planning and scheduling the project"; "monitoring project performance"; "managing project quality"; "managing project safety" and "assessing the project risks".

Presenting now a resume about what was shown previously, the project manager is:

- Part of the owner/client team;
- Should defend the owner/client interests;
- Works with all the departments of the organization that are involved in the project;
- Is responsible for all the tasks that are involved within the project;
- Is responsible for coordinating everything which the project involves;

The construction manager:

- Can be any participant in the project since work within construction management tasks;

- The construction manager defends primarily the contractor interests;
- The construction manager is responsible for the project but only inside his/her department.

From the author's perspective, and following the definitions and roles presented above, the project manager can be also part of the contractor organization and being given this title. The project management role will be, linking all the departments involved in the project, in similarity with what was presented above in Figure 3.1. Then the construction manager will be the responsible for all the tasks of the project, but in the construction site. Also the project manager can be usually responsible for a certain amount of projects, depending on the organization structure and load of work.

3.3 Project stakeholders and intervenients

The project stakeholders involved in a project can be of several fields and areas, which leads to a huge diversity of backgrounds and experiences. The way they interact within the project, as well as between themselves can be somehow complex. To approach this topic, it will be presented first an overall picture of some particular characteristics of a construction project. After, the stakeholders and their roles will be presented according to the entity they represent, as well as the project stage they take part.

The facility which results from a construction project is the end product outcoming from a sequence of a series of manufacturing processes, being "sold" after its completion. A construction project process is not as linear as the other manufacturing processes, in construction projects. There is a huge amount of variables, constraints and factors that must be taken into account when working in a construction project. In addition, there is also the fact that, even inside the same sector of projects (better explained into 3.5.1), there are not two identical projects. The errors and fails done through the first product cannot be corrected for the second one. Before going through the explanation about the stakeholders themselves in a more individually perspective, will be presented the three main organizations involved in a construction project.

When looking to a construction project, three main actors are involved since the conception of the idea until the sale of the final product. These actors are the owner of the project, the designer and the contractor. In Figure 3.2 is shown the relation these three main actors have between them, having the project as the center and common interest. The reader should be aware that this is a general picture about the actors involving the scenario in which the project is inserted. As it will be explained later into 3.5.3, these bidirectional relations between these actors may vary.

Figure 3.2 - The main actors around a construction project.

Along the previous paragraphs, there was made an introduction about the "production line" of a construction project. In addiction, the main actors involved in this "line" where presented as well. Yet it was mentioned that the construction industry is different from all other industries, by stressing the fact that each project is a unique project. To better understand these unique characteristics of the construction projects, these three actors will be seen as organizations. These organizations can be constituted by several departments or sub-organizations. In the coming paragraphs it will be presented how can be the mentioned organizations constituted.

Presenting first the organization owner, this can be divided up as being a public organization (such as municipalities, national roads) or a private organization (like a sport club, individual person). "The owner is where the project born" (Gould and Joyce, 2003), being the responsible for the creation and realization of the project. The owner is usually out of resources to design, to construct the project and to follow up the track of these tasks. However, there may be some of the exceptions, eespecially public organizations, which might have the ability to do the design of the project and/or to follow up the construction works in the site. There is also a category which is not mentioned on the read literature, the consultancy companies. These consultancy companies are usually hired for the owner to represent the owner through the design stage of the project and/or the construction stage of the project (being CM@R, presented in 3.5.3, one of the example).

The designer organization can be a little more complex of analyzing, once this organization can assume several shapes and structures. In the design organization, according to what is presented in Bennett (2003) and Gould and Joyce (2003), the parties that can take contribution in the design process of the project can be of architectural, engineering and geotechnical[1] branches. Into these

[1] Not mentioned in Gould and Joyce (2003)

branches there are the parties responsible for the specialties, which work with a very specific component of the project.

Next will be shown the specialties that can be included into the branches (Figure 3.3). Starting with the architecture, in these branch can be included, according Gould and Joyce (2003), the:

- interior designers;
- landscape architects

The engineering branch can be composed, just to cite some examples (due to the extensive range of specialties in this category) according Gould and Joyce (2003), Bennett (2003) and Correia dos Reis (2008), by:

- structural engineers (Gould and Joyce, 2003; Bennett, 2003 and Correia dos Reis, 2008);
- mechanical engineers (Gould and Joyce, 2003 and Bennett, 2003);
- HVAC (Gould and Joyce, 2003; Bennett, 2003 and Correia dos Reis, 2008);
- electrical engineers (Gould and Joyce, 2003; Bennett, 2003 and Correia dos Reis, 2008);
- and so forth ...

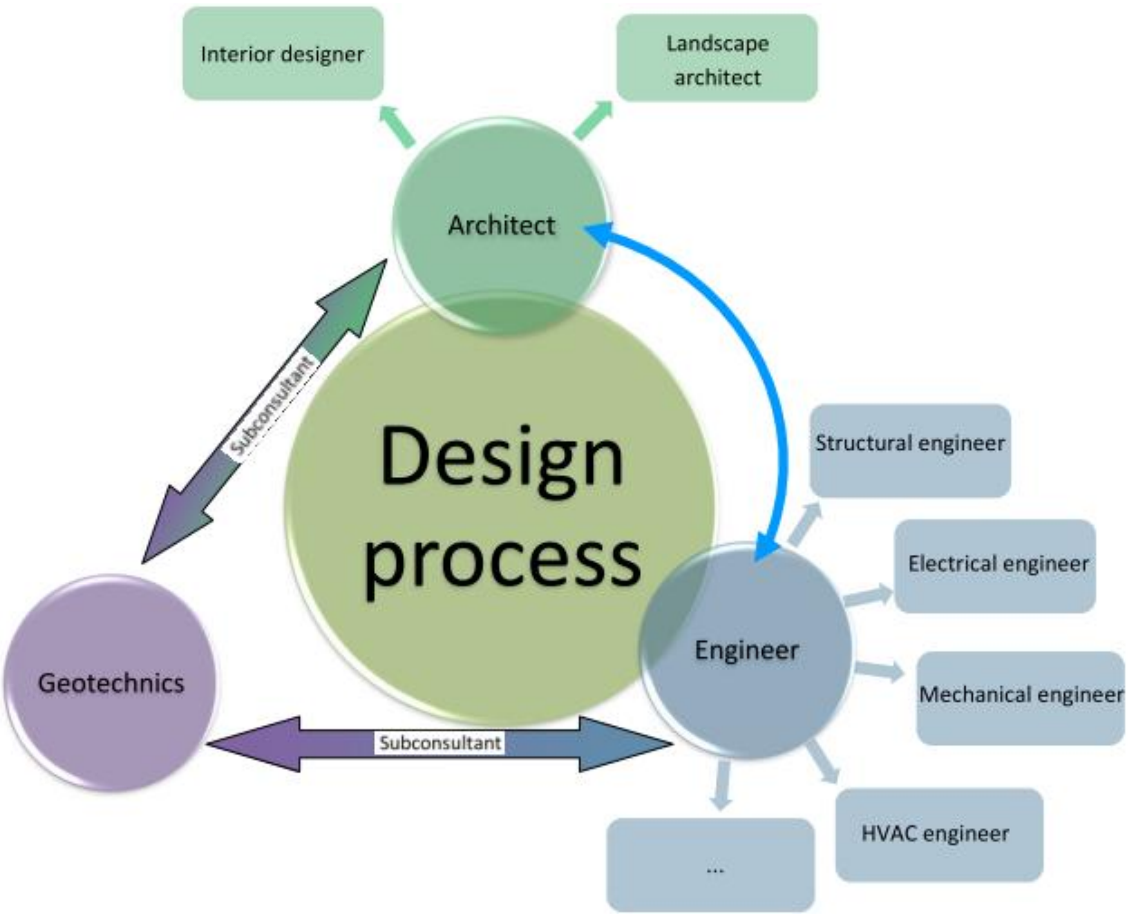

Figure 3.3 - Branches and specialties involved in the design process and their interconnection.

The geotechnical branch is a need which is implicit in almost all the projects, although its role is mostly as a subconsultant for the main designer (Bennett, 2003). The participants in the design process of a project can vary according to the sector industry, the type of project and the type or works/tasks that will be used to reach the final product. Also, depending on all these variables, as mentioned in Bennett (2003) and Gould and Joyce (2003), the leadership of the design process will be assumed by the engineer (for infrastructure and industrial buildings projects) or by the architect (in building and residential projects), despite both categories be always present, independently of type of the project. If a more detailed scenario will be analyzed to introduce the specialties, the importance these parties will have in the project will again be dependent on the specific type of project. Considering for example, a project of a larger industrial central power supply, the structural and electrical engineers, will be the key of the project.

The contractor is the party responsible for all the construction process of the project. The constructing organization for the overall project can assume several shapes. These will be dependent beside the project content, also the contractor's company structure. Several scenarios can be seen. To mention some of these scenarios, can happens the contractor itself not having enough capacity for the entire project and so, to join forces with one or more contractors through a joint venture process. Using a practical example, in a project for constructing a dam in a river to produce and supply energy (some examples can be seen on the website http://www.hydroworld.com), there is a demand for large amounts of materials, manpower and equipment. Also, a great variety of specialties works are involved, such for example, earth works, concrete and steel, civil works, infrastructures, electricity and so forth. Some big contractors companies (introduced later on 3.4) can be involved in the project by working together in joint venture, constituting a single temporary company. Another scenario is that, the contractor organization can have the own resources for the majority of the specialties of which the project is comprised, then very few subcontractors will be involved in the project. It is also possible that a contractor company which is well known as a main contractor, to play the role of subcontractor for some specific tasks. A main contractor can even play only the role of a material supplier for a certain project. A very common example for this scenario occurs in contractors working with transportation infrastructures projects, such as roads and highways. These contractors have their own resources and capacity to manufacture bituminous, so, they can assign their paving "sub-company" to work as a subcontractor or/and as a material supplier. The possibility for the main contractor of using subcontractors for the majority of the specialties and works is also a very common scenario. In this case, the main contractor, play a role more of managing the construction project.

The participants in the construction process will be the main contractor(s), the subcontractors, material suppliers and/or material manufacturers and equipment suppliers. In the Figure 3.4 is shown an overall and generalized perspective of the construction process. Again, in similarity with the design process there will be also specialties involved into the categories such as electricity, mechanics, concrete, painting, steel, earth works, carpentry, pre-casted material and so forth.

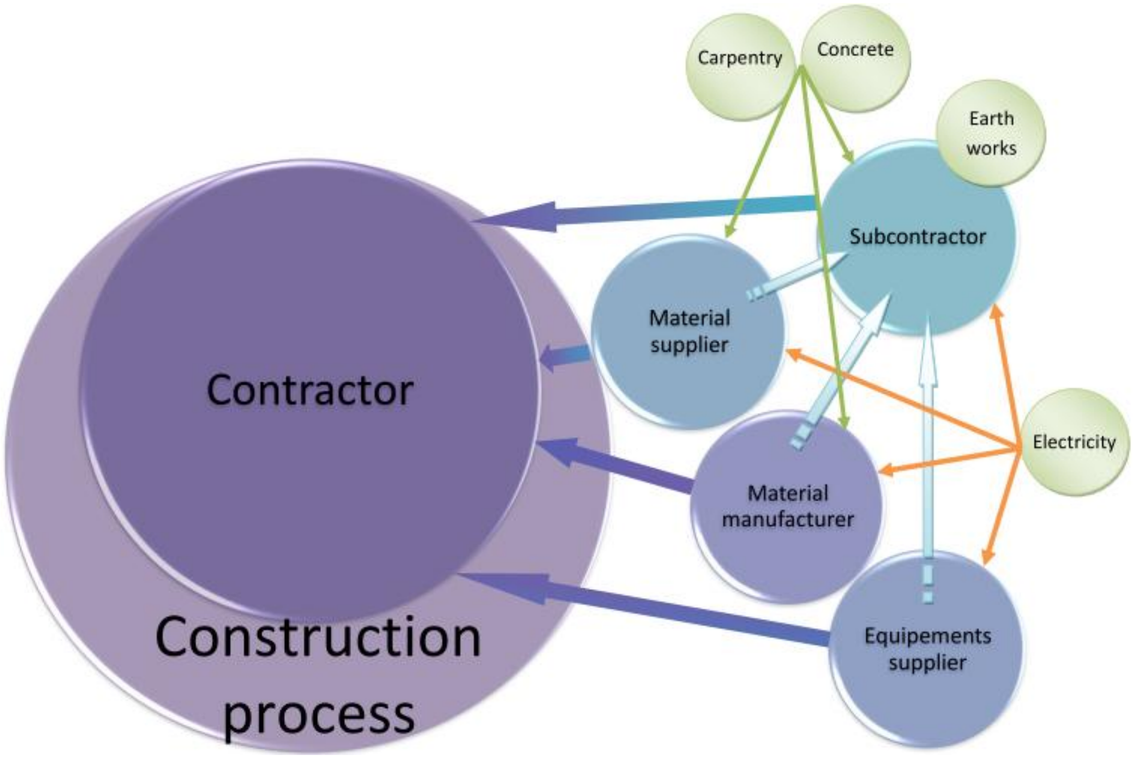

Figure 3.4 - Construction process parties categories and specialties and their interaction.

3.4 Construction Companies - Structure and Organization

In the previous section it was shown the participants involved in the construction stage of the project. In this section, the analysis about how the construction companies can be organized and structured will be made. In this thesis, special attention will be given to the contractor's organization, emphasising more the big and medium size organizations. The type of projects in which the big companies and medium companies are involved have bigger dimensions and greater complexity. This way, it demands a big amount of manpower, equipment, materials and so forth. Yet, the structure and the process of the project until being handed out to the owner are large and complex. This leads to several steps through the stages of the project inside the contractor organization, which induce to a greater risk for information and data losses.

In the construction sector there are several types of companies involved along the entire construction phase. These companies are constituted of different sizes, organizational structures and processes, as well as the level of the works they are qualified to perform. In these range of companies are included the contractors and the manufacturers. Within the contractors, it can be distinguished between the main contractor and subcontractors. The subcontractors are usually small or medium size companies hired by the main contractor. The subcontractors are usually organizations specialized in some type of work(s) such as for example, drainage works, electrical works, paving, painting, and so forth. However these mentioned subcontractors usually do specific works in a project, they can also play the role of main contractors. On the other hand, the big companies, usually main contractors, can also work as a subcontractor, i. e. there is not such a rule or specific characteristic that defines the company J or K is either a subcontractor or a main contractor. The definition of main contractor or sub-contractor for a certain company will be pretty much dependent on the type of project and the works/tasks involved in the project, as well as the size of the project. So, it can be said that, there is not a definition of contractor when relating to a specific company, but yes, related to the role of the company in the project.

On the stakeholders involved within the construction phase, are also the manufacturer companies which can work as a contractor, beside doing the production and delivering of the products.

According to Correia dos Reis (2008), within the construction companies, these can be divided into four main groups. This division is made according their size, number of employees, their working capacity and business values volume. For Correia dos Reis (2008), these groups are:

- the big enterprises;
- the small and medium-sized enterprises (SMEs);
- the sub-contractors;
- the construction materials and components suppliers.

As seen before, the author would like to call the attention for the way Correia dos Reis (2008) divide the construction companies. It is visible that, the reference to the micro enterprises is not done. Also, a group is left for the sub-contractor. Thus, from the author's perspective, instead the group sub-contractor, should be presented the group for the micro enterprises, once any enterprise, independently from the size can play the sub-contractor role.

The big enterprises are defined in Correia dos Reis (2008), as those which have a turnover exceeding 500 million Euros (around 3.740 million DKK). Still referring to Correia dos Reis (2008), these are companies which have their business in the national and international markets. The big enterprises can be characterized as being of public construction works, real estate or civil construction works and usually they are more sub-contracts managers having around 20-30% of their own turnover (Correia dos Reis, 2008).

The SMEs, are enterprises with turnovers between 100 and 250 million Euros (around 746 and 1.865 million DKK). These SMEs have their business more centred nationally, being although possible of having some business internationally and are split essentially into the real estate business and infrastructure works (Correia dos Reis, 2008). The SMEs are defined by the European Union through the 96/280/EC. For defining what are SMEs, the European Union (1996), takes into consideration the "number of persons employed, turnover, balance-sheet total and independence". Following, is shown what is proposed by the European Union (1996) for the criteria mentioned;

- 50 employees for the small enterprises and 250 for the medium-sized enterprises;
- For the balance-sheet, the threshold is at the 27 million Euros (202 million DKK);
- "The average ratio between turnover and balance sheet total is 1:5"

European Union (1996) also makes a reference in this SMEs group to another enterprise size, the micro-enterprises. In the considerations for these enterprises is set out as maximum turnover of 7 million Euros (52 million DKK) and 5 million (37 million DKK) Euros for the balance sheet. For a more detailed information about the definition and considerations for the SMEs, the Annex of the 96/280/CE from European Union (1996) can be found in the Appendix A.2 a).

Following it will be introduced the organization structure, some standard organization charts will be shown, as well as, some organization charts for real contractor organizations.

The organization charts give the idea of how an organization is structured. Through the organization chart it is possible to have an impression about the enterprise size and how it is organized. The hierarchy levels are also shown, as well as their connection and the connection between the internal departments. These organizational charts can given an overall idea about the organization structure, but also can be only for a section or sector of the organization. One example of a partial chart is for the construction team which on the construction site or the team inside a department.

One example of an organization chart for a SME and for a big enterprise, are shown in Figure 3.5 and Figure 3.6 respectively, given by Correia dos Reis (1996) (these charts will are presented in the Appendix A.1 b) and Appendix A.1 c), respectively, in bigger size).

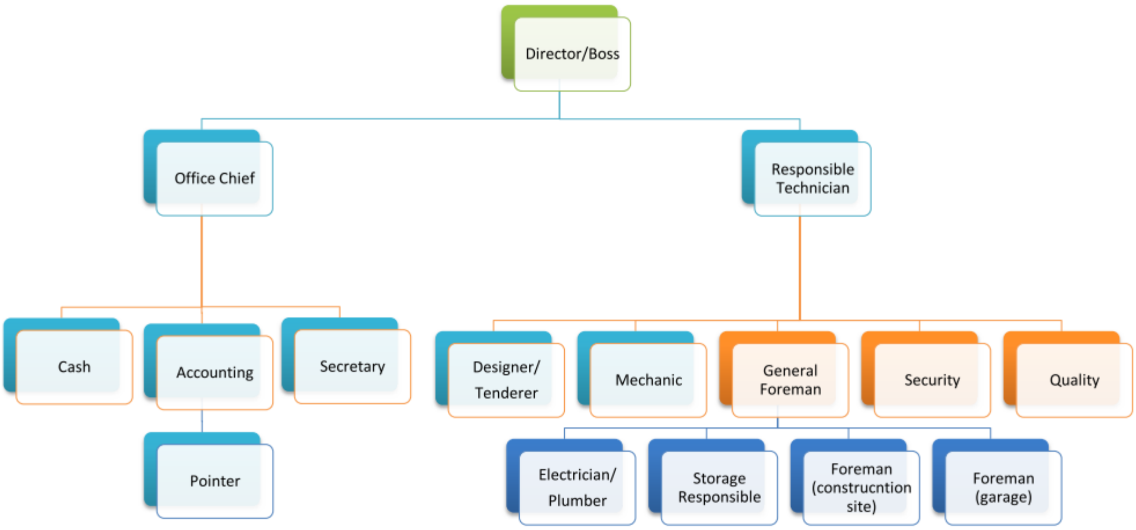

Figure 3.5 - SME construction structure - standard chart example (adapted from Correia dos Reis, 1996).

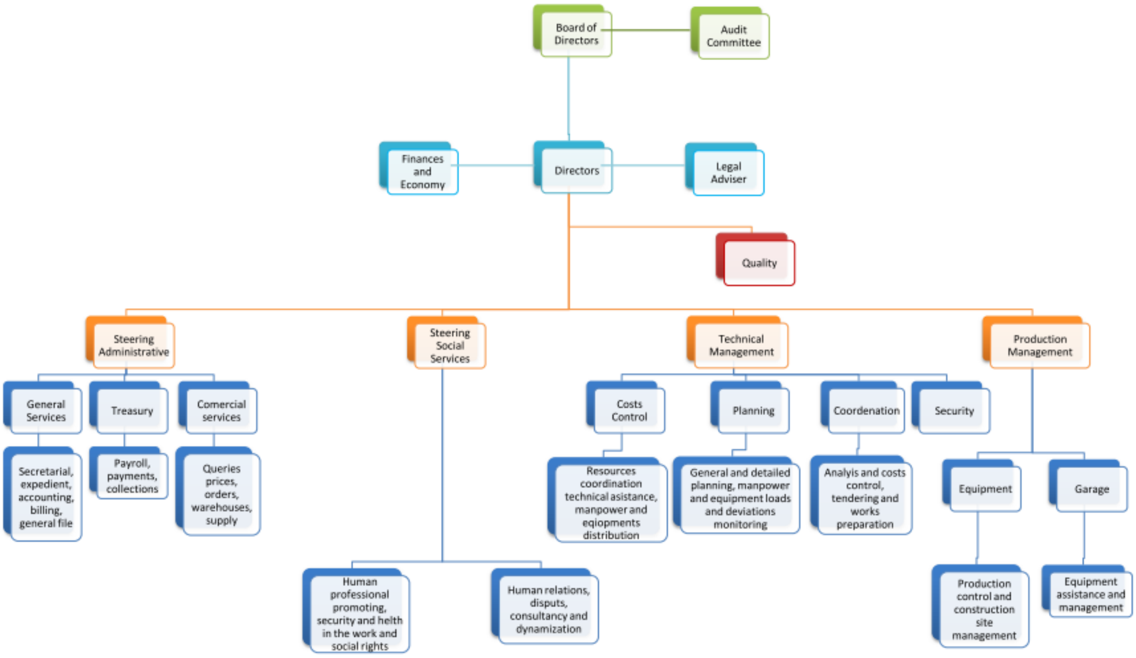

Figure 3.6 - Big construction enterprise structure - standard chart example (adapted from Correia dos Reis, 1996).

In Figure 3.7 is shown an example of a company chart, but searching in the internet it is also possible to see some organizational charts for some of the companies as for example:

- MT Højgaard group (http://mth.com/About_Us/Organisation/OrganisationChart-2014.aspx);
- VEJDIREKTORATET (http://vejdirektoratet.dk/da/om-os/organisation/sider/default.aspx)

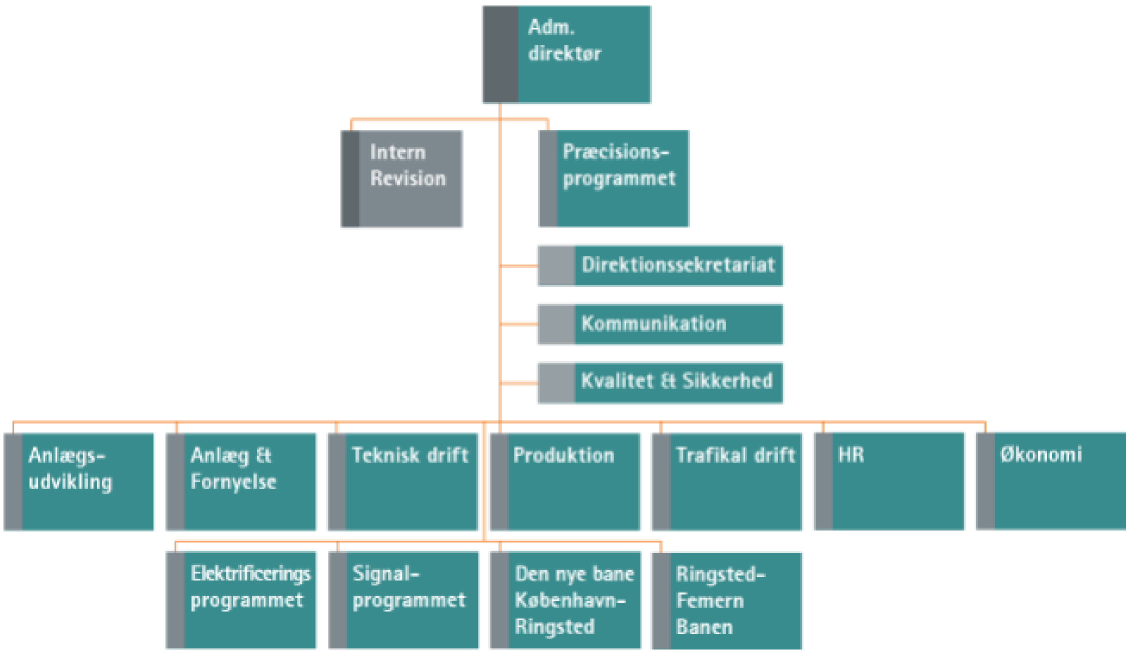

Figure 3.7 - Organiztional chart (Banedanmark - http://www.bane.dk/visArtikelBred.asp?artikelID=141, seen in 11/04/2014).

3.5 Projects, Processes and Developments

In this section, will be introduced the types of projects within the construction sector. The project lifecycle will be approached, by defining the steps, phases and stages through the course of the process of a construction project.

3.5.1 Sectors in the construction industry and projects types

Along the previous sections, was stated the characteristics of a construction project, presented the participants and the roles they play along the project lifecycle, as well as the way the organizations have their structure organized. It was seen that all of these characteristics and features are much dependent on the construction sector and project type. Along this subsection it will be presented the sectors in the construction industry and the project types.

There are several approaches along the literature about how the construction industry sectors can be split. So, starting this analysis by the project's category, these can be of public interests (public sector) or for private use (private sector). The classification for public or private sector is related with the final destination and use for the facilities to be built and also according the classification of the owner, i. e., if it is a public or a private organization. Benton and McHenry (2010), present the following classification for the project types according their category:

- "private sector housing (e.g., residential, apartment, and subdivision development projects)";
- "private sector commercial (e.g., retail stores, manufacturing plants, businesses, restaurants, and warehouses)";
- "public sector building/vertical (e.g., schools, universities, airports, hospitals, and state buildings)";
- "public and private sector heavy/horizontal (e.g., highways, bridges, and dams)".

So, somehow, it can be said that Benton and McHenry (2010), classify the construction projects into two categories, the public sector and the private sector. Then, for the private sector they distinguish between habitational and commercial buildings. In the public sector, the distinction is done for the two types of projects, the buildings and heavy construction. The reader should notice that, for the private sector, Benton and McHenry (2010) differentiate the buildings type according to their final purpose of use.

There is also another interesting concept that Benton and McHenry (2010) apply. This concept classification is according to how the construction of the facility(ies) develops. These classifications are; vertical, for the project of building type and horizontal, for the heavy construction projects. The resume about how Benton and McHenry (2010) classify the construction sector and project types is expressed in the diagram of Figure 3.8. From the author's perspective this is a good approach for distinguishing the types of projects and the industry sector, as well as the designations given according to the way the construction process develops.

Taking now a look into other authors classification. For instance, Halpin and Woodhead (1998) classify the construction projects into three types; "building construction", "engineered construction" and "industrial construction". For these authors the base for the presented classification, is in the use and functionality of the facility, such as housing, public works or manufacturing process. In the engineered construction, two divisions are made; for highway construction and heavy construction. The industrial construction is taken as a special case of project type, where Halpin and Woodhead (1998) consider specific projects of manufacturing and processing of products. The resume of how the construction sector and project types are classified by Halpin and Woodhead (1998) is shown in Figure 3.9. The facilities are assigned by these authors as follows:

- Building construction - facilities "for habitational, institutional, educational, light industrial, commercial, social and recreational purposes";
- Highway projects - only refers to highways and all the works which are involved in these projects, such as "excavation, fill, paving",...;
- Heavy construction - "sewage plants, flood protection, dams, transportation projects (other than highways), pipelines and waterways".

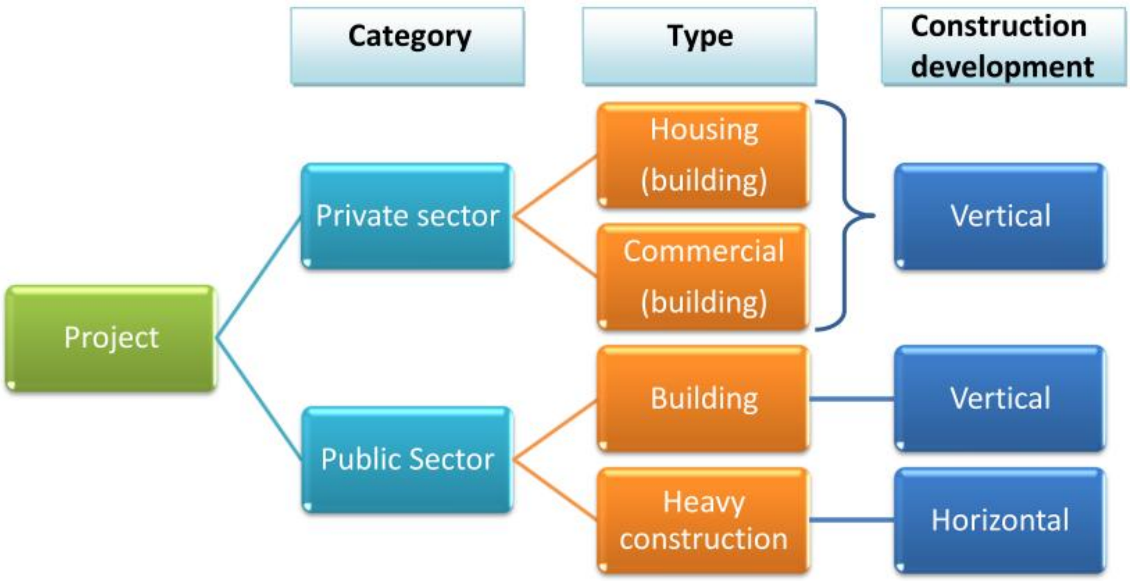

Figure 3.8 - Resume for the industry sector and project types classification by Benton and McHenry (2010) vision.

Gould and Joyce (2003) and Jackson (2010) have a similar approach about the industry sectors and project types. Yet, in the author's opinion, Jackson (2010) presents this topic in a more complete and detailed way. Gould and Joyce (2003) takes into consideration the "residential", "commercial building", "infrastructure and heavy highway" and "industrial" project types. Jackson (2010), beside mentioning the previous four types adds the "environmental construction" type. Jackson (2010) don't makes also any distinction from the highways and infrastructures, but yes, giving the designation of heavy civil construction. Following, it is presented how Gould and Joyce (2003) and Jackson (2010) classify the project types, being shown through Figure 3.10 the resume for this classification:

- Residential: "individual homes", "condominiums", "apartments", ...;
- Commercial building: "shopping malls", "hospitals", "theatres", "universities", "schools", ...;

- Heavy civil construction[2]: "roadways", "bridges", "dams", "tunnels", ...;
- Industrial: "steel mills", "chemical processing plants", ...;
- Environmental[2]: "conveyance systems", treatment plants" and "operation facilities"(...) "to collect, treat, reclaim and distribute water".

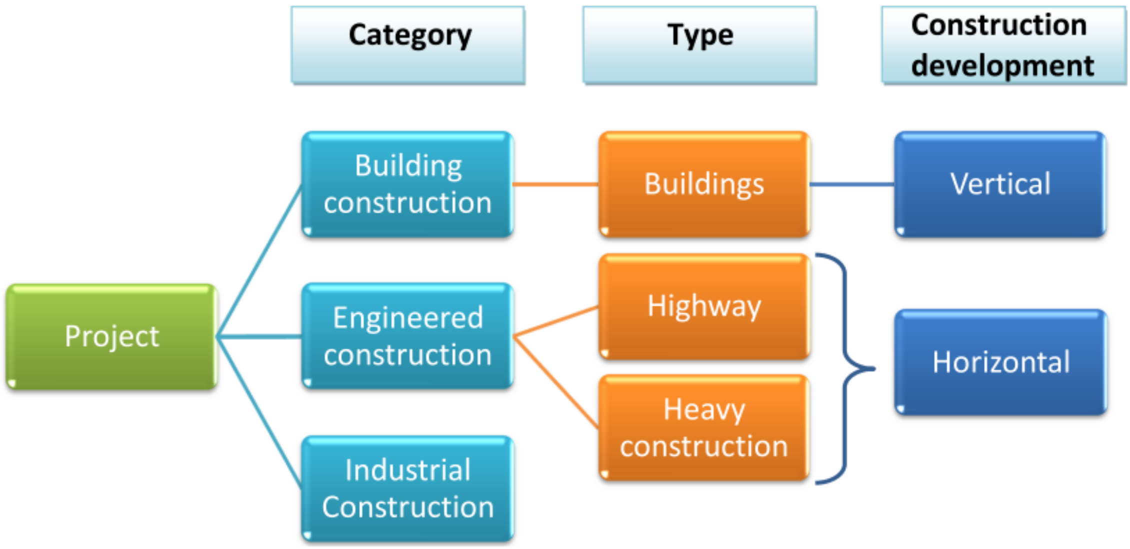

Figure 3.9 - Resume for the industry sector and project types classification by Halpin and Woodhead (1998) vision.

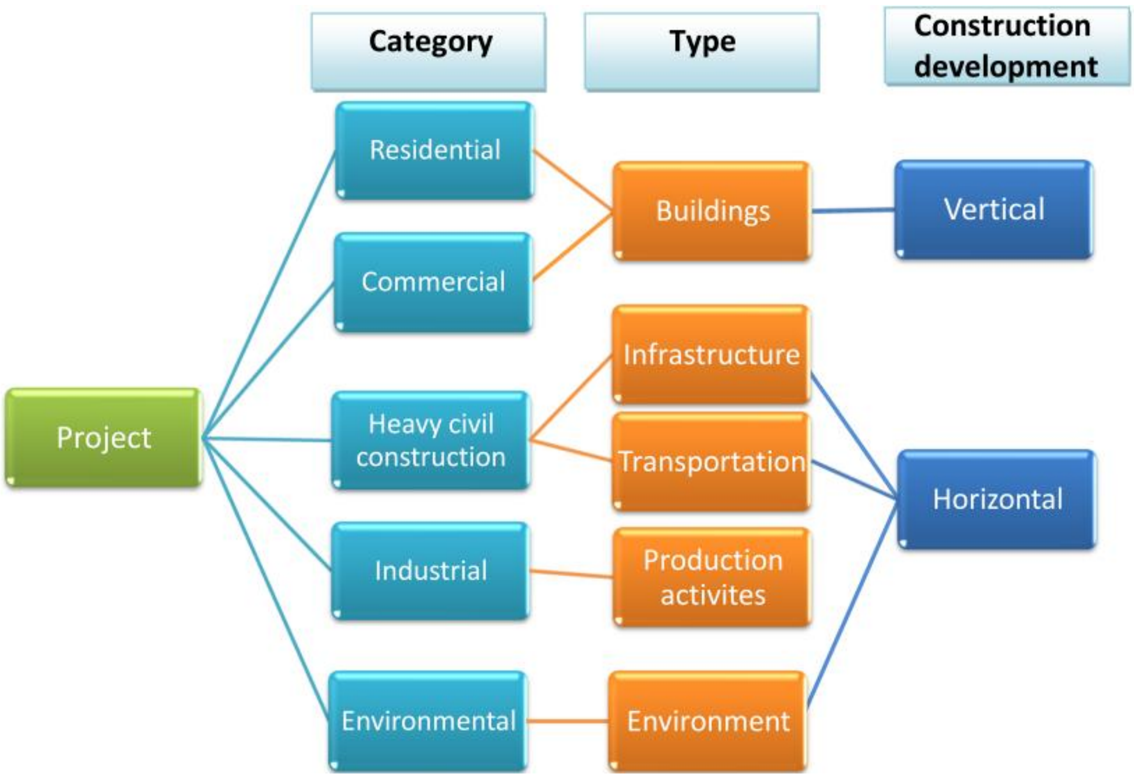

Figure 3.10 - Resume for the industry sector and project types classification by Gould and Joyce (2003) and Jackson (2010) visions.

The author's vision and perspective about this topic is that, the classification for the construction sector and projects types can be done by using the following distribution shown in Figure 3.11. The

[2] Jackson (2010) designation

public and private sectors choice comes to meet what has been presented along this thesis and according to what was read throughout the literature. So, analysing the designations "building construction" and "infrastructures", the first is totally related to buildings, independently theeir design purpose. This analysis meet the following definition for building construction presented by Davies and Jokiniemi (2008): "the discipline, process etc. of constructing buildings; matters pertaining to this". These types of projects are associated to both of private and public sectors according to the role the buildings were designed for. The connections shown in Figure 3.11 are also of different sizes, to represent the difference in the number of projects between the both sectors, based on the literature (Halpin and Woodhead (1998), Gould and Joyce (2003) and Jackson (2010)). The reader should notice that, the difference in the thickness between the lines have the purpose to express the difference for the amount of projects, between the project types mostly common in the private or public sector. Also, the dashed line means that, very few infrastructures projects are for the private sector. There are also different line widths, which mean the relation between all the project types and categories.

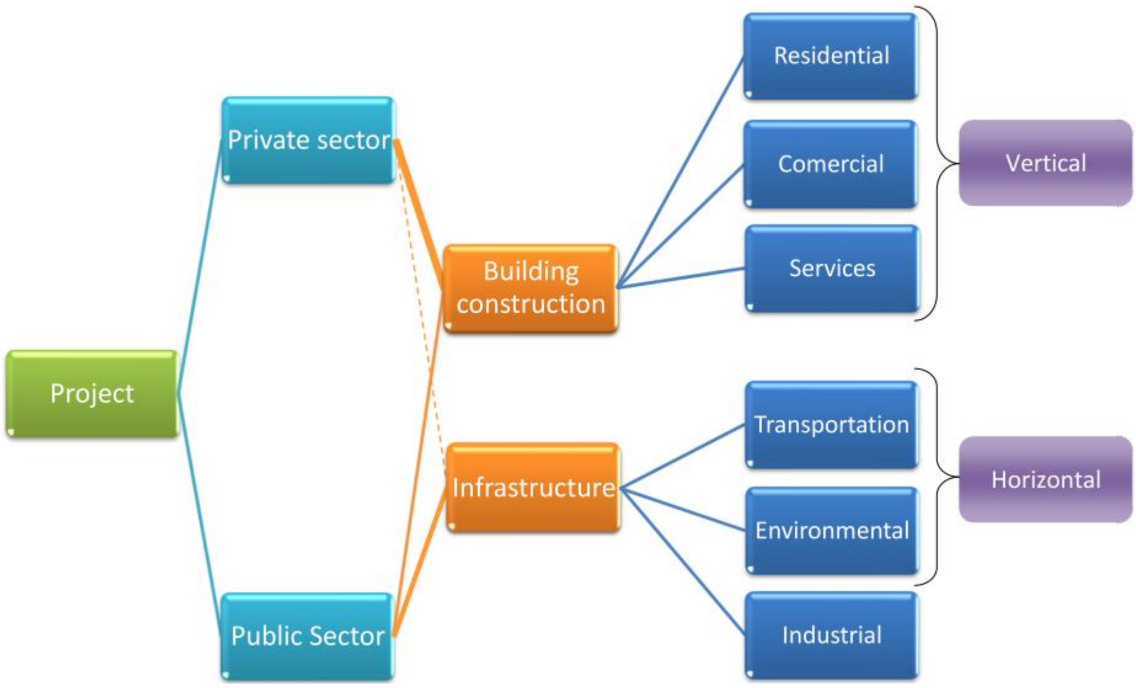

Figure 3.11 - Author's view for the industry sector and project types division.

The designation of infrastructure assigned to the other projects then buildings, arises from the idea to all those "structures" that support a better quality for the population's daily life. These structures help in making the life become easier, contributing for the mobility of people and improving environment and health quality, to cite some characteristics. These are also projects which in their great majority are of public interest. The relation with the infrastructures project type is expressed through Figure 3.11 with the continuous line, meaning the dashed line some individual cases of private infrastructures projects. If taking into consideration the following definition from Davies and Jokiniemi (2008), being an infrastructure "the basic public installations, utilities and facilities, housing, roads, sewers and power, which form the physical foundation of an urban community" it comes close to the designation given by the author. However, if looking at Jackson (2010), who defines infrastructure as "the basic roadways, bridges and road networks that supports a community or society", her definition only takes into account the transportation facilities.

Now, a small discussion about the way the construction of the projects develops will be present. Through the literature, as mentioned before, the designation of vertical and horizontal development is related to the manner in which the building construction and infrastructures projects respectively "grow". The author also knows the designations: point and linear works. The meaning for these designations is the same for the vertical and horizontal. However, point development means that the works only their development on that point. The linear development means that the works have their development along a large extent, being the length much larger than the height and the width.

The industrial projects are those which, in the author's perspective, can be little more difficult to classify, due to its diversity of purposes. However, if considering the definition, even though these types can assume in some projects the building shape, they belong to a "foundation of a urban community". The same happens when classifying the industrial projects as to how they develop. It can be a vertical development, in the case of a building project, but also a horizontal development for a wind farm, for example.

Along this chapter references were made to the particularity and specific characteristics of the project types, as presented in section 3.3, when approaching the project participants topic. Now that the project types were introduced, it will be made the bridge between the intervenients roles according the project type.

Analyzing first the building construction type, these are projects which can vary from a simple small house to a very complex skyscraper, from a small convenience shop to a huge shopping center, and so forth. Thus, although these are projects for buildings, depending on the purpose it is intended for the facility, there will be the actors involved in the project. Considering first the small scale facilities, usually, these are projects of quite simple design and building process. All the design organizations are qualified and able to work within these type of projects. These projects can be designed either only by architects or engineers, though, being most commonly designed by architects (Gould and Joyce (2003). Additionally, in some cases, that the builder may be capable of design the structure (Gould and Joyce, 2003). The construction enterprises involved in the construction process are in majority of micro or small size. In these small scale facilities projects, the materials used can vary from country or even region. If reading the literature, there are authors referring to wood materials, there are others who mention the use of pre-manufactured materials, the use of bricks and concrete, and so forth. So, according to the climate conditions, traditional and available materials, there will be the used construction materials. For the bigger scale buildings, the design is usually taken by the architects (Halpin and Woodhead, 1998; Gould and Joyce, 2003 and Jackson, 2010). However it can also happens the design to be done by the architect supported by the engineer (Halpin and Woodhead, 1998 and Gould and Joyce, 2003). In these type of projects, the medium and big enterprises are the responsible for the construction. However, specialized small and micro enterprises can also participate in the construction process, working as subcontractors for the main contractor(s). The main materials present on this type of projects are concrete, steel and glass (Jackson, 2010). The services projects can vary in the sizes, being those of small size, possible to be compared with the first ones mentioned in this paragraph, and the big size service buildings compared to the last ones.

For the infrastructures projects, the main responsibility for the design is of the engineers. In the opposite to the building projects, these are projects which demand a great need of heavy construction equipment. In the transportation and environmental projects, it can be said that the equipment used is the same. These are also projects that can last for years (Jackson, 2010), according the regional and global needs. From the author's experience it has seen that, the environmental and transportation projects are split into phases which can be in sequence or intercalated. Related to the materials, these are also almost the same, but with different amounts. The main materials it can be said to be, asphalt, rebar, steel, piping, pre-casted concrete (Jackson, 2010). Usually the main responsible for the construction of these type of projects are the big or medium contractors organizations. Referring now to the industrial projects, this is a "high specialized industry and requires firms with vast resources and significant construction and engineering expertise" (Jackson, 2010). Due to this characteristic, there are a limited number of contractor organizations qualified for doing these type of works. However, the somehow similar characteristics to the environmental and transportation projects, the materials are the same as those used in the commercial projects.

3.5.2 Project lifecycle

In all construction projects can be considered three major stages in their lifecycle, i. e., since the idea or the need for one or various facilities is found, until the moment that facility stops being used and is deactivated or demolished. In this thesis the three main stages to be considered will be the design stage, the construction stage and maintenance stage (Figure 3.12). The design stage, construction stage and maintenance stage can be considered as a chain of a continuous process inside the project lifecycle. These stages are strongly intertwined between them. Thus, what happens at a point in time of this chain, will strongly influence the upcoming This will become bigger with the progression of time for the project (Figure 3.12). Inside these three major stages there are also phases through which the project have to pass. To mention some examples, the planning, tendering, costs control and so forth.

Before introducing how these three major stages will be treated along this document, will be made a brief introduction to how in the literature the project lifecycle is described. Jackson (2010) presents the following stages for the project lifecycle: design; pre-construction; procurement; construction, post-construction and owner occupancy. With a similar structure, Windapo (2013) treats the project lifecycle as going through the concept stage, pre-construction stage, construction stage and post-construction stage. This same concept of project lifecycle is presented by Bennett (2003) as having the pre-project phase, planning and design phase, contractor selection phase, contractor mobilization phase, project operations phase and project closeout and termination phase. To make the bridge between what is considered in the literature and the way will be treated in this work, Figure 3.13 can be followed. In Figure 3.13 are shown the concepts included, the stage where they will be considered, according the descriptions found in Bennett (2003) and Jackson (2010). On the left of Figure 3.13, are the phases that will be analysed and the stages in which they are considered for this thesis and according the literature. From the construction stage all the project flow will be considered, being then, on the maintenance stage only mentioned the bridge between the project delivery and the owners occupancy.

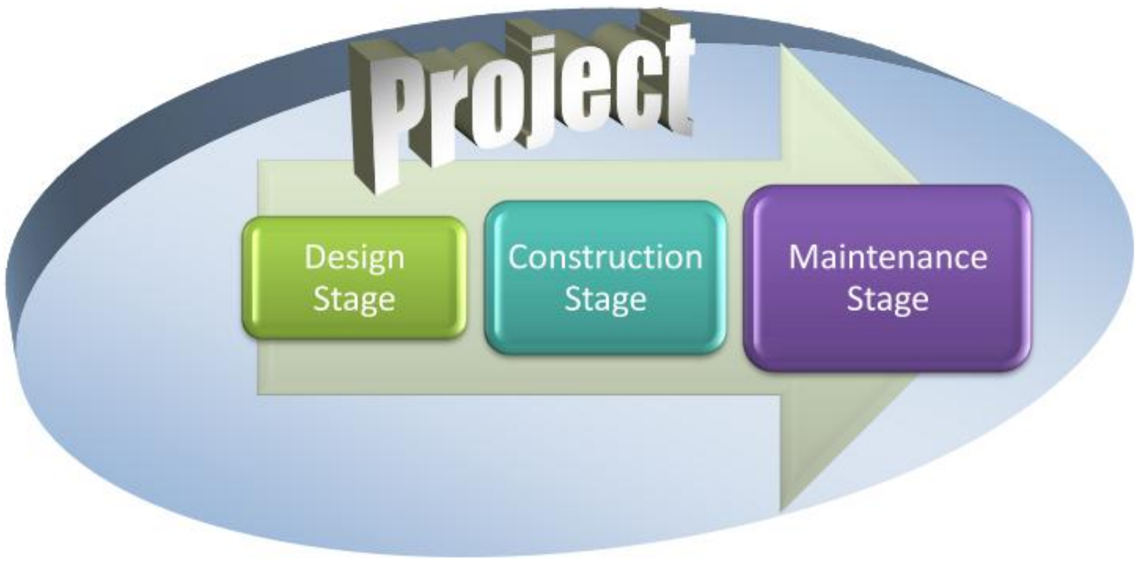

Figure 3.12- Project lifecycle chain.

Along the literature the biding phase is considered part of the design stage (the dashed line in Figure 3.13 leading to bidding phase). Between the bidding phase and the phase when the contractor receives the notice of getting the project, the literature also consider other phases on the design stage. But, once the main focus in this thesis is the contractor role in the project, to have a sequence in the contractor role, the bidding phase will be considered as part of the construction stage (Figure 3.13). With similarity to the bidding phase, the project delivery phase will be considered part of the construction phase. As shown also into Figure 3.13, in the literature the pre-construction, procurement and construction are considered as stages. In this project, these stages are considered as phases inside the construction stage.

In Figure 3.13 all the concepts from the literature were taken from Jackson (2010) with the exception for the pre-project stage which was taken from Bennett (2003). The reason for this approach was because planning and design phase and the contractor selection phase from Bennett (2003) is included on the design phase from Jackson (2010), as well as for the purposes of this thesis it seems to Jackson (2010) the best description.

The design stage will be considered as being constituted by the phases where only the owner and the design members are involved, being the contractors out of what may happens during this process. Attention should be called that, the contractor can have some participation during the design of the project. The bidding phase is totally done by the contractor, but according to Jackson (2010), this phase is included into the design stage. If recalling the problem studied, in this thesis, the bidding phase will be considered on the construction stage for simplifications purposes. The point in approaching the topics about the project delivery method, which is part of the design stage, is to help understanding some concepts of BIM, as well as because depending on this, the approach by the contractor to the project will be different to adapt to the delivery method.

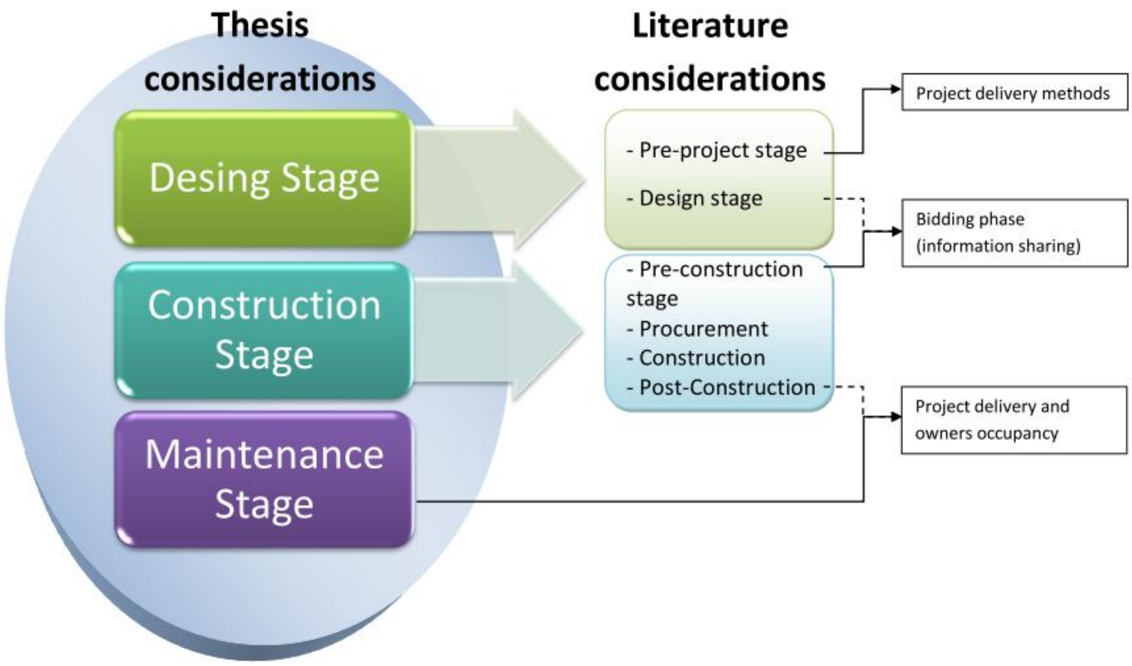

Figure 3.13 - Considerations and concepts used.

The maintenance stage is considered with the purpose of showing how BIM can be important through the entire project lifecycle. The idea is to show its collaborative feature and how important it is also in the communication flow after all the construction process being completed. Inside the maintenance stage, through the continuation of the facility(ies) life, a new project can be done with a new lifecycle. An example are the projects for rehabilitation, restoration, amplification and so forth. These projects can be "full" projects with a design and construction stage included on it. In these situations all the documentation and information from the previous work done becomes very important. Is in this process that the information sharing and collaborative work feature of BIM becomes an important capability.

This project lifecycle description can be seen in Figure 3.14 in a very simple schematic form. The timeline for the lifecycle of a project is shown in Figure 3.15. The time between the end of the design stage and the beginning of the construction stage can vary from weeks to years. The duration of the design and the construction stages are also variable, being generally the construction time longer then the design stage. The interval between the end of the construction phase and the beginning of the maintenance stage is much smaller, while the duration for the maintenance stage can least for decades or even centuries, as the example given further on subsection 4.6.3 for the Sydney Opera House. Also inside the maintenance stage, several cycles of design and construction can occur.

Through a project lifecycle, some variables should be taken into account. Those variables are the costs, the time, the quality and safety. From the author's experience, it can be said that, safety is not much taken into consideration during the design stage or maintenance stage, but yes during the construction stage. These four aspects of the project are interconnected within each other by having a strong influence between themselves i. e., when one is changed all the others will undergo changes inevitably.

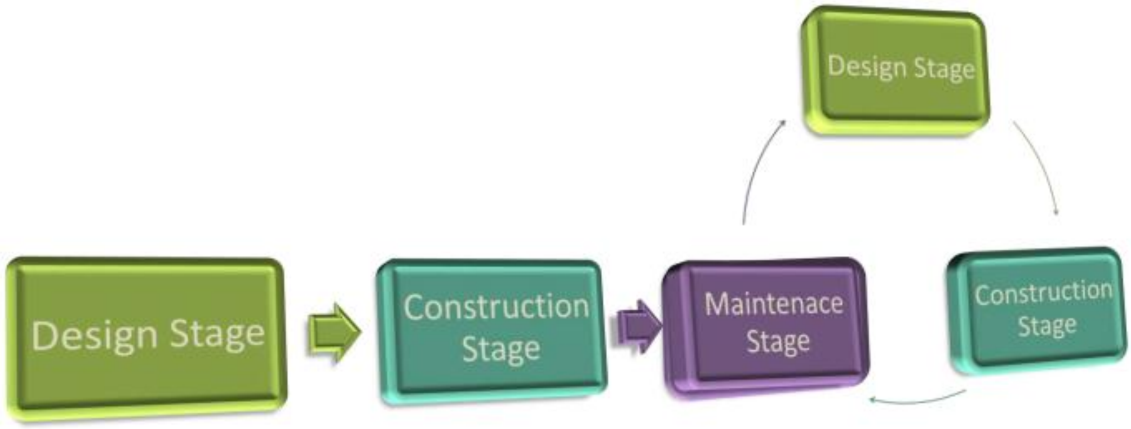

Figure 3.14 - Project lifecycle simplified diagram.

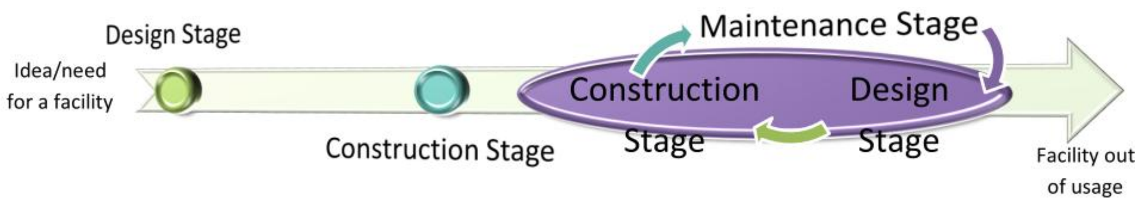

Figure 3.15 - Timeline for a project lifecycle.

3.5.3 Project delivery methods

The project delivery method is related with how the main parties involved in the project, owner, designer and contractor, will interact between them. This is a process which occurs in the beginning of the design stage and is done by the owner of the project. Jackson (2010) describes project delivery as "the process by which all the procedures and components of the designing and building a facility are organized and put together in an agreement that results in a completed project". The "owners primary goal in choosing a delivery method is to ensure that it will meet the project objectives and at the same time allow the project to be delivered on time and within the budget" (Gould and Joyce, 2003)

Four main contract delivery methods can be used by the project owners, which according to Eastman et *al.*(2011), Hardi (2009) and Jackson (2010) are; Design-Bid-Build (DBB), Design-Build (DB), Construction Management at Risk (CM@R) and Integrated Project Delivery (IPD). In the older literature related with project/construction management the IPD method is not mentioned (Bennett, 2003 and Gould and Joyce, 2003). The IPD method is only referred into the literature about BIM. The main reason for this, might be because the IPD method was a new concept created with the emergence of BIM approach.

The presentation of these project delivery methods will be done only by mentioning what they are and featuring some of its characteristics. The purpose is to make the link with the collaborative feature of BIM for the information flow, transferring and sharing through the project lifecycle and thus through the construction phase.

3.5.3.1 Design-Bid-Build (DBB) method

As the name suggests, this method consists of three consecutive but independent phases (Figure 3.16). In Hardin (2009) and Eastman et *al.*

(2011), this method procedure is described as, the client first hires a design company which will be responsible for the entire design of the project. All the tasks related with the design of the project such as the preliminary planning, the design work and all the documents related with the project and the contract, according the owner's goals and all the codes related with the environment the project will be done (Bennett, 2003). A chain of documents is developed either in drawings and text, where all the specifications, information, details and procedures are included.

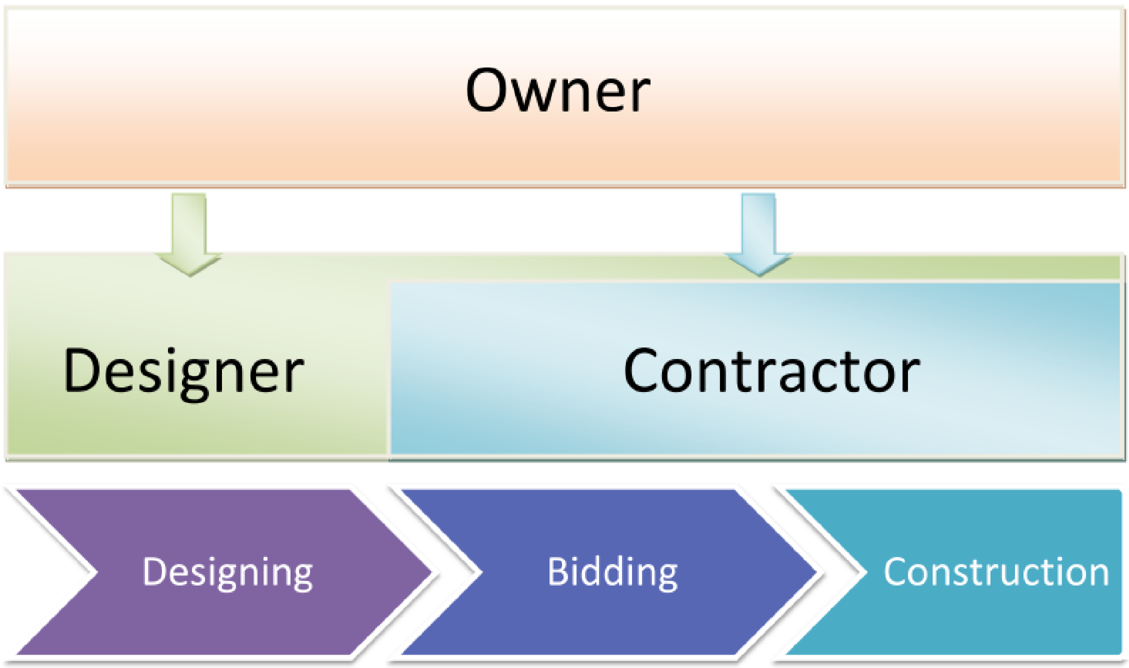

Figure 3.16 - Interaction between the three parties involved and their interaction through the phases in the DBB method.

Finished all the process related with the design of the project, the contractor(s) get inside it, through the owner contact to get a bid for the construction of the project from each contractor. At this point, the documents belonging to the project are delivered to a certain number of contractors for presenting their bids, based on the documents which comprise the project. The contractors allowed to present their bids will be chosen by the contractor and architect, being the chosen contractor usually based on the lowest bid presented (Eastman et *al.*, 2011). When the bidding process is finished and the contractor is selected, "the owner enters into a contract with the successful contractor for the assembly of the project elements in the field" as mentioned in Bennett (2003). In Figure 3.16 can be seen the entire process for this method. Figure 3.16 also shows the way the owner interacts with the two independent parties (the designer and the contractor). In addition, the three phases of this method and the involvement for the three main organizations involved in the project are shown as well in Figure 3.16. To reinforce what was introduced, Bennett (2003) mentions how this method is characterized by the designer and contractor working independently.

Hardin (2009) describes this method as a linear process, while according to DBIA (2007), in Eastman et *al.* (2011), in USA, this was the method used in the majority of the projects in 2002 within the public construction sector with percentage of 90%, representing this in the private construction sector around 40%.

3.5.3.2 Design-Build (DB)

In this method there is only one organization which the owner contacts for executing the works. The entire design and construction phases are of total responsibility of the contracted organization, as shown in Figure 3.17. The organization responsible for the project can be structured as a single organization, in the case where the company has a complete structure for designing and constructing the project. Or an association with independent designing and construction companies by working together as one single organization. In Hardin (2009), this method is seen a "more integrated than DBB". This is easy to understand due to its feature of the design team and the construction team working together from the begging of the process. This statement is reinforced again by the same author when mentions that this method "allows for the contracting team to have early involvement in a project".

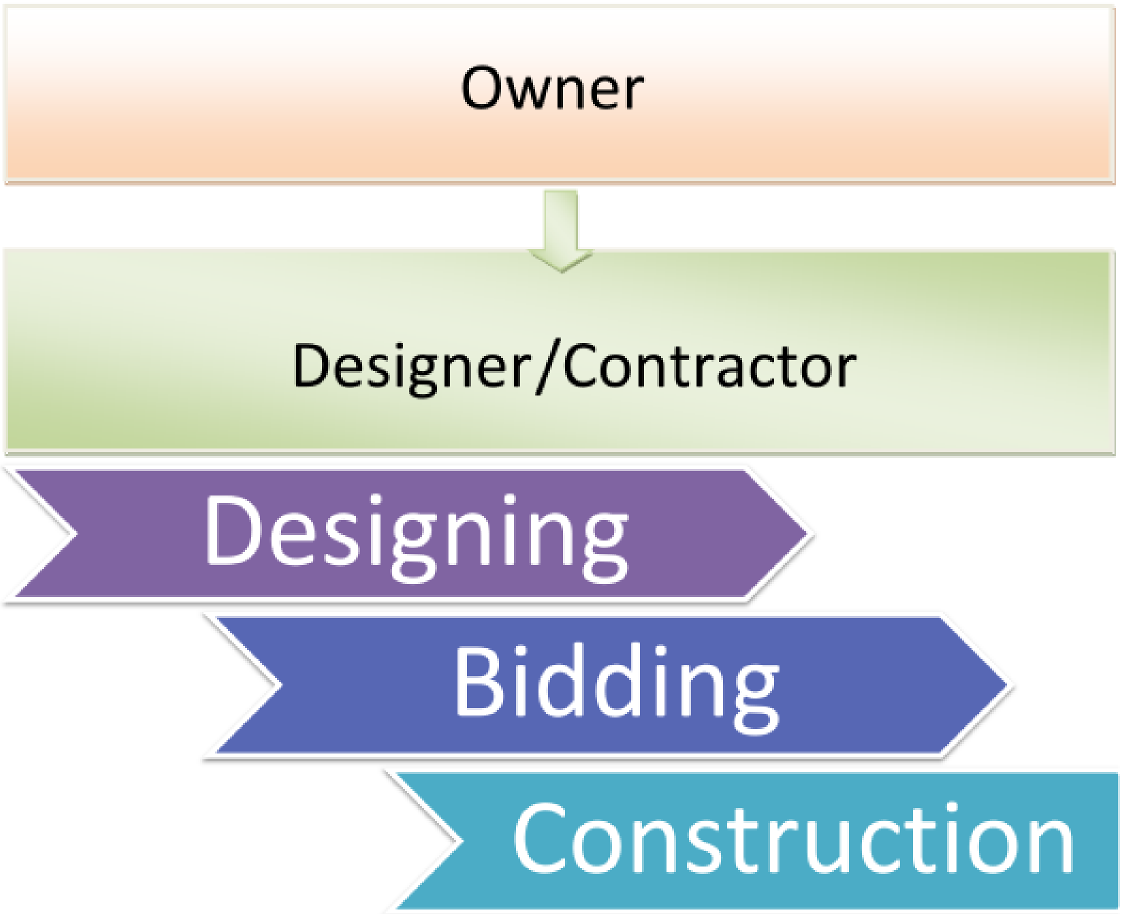

Figure 3.17 - Interaction between the two/three parties involved and their interaction through the phases in the DB method.

According Beard et *al.* (2005), in Eastman et *al.* (2011), this method "was developed to consolidate the responsibility for the design and construction into a single contracting entity". Eastman et. *al.* (2011) describes the DB method by a process where "the owner contracts directly with the design-build team ... to develop a well defined building program and a schematic design that meets the owner's needs". In this method, the entire project is of the "two teams" responsibility, including changes in the design during the construction phase, errors and omissions or other incoherencies on the project. This method also allows for a delivery of not so detailed drawing in the an earlier stage, being these draws possible of being completed along the construction phase.

3.5.3.3 Construction Management at Risk (CM@R)

With the previous two methods, the management is done by the organizations responsible for the design and construction of the project. In the CM@R the difference lies precisely in that point. The owner uses its own resources or hire an external organization to represent him in the management of the design and construction, as shown in Figure 3.18.

As described in Eastman et *al.* (2011) in this method the "owner retains a designer to furnish design services and also retains a construction manager to provide construction management for a project throughout the pre-construction and construction phases". This method "brings the constructor into the design process at a stage where they can have a definitive input". There is also another feature in this method, the guaranteed maximum price (GMP) which according what is described by Hardin (2009) is the price which sets the highest limit for "the delivery of the whole project".

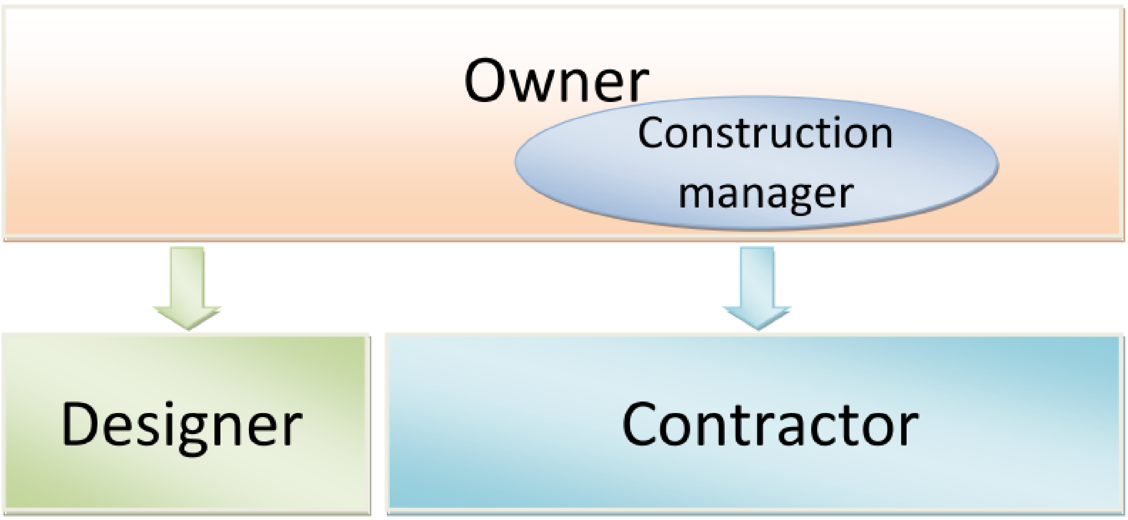

Figure 3.18 - Interaction between the parties involved and their interaction in the DB method.

3.5.3.4 Integrated Project Delivery (IPD)

This method is according Eastman et *al.* (2011), a somehow recent method, which started gaining adepts with the rise and BIM´s expansion. This can be also noticed looking into some of the older literature related with the construction management and project management. No references are made to this method. However in a more recent literature related with BIM or even with the construction management and project management, as for instance Jackson (2010). Hardin (2009) presents the following from AIA California Council (2007) about IPD method stating that "Integrated Project Delivery is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction".

When choosing the IPD method an involvement from all the main stakeholders of the project is done through all the phases of the project. The intervenients get together, by cooperating as if only one organization was involved, existing between them a bilateral relationship that involves the as the core of this relation, as shown in Figure 3.19.

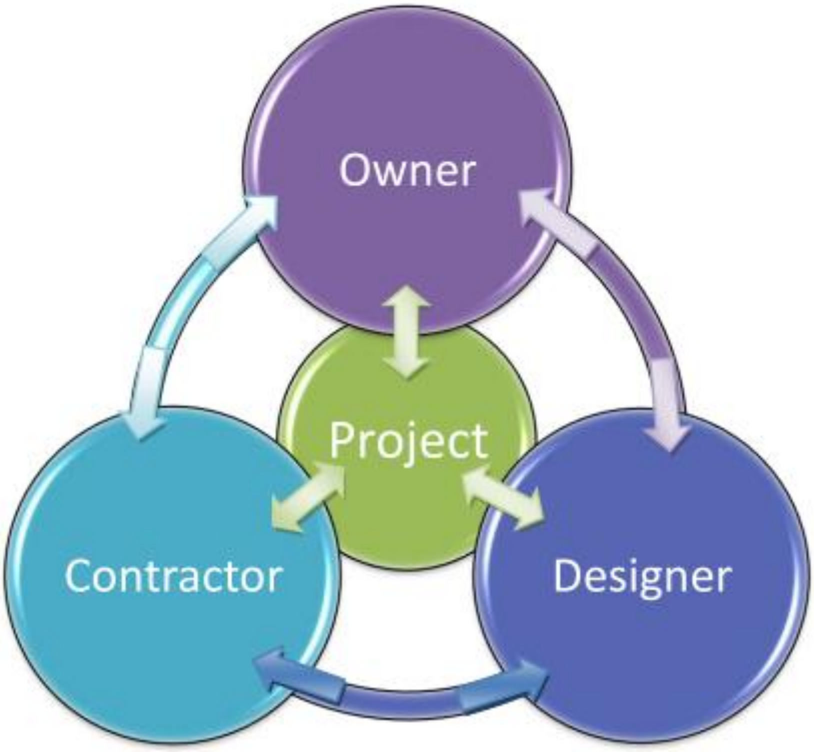

Figure 3.19 - Interaction between the parties involved and their interaction in the IPD method.

"These method is "distinguished by effective collaboration among the owner, the prime (and possibly sub-) designers, the prime (and possibly key sub-) contractors", being thus "the key concept is that this project team works together using the best collaborative tool at their disposal to ensure that the project will me the owner requirements at significantly reduced time and cost" (Eastman et *al.*, 2011).

3.5.4 The project and it's documents

The project itself is a set of documents, built along the design stage. This set of documents contains all the information "needed" for the facilitiy(ies) to be raised through the construction stage, and for further maintenance. The documents which are part of the project are also the used ones for the realization of the contract. The project documents are built based on the needs, instructions and laws and legislations. These same documents are then given to the contractor(s) for tendering purposes (3.5.6 and 3.5.7), to serve as base for the contract (3.5.5) and further on along the construction process (3.5.8 and 3.5.9). Thus, the documents constituting the project should contain all the technical information to be used along the entire project life cycle.

The documents constituting the project can be split into two components (Figure 3.20), the drawing component and the specifications component. The specifications component is also many times described as written documents.

The drawings give a visual idea about what the project will be. Also from the drawings are shown the shapes, quantities, locations, site plan and implantation information, relations between the elements, and so forth. The drawings can be split by the specialities (3.3) involved in the project. The drawing component can be then constituted (Figure 3.21), for example, by the architectural, structural, electrical, mechanical, ..., drawings. The drawings lead the persons involved in the project through a path, for reaching the final goal. The drawings are like a map, containing all the information to guide the crew to their final destination. "The drawings are a graphical set of directives prepared by the architects and engineers in order to communicate the wishes and desires of the owner" (Jackson, 2010).

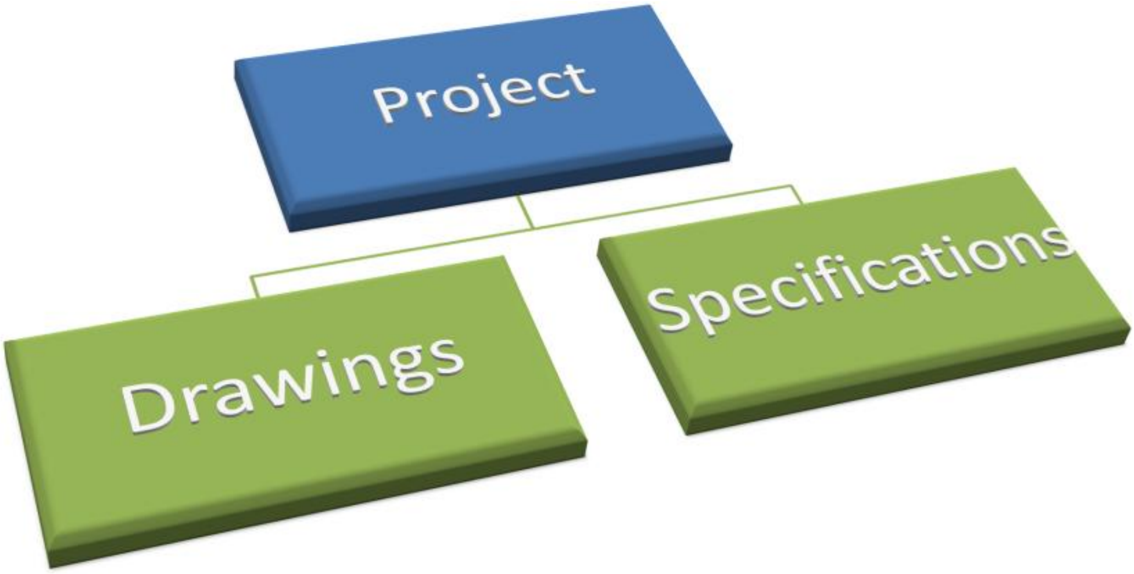

Figure 3.20 - Project components.

The specifications are a set of documents containing the information about the materials specifications, regulations, construction methods, legislation, constraints, explanations. Jackson (2010) presents the following types of specifications, shown into , calling to the specifications the project manual.

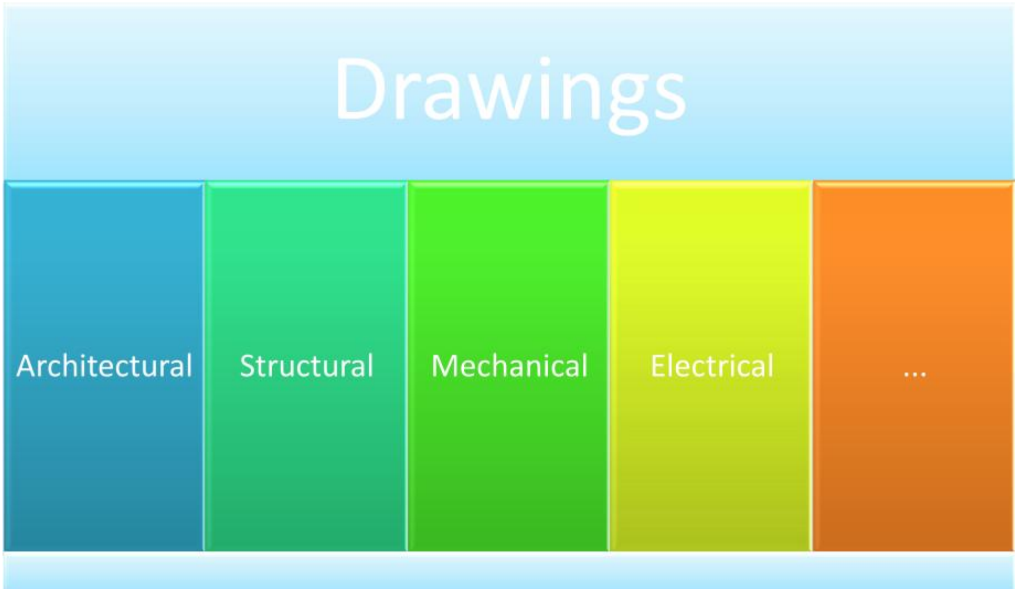

Figure 3.21 - Elements constituting drawing component.

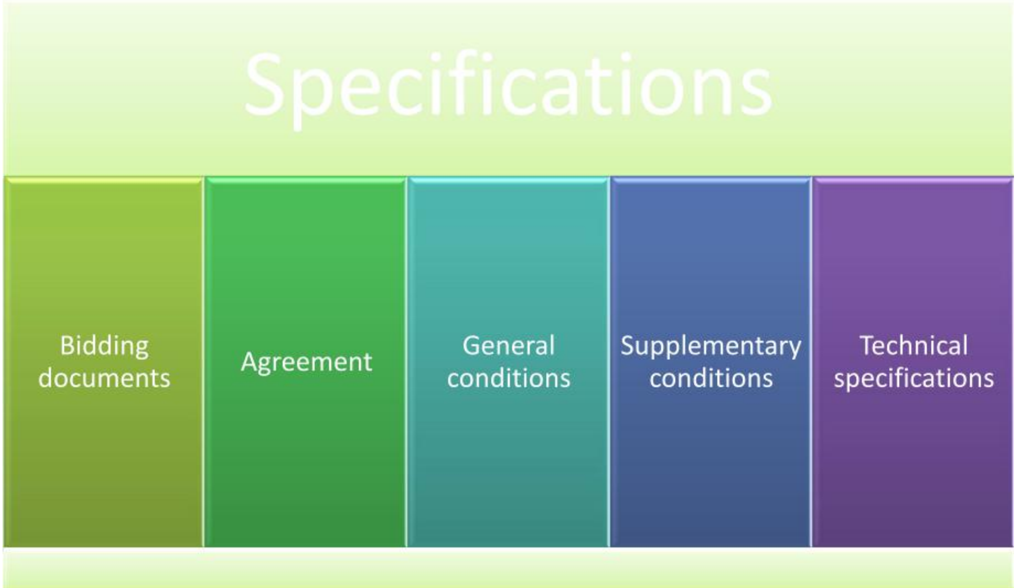

Figure 3.22 - Elements constituting specifications component(adapted from Jackson, 2010).

The bidding documents are constituted by the presentation for the owner to build certain facility(ies). This document contains the information related with the owner, a brief description about the contract, legal, economical, financial and technical information, information about the tendering process, and so forth. The agreement, is nothing more then the terms of contract celebrated between the parties involved. The general conditions are related with all the information about the solutions and assumptions taken during the design, i.e. the design considerations. Into the general conditions are presented the responsibilities for both the contractor(s) and the owner(s). The detailed legal conditions, contracts, payments, safety, health and environment (SHE) and so forth, are also included into the general conditions. The supplementary conditions are related with the specific conditions for the project itself. While the general conditions are usually used in the more wide range related with the type of project and the owner's organization procedures, the supplementary conditions are more to cover the point parts of the project not covered in general conditions. For example, in a general form for the construction of earth embankments should be done compaction with a type of compactor, for that specific project another type of compactor should be used. Also, it can happens that, in a general situation, a compaction test might need to be performed every two kilometres, but due to some limitations for this project, compaction tests are needed every kilometre.

The technical specifications is where are contained all the information about the materials, laboratory or field tests need to be carried, methods and construction techniques.

3.5.5 Contract types

In 3.5.3 the delivery methods were introduced. It was seen that, the delivery methods are more related to the design process. In this subsection, the contract types will be presented. The contract is what relates two or more parties involved in a transaction. Davies and Jokiniemi (2008) define contract from two perspectives: the "contractual agreement; a legally enforcing agreement between two or more parties regarding provision of goods, work or services, the scope of work included there in" and "building contract" as "an agreement by which a building contractor is committed to construct a building, carry out building works etc. for a certain price within a certain time and to documented designs. If taking into consideration what was said before, about the projects types, this building contract might be referring uniquely to the building projects types. So, to have a more generalized concept of contract, the definition for contractual agreement will be kept. Also if looking for instance to Gould and Joyce (2003) when introducing this topic, they refer to the contract in a very precise definition.

From the literature read, there were several mentions to the existing types of contracts. Halpin and Woodhead (1998), Gould and Joyce (2003) and Bennett (2003) for instance, make reference to three contract types, the "lump sum" (single fixed price[3]), "unit price and cost plus a fee". Jackson (2010) and Gould and Joyce (2003) make reference also to the "guaranteed maximum price" (GMP) contract type. Yet, the GMP is considered by these two authors as a variation for the cost plus.

Mentioned the contract types existing in the literature, it will be now present their features. The contract types treated in this subsection, will be the "lump sum, unit price, cost plus a fee and guaranteed maximum price".

3.5.5.1 *Lump sum contract type*

When the value of the project is agreed by a fixed certain amount of money, the contract type is called *lump sum* contract (Halpin and Woodhead, 1998; Gould and Joyce, 2003; Bennett, 2003 and Jackson (2010). This type of contract is also designated as "stipulated sum" by Halpin and Woodhead (1998) and Bennett (2003), due to its characteristic of being given as the sum of all the works. The *lump sum* contracts are, according to Halpin and Woodhead (1998), Bennet (2003), Gould and Joyce (2003) and Jackson (2010) better suitable for the building construction projects types. Halpin and Wodhead (1998) explain that, for this type of contracts "detailed plans and specifications requiring little or no modifications can be developed". So, this are the type of projects "which can be completely designed and whose quantities are thus definable, in the beginning of the project" (Bennet, 2003). Mention is also made in Gould and Joyce (2003) and Jackson (2010) to the use of the *lump sum* contract type with the DBB delivery method. The *lump sum* type of contract will be explained by taking the example shown in Table 3.1.

The Table 3.1 contains part of the work tasks from the project will be used as example shown in Chapter 0. In the *lump sum* contract type the owner asks for a price for the execution of the whole project. The enquiry is done based "on a set of documents" prepared by the owner and presented to the contractor to tender (Gould and Joyce, 2003). In Table 3.1 are presented the work tasks, the units related to those tasks, the quantity related to the work for the tasks and the price for doing all that work with the related quantities. The reader should notice also that, the works presented in Table 3.1, can be differentiated as building construction works and infrastructure works. This was done with the purpose of giving the reader a better idea for the application of the contract types. But, although these

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[3] Designation according to Gould and Joyce (2003).

two "divisions", the reader should be aware that this project is classified as an environmental project, as it will better developed further in 5.3.3..

Table 3.1 - Example of a contractor's price list for *lump sum* contract type (part taken from the project used in this thesis).

WORK TASKS DESCRIPRION	UN.	QUANT.	PRICE
EARTH MOVEMENTS			
Excavation in trenching and/or foundations for deployment of the work, including transshipment, shoring, drainage and all additional work in land by ripper blade or removable by mechanical means (soil) estimated 50% of the total volume.	m^3	525,29	682.407,44kr
Excavation in trenching and/or foundations for deployment of the work, including transshipment, shoring, drainage and all additional work in land by pneumatic hammer or explosives (rock) estimated 50% of the total volume.	m^3	525,29	
Landfill with sandy or non clayey material duly winnowed, clamped between the pipes and the trench walls (greater than 95% of the normal Proctor compaction test).	m^3	141,55	
Landfill with well compacted soil to the weight of the ram not more than 4kg (or higher compaction to 95% of the normal Proctor test) with material free stones.	m^3	223,50	
Loading, transport and unloading to a deposit and/or authorized dump of the leftover products, by not considering any shoaling coefficient.	m^3	711,54	
Landfill with material with a compacting degree equal or greater to 95% to the normal Proctor compaction test, done by mechanical or manual processes using equipment that does not transmit a force not greater than the weight of a ram of 15kg	m^3	115,54	
Drilling and installation of DN 600 steel chafer in a distance of ± 20 m, including equipment assembly and disassembly, attack and outlet wells and all the necessary and complementary works, to cross the railway.	Un	1,00	
HOSES AND FITTINGS			
Ductile iron pipes with standard automatic joints, DN 250.	m	651,00	
Ductile iron pipes with locked joints, DN 250.	m	94,00	
DN40 HDPE SN8 tritube for installation of signal cable.	m	800,00	
Band in blue PVC for conduit signaling	m	800,00	
Band in green PVC for signaling of the signal cable.	m	800,00	
Construction of a complete pre-casted concrete box type "NR1", including stairs, cover in Ductile Cast Iron class D400 with inscriptions and all the needed accessories and complementary works.	Un	9,00	
Curves in Ductile Cast Iron DN 250 with 11°15' and locked joint.	Un	2,00	
Curves in Ductile Cast Iron DN 250 with 22° 30' and locked joint.	Un	2,00	
Curves in Ductile Cast Iron DN 250 with 45° and locked joint.	Un	1,00	
DELIVERY STATION			
CONCRETE STRUCTURES			
Concrete of 160 kg/m3, applied as a clean layer or foundation settlement with a thickness of 0,05m.	m2	14,37	
Concrete with strength class C20/25 and exposure class 2a, including construction joints where necessary, formwork, stiking and armor rods in steel grade A400 NR.	m3	16,67	
Painting with three crossed layers of paint based asphaltic bitumen applied to exterior surfaces buried	m2	41,36	

Prefabricated slabs of reinforced concrete, with 1.30x0.50x0.15 m, including sealing and all additional work	un	5,00	
Gravel with average ø of 4 cm, applied layer with 0:20 m thick	m2	0,80	

The value for executing all the works which form the project is given by the contractor as if it was a single "piece". So, the agreement between the owner and the contractor organization is done based in what is "specified in the plans and specs for a single fixed amount of money" (Jackson, 2010). This means that the "project must be completely defined by the contract documents prior to" the tendering process (Bennett, 2003). In this type of contract, the owner knows from the beginning how much the entire "package" will cost. However, as stated in Gould and Joyce (2003), the *lump sum* contracts, have always the risk for the owner, the given price vary, once the price is based on the documents delivered, being thus the final value to be paid dependent on the accuracy of these documents. This can happens due to "flaws errors and omissions in the plants and specs" leading thus to a "change order" (Jackson, 2010). In the situation where errors or changes might occur or to be needed, the initial given value will be affected, being then the "new events" subjected to negotiations (Gould and Joyce, 2003).

Seeing this type of contract from the owner perspective, it brings the advantage of the owner knowing how much will be spent before the construction process start (Halpin and Woodhead, 1998; Bennett, 2003 and Gould and Joyce, 2003). However, the *lump sum* contract type brigs the disadvantages for the owner of needing a very accurate project design and documents, so no changes in the price will arise. Yet, due to this needed accuracy the entire "process will take longer", as stated in Gould and Joyce (2003). The entire quality of the project might be compromised, due to the contractor seek for maximizing the profits, as Bennett (2003) refers, or trying to cover some estimating error or mistake. There is no flexibility in this contract type, i.e., "any deviation from the original plans and specifications ... must be handled as a change order" (Halpin and Woodhead, 1998).

For the contractor, the *lump sum* contract carry the disadvantage, referred by Bennett (2003), of poorly managed the risk of having loses for the contractor is significant. Also, a bad estimation might lead into loses for the contractor. Thus, if well managed, as Bennett (2003) states, the contractor have the possibility of achieving a satisfactory profit. "The contractor does not need to 'prove' its costs in order to be paid" (Bennett 2003). From this last statement and also as Bennett (2003) mentions, there is more the possibility of increasing the profit, if changes will be requested by the owner, after signed the contract.

3.5.5.2 Unit price contract type

In the *unit price* contract type, the total price for the construction of the project is given by the cost for constructing a unity of the work items. These work items are measured by cubic meters, meters, units, squared meters (Table 3.2). The measurements for the items are done according to specific rules for measuring in the construction sector. These rules are usually defined and given by the institutions for the engineers, institutions which represent the engineering roles or institutions that work within the development for engineering. For instance in UK there is the Institution of Civil Engineers and the

Federation of Civil Engineering Contractors, where the first entity set through ICE (1985), standards for measurements. In Portugal there is the National Laboratory for Civil Engineering (Laboratório Nacional de Engenharia Civil - LNEC) which set the measurement standards through Santos Fonseca (2010). In Denmark there are new rules being devolped (http://cuneco.dk/nyhed/video-ccs-m%C3%A5leregler-og-standardiserede-tilbudslister , seen in 24.04.2014) and the rules wich are still being used (http://bips.dk/v%C3%A6rkt%C3%B8jsemne/opm%C3%A5lingsregler-udtagning-af-m%C3%A6ngder#0 , seen in 24.04.2014).

Based on the quantities given by the owner within the project (as in the example of Table 3.2), the contractor gives his prices for each unit of the referred work task. In opposition to the *lump sum* contract, the prices in this type of contract are defined according to the amount of work done per task. In 3.5.5.1 was mentioned a "micro" division into the type of projects for building construction and infrastructures. This division consideration in these two sections will make more sense now. So, according to Halpin and Woodhead (1998), Bennett (2003), Gould and Joyce (2003) and Jackson (2010) this type of contracts are better suitable for infrastructure projects. The reason presented by authors, is the non possibility for determining the quantities of work tasks accurately. So, if taking a look into Table 3.2, the items 1 and 2 can be associated to infrastructure projects. These items are quite difficult of measuring accurately the quantities, in special the items from 1, related earthworks. In 1.1 and 1.2 for instance it is possible to see the estimation of 50%-50% for finding soil or rock through the pipeline path. Also depending on presence of rock or soil, there will be the excavation depth and width, thus the landfill needed, and so forth.

Table 3.2 - Example of a contractor's price list for *unit price* contract type (part taken from the project used in this thesis).

Item nr.	WORK TASKS DESCRIPRION	UN.	QUANT.	Unit Value	Total Value
1	**EARTH MOVEMENTS**				
1.1	Excavation in trenching and/or foundations for deployment of the work, including transshipment, shoring, drainage and all additional work in land by ripper blade or removable by mechanical means (soil) estimated 50% of the total volume.	m^3	525,29	kr. 37,34	kr. 19.614,33
1.2	Excavation in trenching and/or foundations for deployment of the work, including transshipment, shoring, drainage and all additional work in land by pneumatic hammer or explosives (rock) estimated 50% of the total volume.	m^3	525,29	kr. 59,74	kr. 31.382,93
1.3	Landfill with sandy or non clayey material duly winnowed, clamped between the pipes and the trench walls (greater than 95% of the normal Proctor compaction test).	m^3	141,55	kr. 82,15	kr. 11.628,05
1.4	Landfill with well compacted soil to the weight of the ram not more than 4kg (or higher compaction to 95% of the normal Proctor test) with material free stones.	m^3	223,50	kr. 29,87	kr. 6.676,39
1.5	Loading, transport and unloading to a deposit and/or authorized dump of the leftover products, by not considering any shoaling coefficient.	m^3	711,54	kr. 18,67	kr. 13.284,45
1.6	Landfill with material with a compacting degree equal or greater to 95% to the normal Proctor compaction test, done by mechanical or manual processes using equipment that does not transmit a force not greater than the weight of a ram of	m^3	115,54	kr. 44,81	kr. 5.177,12

	15kg				
1.7	Drilling and installation of DN 600 steel chafer in a distance of ± 20 m, including equipment assembly and disassembly, attack and outlet wells and all the necessary and complementary works, to cross the railway.	Un	1,00	kr. 138.158,00	
2	**HOSES AND FITTINGS**				
2.1	Ductile iron pipes with standard automatic joints, DN 250.	m	651,00	kr. 410,74	kr. 267.391,74
2.2	Ductile iron pipes with locked joints, DN 250.	m	94,00	kr. 522,76	kr. 49.139,44
2.3	DN40 HDPE SN8 tritube for installation of signal cable.	m	800,00	kr. 26,14	kr. 20.910,40
2.4	Band in blue PVC for conduit signaling	m	800,00	kr. 5,23	kr. 4.182,08
2.5	Band in green PVC for signaling of the signal cable.	m	800,00	kr. 5,23	kr. 4.182,08
2.6	Construction of a complete pre-casted concrete box type "NR1", including stairs, cover in Ductile Cast Iron class D400 with inscriptions and all the needed accessories and complementary works.	Un	9,00	kr. 4.107,40	kr. 36.966,60
2.7	Curves in Ductile Cast Iron DN 250 with 11°15' and locked joint.	Un	2,00	kr. 2.053,70	kr. 4.107,40
2.8	Curves in Ductile Cast Iron DN 250 with 22° 30' and locked joint.	Un	2,00	kr. 1.941,68	kr. 3.883,36
2.9	Curves in Ductile Cast Iron DN 250 with 45° and locked joint.	Un	1,00	kr. 2.128,38	kr. 2.128,38
3	**DELIVERY STATION**				
3.1	**CONCRETE STRUCTURES**				
3.2	Concrete of 160 kg/m3, applied as a clean layer or foundation settlement with a thickness of 0,05m.	m2	14,37	kr. 746,80	kr. 10.731,52
3.3	Concrete with strength class C20/25 and exposure class 2a, including construction joints where necessary, formwork, stiking and armor rods in steel grade A400 NR.	m3	16,67	kr. 2.613,80	kr. 43.572,05
3.4	Painting with three crossed layers of paint based asphaltic bitumen applied to exterior surfaces buried	m2	41,36	kr. 112,02	kr. 4.633,15
3.5	Prefabricated slabs of reinforced concrete, with 1.30x0.50x0.15 m, including sealing and all additional work	un	5,00	kr. 1.120,20	kr. 5.601,00
3.6	Gravel with average ø of 4 cm, applied layer with 0:20 m thick	m2	0,80	kr. 149,36	kr. 119,49

3.5.5.3 Cost plus a fee contract type

The *cost plus a fee* contract, as mentioned in Halpin and Woodhead (1998), Gould and Joyce (2003) and Jackson (2010), is done based in the reimbursement for part of the project, a fee (that can be in percentage) for the other part. "The contract describes in detail the nature of the expenses that are reimbursed" (Halpin and Woodhead, 1998). According to Jackson (2010) the part which is usually reimbursed is related with the direct costs, i.e., the labor, the materials, the equipment and the subcontracts. According to Halpin and Woodhead (1993), all the costs related with the contractor's expertise and all the other costs for supporting the job are the non reimbursed costs. Bennett (2003) mentions the American Institute of Architects (1997, 2001) where in its standards are regulated the terms for these type of contracts. Within the *cost plus a fee* contract, the works can start without the design process be totally completed., Thus, this type of contract is very suitable with the DB delivery method. One of the disadvantages of this type of contract, for both the owner and contractor, is the great need for paperwork, as Jackson (2010) describes. The disadvantages for the owner are, the need of being careful with the terms of the contract, or "he may be surprised to find out he has agreed to pay for the contractor's new computer" (Halpin and Woodhead, 1998). Also with this type o contract, the contractor will have "little incentive to be efficient and economical" (Bennett, 2003), which will lead to more costs for the owner. When using the *cost plus a fee* contract, "there is no limit set for the project cost" (Jackson, 2010). The contractor have the advantage, as seen through the entire explanation, of having always profit with these type of contracts.

3.5.5.4 Guaranteed Maximum Price (GMP)

As mentioned earlier when introducing the contract types, the GMP is taken as variation to the *cost plus a fee* contract type. The main feature in the GMP type, as presented by Gould and Joyce (2003) and Jackson (2010), is that an upper value limit for the costs of the project is stipulated. Jackson (2010) calls the attention for the particularity of this type of contract having "the best features of the *lump sum* and *cost plus a fee* contracts". But, although the GMP giving an idea for the best scenario, due to this upper limit, the scope and the quality of the project might be sacrificed, as mentioned by Bennett (2003). The variations with the costs, time and quality mentioned in this type of contract, as for the previous ones, will be analyzed in subsection 3.5.9.4, when presenting the "Golden Triangle" which connects the costs, the quality and the time together with the safety. This exposure for the scope and the quality of the project is due to the contractor beeing responsible for all the costs which will pass the regulated amount in the contract.

3.5.6 Bidding Phase

After the owner have the project totally or partially (depending on the delivery method) designed and accepted, he express the intention of building the project by asking prices for building the project (tender requests). The contractor organization can submit a bid to a project that was advertised publicly or it can be invited by the owner for tendering the project. In the bidding phase is where the contractor usually have the first contact with the project. In this phase, usually there are two departments responsible for the project; the Estimating department and the Safety, Health and Environment (SHE) department.

The estimation, it can be said that, can have a great impact in the contractor organization. On the estimate process relies part of the survival of a contractor enterprise. Without work, the organization cannot survive, but also with bad estimates, the risk of loses may lead the organization to bankrupt. The goal of a construction estimate is to have the estimated cost, at least equal to the real cost of the project (Jackson, 2010). The estimate should be competitive to win the job, but as accurate as possible (Jackson, 2010), so the company have the load of work without loses in the overall panorama. Also, "the planning and calculations set the stage for the overall targets for the entire project" (Jackson, 2010). Somehow, what will be result from the estimate will be reflected through the entire construction stage, being then reflected on the final results.

Analysing the estimating department, an example of how this department can be structured is shown in Figure 3.23. The reader should be aware that the chart shown in Figure 3.23 is a mere example for medium and big enterprises organizations. In small and micro enterprises the estimating department might not even exist. For the small and micro enterprises, it is usually the owner of the company or the engineer responsible for the firm doing the estimation and quotation for the requested works. Also for big or medium enterprises, especially for these last ones, there might not exist the computer assistants and/or planners.

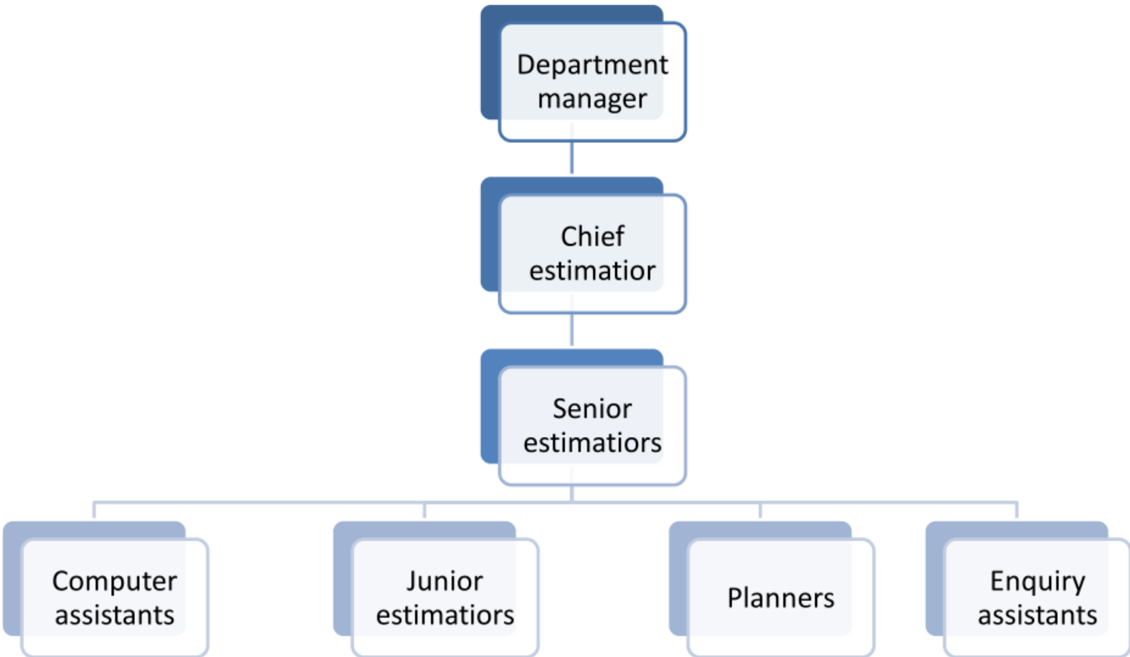


Figure 3.23 - Example for a estimating department structure.

The construction estimate relies on three main points that should be done; the quantities (which identifies how many), the pricing (which informs how much) and the productivity (which indicates how long) (Jackson, 2010). Usually, in the big and medium enterprises, the estimating is done based considering of using the subcontractors for executing the works. The estimating relies more into a process of management, where the contractor looks over the materials and the subcontractors (taking into consideration the equipment as a subcontractor). The main contractor will be more a manager for these subcontractors and for the materials by "buying" them, taking them into the construction site and managing their use. So, the estimating process is done based on the subcontractors prices, materials costs, equipment costs and the costs related with the SHE department in the construction site and the company's structure. For the small and micro enterprises, the estimating is done more based on their own resources costs, i. e., labour, equipment and organization structure costs. In the big and medium enterprises, the productivity accounting doesn't have such impact as in the small and micro enterprises. The reason behind this statement, is that the big and medium enterprises are buying the "entire package" to the small and micro enterprises. Thus, somehow there is no need to be taken into account the productivity as it has to be done into the small and micro enterprises.

Related to the estimating process itself and the method, Harris et *al.* (2013) refers to the Bill of Quantities (BOQ) as the most common estimation method. Beside the BOQ, there are other variants to this method. If looking through Dagostino and Peterson (2001) for instance, more details will be found about the entire estimating processes and techniques. Getting back to the BOQ method, this is done on the basis of the bill of quantities and other documents which are part of the project. So, analysing the estimating process, according to Harris et *al.* (2013), it goes through the following steps:

- decision to tender;
- programming the estimate
- collection and calculation of cost information;
- project study;
- preparing the estimate;
- site overheads;
- estimator's reports.

Next the estimating steps will be presented, by giving more emphasis to those where the information and data is collected and treated. The decision to tender is taken by the department manager or by the chief estimator, according to the company interests and resources and to the project (Harris et *al.*, 2013). Made the decision for tendering and received the documents, the estimate has to be programmed.

The estimation process is usually of very short time to be done. So, due to the short period of time for the estimation, the milestones should be set by the key dates (Harris et al., 2013). The collection and calculation of cost information, as well as the productivity, are the most fundamental parts of the process. From this will result the final price for doing the project. Errors and fails in this step might lead to losses and serious damages for the organization. So, the calculation for the costs is where everything related with the project will be measured, i. e. the labour, the materials, the subcontractors and the equipment will be quantified. The costs for the labour are all of those related with the contractor's own resources, either for the manpower and/or the equipment Harris et *al.* (2013). The labour is allocated by categories and associated to the tasks of the project. For the manpower costs, this is done usually by "hourly rate covering all wages and emoluments paid to the operative, all statutory costs incurred and allowances for holidays and non-productive overtime" Harris et *al.* (2013). Related with the equipment, the calculation for the costs can be done by two ways, and this is dependent of the organization structure. For the small and micro enterprises, the costs calculation for the equipment are made in similarity to the manpower. It needs to be estimated the maintenance costs, the consumption, productivity and so forth, related the equipment expenditures. Then, these costs are considered into the labour costs. For big and medium size enterprises, which have an equipment department (the garage, from Figure 3.6), this department can work as other structure inside the mother organization. In this situation it is the equipment department which assumes the total responsibility for the equipment. So, all the calculations related with the costs for the equipment mentioned for the small and micro enterprises are done by the equipment department. If the contractor organization has an equipment department, the costs for the equipment are assumed as if it were a subcontractor. It can also happens that due to the location of the project or due to workload, the labour costs will be taken as a subcontract.

The calculation for the costs of the subcontractors are made based on the enquiries sent for other contractors companies according the scheme shown in Figure 3.4. From the enquiries, the interested contractors will reply with a quotation. The quotations received should then be analysed, not only the prices, but also what they may contain. There are quotations which contain only the costs for the execution of the works. This way, the materials must be then accounted for the respective item(s) into the estimate. For the quotations which are with the materials included, the estimation of the works is directly done by imputing the quotation values.

When estimating the materials, attention should be given, because these are not so linear and direct as the subcontractors. When analysing the project for the materials estimating and proceeding to the enquiries some aspects should be taken into account. The quantities, specifications and predicted delivering time (Harris et *al.*, 2013). It is also important in some specific materials to be aware of the possible alternatives. These alternatives might reveal very important for a competitive tendering, as well as through the construction process. When analysing the received materials quotations, attention should be taken to the conditions as well as the packages prices. It is very important to be quantified not only the materials themselves, but also the transportation.

The project study can reveals a very important step for a good estimation, but also in the future, during the construction process. So, in the project study there are the following three main tasks to take into account as suggested by Harris et *al.* (2013):

- "a study of the drawing";
- "a site visit and meeting with the client's or promoter's representatives";
- "the preparation of a method statement determining how the project will be constructed".

By own experience, the author would like to call the attention for the written parts of the project, beside the drawings. It might happen that through the technical specifications or construction procedures some tricky points are described. This way a better prediction for what might be found in the construction site can be detected earlier, be aware for some restrictions, as well as, methods, techniques or equipment that might not be allowed to be used. These situations can reveal of extreme importance for earthworks which are highly dependent of heavy equipment and soil site conditions. A bad estimation of time or equipment might lead to a significant difference between the estimated values and the costs "*in situ*".

The site visit is valuable in the way that will give a real impression of what are most of the conditions, variables and possible obstacles. Also from the site visit a more accurate estimation can be done, especially for the equipment and construction yard. According to the presented by Harris et *al.* (2013) from the site visit it should be noted the:

- "description of the site";
- "positions of existing services";
- "description of ground conditions";
- "assessment of the availability of labour";
- "any problems related to the security of the site";

- "description of the access to the site;
- "topographical details of the site";
- "description of the facilities available for the disposal of the spoil";
- "description of any demolition works or temporary works adjoining buildings".

The "method statements are descriptions of how the work will be executed with details of the type of labour and plant required and a pre-tender program". It was mentioned before the possible alternatives to materials, equipment and methods. Harris et *al.* (2013) refers to these alternatives in these method statements, as well as to "alternative sequences of work, differing rates of construction and alternative site layouts".

The process for preparing the estimate, is described by Harris et *al.* (2013), as the join for both of the direct costs and the indirect costs. The direct costs are those related to the construction works and tasks itself, i.e. the labour, plant, subcontractors and materials. The "direct costs are found by selecting the appropriate resources of labour, plant and materials for the item of work, selecting the output or usage rates for each resource or determining the elapsed time that labour and plant will be employed. This is then combined with the quotations received through the processes mentioned previously giving then the direct costs. The indirect costs, which include the "site overheads, head-office overheads and profit, are added to the estimation by the department director or the chief estimator (Harris et *al.*, 2013).

The site overheads is where are included costs of all the logistics part of the work. These are also the so called indirect costs. These indirect costs are according to Harris et *al.* (2013) the:

- "site staff";
- "cleaning site and clearing rubbish";
- "mechanical plant not previously included in the item rates";
- "scaffolding and gantries";
- "site accommodation";
- "small plant";
- "temporary services";
- "welfare, first-aid and safety provision";
- "final clearance and handover";
- "defects liability";
- "transport of operatives to site";
- "abnormal overtime";
- "risk".

The estimating process, due to its characteristics and specificity it plays a very important role through the construction stage and for the contractor organization. It is very important that "every person in construction management must be familiar with the estimating process" (Jackson, 2010). However, it is very important that the data related with the estimation is detailed and explicit as possible. This will help the site construction team through all the construction process of the project. From the author's experience it happens that many times, the contractors and material suppliers which enquired and presented a quotation, are not approached in the construction phase. Going even further, it happens that the quotations used for building the estimate aren't even taken into account.

3.5.7 Taking off quantities

Takeoff is defined in Jackson (2010) as "a term commonly used in the construction industry to describe the process measuring the plants to quantify the materials, labour and equipment". Tweeds (1995) presents taking off as a "measuring from the drawings and entering the dimensions on to especially ruled dimension paper". The takeoff processes for its definition it is mostly associated to the owner/designer organization. The reader should notice that, this document is similar to those presented in Tweeds (1995). Usually, the owner/designer proceeds to the quantification and measuring of the project for costs estimation overview. During this process, the materials are quantified and numerated on the bill of quantities. These bill of quantities, which is part of the written documents of the project, is sent with the project to the contractor for tendering. An example of a bill of quantities can be Table 3.1 and Table 3.2, but without the prices in it. Then, usually the contractor only concerns about the quantities from the bill of quantities for tendering. This happens due to the limited time for tendering. And the quantities takeoff can be somehow a long and time consuming process. Yet, for Gould and Joyce (2003), the quantity takeoff is seen as the "foundation of the estimate", stating that the goal "is to calculate every item of the project - no more, no less".

3.5.8 Preparation, planning and scheduling phase

Previously, it was presented the estimating phase for the project. Now the processes proceeding and during the construction "*in situ*", for the estimated project, will be developed. Here it will be presented the steps for preparing the beginning of the construction process. The preparation, the planning process and the scheduling process will be introduced along the present subsection.

As mentioned, the estimation process is done by the estimating department. In that process, a pre-planning and schedule is done as well. But, more into a basis of fitting the activities into the time given by the owner for completing the construction of the facility(ies). In the estimation phase, the predictions which are done related to the planning are more to get close of the constitution of the teams, i.e. estimating the productivity according the time available with a certain constitution of a team. Now, the construction for the project was handed to the contractor, the preparation for the construction will need to be made and the planning and scheduling should be done more detailed and carefully.

The preparation, planning and scheduling processes are the basis of support for starting the project and tracking the works by taking into account the variable time. On these three process relies all accountability to the project owner and the subcontractors. The planning and scheduling allow, to all the participants involved in the construction phase, to "know in advance when to expect a certain action to take place" (Gould and Joyce, 2003). So, for instance the construction manager can prepare the request for material and/or equipment, avoiding thus having to wait for that resource(s) or having them consuming money without working. It also helps the equipment department planning the distribution of the equipment, as well as, the subcontractors.

In subsection 3.5.9, the costs control will be better introduced, but the deviation to the costs may also undergo due to a bad preparation and planning prior to the construction. The costs that result from a bad preparation and planning can be in many cases even bigger and more relevant than the costs coming from the subcontractors or materials. Thus, as stated by Jackson (2010), "a good plan and a reliable schedule will help ... prepare and avoid some of those factors that can derail the project".

The planning and scheduling for the construction process of the project can be done by using two techniques, according to their approaches. The approaches are based into the analysis made related with the breakdown structure, i.e., if the breakdown structure is done for the work tasks, a Work Breakdown Structure (WBS) or for the location where the tasks are executed, a Location Breakdown Structure (LBS). The approaches where the breakdown structure for work tasks is used, are designated by activity-based. The approaches using a breakdown structure for the location are called as location-based.

When preparing the project for starting the construction process, there are seven steps to take into account, as Gould and Joyce (2003) mentions. These steps are as follows:

- "establish the objective";
- "identify project activities";
- "determine activity sequence";
- "determine activity durations";
- "perform schedule calculations";
- "revise and adjust";
- "monitor and control".

3.5.8.1 Activity-Based Methods (ABM)

Along this section will be approached the CPM method and Gantt chart method. These methods are the most common scheduling methods into the construction sector, eespecially the CPM method. This previous idea meets the statement "Traditionally, over 90 percent of the construction firms in the United States utilize the critical path method (CPM) of scheduling to control and manage their projects" by Nageeb and Johnson (2009). Also, Kala et *al.* (2012) share the same opinion by presenting that the "Critical Path Method (CPM) scheduling is currently the dominant scheduling system in use in construction". Along this section, the activity-based scheduling will be presented.

It is of extreme importance to split the project into the various "sub construction process". As mentioned in Bennett (2003), the Work Breakdown Structure (WBS) should be done when starting the preparation of the project for studying, planning and scheduling the project. This WBS will be very useful for establishing the objectives and indentifying the project activities. Along the preparation and study of the project, the analysis to the type of works should be done and then these work types should be divided into groups. As stated in Halpin and Woodhead (1998), when planning, the project is breakdown "into elements that are appropriate for time control". Bennett (2003) uses the family tree as a reference and comparison to the WBS. Somehow, this is a quite accurate reference, once the WBS can be represented by the way of a chart starting from the project, flowing to the groups and tasks that constitute the overall project. This, in some way, transmits to the viewer how the "families" of works are distributed. In Figure 3.24 is represented a WBS structure, which will lead further to the constitution for the charts that will be in the base of the planning and scheduling. The WBS in Figure 3.24 is taken from the same example Figure 3.27 is based. Thus, further when presenting the planning and scheduling charts, the reader can see how a WBS will be helpful and useful in building the planning and scheduling charts. The example will be taken only from a section of the project that was given to a subcontractor.

When performing the WBS method for producing the charts and/or the planning and scheduling charts, there is no specific rule for it. From the author's experience, it was seen that, the construction of these charts are more based in the person's experience and with the project characteristics and needs.

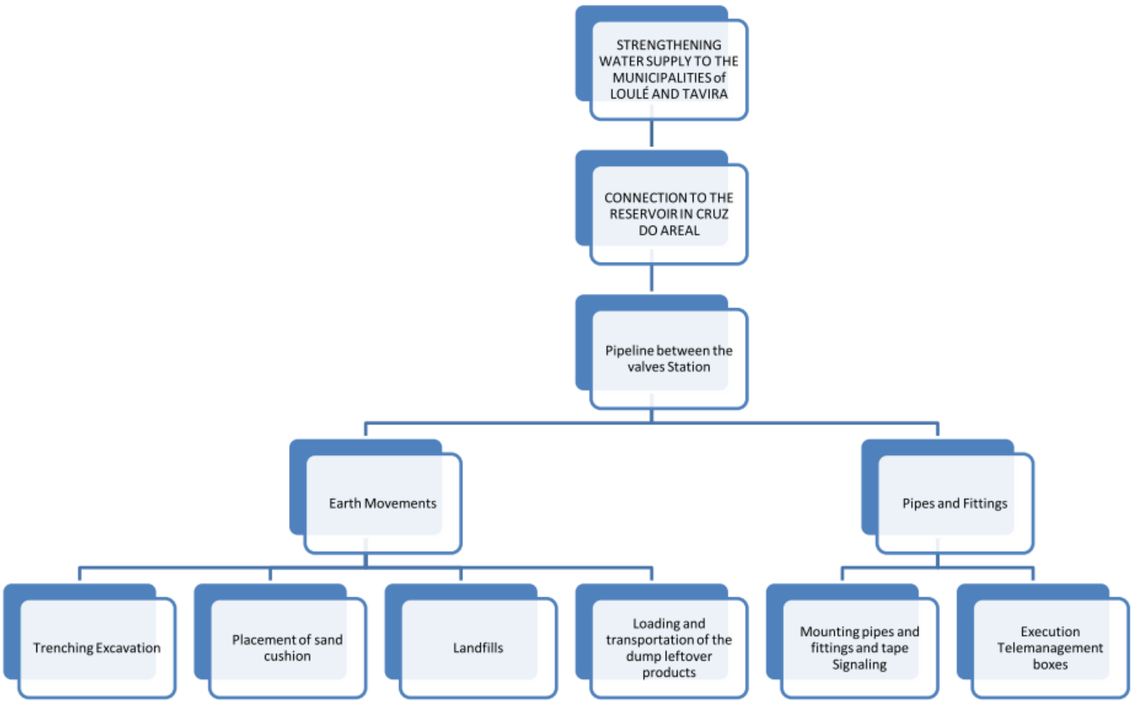


Figure 3.24 - Example of a WBS chart (partially taken from the project used as an example in this thesis).

The WBS structure, according to Bennett (2003) give the possibility for the persons involved in the construction phase of the project to:

- "plan and schedule the work and thus describe the project's total program";
- "estimate costs and budgets";

- "authorise parcels of works and assign responsibilities";
- "track schedule, cost and quality performance as the project proceeds".

Gould and Joyce (2003) refers to schedules as "timetables that identify at which point in the time each action will occur". In the planning and schedules, several information can be added to help the construction manager and the project manager keeping the track to the project status. Schedules and planning charts can contain, allocated to the tasks, the teams working on the tasks. According to the literature, there are two main techniques for representing the planning and the scheduling. The planning can be represented through a bars chart, this one also very often called by Gantt chart (Jackson, 2010) (Figure 3.25), and the networking (Figure 3.26) planning. However, a third technique can be, somehow also considered, eespecially when using the computer software available in the market (the example for Microsoft Project).

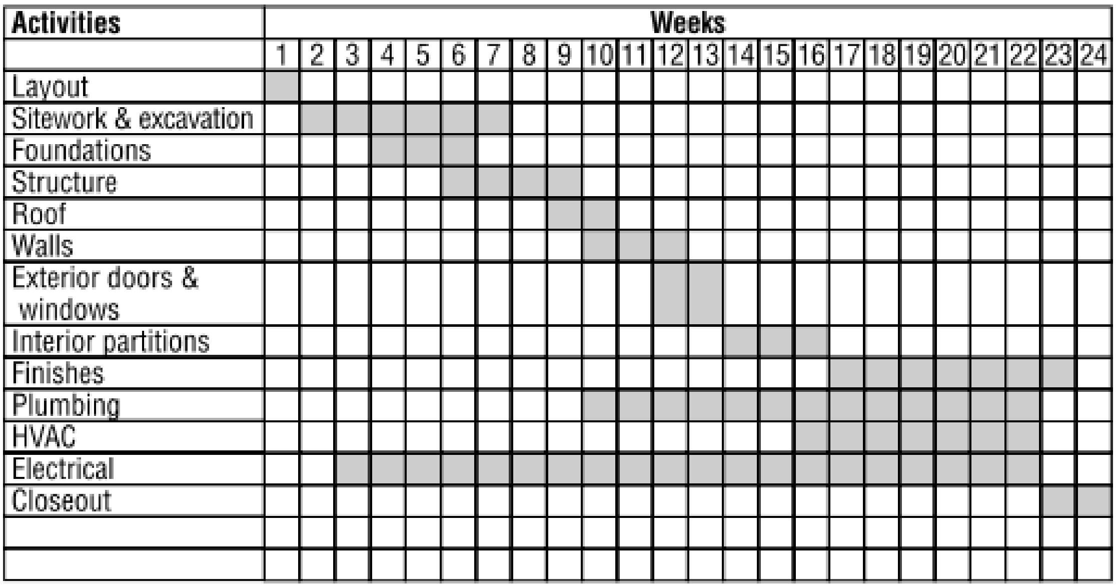


Figure 3.25 - Gantt chart example taken from Jackson (2010).

The Gantt (bar) chart as Halpin and Woodhead (1998) describes, represents the development of an activity or work item through the time, by the mean of a bar, as shown in Figure 3.25. Also it is possible to be seen into Figure 3.27, that the breaking down for the tasks included in the project are on the base for building up the Gantt chart. These Gantt charts are, according to Bennett (2003) very popular especially for small projects.

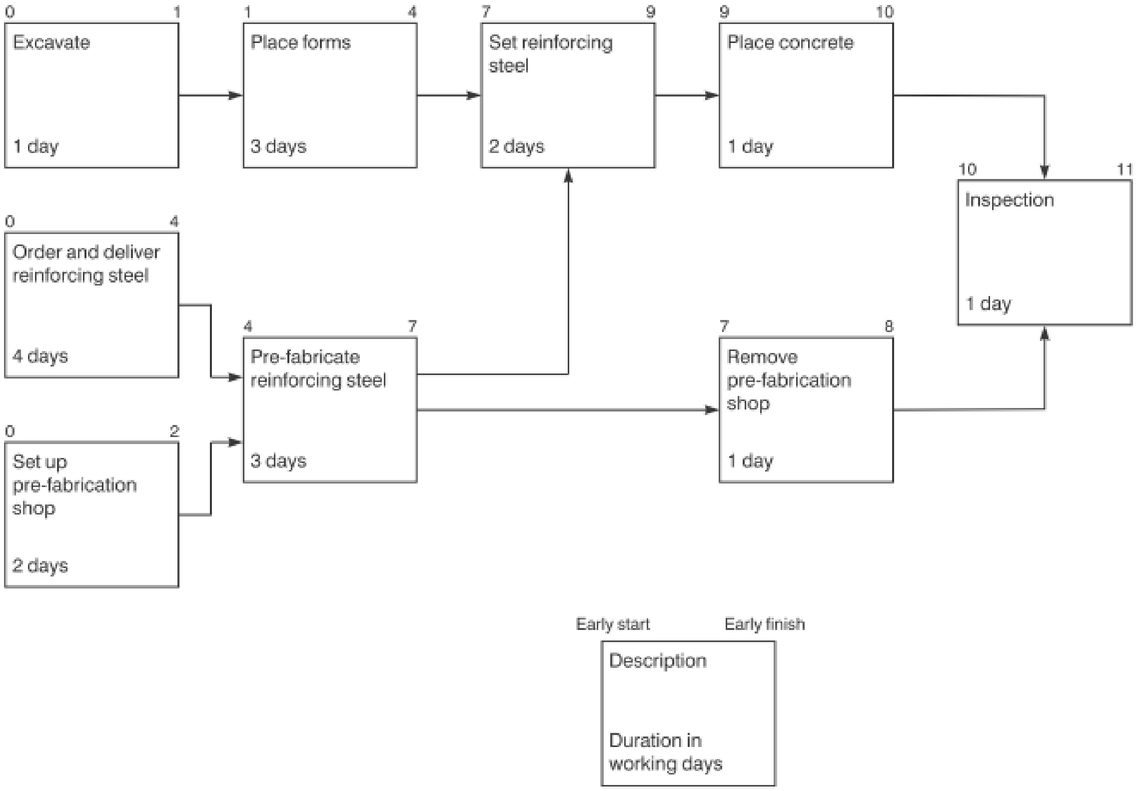


Figure 3.26 - Network schedule from an example taken from Bennett (2003)

When considering the planning for the activities of the project, to build the charts presented above, should be taken into consideration the sequence for the works (Figure 3.27). Also the planning will have to be bounded by two key dates. It is important to settle this dates according the information given by the owner related to the construction time and for the starting of the works. So, when considering the planning and scheduling, these two dates should be placed as milestones for the project. One example for this is shown into Figure 3.27. Due to the size of the document and the lack quality of visualization, this example will be also shown into the attachments (Appendix A.1 d)), in a bigger size with a proper visualization conditions. Due to the great dimensions of the project only the part here was shown as an example. The reader should notice that, the example shown in Figure 3.27 is related to the work which was awarded to a subcontractor as part of the contract. So, in the example from Figure 3.27, it was imposed to the subcontractor a starting date for 15th of September 2008, being the maximum duration for the works of 42 days. So, this part of the project was bounded between 15/09/2008 and 26/10/2008. Between these two dates, should then be placed all the other tasks. The duration for the tasks will be then greatly influenced by the constitution of the teams that will be working on those tasks. Thus, the teams will need to be constituted according to their productivity, so that tasks can be performed within the time interval.

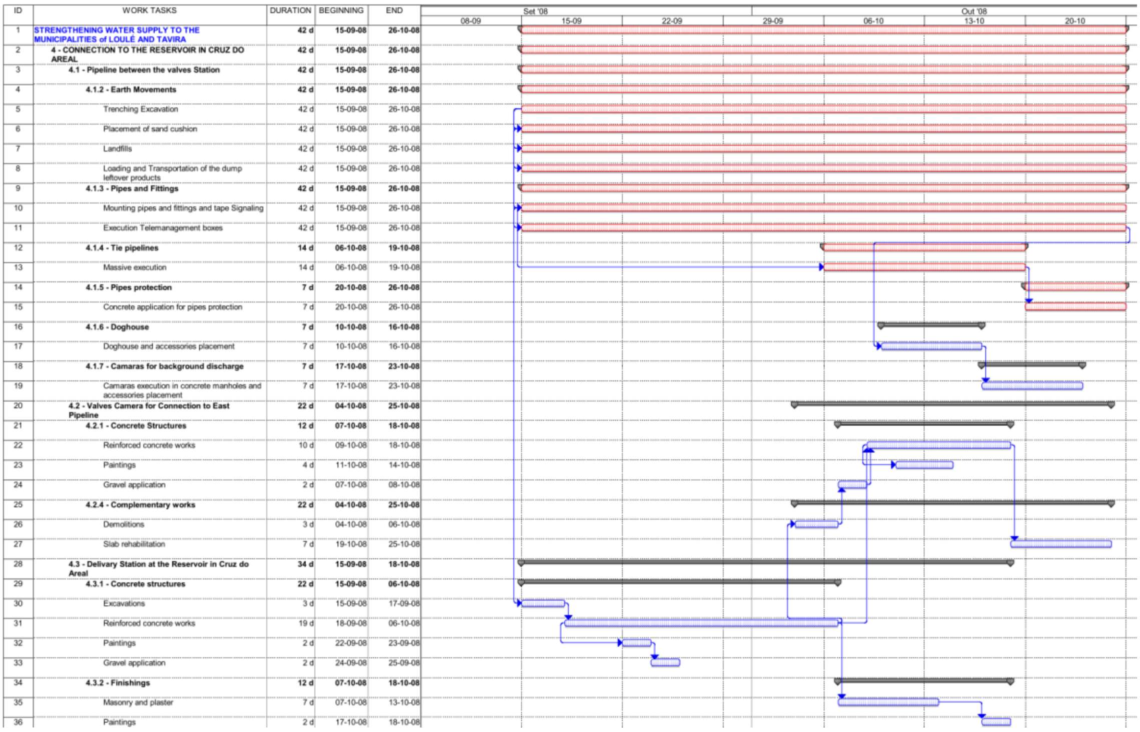


Figure 3.27 - Gantt chart example for the project used as examples, for a subcontractor.

Above was started the question related to the duration for the tasks, between the two milestones dates, bounding the duration for the project. Now the duration for the activities and the resources assignment will be developed. The duration for the tasks will be very dependent on the resources which are allocated to them, as well as, the productivity for those resources. Also the methods and techniques used in performing the tasks will have influence on the duration of the works. But, beside the factors mentioned above, there also other factors which will have influence into the productivity. These are the quantities of work in the tasks, the available physical space to execute the tasks, as well as, the way the teams are constituted. So, when determining the duration for the tasks, the person responsible for the planning, the construction manager and the project manager will have to consider their own experience, but also the site supervisor and foreman experience, for instance. There are also some publications about the productivity and yields for the equipment, labour and some standard constitution of teams. This productivity, eespecially when manpower is involved, is subjected to several external factors such as the weather conditions, environment conditions and so forth. However, from the author's perspective, this is also a topic which could be better studied and developed, giving thus a better and close view for the productivity of all the resources. Thus, more accurate plans and estimations can be produced, as well as the management of the construction process.

Some of the features for this Gantt chart representation are given by Gould and Joyce (2003) as being "the simplest of the scheduling methods", "can be produced more quickly than any of the other methods", allows a quick view for the "overall timing, owners, designers and construction professionals". Bennett (2003), in the same line as Gould and Joyce (2003), mentions the advantages of using this type of charts because they are "simple to construct and easy to comprehend", they have a "convenient organisation by work breakdown structure elements", they are "relatively inexpensive to use", and they use "summaries at any desired WBS level". In addition, the Gantt chart have the limitation of not defining "individual activity dependencies" and they "cannot be used to calculate specific activity start dates, completion dates, and available float time" (Gould and Joyce, 2003). So, they don't show any "interrelationships between among the activities", the analysis tend to be made more based on the "available timeframe" not in the required time (Bennett, 2003). These charts also don't show the allocation for the resources on the period of time, but only the time, "are impractical for complex projects", and are much time consuming when being updated manually, as Bennett (2003) describes.

The second method, the network method, is also referred as the Critical Path Method (CPM) by Halpin and Woodhead (1998). Gould and Joyce (2003) add to the CPM, the Performance Evaluation and Review Technique (PERT) method. This is a method where the scheduling is done by "networking the activities" as stated by Halpin and Woodhead (1998). So, using the description given by Halpin and Woodhead (1998), this method is made of a network constituted by nodes and links. The nodes can represent either events or activities with time information, being the links representing the activities or linking the activities sequentially. To what is represented in the nodes, states Gould and Joyce (2003), "is given a duration". The scale for the durations assembled to the activities will be given according to the project size and characteristics, i.e., it can be in hours, days, months or years. Gould and Joyce (2003) compares the network schedule to a road map. This comparison is very interesting and well illustrative for this network method, taking into account that, in a road map for a certain path to follow there is always a start and ending point, and in between there will be always some other points that need to be followed sequentially to reach the destination.

Halpin and Woodhead (1998), presents the following goals, when analysing the project with the network method:

- "find the critical path that establishes the minimum duration of the project";
- "calculate the early start times for each activity";
- "calculate the late start times for each activity";
- "calculate the float, or time, available for delay for each activity".

The critical path represents the most important tasks in the project, when related to the project duration. This means that all the work tasks in this path will determine the duration of the project. Thus, the work tasks belonging to this path will be the critical work tasks. So, if any one of this tasks will be delayed, consequently the duration of the project will increase. Yet, if the duration of one or several critical tasks will be shorter, it doesn't mean that the project duration will be shorter. To analyse and better define what is the critical path, Figure 3.27 will be used again as an example. The red path represents the critical path. All the works directly related with the pipes installation will be critical. This is easy of understanding, once these are the main work tasks of the project. Also the adjacent infrastructures to the pipes can/should be build while the installation for the conduit. However, the excavation or the landfill cannot be done independently from the installation of the pipe conduit. So, any one of these tasks are critical and if for instance one of it gets delayed, the entire duration for the project will be compromised. But, if all these tasks related with the conduit application will be done faster, the project might be able of being finished prior to the final date. This statement is true if any of the tasks that are non critical will suffer "small" or no delay.

The critical path and critical tasks were presented, and mention was made for the others work tasks. Now these tasks that are not critical will be introduced. The non critical work tasks are designated according to Halpin and Woodhead (1998) by work task[4] float. These tasks are tasks which have some flexibility in being executed, i.e., they can either begin earlier or later and/or finish later without changing the project duration. In a work task float there is a lag between the beginning and/or the ending of the task, in which the duration for the project will not be affected. Recalling again Figure 3.27, all the work tasks in blue a work task float. It can be seen that in all of these tasks there is some space between their finishing date and the milestone date for the end of the project. Now imagining that, for some reason, the reinforced concrete works in the item 22 will suffer a delay of two days. In this situation, the duration for the reinforced concrete works will change for twenty two days, and the duration of the project will increase one day. Also, the path starting in the item 30 will become the critical path.

The third method mentioned can be considered as the conjugation between the Gantt chart method and the network method. Gould and Joyce (2003) also refer to the possibility for the conjugation between the two methods, due to the limitations Gantt charts have. One example for this conjugation is shown in Figure 3.27, build using Microsoft Project software. Along the literature read about project management and construction management, only was found the possibility of conjugation the Gantt chart with the network method. Mention is also made for the conjugation for these two methods by the scheduling software available in the market. For example, in Jackson (2010) it is possible of seeing some references to software for project scheduling. In these presented references can be found "Microsoft Office Project", "Primavera P6", "FastTrack Schedule 9", "Tractime", "BuildIT". The first two mentioned software are also referred by Hardin 2009. But, beside what was presented into this paragraph, nothing more was mentioned about the method possibility for conjugating Gantt chart and network chart.

[4] Halpin and Woodhed uses the designation "activity float". The designation work task float is given by the author to follow the same designation along the text.

Thus, it was seen that, the conjugation between the Gantt chart and the network chart is used by the presented software. So, to have the perspective how this is seen into these software community, it will be presented the view point from the related literature.

Starting the analysis with Microsoft project, into Marmel (2010), when presenting the "diagrams that aid project management", refers to the chart shown in Figure 3.28 as a Gantt chart. The description presented in Marmel (2010) for the Gantt chart is as follows: "A Gantt Chart represents the tasks in a project with bars that reflect the duration of individual tasks". Later on, when presenting the dependencies, in Marmel (2010) can be seen the following statement: "Tasks with dependency relationships are linked. Gantt Charts show these links as lines running between task bars ...". Recalling then what was presented above about the limitations, when presenting the Gantt chart, Bennett (2003) and Gould and Joyce (2003) mentioned that these charts don't define the activity. It is also emphasized by these authors that, Gantt charts are not proper for calculating the times related with the activities. Somehow, it seems to have here some divergence between the designations for this conjugated method and the Gantt chart method. Also in Marmel (2010) reference is made to the network chart (Figure 3.29), but, this one is done according to what was presented before. Looking into other author, Muir (2010) presents the Gantt chart method through Figure 3.30. This same approach can be seen into Marmel and Muir (2007).

Seeing for the Primavera P6 perspective, it can be found in Oracle (2009) when referring to the Gantt chart, Oracle (2009) points to "use the Gantt chart to view relationships according to time". Here also, somehow it goes against to what was presented for the Gantt chart.

From the presented literature related with scheduling software, it was seen that the ideas and designations tend to diverge from the literature related with the project management and construction management. Above when presenting the activity-based methods, was seen that the Gantt charts are only simple bars without any links between themselves. Thus, when presenting the scheduling charts from the software literature, these are also designated by Gantt charts. However, these "Gantt charts" contain the features from the Gantt chart and the network chart.

From the author's perspective, the reason for this divergence might lies into the designation from the software manufacturers. It can be seen several times into Marmel (2010), Muir (2010) and Oracle (2009) the reference to the "Gantt chart view". But, "Gant chart view" is the designation given from the manufacturers to the view presenting the chart with the bars linked. This reference is made when calling for the view into the software, which comes with the software. From the general literature related with this third method, the designation that comes out for the method is "Gantt chat". But, as already mentioned, the Gantt chart have different features. Following, it will be shown a consideration made by two authors about the concept for this third method. The reason why this method is called by "Gantt chart" might have arisen from the considerations taken by those two authors.

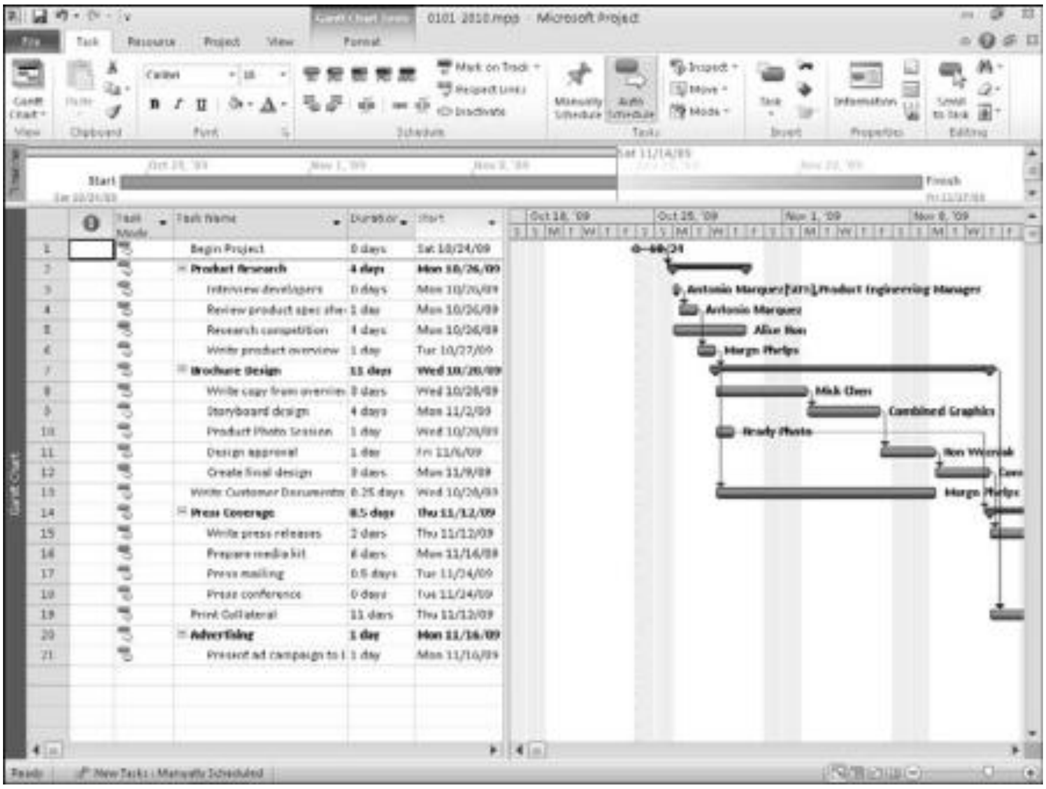


Figure 3.28 - "Gantt chart" representation with Microsoft Office Project 2010 (Marmel, 2010).

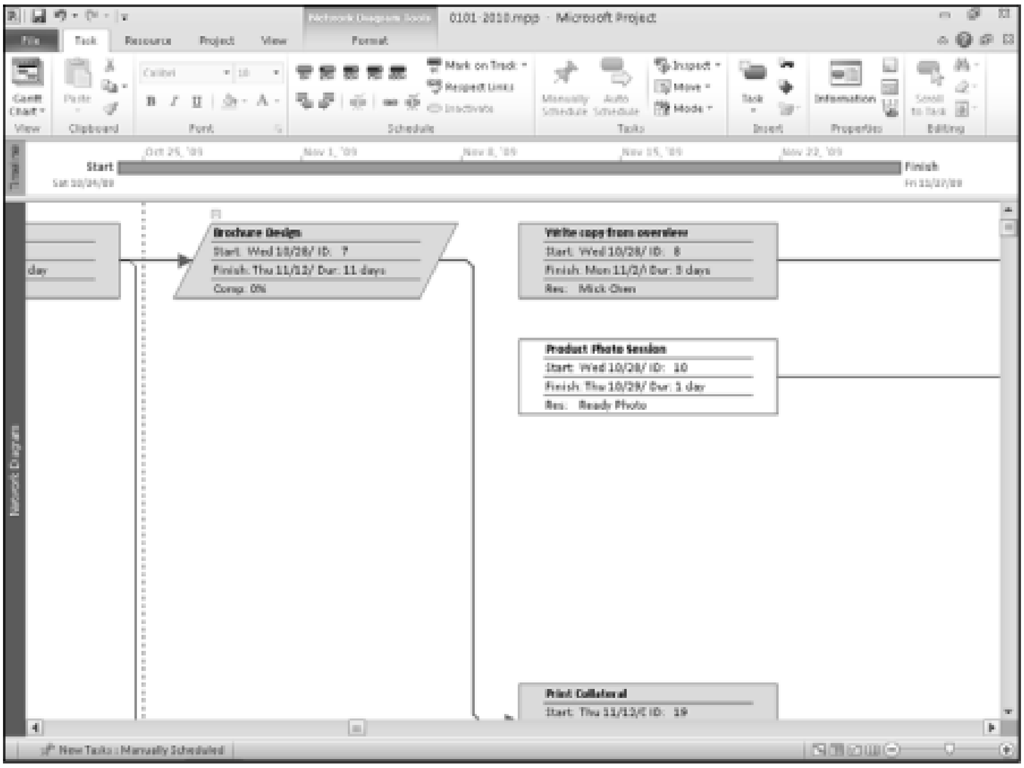


Figure 3.29 - Network chart representation with Microsoft Office Project 2010 (Marmel, 2010).

From these ideas about the Gantt chart, arises a concept which can be see into McDaniel and Bahnmaier (1986). These authors present the milestone chart beside the Gantt chart. Then from these two charts, McDaniel and Bahnmaier (1986) came up with a concept for the "Gantt chart with Amplifying Information". First going into the milestone chart (Figure 3.31), this a type of chart where only the milestones are included. So, the concept for this milestone chart is show "when an event is scheduled and when it is actually accomplished" (McDaniel and Bahnmaier, 1986). The milestone describes the events for the completion of an activity, as McDaniel and Bahnmaier (1986) describes. The way the control of the schedule is done, is just through the completion of the task, but not if it is into the rail or have derailed somewhere. McDaniel and Bahnmaier (1986) call the attention for the need of more information, "to plan, monitoring , and control activities" when reading a Gantt chart, due to it's limitations. In the sequence of this need for more information, appears the reference to the schedule software which allows for including the information. This "Gantt chart with Amplifying Information" is shown in Figure 3.32.

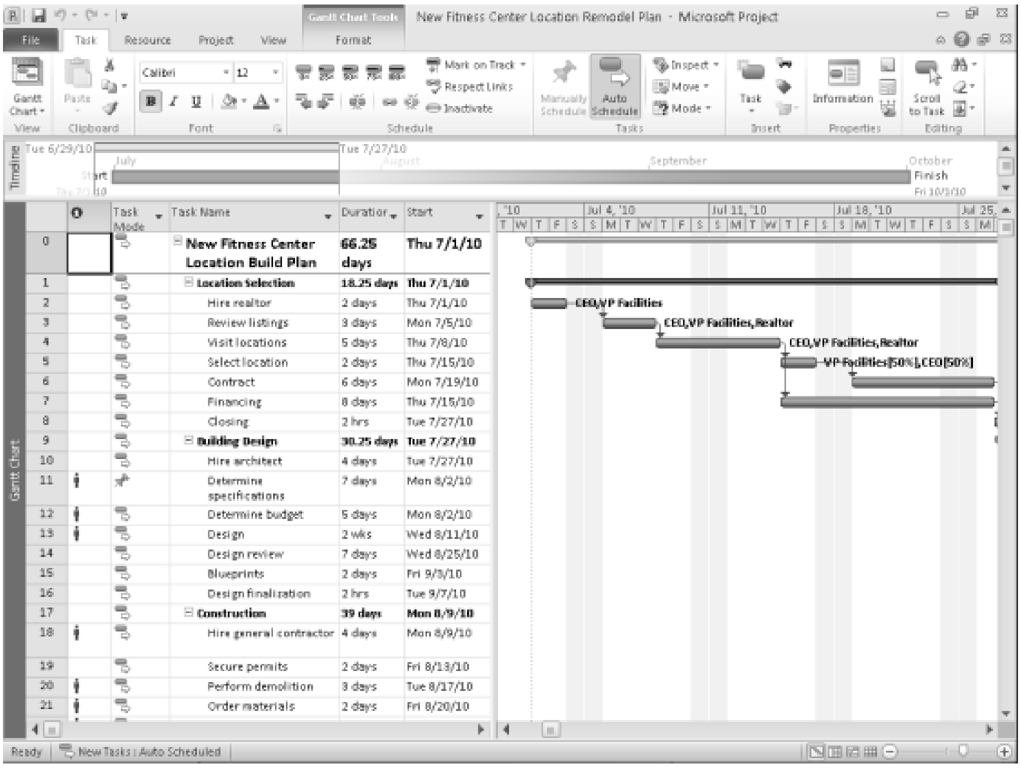


Figure 3.30 - "Gantt chart" method from Microsoft Project, according to Muir (2010).

From the author's perspective, the designation given by McDaniel and Bahnmaier (1986) seems to be very suitable for the Gantt charts produced by the scheduling software. Yet it is understandable that this designation is not the most adequate for treating this Gantt chart and network chart conjugation method. Thus, rather than calling "Gantt chart with Amplifying Information", it becomes easier to refer to it as a Gantt chart.

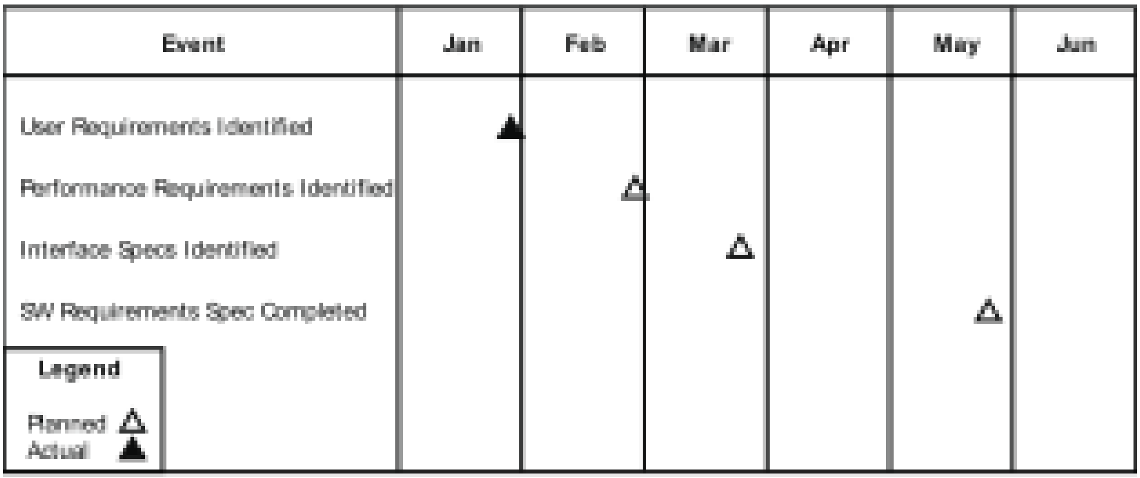


Figure 3.31 - Example of a milestone chart (McDaniel and Bahnmaier, 1986).

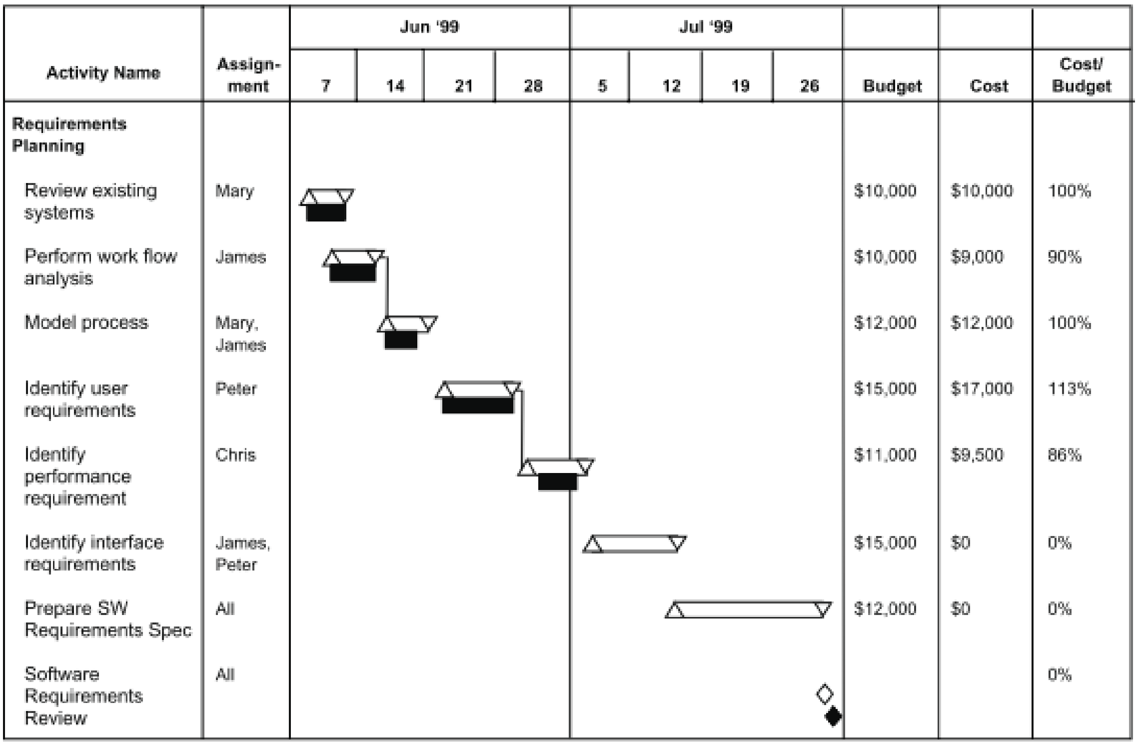


Figure 3.32 - "Gantt chart with Amplifying Information" (McDaniel and Bahnmaier, 1986).

3.5.8.2 Location-Based Methods (LBM)

To facing the lack suitability from the CPM techniques for linear projects, Georgy (2008) refers to the LOB technique and to the LSM as valid alternatives presented through the literature. In opposition to the CPM, LSM method only recently started to gain status into the scheduling and management of construction projects. However LBS was already used in 1929 for the construction of the Empire State Building (Lowe et *al.*, 2012). The LBM approach can be made by using two methods, the Line-of-Balance method or the Linear Scheduling Method.

Location-based scheduling

As mentioned above, when presenting the categories of approaches for the project scheduling, the Location-Based Scheduling is based into the breakdown structure for the location where the tasks occurs. When using a LBS for approaching the scheduling for the project, the physical sections of the works are considered. These sections can be, according to Nageeb and Johnson (2009), locations, zones, sections or floors.

Into the literature read, the author found the reference for the Linear Scheduling Method (LSM), the Location-Based Method (LBM) and to the Line Of Balance (LOB) method. However, as presented in Andersen and Christensen (2007), the LSM are also known as "repetitive or linear scheduling methods". Thus, the LSM is characterised by having as breakdown structure the locations for the tasks of the project, thus, as Andersen and Christensen (2007) mentions, the LSM can be also called as Location-Based Method. In this work the designation of Linear Scheduling Method will be adopted now on. The reason it took the author for choosing this designation, lies on being one of the goals of this thesis, the use of BIM into infrastructure projects. Also, along the literature read, when referring to infrastructure projects mainly the LSM is the designation used, as for example in Duffy (2009), Leong and Kass (2010). In opposition, the authors referring to building construction projects adopt the designation of LBS, as in the example of Anderson and Christensen (2007). Other consideration taken when doing this choice is the applicability for this method into **linear** projects, thus, it seems to make some logic to give the designation for **Linear** Scheduling Method. Due to these different designations for this linear scheduling method mentioned, should the reader be aware that, the designation LBS might appear when presenting other authors statements and references.

The origin for the LSM came from the theory of the LOB method has its foundations from "the theories of line-of-balance" (Anderson and Christensen, 2007). According to Georgy (2008), the LSM have "a direct relationship to the LOB method". The LSM is, according to Nageeb and Johnson (2009), better suitable for linear/horizontal projects when comparing with the CPM. Yamin and Harmenlink (2001), in Nageeb and Johnson (2009) refer to this better suitability, by stating that the LSM "perform optimally when scheduling linear continuous projects, such as highway construction. However, LSM can be very inefficient when scheduling complex discrete projects (bridges, buildings, etc.)". The reason why the LSM fits better for scheduling infrastructures projects, is due to this method being "composed of continuous activities" (Spencer and Lewis, 2005, in Nageeb and Johnson, 2009). Dufy (2009) mentions the LSM as the technique which "applies to distance-based ... projects". According to Duffy (2009), into distance-based projects.

Still analysing the suitability for the application of this method, Anderson and Christensen (2007) share the opinion of "linear scheduling methods, have proven to be well suited for projects of a repetitive nature, such as building projects". Thus, Georgy (2008), refers to linear projects as, "highways, high-rise building, pipeline networks...". Duffy (2009) for example shows the division for the projects as repetitive projects. Then, from the repetitive projects, two groups are distinguished; the "*point-based projects*" and the "*distance-based projects*" (Duffy, 2009). In the first group are included the "big" projects of the building construction such as tall buildings, housing complexes construction, The distance-based projects are the considered horizontal projects, the highways, roads, pipelines and so forth. This opinion from Duffy (2009), is also shared by the author, who sees the repetitive projects from the same point of view. The author also have the opinion that, the term linear projects, the way has been presented here and trough most of the literature read, is not the most suitable. As it was seen in 3.5.1, the terms linear projects and point-location were used to define the building construction projects and the infrastructure projects. This definition meets also the concepts presented by Duffy (2009). The building construction projects for tall buildings can be for instance repetitive along the stores of the building, for the slabs, floors, columns, painting, placing the concrete, shaping rebar, and so forth. The same can happens for a highway or a pipeline project, where along the course of project repetitive works occur for the excavations, embankments, placing the pipes, placing the bituminous, painting, etc. So, for purposes of scheduling using this method, the project types can be defined and split as shown into Figure 3.33.

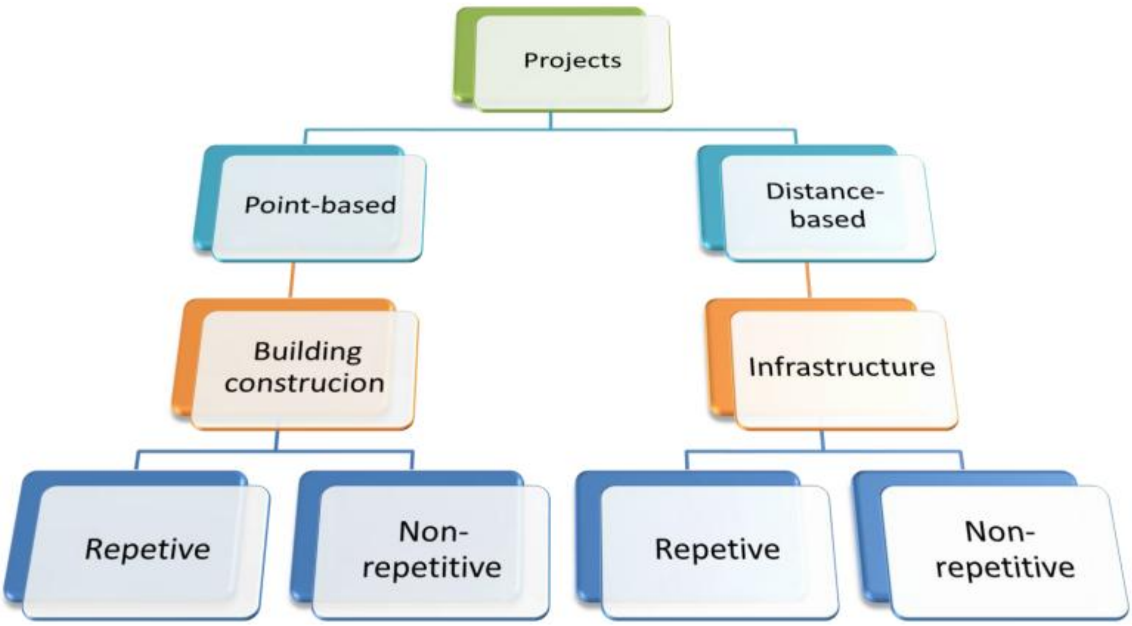


Figure 3.33 - Classification for LSM scheduling.

Figure 3.34 shows an example for a LSM of distance-based project taken from Duffy (2009). In Figure 3.34 it is possible to be seen the x-axis representing the distances related to the origin, and the time represented along the y-axis. From the information contained into these type of charts, it is possible of determining the productivity for the specific task in a precise location, through the inclination of a line. It is possible also of verifying possible conflicts between different teams for a certain location. These charts also show the information for the progression of the works and the availability for new works starting.

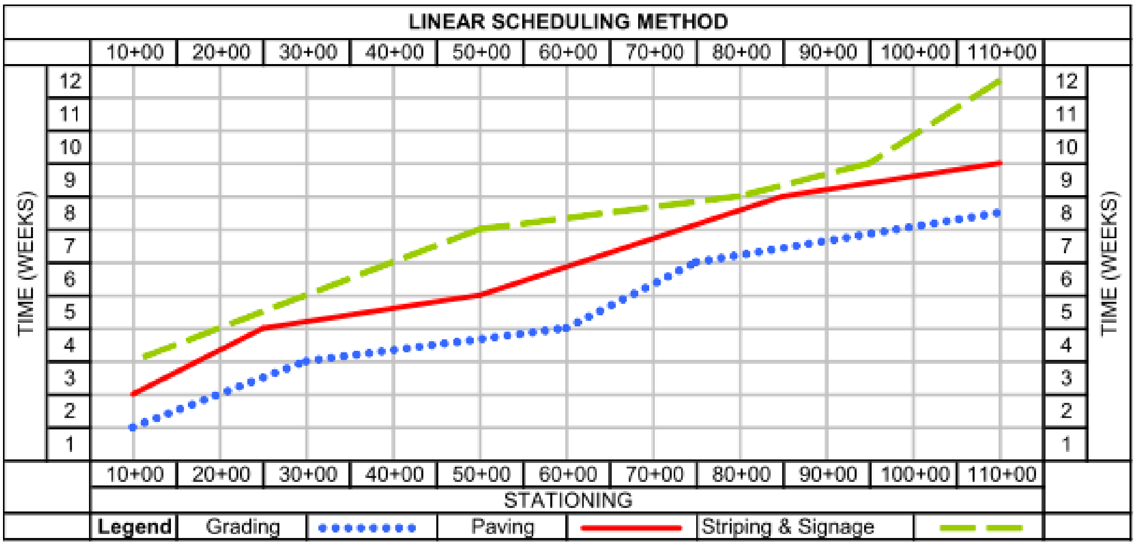


Figure 3.34 - LSM for a road/highway (Duffy, 2009).

Into Figure 3.35 is shown a graphical representation for the LSM given by Georgy (2008). The reader should notice that, in a somehow contradiction for what was presented above about suitability for this LSM, the author presents the location (generally for vertical development) and distance (for the horizontal development). However, the concept is more to present the features for this type of chart, thus, the question for the location *vs.* distance isn't relevant for the discussion presented. From the representation in Figure 3.35, it is seen that, the x-axis is representing the location or distance. The meaning for these two terms will depend on the type of project, i.e., if it is an infrastructure project or a building construction project. In the x-axis is represented the location breakdown structure. Along the y-axis is represented the time.

In Figure 3.35 are shown three types of activities, the linear activities, bar activities and block activities, according to Hamerlink and Rowings (1998). From the presentation given in Georgy (2008), these activities have the following meaning:

- "Linear activities represent construction activities that consume time while gradually advancing in location";
- " Bar activities, ..., consume time without changing their location";
- "Block activities resemble their bar counterparts while being executed over a larger area of the project".

Georgy (2008) gives the example for the linear activities, as those which are most commonly associated to linear projects. So, along the development of the work, the line is being drawn. Making an analogy, it can be said that, the line represents the path traveled by, for example, a car along its trajectory and the different speeds during its travelling. Linear tasks have as their main characteristic, "their rate of progress" (Georgy, 2008). The rate of progress is the relationship between the progress of work done of an activity with the time. The rate of progress for a task gives the information about the productivity for that respective task. Into the activities D and C, is assumed by Georgy (2008) to share the same resources/team for executing the work. For this reason the meaning for the "transfer and setup time" presented in Figure 3.35 represents the "blank" time for the team changing location and settling and preparing to start this new work task. In the transition of tasks C and D is represented the minimum needed time for starting the subsequent task (least time) or the minimum "distance" for the position where the tasks are being executed (least distance) in the same interval of time. In Duffy (2009) is also presented a third concept described into Harmelink (1995), the coincident duration. This coincident duration (Figure 3.36), represents the "interval in time during which the two activities connected by the least time interval are both in progress." In the example of Figure 3.36, the interval from the 7th week to the 9th week inclusive, represent a coincident duration. It is possible to be seen that the task for the paving is concluded in the end of 9th, thus the striping and signage starts the beginning of the 7th week. So, during this time, these two tasks are occurring at the same time.

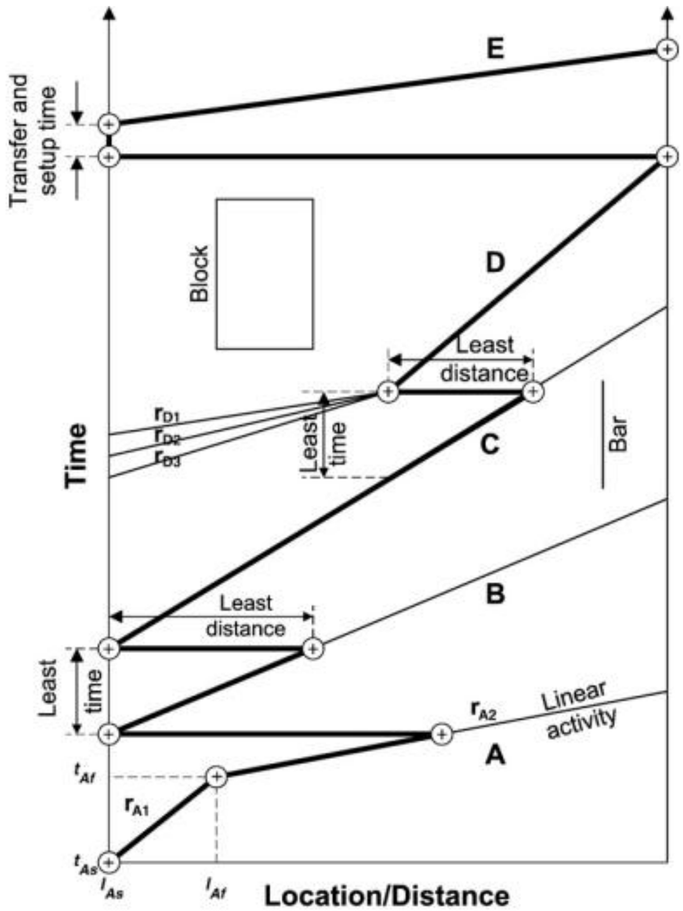


Figure 3.35 - LSM graphical representation (Georgy, 2007).

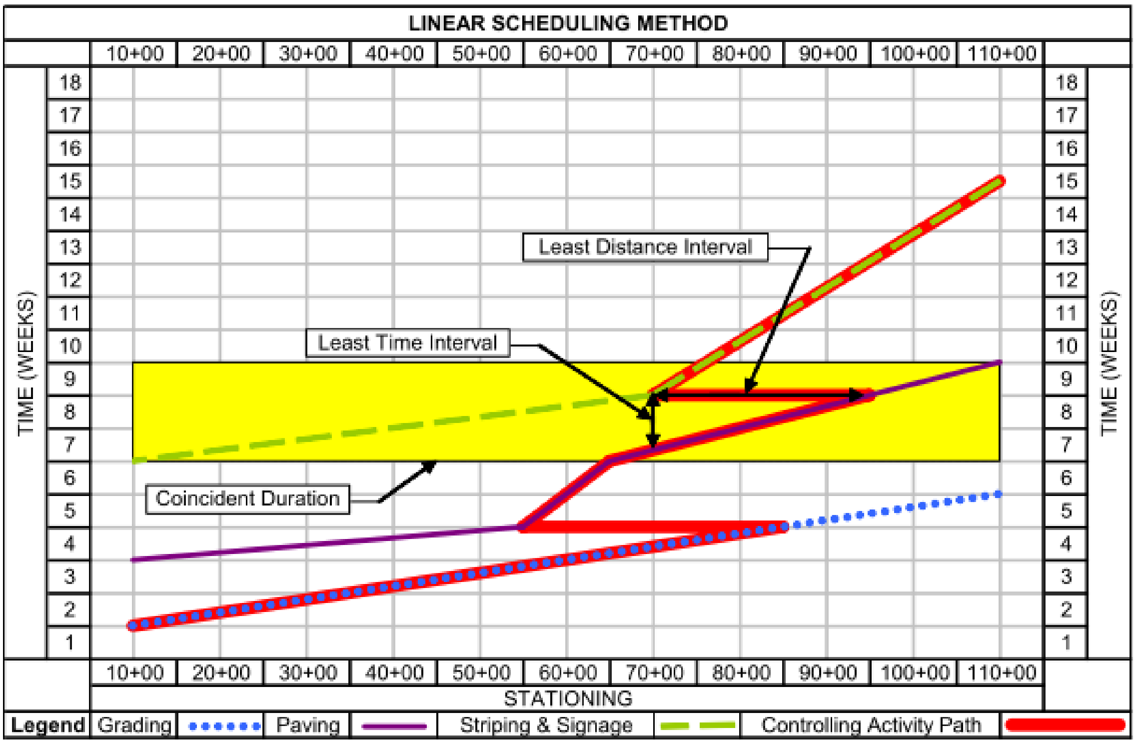


Figure 3.36 - Least distance interval, least time interval and coincident duration concepts (Duffy,2009)

The bar activities, as mentioned are the activities which don't change their location with the time. Duffy (2009) presents the good example for the construction of "box culverts". While the pipeline or the paving are advancing along the space with the time, a box culvert is a "stationary" work, which consumes time to be build in that specific location. This is represented into Figure 3.35 by the vertical "bar".

Block activities are activities "that takes place over a given space for a period of time" (Duffy, 2000). These activities demand for a certain amount of space available for executing the works, not allowing "for a continuous and smooth progression from one area to the next" (Duffy, 2009). One example for a block activity can be compaction works for the layers in roads/highways or when covering the pipes. Duffy (2009) also refers to the possibility for the constraints, such as restricting access, being represented by blocks. shows the representation for the different types of activities representation.

Chrzanowski and Johnston (1986), in Nageeb and Johnson (2009) cites the advantages of using this method as its "simplicity", the "diagrams easily convey detailed information" and " allows schedule updates, changes in job progress, and resource allocations to be performed quickly and with minimal difficulty" if compared with CPM.

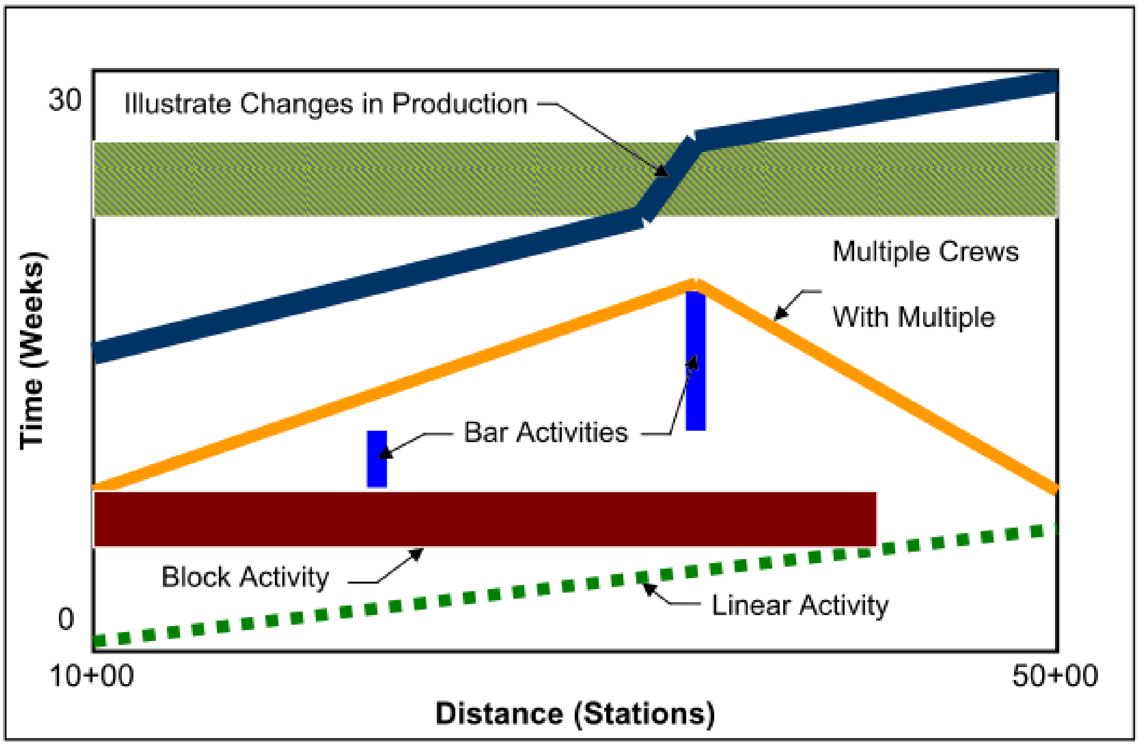


Figure 3.37 - Activities representation in a LSM (Duffy, 2009).

Line of Balance

"The Line of Balance Scheduling (LOB) is a location-based scheduling technique" (Nageeb and Johnson, 2009). Jongeling and Olofsson (2007), in Nageeb and Johnson (2009) define the LOB method as "a visual scheduling technique that allows the planner to explicitly account for flow of a project. The origins for the LOB are dated from the 1940s, attributed to the Goodyear Company (Arditi et *al*. 2001). Later on in the 1950s, the LOB was better developed by the US Navy (Arditi et *al*. 2001). Line of Balance uses lines in diagrams to represent different types of work performed by various construction crews that work on specific locations in a project". SO, the purposes of the LOB are, according to Halpin and Senior (2011), "to control production and ... to act as a project management aid".

Nageeb and Johnson (2009) mentions that LOB scheduling in repetitive projects as been used with great success. The LOB is a technique which is more appropriated for point-based projects, because the tasks involved in these type of projects, similar units are build (the apartments, levels, villas, ...) by performing discrete tasks (painting, placing concrete, ...) (Duffy, 2009). So, from Duffy (2009) statement, "the repetitive activities are scheduled using the Line of Balance (LOB) technique". In is shown an example taken from Duffy (2009) for a LOB application for a construction of two similar buildings.

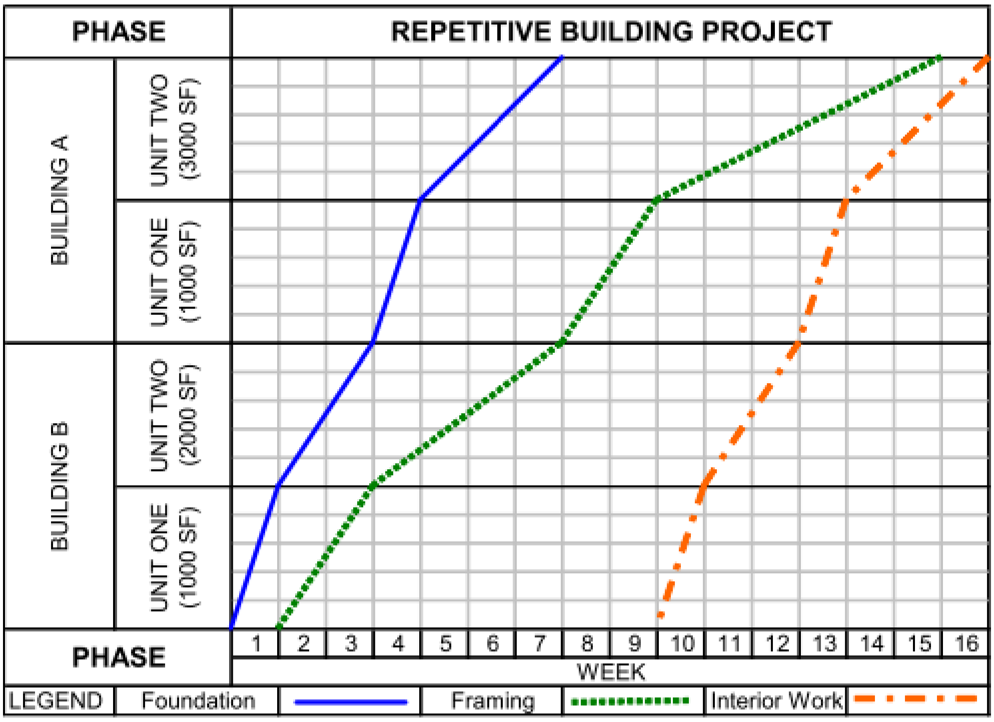


Figure 3.38 - LOB for a two storey buildings (Duffy, 2009).

3.5.9 Monitoring and Control Phase

Along the present subsection the monitoring of the construction process will be presented. Within the monitoring of a construction project, it is included everything needed for reaching successfully the final product. This success is "defined" by finishing the construction of the project inside the goals settled in the contract with the owner and also within the internal goals for the contractor organization. The goals of the contract between the owner and the contactor are the terms agreed between the two parties for the execution of the project, i.e., the duration for the construction and the quality of the final product. The internal goals for the contractor are to finish the project within the budget established and inside the agreed duration. This means that, the time, the costs and the quality, must be controlled and monitored to avoid deviations from what was settled in the beginning. Bennett (2003) defines the concepts of control as "the actions taken to attempt to bring deficient aspects of the project performance" and monitoring as the "methods for comparing actual with performance". So, along the construction process, the costs, the time and the quality will be compared with those established initially before starting the project. Then, if any deviations will occur, these are analyzed and the respective measures are taken to get the project on track again. With the control and monitoring, deviations can be predicted, corrections measures can be taken and improvements can be done. Thus, the control and monitoring will work as an evaluation for the performance related to what was initially settled for the costs, quality and time.

The control and monitoring for the construction of the project is a continuous process (Jackson, 2010). As Bennett (2003) mentions, "during project operations, it is essential that actual performance be compared with planned performance in all of these areas and action taken to remedy any indicated deficiencies".

Jackson (2010), makes a presentation about the project control cycle (shown in Figure 3.39), were she presents the following steps:

- "develop the project plan";
- "establish the project benchmarks";
- "monitor the project performance";
- "indentify performance deviations";
- "evaluate corrective options";
- "make adjustments as need";
- "document, report, and evaluate results".

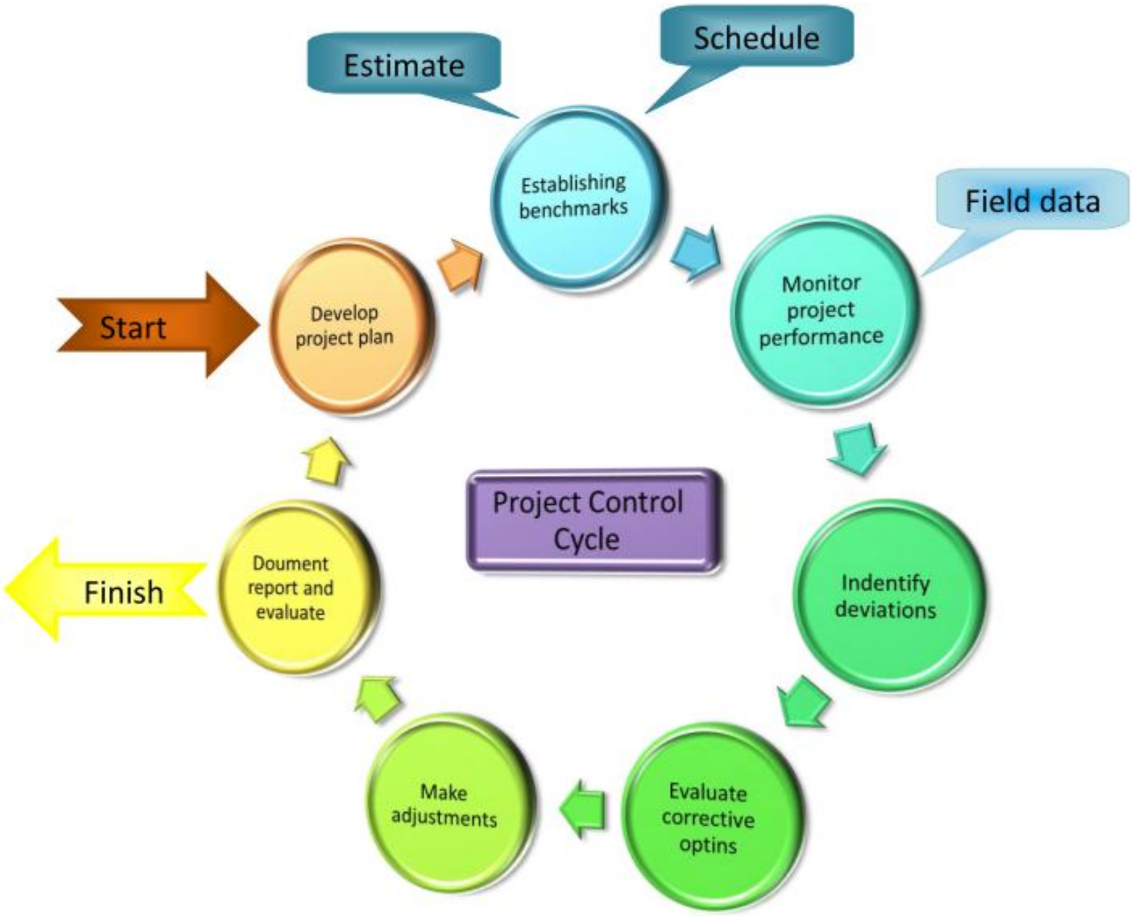


Figure 3.39 - Project Control Cycle, adapted from Jackson (2010).

Analysing then Figure 3.39, it can be seen that, the control and monitoring for the construction of the project starts by developing a plan for the project. This plan, is set by the incoming information of the project given by the owner, that will lead to the first planning, scheduling and estimating by the estimating department, as already shown in a previous section. Also Gould and Joyce (2003) make reference to this first approach by stating that "the control process begins with the initial project plan which includes budget, schedule, and quality along with other planning information such as staffing and administrative procedures". This first approach to the project is what will set the benchmarks that will work as the baseline for the monitoring and control for the construction process. As Gould and Joyce (2003) mentions, "the project plan is used to initiate the field operations" which determines also "the order in which the work is completed and the type and level of staffing". So, resuming, as Gould and Joyce states, "the plan is the roadmap that allows the project team to constantly monitor and take corrections as necessary".

However, new planning, scheduling and estimated can/should be done after the contractor awarding the project for construction. This second evaluation is done with the updated information for the construction process in the site. It is with this second estimating, planning and scheduling process, which can be called as a re-estimating, re-planning and re-scheduling, that possible deviations from the initial plan start being detected. The deviations in this review for the initial plan can be due to differences in the prices used in the estimation and the actual prices. Also, from the information which arrives from the field along the construction process, the possible deviations can be identified. With the source from the possible deviations, the team involved in the construction of the project will study the possible solutions for correcting these deviations and make the needed adjustments. Upon the completion of the construction of the project, it is of extreme importance building a report, where all the occurrences and events should be stated. This is emphasised along the read literature, but also the author from the own experience, recalls the attention for the realization of this report. With this report many points and details can be improved by learning from the experience taken from the already concluded projects. Some of the examples are the productivity, the quality and efficiency from the subcontractors and materials suppliers and so forth. For instance, Gould and Joyce (2003) call the attention for this when saying that the "actual cost and schedule performance information can be stored for reference when estimating and scheduling future projects".

However, a good and accurate control and monitoring cannot be done without the information and feedback that arrives from the work site and work fronts, as already mentioned above. By work fronts, the author refers to the precise places where the construction works occur. This concept might be more relevant and easy of understanding for the horizontal construction projects, where several points focus of the construction works can occur at the same time. The information and feedback which comes from the construction site plays a very important role in anticipating and predicting the deviations for the estimation, planning and scheduling done initially. This way, it is vital that all the information that should arrive from the works site, is precise, accurate and delivered within the proper time. If some of the conditions fail, wrong analysis and measures will be taken. The information which arrives from the construction site can come from the several forms shown below, as presented by Jackson (2010).

- "daily field reports";
- "time cards";
- "subcontractor billing statements";
- "delivery tickets";
- "material invoices";

- "equipment tickets";
- "job logs".

To avoid large and irreparable deviations, it is of extreme importance that the monitoring is done frequently by checking the progress and the performance of the project. Gould and Joyce call the attention for this by stating that

Gould and Joyce (2003) "the project team will continuously use these standards to check the progress". "drawings and specifications define the standards for quality control". "drawings define the quantity of work required, locations, and widths and heights". "Specifications provide performance standards, that address alignment, compression strengths, finishes, and so on".

3.5.9.1 Planning and scheduling monitoring and control

Along the previous subsection, the project planning and scheduling topic was approached. Yet, the reader should be aware of, in the previous mentioned approach, this was more in within the first contact and study of the project to get an idea of the resources and to prepare the beginning of the works. So, in the monitoring and controlling phase, the planning and scheduling done previously will be the reference along the construction process. "The schedule defines when specific work items need to be accomplished as well as provides key milestones and delivery dates" (Gould and Joyce, 2003). Thus, this first planning and scheduling should be monitored and updated according to the events along the construction process. The planning and scheduling updates are made based on the construction evolution, as it will be shown in chapter 5. A good and accurate control and monitoring of the planning and scheduling is of extreme importance, once from deviations which will result from here will be highly related with the costs for the contractor. Some examples for these costs, can be for instance, the fees from the owner due to delays in finishing the works, excess of costs from the "extra time" for the equipment and manpower allocated to the project, and so forth. To avoid deviations within the deadlines set in the beginning, the monitoring and control for the project should be done continuously. Bennett (2003) emphasises this by referring that, "periodically, the contractor will compare schedule progress with that shown on the project programme". The periodicity for the monitoring and control for the schedule should be adjusted according the needs for the project. The deviations for the work tasks related with the activities, can be to the constitution of the working teams allocated to the work task, the weather, delay in material and/or equipment deliveries, inspected site conditions, and so on. Bennett (2003) presents two main purposes for the updates, the first "is to determine whether the various activities that were planned to be active ... were actually active, the extent of their progress and, eespecially, the anticipated project completion". The second purpose presented by Bennett (2003) is " to incorporate any new information about already planned activities, to add information about any new work not previously planned and to determine their impacts on other activities and on the overall project completion date"

The considerations for the evolution are more into the amount of work tasks finished. Thus from these updates, it is possible monitoring the possible delays in the present and upcoming activities, delay times, consequences in the overall project or in a specific work front, new starting and finishing dates. As mentioned in Bennett (2003), "the monitoring and control process provides an important opportunity to evaluate the progress of each activity", so, "the updating process also affords an opportunity to look at, and revise if appropriate, the durations of activities not yet started".

Bennett (2003) presents the following methods from Mincks and Johnston (1998) to take back the project to its track:

- "altering the activity sequences so as to compress the schedule by carrying out some activities earlier than originally planned and shortening the critical path";
- reducing the durations of some of the activities currently underway, by implementing such approaches as increasing crew sizes, changing methods or adding shifts";
- "attempting to gain time later in the project by re-evaluating future activities".

3.5.9.2 Costs monitoring and control

The control and monitoring for the costs have as baseline the estimating done when bidding the project. "The project estimate establishes the overall budget for the project and can be broken down to specify the milestone costs for each component of work" (Gould and Joyce, 2003). The estimation for the costs of the project as mentioned in 3.5.6, there were several considerations taken for prices, productivity, teams constitution and so forth. But when coming for the construction process "even if an activity has not yet been started, new information or decisions that alter these assumptions may result in revised activity durations" (Bennett, 2003). When looking over the costs during the construction phase, the indirect costs, the equipment, materials, subcontractors and the labour, are the considered parts involved in the costs for the construction of the project.

The subcontractors have their cost fixed according to the contract made between the main contractor and the subcontractor. The variations for the prices for the subcontractors can occur due to differences between the prices given in the estimation process and the prices for the construction phase. Can also happens that for a specific speciality works, no quotations were received in the estimation process, so the prices were estimated for some other process, and these will not meet the present project. Additionally, it can be said that, the subcontractor's prices are fixed prices, thus, it will become hard to decrease the costs by trying to "play" with these costs. The monitoring costs for the materials is similar for the subcontractors. These are also fixed costs which are those negotiated with the suppliers. This analysis for the costs and materials is also seen by Bennett (2003) when he states that "unless an error is made in the cost-estimating process, the cost of materials, subcontractors, ... usually don not vary from their budgeted amounts".

The costs for the equipment and for the labour, will be dependent on how these costs are negotiated, i. e. if are allocated by the amount of work done or by time. Thus, these two elements will demand a close control. The costs can highly increase due to the production, as it was seen when analysing the planning monitoring. This is more susceptible of happening when the labour and the equipment are negotiated by time, where it is of interest for the subcontractor to do the works in a longer period. On the other hand if the contract is negotiated by the amount of work done, it might be of interest for the subcontractor to do the work faster. So, as Bennett (2003) refers, "the successful construction contract, from a cost standpoint, is the one whose labour and equipment costs are controlled in a timely and effective manner".

According to Halpin and Woodhead (1998), "the early detection of actual or potential cost overruns in field construction is vital for the managements". The earlier detection of deviations enables to bring the costs to what was initially set, making even possible to eliminate these deviations.

The control for the costs is done by the forms already mentioned above. For the labour costs, it is used usually the time cards, where the is the information about the number of workers and their working hours. Also, daily field reports can be used to complement the time cards, with the information for the work tasks executed and their progress. The allocation for the costs of the equipment is done in a similar way to what is done for the labour, as also Bennett (2003) refers. So, time cards and daily field reports are used for controlling the equipment costs. However, some particularities exist for the equipment, related with the ownership, i.e., if it does belong to the contractor, if it is a subcontract or is a rental contract. For the subcontracts and rental contracts, the equipment tickets might be used as well.

Bennet (2003) states that "two related outcomes are expected from the periodic monitoring of costs": the "identification of any work items whose costs are exceeding their budgeted costs, with subsequent actions to try to bring those costs into conformance with the budget", and the "estimating the total cost of the project at completions, based on the cost record so far and expectations of the cost to complete unfinished items".

3.5.9.3 Quality monitoring and control

In 3.5.4, the documents which are part of the project were introduced. When introducing the project, mention was made to the plans and the specifications. These two elements of the project will be the base for the quality control and monitoring. It is common in many of the construction companies the existence of a quality department. This quality department is usually the responsible for the control of the quality, eespecially when related with the materials. For monitoring and controlling the quality, several procedures can be done. Jackson (2010), mentions the "field observations", "submittals", "shop drawings", "mock-ups", "inspections", "field tests". In addition to these procedures, the reader should be aware, that several more can exist. Also these procedures are pretty much dependent from the project type and the owner's system.

3.5.9.4 Decision support and risk management

When monitoring and controlling the planning and schedule, the type of project will have also a great influence in the approach to be taken. So, analysing first the features for monitoring and controlling, the infra-structure type are projects where, as a general rule, the equipment tend to have a greater weight in the construction process, then labour and the materials. It can be said, from the author's experience that, the equipment have a weight around 45%-55%, the labour a weight of 30%-35% and the materials weight with 15%-25%. The previous statement is also confirmed by Bennett (2003), who say that, the "equipment plays a larger role and has a larger proportion of the budget in a highway or heavy construction project, then it does in a project to construct a building. In this situation, it will be relevant to give attention to the equipment and to the labour. Beside these being the most relevant contributing for the costs directly, they will have also a great influence in the duration of the project and indirectly in the costs due to the time. The majority of the equipment used in these type of projects have they productivity also subjected to almost all the conditions, since weather, driver, environmental and so forth.

If looking in the same way for the building construction project types, it can be said that, the materials will have a weight of 35%-45%, the labour a weight of 35%-40% and the equipment 15%-30%. So, for the building construction projects, the greater attention will be in the materials and in the labour. This means the in these projects the risk for deviations in the costs will be more due to bad estimating costs. The deviations in the time will be more due to the late delivery for the materials or due to productivity of the labour. Also the equipment used in these type of projects are "static" equipment, which mostly have a constant productivity under whatever the conditions will be.

Along the present subsection, it was presented the constraints cost, time and quality and its features. It was also mentioned how the time can have influence on the costs. However nothing about their interaction and how can they affect each other was mentioned. Other interesting analysis is to see how all these three constraints, the cost, the time and the quality affect each other. Also, beside the three constraints already mentioned, if including a fourth constrain, the SHE in the construction site, how all these constraints will work together. In a first approach, what would be the best situation for the owner? The owner would like to have the project constructed with the highest quality, by the lowest price and within the minimum time. The same rule is valid for the contractor. For the owner, it would bring bigger profit, because it would be able to star using great quality facilities earlier without spending many money. As well as the contractor, which would get more profit for the low value of construction with recognition for the work done and being able to allocate resources faster to other projects. Howevwer, this ideal conjugation is impossible to achieve. From this question arises the project decision making, i.e., a choice has to be done. Which choice has to be done? Knowing that is impossible of having the three constraints at the same time, two of them will be possible to achieve. Thus, a choice needs to be taken about which of those two will be taken.

For a better understanding, it will be first presented the "iron triangle" shown in Figure 3.40 which is very known along the project management and project decision-making literature. According to Atkinson (1999), in Ebbesen and Hope (2013), the "iron triangle" "places the Cost, Time and Quality at the center of the project success". As it was seen along the present subsection, these three constraints are indeed the focus for the good project management performance. So, "the concept of the Iron Triangle, is the mutual dependency between the three constraints" (Ebbesen and Hope, 2013).

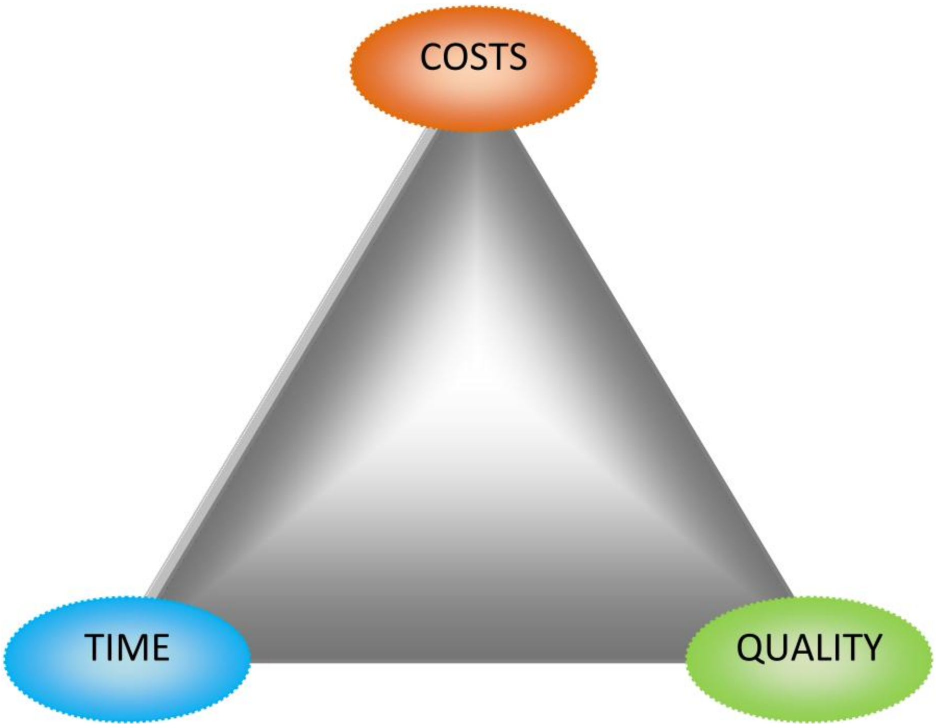


Figure 3.40 - The Golden triangle, adapted from Ebbesen and Hope (2013).

From this "iron triangle" concept it is possible of observing that only two of these constraints can be good by "sacrificing" the third one. Thus, analysing now how this "iron triangle" works by what was presented above to the ideal scenario, it can be seen that:

- if the goal is to decrease the time and the costs for the construction, so the quality will also decrease;
- if the goal is to have a good quality by decreasing the construction time, then the costs for the construction of the project will increase;
- if the goal is to have a good quality with lower costs associated, the time needed for constructing the project will have to increase.

Now that the triangle was introduced, how can this fit inside the project monitoring and control cycle? The author would like to suggest the following idea, shown in Figure 3.41. The concept is that, when going to the construction site, the productivity is directly related with the costs and duration. Thus, these two constraints will be affect by the productivity. Seeing the example for an activity taking for instance three weeks, if the productivity will decrease, the costs will increase as well as the needed time. In the other hand, to decrease the duration, the productivity will need to be increased. The increase of the productivity, will need to be done through increasing the resources allocation. Thus, the costs related to that work task will increase. Also the labour, materials, equipment and subcontractors are related with the quality and the costs. So, if the materials, for instance will be of better quality, or the execution for the works will be more detailed and careful, the costs will increase. The techniques and methods are related with the time and the quality, by meaning that better quality, more precision in executing the tasks, thus more time will be needed for completing the work.

When the construction of the project is concluded, a report should be done, as an output for the project. The idea for this report is to present the decisions taken, the reasons that lead to those decisions and the results achieved. This final report should get back to the estimating department, for beginning a cycle of the construction stage. This report can then give a valuable help in the estimating phase. The reader should notice that, also the estimating phase goes through a process like this shown in the triangle. When estimating guesses and decisions are done based on the variables of the triangle will be given more importance.

If in the cycle shown in Figure 3.41 will be added the SHE, as this last one being represented by the area of the triangle (Figure 3.42). So, means that, the SHE is intertwined with the other three constraints and will also vary according to the variations of the time, costs and quality. So, if decreasing the time and the costs, it implies a decreasing in the SHE. This is due to the lack of attention given to the SHE, to finish the works faster and to spend less money, the equipment are also little forgotten.

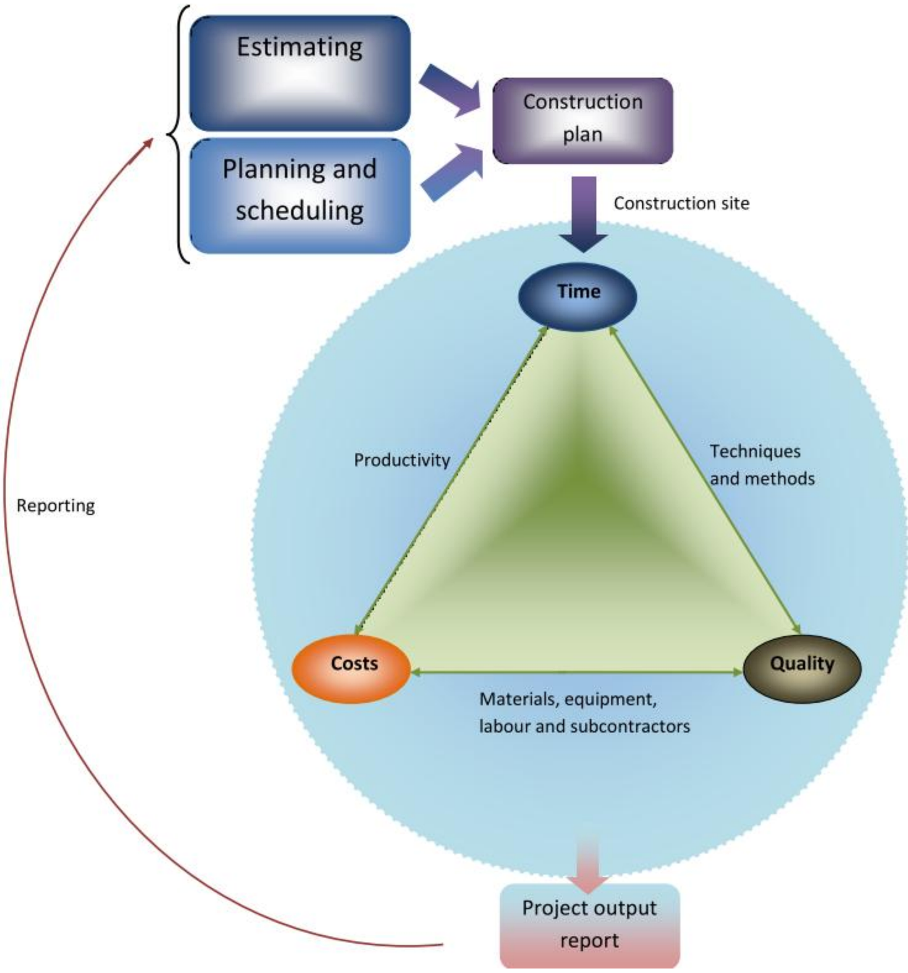


Figure 3.41 - Project monitoring and control management cycle.

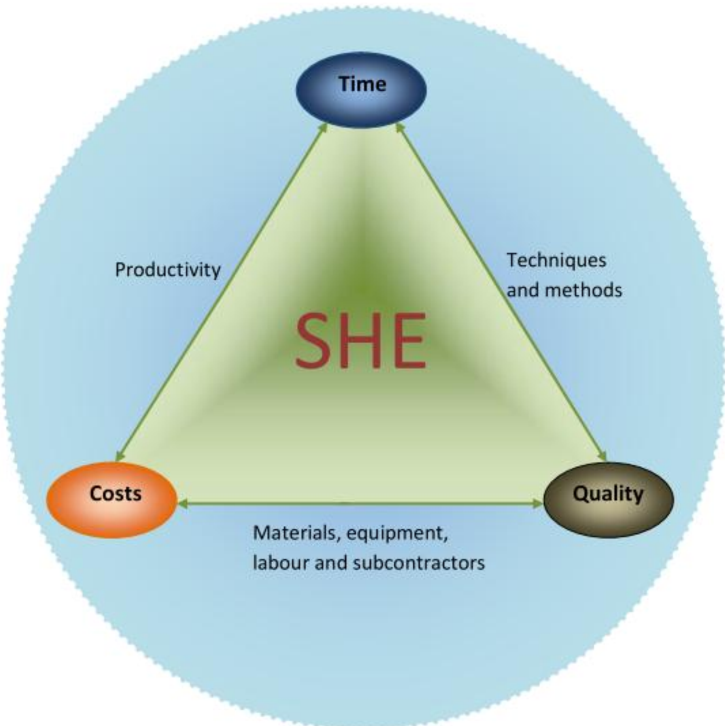


Figure 3.42 - Project monitoring and control management cycle with the SHE constrain included.

3.6 Summary

The project in the contractor is managed by the project manager and construction manager. The project manager is the responsible for managing the project in overall. Is the project manager who establishes the connection between all the participants involved in the project. The construction manager is the responsible for the project in the construction site. The construction manager is who coordinates the costs, the time and the resources in the construction site. The construction manager is the main responsible for achieving the a final product within the project goals.

In a construction project there are three main actors organizations involved. These are the owner, the designer and the contractor. The owner presents the need for certain facility(ies). The owner can be a public or private organization, and thus the projects as well according to the owner. The designer creates all the elements needed for the project. The contractor is the responsible for the construction of the project. The owner is usually a single entity. the design organization can be constituted by architects and/or engineers. The contractor can assume several shapes according to the size of the enterprise and the size of the project.

The projects can be categorized into public or private projects. These can be then split into building construction type and infrastructure type. In the building construction type, are the projects for commercial, services or residential purpose. The infrastructure type, are the projects intended for purposes for transportation, environmental and industrial.

The project lifecycle is made up of the design stage, construction stage and maintenance stage. In the construction stage are considered the estimating, pre-construction, procurement and construction phases.

The project delivery methods defines how the parties involved in the project will interact. Is with the delivery methods that the rules are set. There are four types of delivery methods, the Design-Bid-Build, Design-Build, Construction Management at Risk and Integrated Project Delivery. In the DBB method the designer and the contractor work independently. If the designer and the contractor work in collaboration as if they were a unique organization, then is a DB method. In the CM@R, the owner assumes the management for the design and construction of the project. In the IPD method, exists an earlier involvement between the intervenients in the project by collaborating together. This collaboration is kept along the design and construction stages.

The contract types which can be celebrated between the owner and contractor are: the Lump Sum, Unit Price, Cost Plus a Fee and Guaranteed Maximum Price. In the lump sum, the value for constructing the project is fixed by a certain amount. This type of contract is more suitable for building construction projects. The unit price contract type is better suitable for infrastructure projects. In this type of contract the prices are given for unit of work. In the cost plus a fee, part of the project, usually the direct costs, are reimbursed to the contractor. The indirect costs are paid at a fee. This type of project fits better with the DB. The GMP sets an upper limit for the costs of the project.

The estimating phase is where the contractor have the first contact with the project. Is in this phase the project starts being managed by the contractor. The estimation can have a big impact in the final results of the project. A bad estimation can lead to losses in the project. Thus, a good estimation, if well managed the project in the construction phase, can lead to good profits to the company.

Scheduling the project is the basis for monitoring and controlling the project related with the time. The scheduling of the project can be done making use of the Activity Based Methods or the Location Based Methods. Examples of ABM are the Gantt chart and network charts. These methods are based in the work breakdown structure for the activities. Examples for the LBM are the Lino of Balance and the Linear Scheduling Method. These methods are based on the location breakdown structure, for the location of the activities.

The monitoring and control of the project, is the management of the costs, time and quality. This management is done by controlling the equipment, labour and productivity. This should be a continuous process along the construction of the project.

4 State of Art

Along the current chapter, it will introduced BIM. A historical approach will be presented. An overall description about BIM and its functionalities will be covered here as well as a mention to its advantages and disadvantages. Also on this chapter will be posted what has been already done in BIM, how this developed by showing some examples.

4.1 Introduction

The main focuses of this chapter will be in introducing Building Information Modelling (BIM, as it will be treaded now on) to the reader. Firstly the concept of BIM will be shown by presenting BIM, and mentioning what is BIM. Modelling and analysis methods will be also exposed here, where the 2D, 3D, 4D and 5D modelling and analysis will be introduced, as well as will be shown which are its potentialities, advantages and disadvantages according to the literature read. A historical background and aspects of BIM, how it has developed along the time and what has been done will be presented after, being then made a reference to the standards by presenting and analysing them. Finishing this chapter there will be given some application examples and case studies by presenting them, proceeded of a short conclusion related with what was said in this chapter. The reader should notice that, although the main focuses of this thesis will be in the contractors side, in this chapter the idea will be to present a more wider view about BIM, its applications, how far and where BIM can be applied. From this large perspective showed, will-go-then narrow this vision to the point of view of the contractor by getting focused more into the project and construction management which are contractors responsibility, converging then into the main goal(s) and purposes of the project.

For presenting this chapter an exhaustive search and study was made in order to collect information and acquire theoretical knowledge and background about BIM and its potentialities. Due the nature of this chapter, the content presented, will be predominantly theoretical and mainly supported by the literature reviewed.

The present chapter will be composed of seven more sections behind this section Introduction as follows; section 4.2 BIM Concept, 4.3 Analysis and Modelling, 4.4 Advantages and Disadvantages, 4.5 BIM History and 4.6 Some Real Examples and Case Studies of BIM usage.

4.2 BIM Concept

Along the extensive literature related with project management and construction management recently edited (around 5 years old), many are the author's mentioning BIM in their books. Some, only presenting brief references to its existence, there are others which are introducing it as a strong and valid alternative to the traditional methods, but without going much further in details or explanations. There are also those authors which present the features and capacities for this new approach (of course in this introduction are not included all those books which treat only the topic BIM). BIM, it can be said, to be a new alternative to the conventional Information Technology (IT) methods used in the construction industry. Azhar et *al.* (2012)

presents also the n-D Modelling and Virtual Prototyping Technology denominations for BIM. Somehow, if taking into account the features and denominations that will be seen along this chapter these can be also used. Sabol (2008) introduces BIM as being "the latest software technology being introduced throughout the AEC profession". This alternative started being developed around the end of 70's/beggining of 80s, started the AEC implementing BIM within the projects around the mid-2000s, as mentioned in Azhar et *al.* (2012). The professionals dedicated within the construction industry started trying to explore BIM's capacities, to learn about it and doing some attempts for implementing BIM in the construction sector. Thus, more recently, since 2012 the interest in BIM as come up again (has it will be better mentioned in the section 4.5 where it is treated the historical evolution of BIM and the topic will be further developed).

So far, the word BIM was mentioned many times, but from this previous presentation talking about BIM, it is normal that two main question will come up. The first one, "what is BIM?" and the other ordinary question is "What does it do?".

Before answering the first question, first will be presented some definitions found along the research made about this subject. Through the literature related with the topic, it can be found many definitions about BIM. Nicole and Cruz (2011) mentions this fact when they states that, "Several definitions of BIM can be found in the specialized literature" This is due to fact that many authors define the concept of BIM in different perspectives, depending if it is from the owner's, designer's or contractors perspective and even in a somehow generalized way. Through this, following some definitions are be presented, being kept always in mind along this project those related with the contractor, once will be that main focus of this work.

Starting with a software developer perspective, in Autodesk (2003), BIM is defined as "an approach to building design, construction and management" which gives "a continuous and immediate availability of project design scope, schedule and cost information that is high quality, reliable, integrated and fully coordinated". This Autodesk perspective is a broader and global definition of what BIM is, by including designing and construction phases of the project. It is somehow understandable Autodesk's definition in this way, due to being Autodesk a manufacturer and seller of this product.

In a book where BIM is addressed to all the stakeholders involved in the construction sector, Eastman et *al.* (2011) presents the following definition, given by National Institute of Building Sciences (NIBS), who sees BIM as "an improved planning, design, construction, operation, and maintenance process, using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle." NIBS (2008) in Eastman et *al.* (2011).

From an owner perspective, HM government (2012) defines BIM as "a collaborative way of working underpinned by the digital technologies with unlock more efficient methods of designing, creating and maintaining our assets".

In a context focused more for contractors, Jackson (2010) presents the definition for BIM as "a 3D digital representation of the physical and functional characteristics of a building" where this "digital representation of the physical and functional characteristics of a building displayed as a 3D model, with the added capability to integrate a whole array of design and construction data related to cost, schedule, materials, assembly, maintenance, energy use, and more".

From the definitions presented above, the one presented by Autodesk (2008) and Eastman et *al.* (2011) are those which somehow converge into the same idea, although all the others have the same meaning. In HM government (2012) the collaborative way of working is introduced within the BIM concept. This concept is somehow related with the delivery methods, discussed and developed along chapter 3 in section 3.5, where the contract types were presented as well. So, from the definitions previously shown, five features of BIM stand out immediately; it can be used along the whole project lifecycle, it gives immediately all the information about the project with high quality and reliability, encourages collaborative working and provides a very close perspective visualization of the facility/facilities.

Specifically addressing to the question of what is BIM, this tool is considered by Jackson (2010) as "one of the most exciting advances in construction today", referring this author also the capacity for adding "a three-dimensional modelling component to traditional two-dimensional plans and specifications, with an added bonus". BIM is in Autodesk (2003) perspective "the intersection of two critical ideas". BIM will consent to the critical information from the design be easier to update and share, being kept in a digital form and to create consistent and real time-time relationships within the digital data, upcoming from this an increase of productivity and quality, time saving (Autodesk, 2003). According to Popov (2008), with BIM the "design is treated as an integral part of the building", which leads to a unique model containing all the information related with the project.

Along the read literature it was possible observing that, BIM is considered for many authors as a technology (such for example in HM government (2012), Jackson (2010) and Sabol (2008). However, in Autodesk (2003) and Azhar (2008), BIM is treated as an approach which works in CAD (Computer Aided Design), Object CAD and Parametric Building Modelling, being those the technologies. From the author's opinion, the way Autodesk (2003) and Azhar (2008) refers to BIM, seems to be the term "approach", the one which fits better when considering what BIM is. The reason why the author thinks this way, is because as it will be shown next, BIM is an approach for the technology of Parametric Building Model. The author thinks to lead this idea is that, the projects are approached using CAD technology by making use of BIM. Before continuing with the main topic of this thesis, to better understand the question about the difference between "technology" and "approach" and to remember what are the previous mentioned technologies it will be made a short description about what CAD, Object CAD and Parametric Building Design are, by presenting a definition with a short description.

Presenting CAD technology, Bilalis (2000) defines CAD as "the use of information (IT) in the Design process" which provides "accurate generated and easily modifiable graphical representation of the product" and "perform complex design analysis in short time". This definition at this point can be little confusing for what was been said so far, but this will be better understood further on this chapter, when presenting what BIM can do, and showing the differences between these CAD technology and Parametric Building Design. Yet and from the author's perspective, CAD technology allows modelling in 2D and 3D. The feature in this technology lies on the base of the construction of objects based into vectors, points and lines where none or few information can be added to the constructed objects. The same principle is also true for the construction of 3D objects, built as an example with AutoCAD, from the 2D objects by using the command extrude. About the technology Object CAD, no specific information was found through the literature, although again from all the information the author collected, the perspective acquired was that these are already existing objects, such as walls, doors, pipes, and so forth, that can be used to build a model, but still without such a big capacity to store information and without the ability for automatically changing or adapting to new situations.

Above, was presented the CAD technology and Object CAD technology, the first one related with the 2D and 3D models based in very simple information, and the second one related with 3D objects without information contained inside and the "intelligence" for adapting. The Parametric Building Design, can be associated with Parametric Objects, which is the base for a good understanding of what is BIM approach. Eastman et *al.* (2011) presents some features which characterizes the Parametric Objects by stating that these are objects consisting "of geometric definitions and associated rules". There is consistence in the overall model within the objects once geometry is not duplicated arising from several 2D perspectives, by meaning this that the "parametric rules for objects automatic modify associated geometries" leading the objects to their correct position according the information they contain (Eastman et *al.*, 2011). The "objects can be defined at different levels of aggregation" which allows changing the final output information from the group of sub-objects which will form the final object, as mentioned Eastman et *al.* (2011). Thus, Eastman et *al.* (2011), refers that, it allows checking for violations of standards, sizes and feasibility according the rules on which the object is based and the "objects have the ability to link to or receive, broadcast, or exposure sets of attributes" according the role they play.

To resume what was said before, by the author's perspective, somehow can be said that, CAD and Object CAD have the same base of elements, being constituted by points, lines and vectors, containing inside of them none or very few information about what they are and about the role they play. The previous idea is confirmed by Sabol (2008) who states that "CAD files are simply geometric data, comprised of primitive elements: lines, arcs, solids and surfaces that represent the physical location and configuration of building components". Object CAD is the creation of solids and shapes from the elements/objects from CAD technology, placed separately to form a complete model. But, with Object CAD as well, one change in a place implies verifying the entire model. When it comes to Parametric Building Design, this technology allows visualizing and modelling in 2D, 3D, 4D and 5D (introduced further into section 4.3). The difference in 2D and 3D modelling lies in the contents from whose objects are formed which brings all the capacities discussed over the present chapter. According to Stine (2011), in Azhar et *al.* (2012), " The term *parametric* describes a process by which an element is modified and an adjacent element or assembly (e.g. a door attached to a wall) is automatically adjusted to maintain a previously established relationship". Nicolle and Cruz (2011) defines this capacity of adapting to the changes, by stating that, the "Product is an intelligent digital representation of the building".

Exploring, the differences between CAD technology and BIM, following what was mentioned above, Eastman et *al.* (2011), states that CAD technology gives as an output files constituted by vectors, points, layers and linetypes. Related with BIM, Eastman et *al.* (2011) emphasises that a "building model can be described by its content (what objects it describes) or its capabilities (what kinds of information requirements it can support)". Referring the conventional 3D CAD, this one is an approach for describing the projects by means of independent 3D objects and views, which have no association between them, as presented for Azhar et *al.* (2008). This means that changing one of element, everything will need to be checked and updated. So, using the conventional 3D CAD leads to many mistakes and incompatibilities in the projects, being in many situations, only detected during the construction phase.

As it will be seen into section 4.3, this approach as mentioned in Eastman et *al.* (2011), allows:

- for visualizations in 3D and 2D, to follow the project along its entire lifecycle by linking databases;
- the use of animations and simulations, to follow the timeline and execution of works through the real time;
- to follow the costs with the different modelling methods and visualizations.

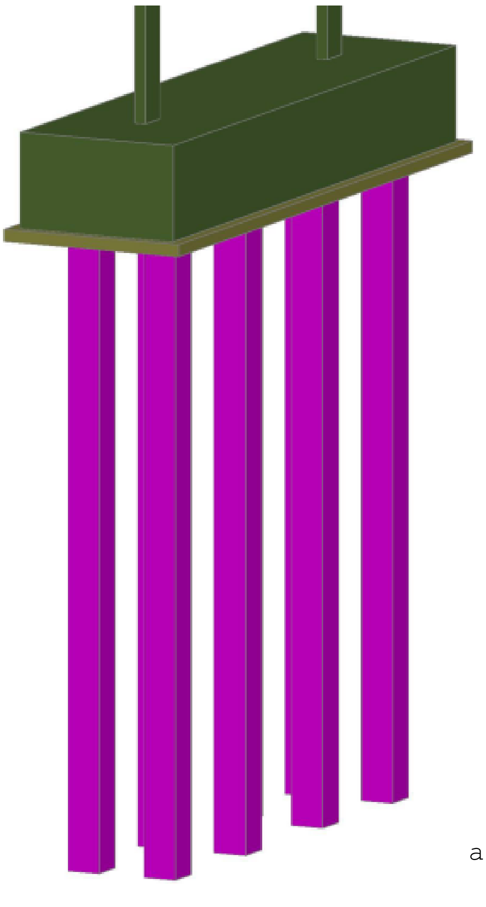
Thus, to differentiate what is BIM and what isn't BIM, Eastman et *al.* (2011) presents the following comparisons:

- "models that contain 3D data only and no (or few) object attributes" as for instance the example of a cube or a wall (depending on the used technology), which will always have the same functions without knowing whether it is possible to apply;
- "models with no support behaviours" being these unable of adapting to changes;
- "models that are composed of multiple 2D CAD reference files that must be combined to define the building" because when putting these models together it doesn't guarantee the viability for the 3D model without errors;
- "models that allow changes to dimensions in one view that are not automatically reflected in other views" as for example the case where a window size and position is changed in of the views on 2D model, but this changes are not reflected into the other 2D views and in the 3D model.

Jackson (2010), refers to the differences between the classic 3D CAD objects and the 3D BIM models, for the capacity of BIM objects assembling the "information about the entire building process" and the role they play through their characteristics, such as the weight, the material they are constituted, the size, the rules for their application. This means that, basically all the information needed is attached to the object. Azhar et *al.* (2008) mentions the difference between BIM and 3D CAD, by stating that in the first approach, the "objects are defined in terms of building elements and systems such as spaces, walls, beams and columns", while in the 3D CAD approach, the draws "are graphical entities only, such as lines, arcs and circles". The description from Azhar et *al.* (2008) goes into the same flow as the one made by Yan and Damian (2008). So, for Yan and Damian (2008), 3D CAD is a modelling process consisting of several "collections of points, lines, 2D shapes and 3D volumes", whereas BIM contains all these functionalities, but the geometrical forms have also a meaning (either abstract or symbolic) and a qualitative or quantitative data.

The comparison between a CAD 3D model and a BIM model can be seen in Figure 4.1. The model in Figure 4.1a) was built in AutoCAD, constructing the piles with a polyline/4 lines forming a square and the head with a rectangular shape. The square and the rectangle were then extruded with the desired height forming then the final shape shown into Figure 4.1a). Imagining the following situation, where a project have twenty of these type of foundations. If there will be a need in changing the height, length for the head, or the distance between the pile this would mean the same number of drawings and possible changes. The model in the Figure 4.1b), is a unique object, containing all the information about the it's characteristics. In Figure 4.2, it is possible to see the dimensions. It also contains for instance information about the material (Figure 4.3), as well as the properties for that material (Figure 4.4). So, considering the example given above, by changing one feature in the places shown in Figure 4.2 and/or Figure 4.3, the changes will be automatically updated for all the other elements.

Some examples of BIM approach are shown in Figure 4.5, where it is possible to see the building's architectural model, the structural model and the plumbing infrastructures model.


a)

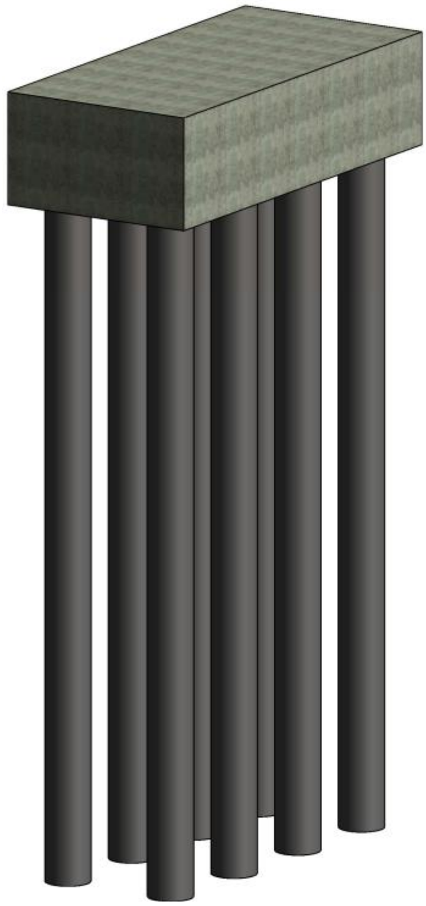

b)

Figure 4.1 - Example of a footing for a bridge in: a) a standard 3D AutoCAD 2007 draw and b) BIM model from REVIT 2014.

Parameter	Value
Construction	
Pile Type<Structural Foundations>	M_Pile-Steel Pipe : 400mm Diameter
Dimensions	
Width	1800.0
Thickness	1000.0
Length	3800.0
Cut-off	150.0
Clearance	375.0
Identity Data	
Assembly Code	A1010130
Keynote	
Model	
Manufacturer	
Type Comments	
URL	
Description	
Assembly Description	Pile Caps
Type Mark	
Cost	
OmniClass Number	23.25.05.11
OmniClass Title	Foundation Piles
Other	
Collum Visibility 2	☑
Collum Visibility 1	☐

Figure 4.2 - Some characteristics for the object shown in Figure 4.1b).

Parameter	Value	Formula	Lock
Construction			
Pile Type<Structural Foundatio	M_Pile-Steel Pipe : 400mm D	=	
Materials and Finishes			
Structural Material (default)	Concrete, Cast-in-Place gray	=	
Dimensions			
Width	1800.0	=	☑
Thickness	1000.0	=	☑
Length	3800.0	=	☑
Cut-off	150.0	=	☑
Clearance	375.0	=	☐
Other			
Collum Visibility 2	☐	=	
Collum Visibility 1	☑	=	
Identity Data			

Figure 4.3 - Some characteristics and properties for the object shown in Figure 4.1b).

a) Identity | Graphics | Appearance | Physical | Thermal — Concrete, Cast-in-Place gray

Information	
Name	Concrete
Description	Default Concrete f'c=3.5 ksi
Keywords	structural,concrete
Type	Concrete
Subclass	Standard
Source	Autodesk
Source URL	
Basic Thermal	
Thermal Expansion Coefficient	0,00001 inv °C
Mechanical	
Behavior	Isotropic
Young's Modulus	23.247,8 MPa
Poisson's Ratio	0,17
Shear Modulus	9.964,0 MPa
Density	2.407,31 kg/m^3
Concrete	
Concrete Compression	24,1 MPa
Shear Strength Modification	1,00
Lightweight	☐
Yield Strength	2,4 MPa
Tensile Strength	2,4 MPa

b) Identity | Graphics | Appearance | Physical | Thermal — Concrete(1)

Information	
Name	Concrete(1)
Description	Concrete, stone aggregate
Keywords	thermal,solid
Type	Solid
Subclass	Concrete
Source	Autodesk
Source URL	
Properties	
Transmits Light	☐
Behavior	Isotropic
Thermal Conductivity	1,0460 W/(m·K)
Specific Heat	0,6570 J/(g·°C)
Density	2.300,00 kg/m^3
Emissivity	0,95
Permeability	182,4000 ng/(Pa·s·m^2)
Porosity	0,01
Reflectivity	0,00
Electrical Resistivity	2.000.000,0000 Ω·m

Figure 4.4 - Material properties for the object shown in Figure 4.1b): a) physical properties and b) thermar properties.

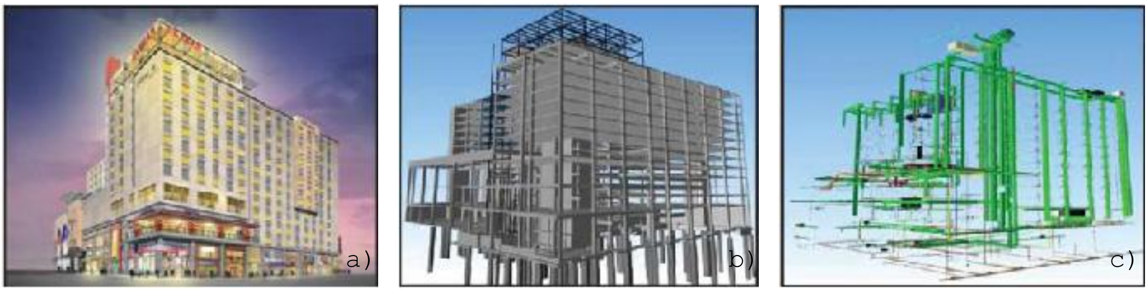


Figure 4.5 - Examples of BIM model from a building with a) the architectural mal model; b) the structural model and c) the plumbing model (Azhar et *al.*, 2008).

Briefly, Azhar et *al.* states that "a building information model characterizes the geometry, spatial relationships, geographic information, quantities and properties of building elements, costs estimates, material inventories and project schedule".

As mentioned above, these three technologies can be used for building information modelling. However, depending on the technology there some advantages and strong points as disadvantages and weak points when implementing BIM. The topic about BIM's implementation will be introduced here, somehow superficially, and mentioned again later on in section 4.4, with the idea to show, which technology is the best and most effective technology for this approach when choosing implementing BIM. Autodesk (2003) treat this problem by comparing these three technologies with the Figure 4.6, where the effectiveness is shown along the y-axis and the needed efforts are shown in the x-axis and the horizontal dash line the degree of effectiveness that can be characterized.

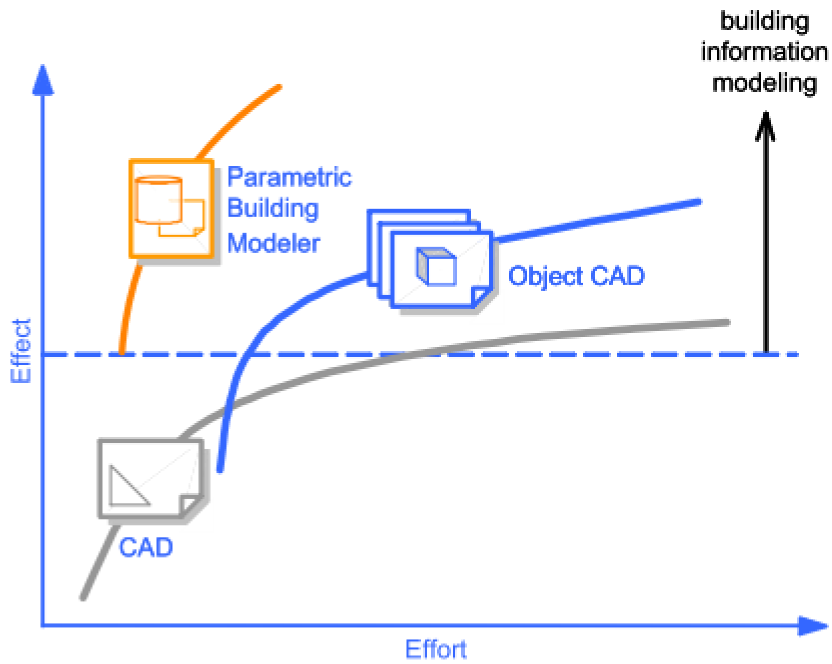


Figure 4.6 - Effectiveness vs. Effort for BIM implementation through different technologies (Autodesk, 2003).

From the Figure 4.6, it is possible to take out the information that the most appropriated technology is Parametric Building Modelling as it will be explained below. Analysing now each technology separately. CAD technology is one of the oldest and most used technology, but it stills suitable and good when it comes to drafting automation. However, when it comes to BIM, the efforts needed for a reasonable level of efficiency, comparing, the other technologies are much higher, being CAD the one which shows lower levels of efficiency. This is easy to understand due to what was explained before when presenting CAD and the characteristics for its objects.

According to Autodesk (2003), Object CAD "can be applied very effectively to help coordinate the various representation of the building in documentation", but also can be extended to BIM, "because it carries rich data about the building in the object structure". Recalling again to the chart in the Figure 4.6, even the levels of effectiveness are higher then CAD, stills requiring a great demand of efforts. This high demand is due to Object CAD being a CAD based technology, so, the problems comes eespecially when in the need for changes. Parametric Building Modelling technology is what is considered for the majority of the authors, the technology in which BIM approach is inserted. As well as mentioned for the other technologies, the reason why Parametric Building Modelling is the best solution can be understood from the previous introduction and comparison between these three technologies.

Following some of the examples for software related with the previous technologies will be shown in Table 4.1. This is only an example with some of the most popular, existing thus several more available in the market. To conclude the discussion above about what BIM is, the Autodesk (2003) and Azhar (2008) consideration seems to be the one better describing BIM, so from here on, BIM will be treated as an approach instead as a technology.

Table 4.1 - Some example of software and respective manufacturers for the three mentioned technologies.

Technology	Software	Manufacturer
CAD	AutoCAD	Autodesk
	MicroStation	Bentley
	FastCAD	Evolution Computing
CAD Object	Autodesk Building Systems	Autodesk
	AutoPlant	Bentley
Parametric Building Modelling	Autodesk Revit	Autodesk
	Autodesk BIM 360	
	Autodesk Navisworks	
	Archicad	Graphisoft
	Bentley Architecture	Bentley
	STAAD Pro	
	Microstation	
	Tekla Structures	Tekla
	Constructor	Vico
	Takeoff Manager	
	Estimator	
	Allplan Engineering	Nemetschek
	Vector Works	
	ArtrA software	Artra

Analysing now the second question about what does BIM do, Azhar et *al.* (2008) very briefly states that "BIM simulates the construction project in a virtual environment". Popov (2008), presents BIM as a tool which "covers virtually every phase of the specific construction product process", by mentioning the "planning, design, estimating, scheduling, fabrication, construction, maintenance and facility management" stages. According to Jackson (2010), BIM gives the "chance to build the project in a virtual environment before building it for real" giving thus all the tools and information needed helping in the construction phase by anticipating any setbacks. With BIM is possible to visualize the surrounding environment and site conditions as well some trick or more critical points in the project (Jackson, 2010). Having this overview of what the whole project will be, the methods and planning to face up the "*in situ*" construction phase can be studied in advance, through simulations of several approaches to the problem. Regarding the topic related with the description and differences between the technologies, Popov (2008) mentions that, in BIM "all the elements or parts have specific 3D shape with the properties of the elements of real structures", being these elements and parts "parametrically controlled and intellectually". When working with some of the software mentioned into Table 4.1, it is possible to use the real dimensions, properties, materials information, constitutions, properties, as to control them along the project cycle, when subjected to changes.

Jackson (2010) emphasises that, BIM also allows working with a fourth dimension (this one related with the time) and a fifth dimension (which allows linking the costs to the model). With these two features, it becomes possible to the contractor to simulate the stages along the construction process, including the time and the costs. From the simulations of the construction process, the contractor can also have an overall idea about the material, manpower, stocks. Thus, this will allow having a global control for managing all the factors allocated to the execution of the project.

All the authors share the same feeling and impressions when it comes to the potential, capacities and advantages of using this tool. BIM gives the chance of being used along all the phases of the project, i. e., since the conception and design stage, along all the construction process and in the post-selling, through the facility management. As mentioned in Autodesk (2003), BIM can "offer access to critical information" along the entire project stages. Autodesk (2003), also refers that, along the design phase it gives the information for the design, scheduling and budget, on the construction phase, the quality, schedule and cost information can be extracted and during the management phase, it can be seen the information about the performance, utilization and financial information.

4.3 Analysis and Modelling

4.3.1 2D and 3D analysis

Once it is out of the scope of this thesis to present and explore CAD technology, it will be only mentioned here how this technology appeared and in what it does consists. This subsection intends thus, to make the bridge to the next visualizations and modelling types.

2D models, are constituted by lines, points, linetypes and layers which help identifying the objects. Here no information is associated to the object. A very good example of a software very well known in the construction sector is AutoCAd. Thus with BIM software this 2D visualization is also possible to be done. In Figure 4.7 and Figure 4.8 is shown one example for the plan view at the same height for the same structure. These two figures were extracted from project a project done in AutoCAD and the same element modelled in REVIT. The reader should notice that, in the AutoCAD model are included the all the elements for the facility. In REVIT the model contains only the architectural component. The goal for these two images is o show the similarity and between the two software by doing these models. In the Appendix A.3 a), Appendix A.3 b) and Appendix A.3 c) is represented the same plan view, but in other possible visual style options.

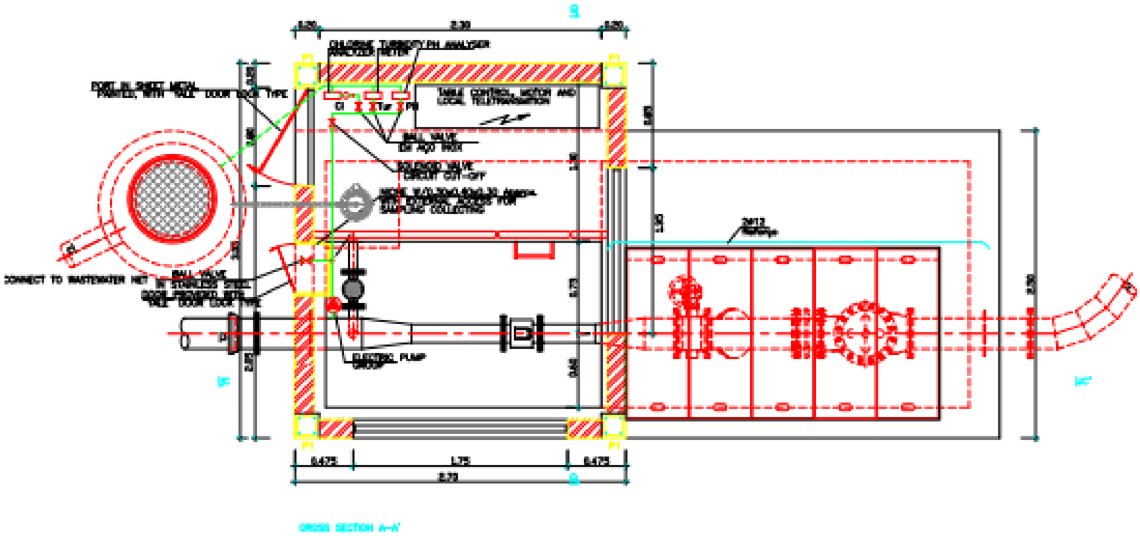


Figure 4.7 - 2D plan model produced for element DS in AutoCAD.

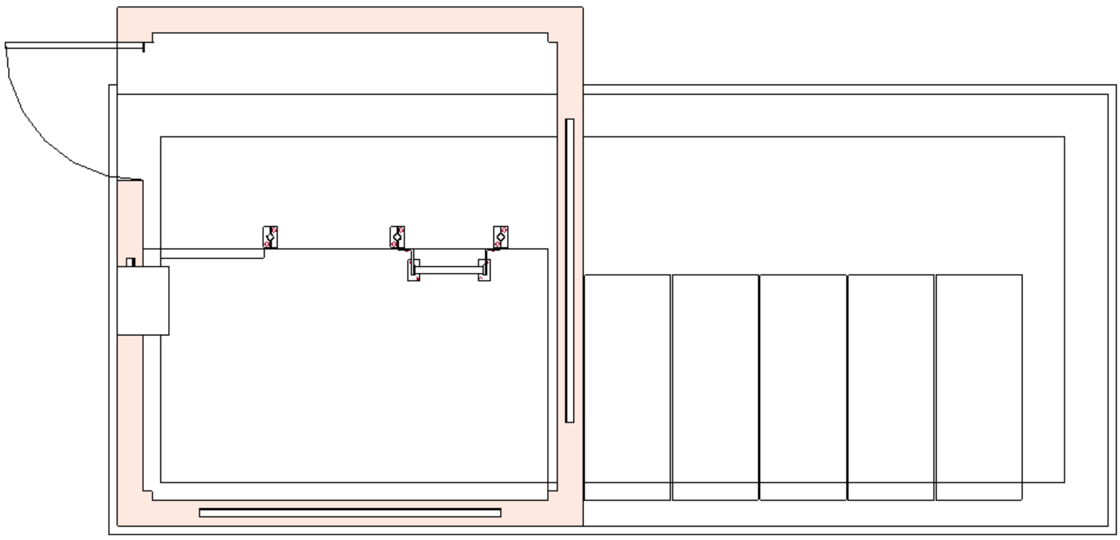


Figure 4.8 - 2D hidden line visual style plan model produced for element DS in REVIT.

In the 3D modelling two separations can be done, as it as has been mentioned throughout this chapter, 3D/CAD object (also AutoCAD can be used as an example) and Parametric Building Model (where BIM is inserted). The discussion about the differences between these two technologies were already developed in section 4.2, so this topic will not be discussed here, being only shown what is in these two types of modelling.

The 3D modelling is the transformation of the 2D objects into 3D objects through blocks, being a big example of this in Autocad, the use of the command extrude. In a BIM software, the models can have a more realistic appearance, and the changes done in one place will be automatically be updated in all the models. In Figure 4.9 is represented a gabions wall. This gabions wall as built through a simple shape of a cube composed by 4 independent lines. These lines were then extruded with the desired height. The resultant shape represents a gabion basket. The wall was built by using several cubes. If some parameter for this wall needs to be changed, all the cubes will be needed to be changed manually. Imagining the time will cost to change a three meters height wall with a length of twenty meters.

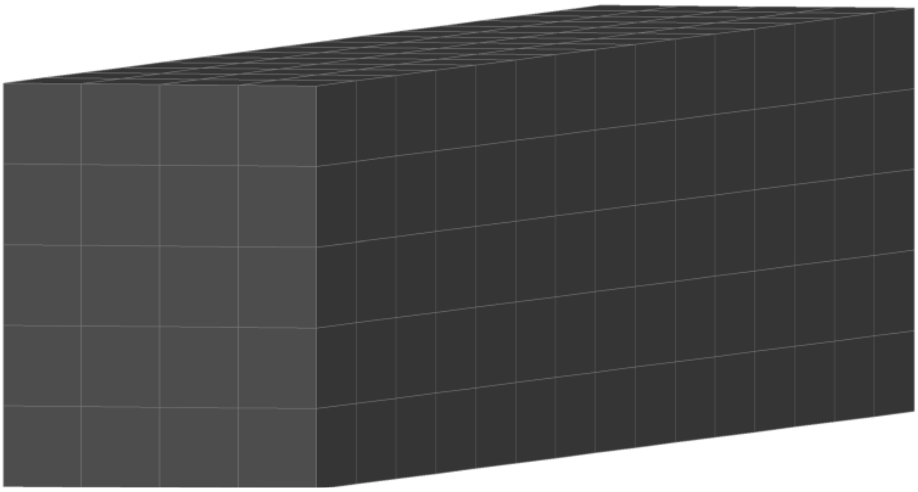


Figure 4.9 - Example of a 3D model for a gabions wall built in AutoCAD.

In Figure 4.10 is represented the same wall, be modelled in REVIT. With BIM approach for building the same wall, only a single element would needed to be changed. All the other elements and the wall itself would adapt to this new reality.

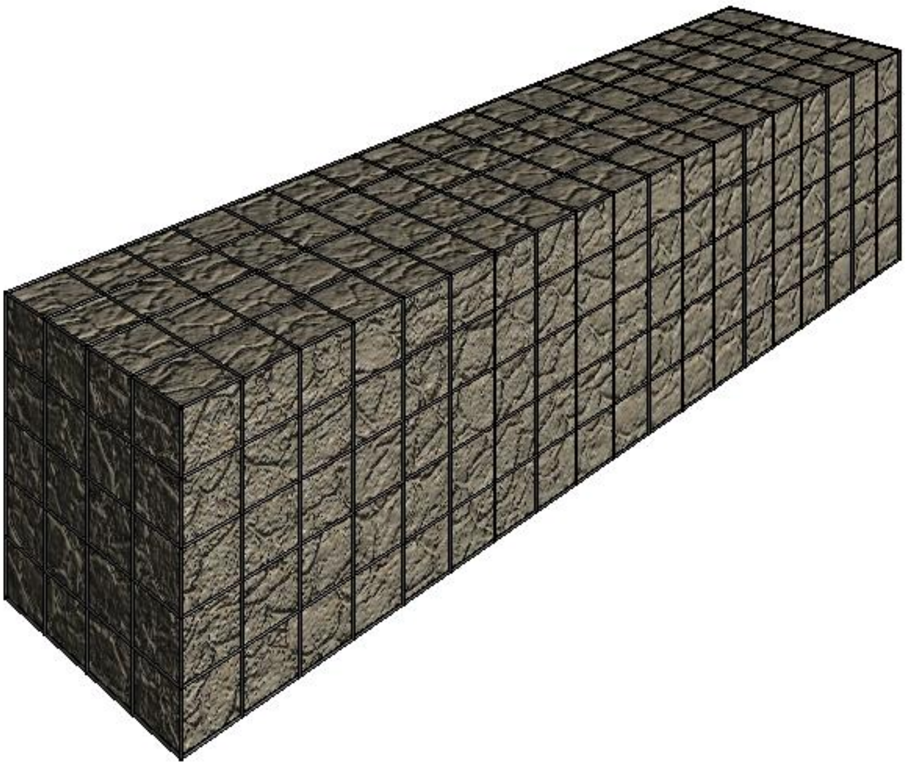


Figure 4.10 - Example of a 3D model for a gabions wall built in REVIT.

4.3.2 Time analysis for the 3D models (4D)

As already mentioned, the 4D modelling is related with the introduction of the component time (the fourth dimension) on the 3D model of the project. From the traditional known 3D visualization (x,y,z) the time is added becoming then the 4D model with the shape of (x,y,z,t). Eastman et *al.* (2011) presents this idea by stating that "4D CAD, ... refers to 3D models that also contain time associations". So, the fourth dimension will add to the 3D model the visualization how it will be the construction progress along the time. The visualization for the construction process sequence can be visualized by linking the construction schedule to the 3D model (Eastman et *al.*, 2011).

One example of a 4D modelling can be seen in Figure 4.11, where is shown the progress for the construction in 07th of May 2014. As Eastman et *al.* (2011) refers, "4D CAD tools allow schedulers to visually plan ... in the context of space and time". From the example shown in Figure 4.11, at the right bottom corner, can be seen the tasks being executed with similarity to what was presented in subsection 3.5.8, for the Gant charts. Also, the visualization for what is "happing in the site" can be seen through the model. In the present example, it can be visible that, the footings are already completed, the foundation beams are also close to completion, occurring the works for the columns and foundation slabs at the same time. Analysing now the bottom right corner of Figure 4.11, it is possible to observe the WBS, approached when introducing the subject planning and scheduling in 3.5.8, in similarity with the one in Figure 3.27. However, when using this software to simulate the visualisation of the construction progress with the time, only the tasks "being executed appear in the WBS field. If looking into Figure 4.12, it is possible to see the complete WBS with the respective schedule for the already created tasks.

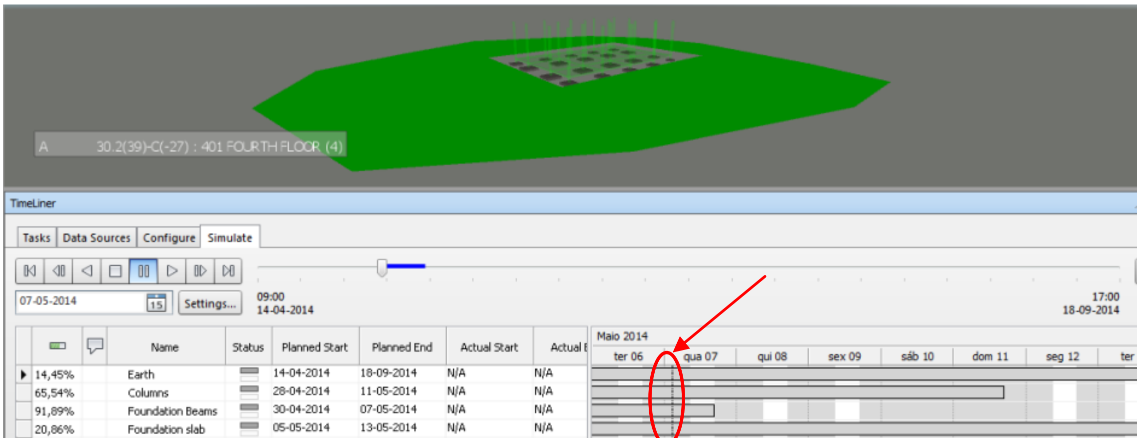


Figure 4.11 - Example for a time construction simulation in NAVISWORKS 2014, for the structural component of a three storey building (adapted from Wing, 2013).

Through this, when scheduling the project it becomes possible visualising the sequence for the activities, simulate how the project will be/is on a certain point of the time. These simulations bring also an extreme help in the planning of the materials, equipment, manpower. It becomes possible to visualize the effects of potential changes the project was submitted and what the impacts these changes cause in the scheduling and in the planning.

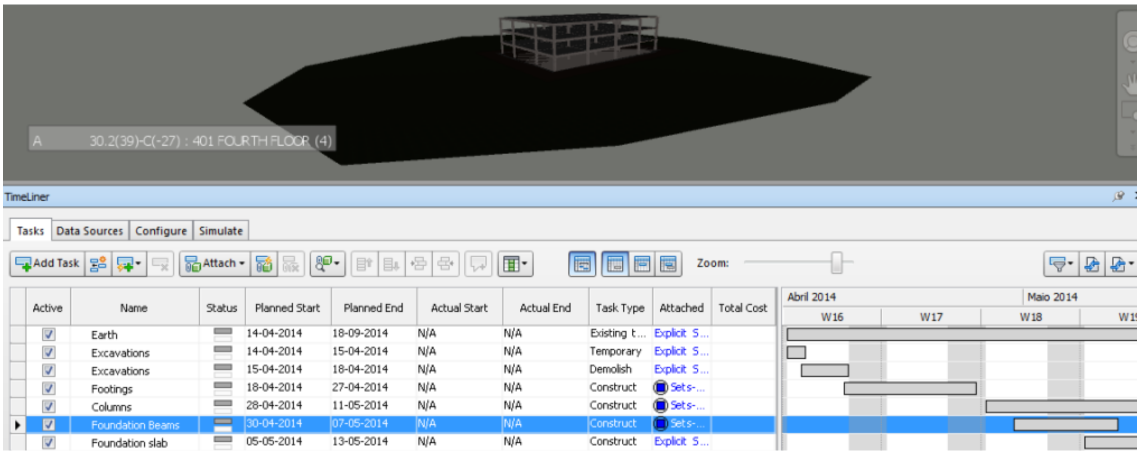


Figure 4.12 - Example for a WBS construction in NAVISWORKS 2014, for the structural component of a three storey building (adapted from Wing, 2013).

Related with the software to perform this task of planning and scheduling, Eastman et *al.* (2011) states that "specialized software packages that are better suited to building construction, such as Vico Control 2009". The previous statement comes in other context, where Eastman et *al.* (2011) wants to refer to the location-based scheduling method used in Vico Software.

4.3.3 Costs and planning monitoring and control (5D modelling)

The concept for the 5D modelling arises from the idea that, a fifth variable is added into the models. To the element(s) containing the 3D model (subsection 4.3.1 2D and 3D analysis), together with the analysis of the variable time, the 4D model (subsection 4.3.2 Time analysis for the 3D models (4D), is added the second variable, the costs (seen in 3.5.9.2 Costs monitoring and control). It will be the introduction for this cost variable, that will afford for the visualization with the fifth dimension. Similarly to the 4D analysis, the 5D analysis will be the model seen through (x,y,z,t,c). So, in reality, what is seen is, the progress for the construction of the project (in the third dimension), with the time (fourth dimension), by showing the costs (fifth dimension) at the same time. However, the concept for this analysis was already used, before BIM started being studied. From this perspective, it seems this approach didn't brought nothing new to what was being done. But, through the use of BIM, it has become possible a real visualization for what happens in the construction site, by the mean of real simulations.

BIM gives the chance to the participants in the project of using a 5D modelling visualization for watching the evolution of the costs with the progress of the project. This feature can help the participant by giving a more close and realistic visualization of the development of the project, bringing in together, the time and the costs. With the 5D modelling becomes possible to have a closer and more reliable knowledge and control of what is happening along the construction process.

Popov (2008), presents four steps for the 5D models and analysis as follows:

- the creation of the 3D model;
- the creation of the list with the quantities, products, resources and costs is done;

- "calculation of duration for certain construction process";
- the analysis for the solutions and/or alternatives for the project if needed.

It was seen that BIM allows for a precise measurement of the quantities involved in the project. This can be done through the quantity takeoff feature BIM offers to the users. In contrast with the traditional method for quantities takeoff, BIM have the capacity for accurate quantities takeoff. Jackson (2010) refers to the capacity of BIM "for linking the costs to these components" resulting from the quantity takeoff. As a result Jackson (2010) presents the possibility for an accurate costs estimation. Through this capacity, when changes are made in the project, easily and quickly can be known the effects these changes will cause in the project costs. (Jackson, 2010).

4.4 Advantages and Disadvantages

Regarding the advantages and disadvantages of using BIM, the first one will be analysed by splitting it into the three main stages of the project lifecycle (see Figure 3.12). The presentation for the disadvantages will be done into a unique subsection, once they will have interference in all the stages and phases of the project.

In order to simplify the analysis for the advantages and disadvantages along the entire lifecycle of a project, this was split in the three stages, already presented in subsection 3.5.2. Recalling again these stages, the design stage, the construction stage and post-construction, post-selling and facility management. These last three, considered an all-in-one which form the maintenance stage. The reason using the expressions post-construction and post-selling lies on the author's perspective, being the first one more related with the period immediately after the conclusion for the construction, checking the work is completely finished, ready to be delivered and to start its functions. The post-selling is the warranty period which starts from the acceptance date, depending this period from what was defined in contract. The design phase is considered from the moment when the owner have the idea/need for the project until the tendering process (presented already in chapter 3 along the section 3.5). The construction phase is considered since the contractor have the first contact with the project, until the moment the work is done and ready for the last inspection.

Before getting into the advantages along the different stages of the project, will be presented some of the advantages along the entire project lifecycle. BIM gives the possibility to store, transport and transfer all the information generated and collected along the entire project lifecycle. Related with the storage feature, Nicolle and Cruz (2011) states that, "A BIM system is a central system that manages various types of information, such as enterprise resource planning, resource analysis packages, technical reports, meeting reports, etc." For the information transport and transfer, Jackson (2010) compares BIM to a transportation vessel when says that, "the power of this technology is that the virtual model is also a vessel in which to load every bit of electronic data that can be collected". Nicolle and Cruz (2011) refers to the transferring and transportation of information by highlighting that, "the main feature of a BIM is the 3D modelling system with data management, data sharing and data exchange during the lifecycle of the building".

As an overall advantage of using this approach, UK government foresee savings of around 54 billion Danish crowns through BIMs adoption. As an example of these savings, the Ministry of Justice in UK mentions savings of around 9 million Danish crowns, in the processes related with approval in the design and procurement stages (HM government, 2012). There is also the possibility of a "greater transparency and collaboration between suppliers and thereby reduce waste", according what's mentioned in HM government (2012).

4.4.1 Advantages on the design stage

Regarding the advantages on the design phase, Popov (2008) presents the component modelling, which "allows working in parallel with all the design data". The meaning for the previous sentence is that, the design can be done using objects where the real environment can be simulated. What makes possible these simulations is the capability of BIM using the real properties, dimensions and attributes of the elements constituting the project. In Autodesk (2003) it is also mentioned the possibility of making changes in the project at any moment without a laborious process, once all the changes will be done automatically on all the pieces of the project related with the modification's place. This ability, allows to the design team to save time avoiding all manual documentation examination. Also this will turn up in a better quality in the final work delivered. Popov (2008) presents the possibility for manipulating objects according to the needs and new ideas that might occur during the design phase. This feature gives the chance for "change and edit the shape of objects rapidly and effectively" without changing their characteristics (Popov, 2008).

When the idea for a certain project arises, before start designing it, an analysis should be performed in order to check the feasibility of the project, costs, size, surroundings, quality. Also it must be analysed if the project will meet the owner's interests and, avoiding thus time consumption and unnecessary costs due to a late perception. Due to the capabilities of BIM, for real simulations and visualisation, the mentioned variables above can be detected in the very beginning of the process, through a construction of a schematic model. As a positive feedback related with this approach, Yan and Damian (2008) states that, "BIM enables better decisions; faster BIM reduces the abstraction and integrates the multiple disciplines, including design and documentation. And BIM integrates plans, sections, details, graphics and data in ways is not possible in 2D".

BIM gives the possibility for an earlier visualization through a 3D model. This allows for a more accurate and efficient overview of the project, thus, precise and specific corrections can be done. By going straight to the points needed to being correct, time, money and resources will be saved. Due to the intelligence the objects contain and their capacity to change and adapt to new modifications only changes in one element are needed, being all the others related to that element in the model changed automatically. "Accurate and consistent drawings can be extracted for any set of objects or specified view of the project" (Eastman et *al.* , 2011). BIM, from its characteristics also allows for estimating costs on the design stage, by association of the costs to the objects.

Resuming the advantages in the design phase using Sabol (2008) analysis, "BIM has the inherent capability to reduce costs and promote efficiencies". The way Sabol (2008) see this possibility is through the following description:

- "It accelerates the processes so that decisions and changes can be made early with a reduced impact to time and costs";
- "The accuracy of the model, and its ability to communicate effectively to diverse parties involved in building projects and management, reduces miscommunication and reinforces understanding visually";
- "Quantities and data can be automatically generated by the model, producing estimates and workflows much more quickly than conventional processes";
- "Data delivered at the project turnover is more complete, more structured".

4.4.2 Advantages on the construction stage

On the tendering and budgeting phase, the contractor is aware of the intention from the owner to undertake a particular project, through for example, direct invitation, public announcement, or others. Also when the project is announced, there are some parameters in which the choice is based. Those parameters can be for example the price, the time, the construction processes and so forth. Beside these parameters which will be taken into account when evaluating the proposal from the owner, there also can be some different weighting factors for the evaluation of these parameters, such as; 100% for the price, 87% for the price and 13% for the time and so forth. Coming now to the tendering itself, this one is based on the project quantities, materials and work types as already introduced in 3.5.6.

When referring to the construction process phase, a control over the estimating and planning presented on the tendering phase should follow the presented in 3.5.9. So, resuming what was presented, the control is done by following and monitoring the schedule, the costs and the building quality. Also during the construction stage, it is needed to take into account the control over the security in the construction site. BIM can be really beneficial and a valuable tool for the contractor along all the construction stage, by helping with these process mentioned.

As presented above, BIM can be the solution for many of the problems which contractors are facing in the present, such estimating, monitoring, planning, costs control and so forth. So, presented briefly the steps and procedures involved in the construction phase, now will be shown the advantages for the contractor. BIM "makes available concurrent information on building quality, schedule and cost", once it becomes possible to "accelerate the quantification of the building for estimating and value-engineering purposes and for the production of updated estimates and construction planning", Autodesk (2003). It is known that as accurate the planning is, faster can the failures, delays and conflicts be detected, faster can act to correct possible deviations, but also easier to improve from the initially planned. The same can be said about the costs control, by giving the capability for a closer and quicker analysis, thus this "means that less time and money are on process and administration issues" (Autodesk, 2003). As presented in Autodesk (2003), "the builder can quickly prepare plans showing site use or renovation phasing for the owner.

From Yan and Damian (2008), it comes out that BIM, gives a good overview for the real time performance of the project, due to its capability for updating the project information along the time and including the economical aspects. Jackson (2010) presents "one of the great benefits of BIM is it allows the contractor, along with their trade and supplier partners, to analyse and test a number of construction "means and methods" approaches before ever going to the job site". This means (as mentioned previously) the possibility for clash detections, finding of some inconsistencies in the project, find out errors and omissions enabling thus a better communication process with the owner by presenting alternatives to these fails in the project. The reader should notice that, although the clash detections are being mentioned here, these can be also of very important role along the design phase. When planning the works, BIM offers the capacity for simulating a number of scenarios to "study the existing and proposed utilities, site access options, safety and evacuation concerns, excavation plans" (Jackson, 2010), as an example of the possibilities that can be analysed and predicted.

In the sequence of what was said, in the construction phase, changes might be found necessary can be quickly done in the entire project at once due to the capacity of automatic changing. Also the detection for errors or omissions can be easily done, since the 2D visualizations come from the 3D model (Eastman et *al.* 2011). BIM can also bring a precious help on the planning tasks. This can be done by the linking the 4D model into the 3D model (Eastman et *al.*, 2011). This way it becomes easy to follow all the steps for the construction works in real time, to simulate how the project will look in the moment or even forecasting some future problems.

4.4.3 Advantages on the post-construction, post-selling and facility management stage

Before going further into properly what BIM can give into this stage, a short explanation will be given. Once this work is being written from the contractor perspective, there will be considered a post-selling phase. This phase is related with the contractor, where the warranty period is included, that depends on the terms of the contract. From the contract it can come out that, all the facilities management are the contractor's responsibility or only some maintenance and specific problems solving. Again, depending on the settled in contract, the facilities management can be the owner's responsibility. In both contract terms, BIM can play a very important role on these stages. The reader should notice that, when mentioning the post-selling and maintenance responsibilities from the contracts, those have nothing to do with the types of contracts presented in 3.5.5, but with the terms agreed in the contract. This means that, whatever the type of contract might be, these terms and responsibilities will be always part of the contract.

From what has been described, it is easy to see that, BIM is a continuous process, which starts being constructed from the very first moment of the project's life, i. e., since the project starts being sketched. When reaching this final stage, all the elements of the project are updated and according to what was constructed in reality. A comment related with this can, be seen in Autodesk (2003), where is mentioned that, BIM "makes available the concurrent information on the use or performance of the building, its occupants and contents; the life of the building over the time; and the financial aspects of the building". Also when renovating, maintaining the construction, BIM will become a very important tool into the project. With BIM, when some specific, more careful and sensitive interventions will be needed on the project, a very precise and detailed information will be available. Some examples of this can be in buildings, where for instance, the needs to acting into pipes, cables and other elements which are inside the walls or hidden. So, through BIM, the precise distance, crossings and overlaps of this infrastructures can be known and thus avoiding secondary damages. This possibility will lead to a less time and money consumption, due to the precise and detailed knowledge about the conditions "*in situ*". The same can be said in linear projects, such as roads, pipelines and other infrastructure projects.

From their study, Yan and Damian (2008) found that, one of the biggest advantages BIM gives, is the decreasing in the construction time. This can be reflected as a big advantage once, money can be saved especially on the indirect costs as all the supporting infrastructures and equipment. It will also spent less time in the construction site as well with all the staff allocated to the project, representing these between 3-7% of the entire project (depending on the type and size of the project, this range can varies).

When delivering the facility(ies) completely constructed, in the documents making up the delivery process to the client, are the documents which are part of the project, the final blueprints and all the documents with the specifications. The final blueprints contain all the information about the location for the materials, for the infrastructures such as electricity, water, gas, and so forth. In the specifications documents is the information collected and built along the construction phase. From the characteristics and capacities BIM holds, the information can be inserted in the object, becoming then a part of the entire project (Eastman et *al.*, 2011). This will then play a very important role when the needs for maintenance, and replacing materials, by giving the real conditions of the space to work and possible needed manoeuvres.

Table 4.2 - BIM application and advantages along the project lifecycle for the main participants in the construction project (adapted from Azhar et *al.*, 2012).

BIM Application	Owners	Designers	Constructors	Facility Managers
Visualizing	X	X	X	X
Analysing Options	X	X	X	
Analysing Sustainability	X	X		
Quantity Surveying		X	X	
Estimating Costs	X	X	X	
Site Logistics and Planning	X		X	
Scheduling and Planning	X	X	X	
Phasing		X	X	
Analysing Constructability		X	X	
Analysing Building Performance	X	X	X	X
Building Management	X			X

As a resume, the advantages of BIM into the construction industry, for all the main participants involved in the project, can be seen in presented by Azhar et *al.* (2010).

4.4.4 Disadvantages

The 3D modelling is an old concept and idea which has already been through several studies and stages, as it will be shown in section 4.5 when presenting BIM's history. The idea for working with 3D models emerged mainly from the mechanical engineering. Thus, in the construction sector, BIM and its availability in IT market it is a new concept and approach. The status of being a new system, tool, etc., somehow, deters the possible users to trying and implementing it. The author remembers by experience when the legislation for public contracts changed, many were the persons connected to the construction who didn't saw and accepted these changes very well. A large amount of workshops for clarifying the new introductions in the legislation were conduced by the professionals. And despite all the efforts made, many were those who showed not much adapted to the changes done. This situation can get even bigger proportions if a whole company needs to change their working systems, IT tools and software, internal organizations and procedures, and so forth. It becomes easy to understand some resistance from the organizations to these changes.

The problem with implementing BIM in an organization is the need for training and specialized manpower to operate with this approach. Beside the costs related with the acquisition for the needed tools, there is the need for training personal and keeping it actualized. This question might be more determinant along the small and micro enterprises which will have to pass almost for the same process then the larger enterprises. The author can refer to a similar experience, by having problems with some subcontractors due to not having/using AutoCAD. This last opinion is also shared by Lahdou and Zetterman (2011), by stating that, "there are also many small enterprises which do not have the economy to invest in new technology." Still related with the participants, in Infocomm (www.infocomm.org, seen in 13/05/2014) mention is also made for the problem with the costs, either related with the software and respective equipment, as with training staff for working with it.

Once BIM is an approach based in the information transfer and collaboration along the project lifecycle, one problem arises related with information protection and copyrights. When using CAD files or pdf files for sharing and transmitting information, no big problems come up related with information or copyrights. In these type of files there are no big secrets contained into the documents, most especially within the pdf files.

Another situation may appear regarding to information introduction or changes during the project lifecycle. Azhar et *al.* (2008) approaches this problem by mentioning the "legal risk to determine" BIM's data ownership "and how to protect it through copyright laws". Azhar et *al.* (2008) gives the example of owner's right in having the rights of ownership for the documents and information that constitutes the project.

Through the literature read, it was found that, there is still some incompatibilities between software manufacturers. This might lead to problems within the connection and linkage of the models between the organizations involved in the project. This is also highlighted by Lahdou and Zetterman (2011) when they refer to the loss of information through the files conversion process. Also Khöler (2008), in Lahdou and Zetterman (2011) recalls to the "problems with the implementation of BIM ... with transfer of data between software." Infocomm (www.infocomm.org, seen in 13/05/2014), refers to this problem as "one of the biggest issues ... the issue of inter-product compatibility".

The question for the innovation is also raised by Infocomm (www.infocomm.org, seen in 13/05/2014). The question arises from the use of "pre-manufactured" models, and until where these system will not get into a vicious cycle. Infocomm (www.infocomm.org, seen in 13/05/2014) refers to the "potential to inhibit innovation which would possibly otherwise occur without the automated processes and shared knowledge that BIM now provides".

These mentioned disadvantages, beside the innovation question, are more barriers for the first big step of implementing BIM into the construction industry. Many of them will vanish over the time. However, the problem related with the innovation might tend to increase. Looking for instance through the problem for starting and adapting to new methods. Believing that, when having an idea, concept, methodology, process somehow automated becomes sometimes hard to change for a new concept or procedure. Thus, with the time, the new concept starts being a habit, becoming then a natural procedure and process. The disadvantage related with the costs, also can be solved over the time. The first products coming into the market tend always to be more expensive, due to the first investments also made by the manufacturers. Then, with the time, the manufacturing systems are already implement, the costs for the manufacturers will be mostly the maintenance. Thus, the costs for the products also will decrease. The amount of persons with know-how about the topic also increases. With the increasing number of experts, also the costs for training becomes lower. The problems related with the compatibility will probably be the biggest challenge. These problems for instance, still can be seen nowadays into quite old software and still not being solved. So, this will be a main issue for BIM as well.

4.5 BIM History

Since its first appearance, BIM has gone through several phases as his assertion in the construction sector until the present days. However, from the literature read and the experience the author acquired along this thesis, BIM's implementation and use is growing and getting its affirmation into the market. It seems that BIM is becoming more and more a fundamental tool for the professionals in the construction industry which can bring great benefits to the sector. In this section will be presented BIM's history, roots and its evolution. Also, the first design processes and first software used in the construction projects will be also approached.

According to Eastman (1999), the first attempts for starting building models arisen in the UK, then in Scotland and lately in the USA. In the UK, as Eastman (1999) presents, "the early building modelling systems were founded by Her Majesty's Health Service". Following is presented the timeline of the events for the CAD technology development, according to Eastman (1999):

- In the UK, the development of first CAD system, OXSYS, started in the 1960s, by the Cambridge CAD Centre. Later on, in 1970, the Applied Research of Cambridge (ARC) was founded with the purpose of commercializing this CAD system;
- The Scottish researchers started their work in the year of 1969 extending up to 1973;
- The "early building models" were developed in the USA "during the 1970s and early 1980", by the CAD-Graphics Laboratory. In 1974, was developed the "solid-modelling-based, building model with permanent store", the Building Description System. In 1977, "an interpretative language with built-in solid modelling capabilities with permanent storage of global variables", the GLIDE was developed. This system gave the origin into the GLIDE-II , developed by the US Army Corps of Engineers.

It is from common knowledge that the first drawings used in the construction sector were handmade. Yan and Damian (2008) and Jackson (2010) refers to this old method by presenting that, the first way of making draws, models and designing projects was resorting to the use of pen, pencil, eraser and paper. No (IT) resources were available in that time, thus, everything was done manually. However, at that time, the pen, pencil, paper and eraser were the only available resources. The process of using the mentioned tools was of a huge demand of manpower. The designing and drawing for the project elements was also very time consuming and the demanded efforts where incredibly large, as mentioned by Jackson (2010). The execution tasks for drawing the plan pieces of the project (presented in 3.5.4) were very meticulous and nitpicking. A small distraction, hand shaking or even a sneeze could throw all the work done to lose. The author had an experience when started his studies in Civil Engineering in the year of 1999 with a project of a small single family house, needed the blueprints to be handmade. The used tools were tracing paper, Indian ink drawing pens, pencil, normal pens, eraser, etc. The work was very time consuming, and many were the times when a small mistake or distraction threw all the work of hours or days to lose. Jackson (2010) refers to this example by mentioning that for the attention when designing a project, in the manpower needed, when changes were required, producing great amounts of waste and being very easily subject to errors.

With the development from the IT, also the construction software started being developed. Eastman (1999) makes reference to the first computer applications used for engineering purposes dated from the mids-50s. Also at that time it was possible to produce drawings by using computers, as Eastman (1999) mentions. This according to this same author, the drawings consisted "of a list of line segments, defined as pairs of X-Y location coordinates". Jackson (2010) refers back to the early 70's, after the Second World War (Yan and Damian, 2008), when CAD technology was introduced in the market through SCKETCHPAD. The great appearance and affirmation for CAD, was from the availability of the "pixel-based bitmap displays" a Eastman (1999) presents. However, it has only started emerging in the early 80's with the first CAD software running into the personal computers, as mentioned in Eastman (1999) and Jackson (2010). As the CAD immediately appeared, soon started the research, between the years of 1970 and 1975, for achieving more features, possibilities and capabilities from CAD technology, as Eastman (1999) presents. So, the features introduced in CAD technology were the symbols, the layers, "user application languages, associative cross-hatching and associative dimensioning, 3D wireframe and surface modelling" and afterwards, the "integrated rendering models and parametric solid modelling".

The introduction of the IT in the construction sector came with a significant help to the professionals. But, as presented in Eastman (1999), in the beginning of CAD's life, there were no distinction between the engineering specialities for the existing software. So, in the IT sector appeared the need for doing specific products for the different specialities. With the use of IT, most of the problems were solved and others were somewhat attenuated (Jackson, 2010). Beside the help the construction software brought in the designing processes, Jackson (2010) also refers for the improvements in the projects quality. Thus, as a result of using these "new" technologies, the time and resources needed start decreasing. Also, with the software, Jackson (2010) calls the attention for becoming possible making more efficient corrections by not needing to start the whole project from the very beginning. The whole process of design a project became faster, with improved quality and less demand of manpower. The surfaces modelling concept was first developed by Steven Coons in 1966 (Eastman, 1999). Also, as mention in Eastman (1999), Pierre Bezier developed techniques for surface modelling, these being his concept still used nowadays. With the development of these surface modelling techniques, says Eastman (1999), CAD's objective was in following it's path, once it was the purpose of representing the objects designed, instead the objects drawn. The 3D objects also became a reality with the evolution of the technology. The first needs for the 3D objects have emerged from the aircraft and automobile industries (Eastman, 1999). These industries have a great demand for visualising the objects, more than looking through 2D drawings. So, "in the late 1970s, 3D wireframe drawings were introduced into general-purpose CAD systems as an early 3D capability" Eastman (1999). The affirmation for the solids and surface modelling was from the mid-80s, even though it's availability in the market started in late70s, as Eastman (1999) presents in his book. From this 3D feature also has become possible the simulation of visiting views inside and outside the model, as Jackson (2010) states. Yan and Damian (2008) mention that the step from the 2D CAD to 3D modelling leaded to "a change in the relationship between the structural engineer and the architectural designer". With the 3D models came the possibility of simulating the project close to the reality. This "new" concept changed the way for visualising the designed buildings.

But although all these "wonderful" capacities, still something was missing. Even though the design process became much easier and faster when compared to the epoch of ruler, square, paper and pen, the corrections and changes were still very time consuming, eespecially for big projects. The 3D object were noting more than that, no information was available as well as the possibility for adapting to their "surrounding environment". Eastman (1999) in his book mentions the new "technological challenge" was "to develop a digital representation of a building project that can first be used for feasibility, then design, then fabrication, and then operations and maintenance". The previous mentioned phases are related to the way Eastman (1999) defines the project lifecycle (Figure 4.13). Thus, with his statement, Eastman (1999) calls already the attention for the need for an approach which allows the flow of information along the entire project lifecycle. Jackson (2010) refers to the needs for the capacity for automatically updating along all the models, objects and views of the project due to changes in one of the models. It is at this point BIM stands, by using intelligent objects containing all information about their role, what they are, their meaning and what they represent. In BIM the objects "know" the way they interact between themselves, can carry the costs, and so on, allowing the objects adjusting to new scenarios due to needed changes.

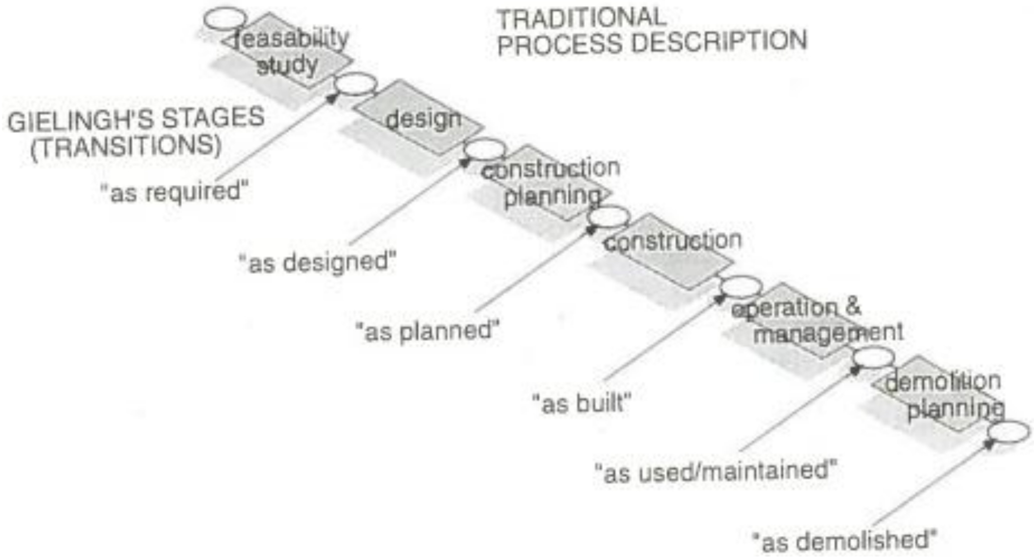


Figure 4.13 - Project lifecycle according to Eastman (1999).

Jackson (2010) states that "the construction benefits are so great that many contractors are opting to use BIM even if architects and engineers they are working with are still delivering the design in a 2D CAD format". From the previous statement comes out the conclusion that contractors first started seeing this approach as a powerful tool for solving their problems, and the investments needed for implementing BIM in their companies leaded to a profitable solution. But, although these previous words from Jackson (2010) and all the advantages mentioned, BIM had encountered enormous barriers to its real affirmation in the construction sector.

From Popov et *al.* (2008) arises the idea that, in 2008 BIM was completely accepted and implemented when these authors states that "building information modelling and process simulation has evolved to a fully accepted and widely used tool for project life cycle management". Yet, this idea is not shared by Yan and Damian (2008) which produced a study about BIM getting into the construction sector.

From their study, Yan and Damian (2008), found out that, the expenses, time consumption and human recourses allocation for implementing BIM would lead to larger costs. Few years ago, in 2008, the scenario about BIM's acceptance in the construction sector in USA and UK, was very bad. From the study done by Yan and Damian (2008), the results were that, less the 50% of the companies were using BIM, being the majority from USA. From a questionnaire done, Yan and Damian (2008) found out that, around 24% of the persons approached didn't even knew about BIM, having 31% only a small knowledge about this approach. The study also revealed that, only 13% showed some knowledge about BIM, but none presented as being an expert.

From a year later study, Suermann and Issa (2009) found out that, the situation about BIM implementation and usage in the USA was still quite far of being an option. From their study, Suermann and Issa (2009) make mention to "16% of the firms surveyed had acquired BIM software and that only 10% of the firms were using the software". From this study, the percentage of enterprises using BIM comes too much bellow than the 50% limit presented by Yan and Damian (2008).

Recently, in UK, the government created a program for implementing BIM in their construction sector. This initiative was taken based on their beliefs for the profits this sector can achieve and as an alternative and solution for facing the recent economical crisis. As already mentioned in the Introduction, and also in Graça (2010) and Graça et *al.* (2012), with the economical crisis starting in the end-2008/beginning-2009 the construction sector has suffered many "damages". The demands for a higher quality in the projects, the strong concurrence inside the construction sector, the lack of contracts and money for investment, led to a crushing prices by contractors. This situation dragged many companies to opening bankruptcy being in some cases these companies forced to close. The previous statement can be reinforced by what the HM Government (2012) presents, for instance.

The program for implementing BIM in UK, stems from the recognition from the UK government for the importance the construction sector ("which procures around 30% of the industry's output" in (UK HM government, 2012)) represents in the economy of a country. Based on economical crisis scenario, the UK government saw on BIM a potential tool to contribute for the development of the country as well as for the economy growth. "*This capability assessment sets out the actions that government and industry will take to create opportunities for the UK construction sector by becoming a world leader in Building Information Modelling (BIM). We will build on the considerable progress already made in embedding BIM into the domestic sector*" (UK HM government, 2012)). To face the actual crisis and help within the country development, the Chief Executiv Officer for the Construction Industry Council in UK, Graham Watts refers to BIM as a tool with of a great importance as following transcript from HM government (2012):

"BIM will integrate the construction process and, therefore, the construction industry. But it will also have many additional benefits for the nation. It will enable intelligent decisions about construction methodology, safer working arrangements, greater energy efficiency leading to carbon reductions and a critical focus on the whole life performance of facilities (or assets)"

According to HM government (2012), good news for BIM's definitely affirmation in the construction sector are arising in the present, although the mentioned disadvantages and barriers in subsection 4.4.4. It seems companies and countries are starting looking to BIM as the best solution for their problems and beginning the process of implementing this technology. Some of the governments started inclusive supporting the companies in the process, as for example for UK and China (HM government, 2012). In HM government (2012) the following statements can be found related to BIM's implementation:

"our long term ambition is to be a global leader in the exploitation of this technology and increasingly as a supplier of BIM services and software by developing the UK's capability in this area"

"BIM will be the future IT solution in China; the Chinese Government is strongly supporting BIM"

The first statement comes from the UK government, which gives the example of the Manchester City Council being already using BIM. The second statement is from Tsinghua University, Beijing.

In UK, the actual perspective from the Government about BIM is such positive, that they are trying all the efforts to expand the use of BIM. In order to promote, help and facilitated the implementation, usage, progress and know-how of BIM, the UK Government together with Salford University and HOK Architects started a program for all the stakeholders in the construction sector, can be found in HM government (2012). Actually BIM is already being well recognized for its potentialities in Europe, starting having a strong position and recognition as the future solution for growth and competitiveness (HM government, 2012).

Following are presented some testimonials from companies or stakeholders already using BIM:

- "The BIM process has helped us clearly identify client and project objectives and improve risk management at the outset of major programmes and projects both in the UK and abroad. Without BIM we would not have been so competitive in our international markets ... Without BIM processes this would not have been identified pre-construction and would not have given our client a high quality product that met his operational requirements" from the Director for Pre-construction, Engineering & Design of Mace, Phil Brown in HM government (2012);
- "Building Information Modelling (BIM) is about more than creating models. It is about unlocking knowledge and insight, creating the platform for more efficient and sustainable solutions. ... BIM is helping to drive a step-change in the increased productivity of the construction process, tangible quality improvements in the end product and the associated reduction in true costs. It promotes greater collaboration and more informed decision-making within unified delivery teams, while allowing the supply chain to see beyond their own activities to a more holistic view of the client’s objectives. Equally important, BIM also acts as a valuable communication tool by bringing the project to life in a virtual world for clients and the workforce", from Ray O'Rourke, the Chairman and Chief Executive of Laing O'Rourke in HM government (2012).

As a brief resume about BIM's history and its evolution until close to the year of 2000, in Figure 4.14 is shown a resume given by Eastman (1999).

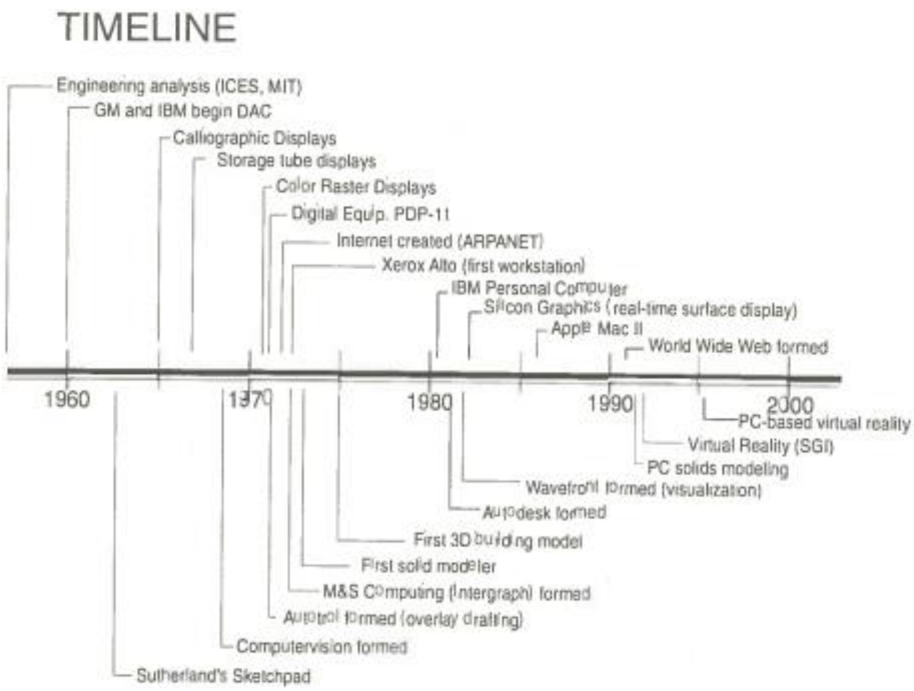


Figure 4.14 - BIM's history and evolution (Eastman, 1999).

4.6 Some Real Examples and Case Studies of BIM usage

Here will be presented some examples and case studies found along the read literature, but only the results and achievements associated to the name of the project will be presented, being left out the details related with the projects. The presentation will be subdivided into the stages of the project lifecycle, according to what was presented into subsection 3.5.2 Project lifecycle.

4.6.1 Design stage

Azhar et *al.* (2008) presents the following two case studies:

- The Hilton Aquarium project in Atlanta, Georgia; where the model was composed by the architectural, structural and MEP models. In this project where detected 590 conflicts between the structural and MEP (Figure 4.15 a)), being these possible of solving before installing "*in situ*". The design coordination was improved, additional costs where improved, the owner was able to keep on revisions and the changes where easy and effective. So, from this there was possible to save around $200.000 and avoid delays in the project due to the early detection of conflicts and problems solving.
- The One Island East Project in Hong Kong; where before the bidding and construction phase, BIM allowed detection of around 2000 clashes and errors (Figure 4.15 b)).

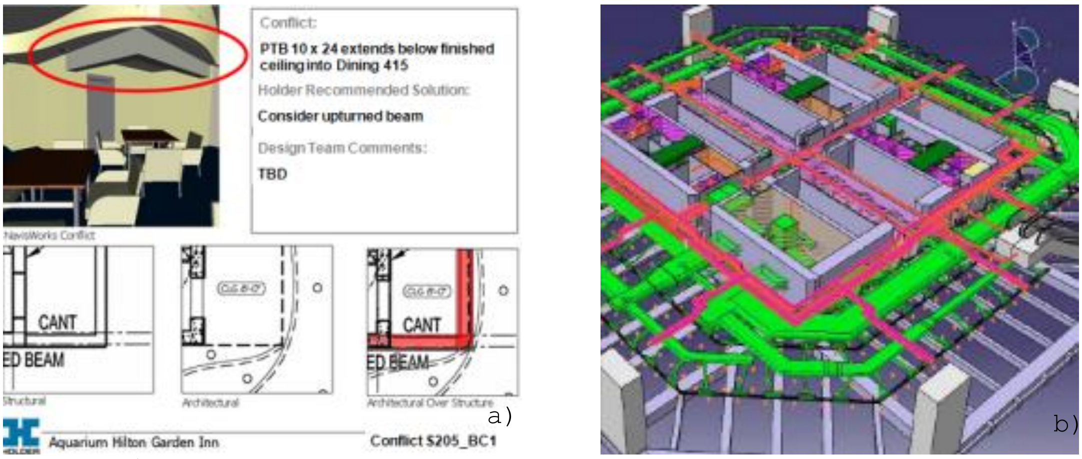


Figure 4.15 - Case studies: a) Hilton Aquarium, Atlanta, Georgia: "Example of Design Conflict Log" and b) One Island East Project, Hong Kong " Automated Clash Detections" (adapted from Azhar et *al.*, 2008)

Azhar et *al.* (2012) presents an example of coordination between the owner, the contractor and the architect for an education facility project. As described by Azhar et *al.* (2012), the collaboration between the mentioned parties occurred "at the schematic design phase to prepare building information models of three different design options". The idea behind this case study is related with the study for the costs within the design stage. So, the three models were prepared with three cost scenarios (Azhar et al., 2012). As it is described by Azhar et *al.* (2012), this was made in two weeks, being the owner able to save around $1,995,000 only when selecting the facility into the "schematic design". The resume of this study is shown in Figure 4.16, taken from Azhar et *al.* (2012).

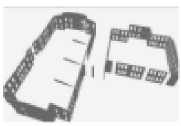
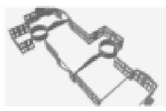
Aspect	Owner's Requirements	Option A	Option B	Option C
Front Elevation		 Option A	 Option B	 Option C
Plan				
Stories	Not specified	2	2	3
Cost Scenarios				
Budget: $147.74/sf	$11,000,000	$12,897,111	$12,270,919	$10,910,894
Mid-Range: $175.00/sf	$13,030,325	$15,276,800	$14,535,140	$12,924,100
High-Range: $200.00/sf	$14,891,800	$17,459,200	$16,611,600	$14,770,400

Figure 4.16 - Study for the costs of a educational facility in the design phase (Azhar et *al.*, 2012).

4.6.2 Construction stage

In the construction phase, the model(s) created along the design stage can play a very important role. This is shown by Azhar et *al.* (2012) in the case study based on the construction of the Wellness Center Building for the Auburn University. The idea for this case study was to see the "use of BIM for safety planning and management" (Azhar et *al.*, 2012). Based on the coordination between the main participants in the project was possible of identifying the site hazards and prepare the mitigation plans and actions. The process was made through 4D animations and simulations, as shown in Figure 4.17, being the feedback from the intervenients in the construction site by considering this as a great tool, according to the statement from Azhar et al. (2012).

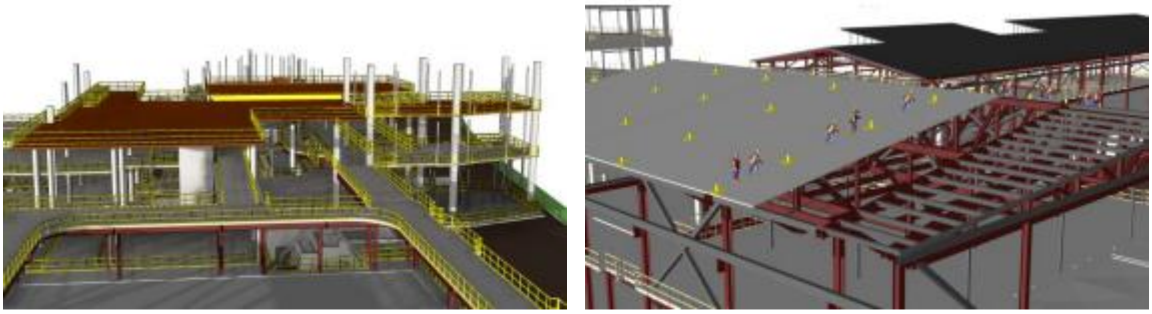


Figure 4.17 - Fall protection simulation: a) of "railings" and b) "for roof workers" (Azhar et *al.* 2012[a], in Azhar et *al.* 2012).

Other example given by Azhar et *al.* (2012), is using the case study for a project of an academic building for the Emory University. In this example, the study done by Azhar et *al.* (2012) has the intention of using the feature for clash detection by the contractor, to minimize the design errors. As Azhar et *al.* (2012), refers, the contactor received the drawings for the structure and MEP systems in 2D. Thus, these plans needed to be converted into 3D models by using BIM approach. Then, through the clash detection feature (shown in 4.3.2) it was possible to see the existing errors within the different parts of the project. According to what is described by Azhar et *al.* (2012), the contractor managed to save around $259,00 (Figure 4.1).

Item	# Of Collisions	Estimated Cost Avoided	Estimated Crew Hours		Coordination Date
Construction (MEP/ Structure Collisions)					
Basement	9	$2,041	5.5	hrs	*December 12, 2007*
Level 1	107	$93,050	188	hrs	*April 14, 2008*
Level 2	43	$41,913	87	hrs	*February 14, 2008*
Level 3	78	$61,070	132	hrs	*May 12, 2008*
Level 4	65	$33,525	77	hrs	*February 29, 2008*
Level 5	87	$78,543	164	hrs	*April 22, 2008*
Penthouse	25	$25,684	52	hrs	*May 12, 2008*
Subtotal Construction Labor	414	$335,826	705.5	hrs	
15% Material Factor		$50,374			
Subtotal Cost Avoidance		$386,200			
Deduct 33% assumed resolved via conventional methods		($127,447)			
Approximate Cost Avoidance		**$258,753**			

Figure 4.18 - Savings from the implementation of BIM into the construction process (adapted from Azhar et *al.*, 2012).

4.6.3 Maintenance stage

Sabol (2008) presents a case study where BIM was used into the facility management of a very known and famous building, the Sydney Opera House (SOH) (Figure 4.19 - Sydney Opera House (Hendseth, 2012 (seen in 14/05/2014)).Figure 4.19). The building according to what Sabol (2008) mentions, was started in 1958 and totally completed in 1973. The project winning the design contest was made by Jørn Utzon, a Danish architect (Commonwealth of Australia (2006), p.21 (see Appendix A.2 b)) and Sydney Opera House, 2014 (seen in 14/05/2014)).

From what was presented in section 4.5, all the documents related with the project for this building were handmade through the traditional methods. In Figure 4.20 can be seen an example for the SOH handmade blueprint. According to Sabol (2008) the original documents for the building were according to the final building. "In the late 1980s", the first CAD files were created, although, these files were "unreliable and uncoordinated" (Sabol, 2008). Since "the building has reached milestone age in terms of condition and maintainability" as Sabol (2008) states, there were a demand for interventions. It is in this context for the facility management, BIM played a very important role. This way, as presented in Sabol (2008), "SOH developed a building information model to be used for the full lifecycle management of the facility". In this model, there were inserted all the information about the "amounts of service, maintenance and cost" (Sabol, 2008). The model also contains the information about the objects of that form the building, "such as lifts, ventilation and fire systems, and the relationship between them" (Sabol, 2008). There were created also independent models for the specialities, as Sabol (2008) presents, such for example the architectural, structural, electrical, mechanical models. In Figure 4.21 is shown an example taken from Sabol (2008) of the structural model and the architectural model done in Bentley Structural and ArchiCAD respectively.

Figure 4.19 - Sydney Opera House (Hendseth, 2012 (seen in 14/05/2014)).

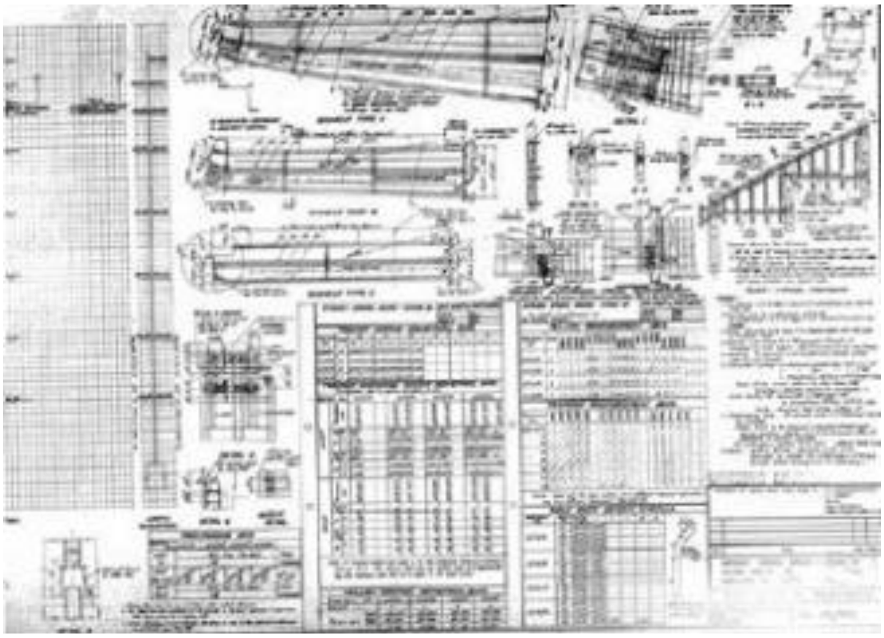


Figure 4.20 - "SOD Construction Drawing" (Sabol, 2008).

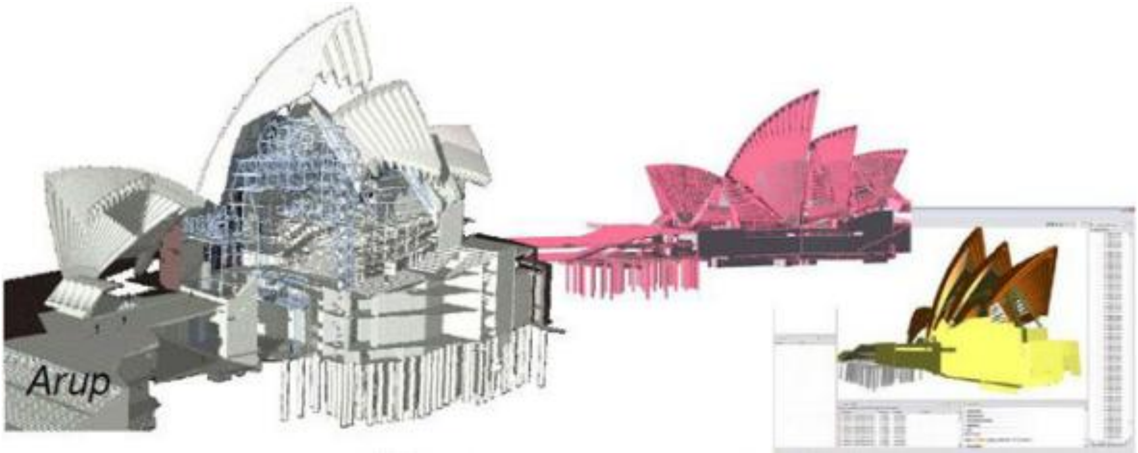


Figure 4.21 - Example for the structural and architectural model for the SOH (Sabol, 2008).

4.7 Summary

BIM brings to the construction industry, a new alternative for the used conventional methods. BIM is a new approach which allows modelling in 3D. From the 3D models, can be done simulations for the construction process. If adding the variable time to the 3D models, a 4D simulation can be performed by showing the progress of the construction works with the time. To this 4D simulation can be added the costs as well. Thus, simulation for the costs with the time and the progress of the works can be done.

With BIM, the changes in the project are easy to update, due to the capacity of the objects in carrying the information with them. BIM also enables the collaborative work, making easy the process of information sharing.

Making an overview regarding the advantages of BIM. It can transport, transfer and store all the information of the project. BIM can bring significant savings into the project. For the design stage, it enables simulating the objects in their environment with their real properties. Due to its parametric modelling , the changes are done automatically for the entire project. BIM enables having a first impression about the feasibility of the project, through simulation in before starting the design of the project. Using a 3D model, it is possible to have an overall view of the project. In the construction stage, it gives the possibility for accurate quantity take off. The clash detection feature allows the contractor to find the conflicts, failures and collisions faster. The means and methods for the construction of the project can be tested. In the maintenance stage, BIM can be useful by carrying all the information related with the project.

BIM has the disadvantages of incompatibilities between the software from different manufacturers. Also, possible problems due to copyright may be found when using BIM, as well as the question about who owns the models. The innovation may be compromised due to using pre-manufacturing models.

The first attempts for starting being building models was in 1960s. But it was around the end of the 70s or beginning of the 80s, when BIM started being developed. Thus, the first tries for implementing it were only recently in mid-2000s. In the literature, the great emergence of information about BIM is dated from around 2005. In 2008 there was still some scepticism to this approach. However it seems that, since 2011/2012 is conquering adherents and beginning to settle in the construction market.

5 BIM Technology in Project Management and Construction Management

In this chapter will be presented the study and analysis to the problems serving as base for this thesis. The analysis about managing the projects, inside the whole organization will be done. After, the project which served as base for this study will be presented. A small introduction about the project and it's choice is shown, followed by a presentation of the features for infrastructure projects. After the project's features are presented. Before going into the analysis of the problem, is made an introduction about some available tools in the market. The models and their features are also presented. In the analysis of the problem, will be presented the adaptations needed inside the contractors organizations for implementing BIM. The approaches to the project by the contractor will be analysed through the delivery methods and contract types. After all the construction stage will be studied, by looking into the problems and presenting some possible solutions. In the construction stage the information sharing and transference will be analysed. Also the implementation on BIM for infrastructure projects inside the contractors will be studied.

5.1 Introduction

The project can be seen as a set of information put together. The compilation of this information starts being built when choosing the delivery method. Along the project lifecycle, the information flows through the stakeholders involved in the project. This flow is made through the stages constituting the process in which the project is involved. As seen in subsection 3.5.4, the project is constituted by several documents containing the information needed for the three stages of the project lifecycle. In the project lifecycle, the information that make up the project is subject to changes, replacements, or even become outdated. Thus, it is important to keep the information of the project clean, updated, available and to avoid losses. It is crucial and of extreme importance for achieving the goals of the project, that no loses of information will occur along the project lifecycle. Also, lack of communication or deficient information introduced in the project can lead to misinterpretations and errors. From these misinterpretations and errors, the goals of the project may not be achieved, as well as the goals of the organizations involved in the project.

In the contractor organization, the project, and so the information, goes through two main phases. The transition from the estimating process to the construction process, and when the construction process is completed to the files.

When the contractor makes the decision to present a bid for the construction of the project. This, as seen previously in 3.5.6, is the first contact the contractor has with the project. After the decision of the owner for awarding the project to the contractor, begins the second main phase, the construction process. Thus, the bridge between these two phases plays a very important role to fulfil the goals of the contractor for the project. After finishing the construction of the project, the bridge between the conclusion of the project and a new estimating process should be made. The importance this step can have inside the construction company, is in the preparation for future projects.

Along the construction stage, the project has to pass through several phases. In these phases, information is also added to the project. So, inside the contractor organization, the project undergo through several processes of analysis, changes and updates. In some manner, information is added to the project. The added information can be for delivering to the owner, together will all the other documents. This information added can be as well, internal information, for control and monitoring the project.

With the introduction of BIM in the construction sector, the companies organization and structure will need to undergo some changes for adapting to this new reality.

In this chapter, will be presented the management of the project inside the contractor organization. The main focus will be given to using BIM in infrastructure projects and how BIM can be used from the contractor for information sharing and transference. The infrastructure projects are projects with very specific characteristics. The variables and the constraints of such projects although general, can become very specific for each different project. Also, when comparing infrastructure projects to construction building projects, the way the variables and constraints affect these two type of projects can be very different. Thus, for infrastructure projects there is a very limited amount of information available. Due to this limitation of information, along the presentation will be taken as base for comparison building construction projects. Then, from the knowledge and experience acquired from the building construction projects types, will be made the analysis for infrastructure projects.

When presenting and referring to the infrastructures projects along this chapter, the reader should be aware that industrial projects are not included. Unless they are explicit mentioned an used as an example. As mentioned into 3.5.1, these projects can be considered as a special case for the projects into the infrastructures type. For this reason they will need to be analysed independently. However, for some specific projects, the analysis done here, with the right adaptations, may be valid. One example can be given for a project of a plant where the buildings and a great extension of pipelines forms the project.

5.2 Managing the Project

Since the moment the contractor makes the decision for presenting a bid to the project, the project needs to be managed by the contractor. Said this way, might seems a little confusing once there is the possibility for the contractor not getting the job. However, it is in this first contact with the project, when estimating for tendering, that many decisions need to be taken. If the contractor will get the job to be done, the final results from the construction of the project, can be highly influenced by the approach taken when estimating the project. When estimating the project, the goals of the contractor organization are taken into account. The goals for the organization can be split into the goals for the organization and the goals for the project. Following the meaning for the goals of the contractor and the goals for the project will be presented.

The goals for the contractor organization can be as follows:

- The profit achieved from the projects constructed;
- Clients portfolio management;
- Projects portfolio management.

The decision of estimating can be taken based on these three presented goals. However, one or two of these goals might not be fulfilled when estimating. An example can be the case of a presenting a bid bellow the profit goals of the company to keep a specific client and/or type of project. It can also happens, the bid be over the profit, to keep the client even though the project is not much of interest.

When coming to the construction process itself, beside needing to be managed the goals already mentioned, will be also needed to be taken into account the goals considered for the project when estimating it. For instance, it can happen the project has been estimated for achieving higher profit then the considered by the organization.

So, when managing the project from the contractor organization side, there are two crucial moments for the success on achieving the goals. When estimating the project for tendering and when transferring the project for the construction team. In the transition of the project from the estimating process to the construction process is where most of the losses occur. Notice that, by loses, the author is referring to the losses resulting from a bad estimation and to the information lost due to not being transferred and shared between these two process. Thus, loses can also occur due to a bad control and monitoring, even though the estimation was very accurate. However, this situation will be more related with the construction process management itself. A third point can be also considered when closing the project after its conclusion. Preparing some good reports may prove to be crucial in future estimations and monitoring and control for new upcoming projects. These reports should contain for example, all the information about the productivity, which external factors interfered in the construction process, how were they overcome and so forth. These reports may reveal to have an extreme importance in the future, bringing the possibility for the contractor being more competitive and presenting more accurate bids.

The reference to this management of the project is not related with the concept of project management presented in 3.2. The concept here for management is related to how the project is handled and conduced in the overall perspective of the contractor organization to meet the contractor interests as whole. However, the concepts presented in 3.2 are implicit into the estimating phase and the construction phase.

The construction stage, as presented in 3.5.2, is considered since the moment the contractor have access to the project for tendering, until the moment the project is finished and handled to the owner. On this stage, the project has a linear progress through its phases (Figure 5.1). As it can be seen from Figure 5.1, the project gets into the construction stage through the bidding phase and leaves the construction stage when being handled to the owner.

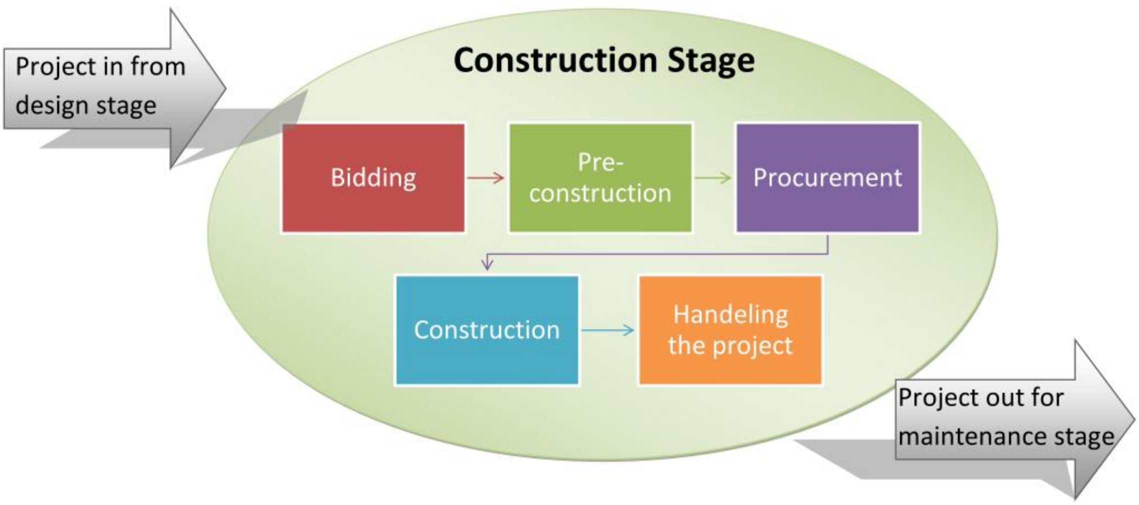


Figure 5.1 - Project flow in the construction stage.

Even though the project is a linear continuous flow, inside the contractor organization, the project should be seen as a "cycle" (Figure 5.2). This cycle is not for "the specific" project, but for the information contained inside the project(s). Besides the information contained in the project from the design stage, the contractor, when working (with) the project also adds information. As presented in Figure 5.2, the project follows its normal path until being handled. Thus when being handled, all the information gathered by the contractor should be reported to the beginning of the cycle. The information added has two purposes, the information for internal use and the information for the client. The information for the client is all the information which follows with the project when handled. This information can be for example changes in the project that occurred during the construction of the facility(ies). The internal information is what will be added by the several phases inside the construction stage. For instance, when estimating, considerations are taken, prices are given and so on, from the pre-construction phase are all the considerations about the preparation and planning and so forth. The internal information can be considered as being the information for managing the project along the construction stage. The external information, can be considered by construction information, since this one will give the information about the real construction of the facility(ies). The information flow through the construction stage is shown into Figure 5.3.

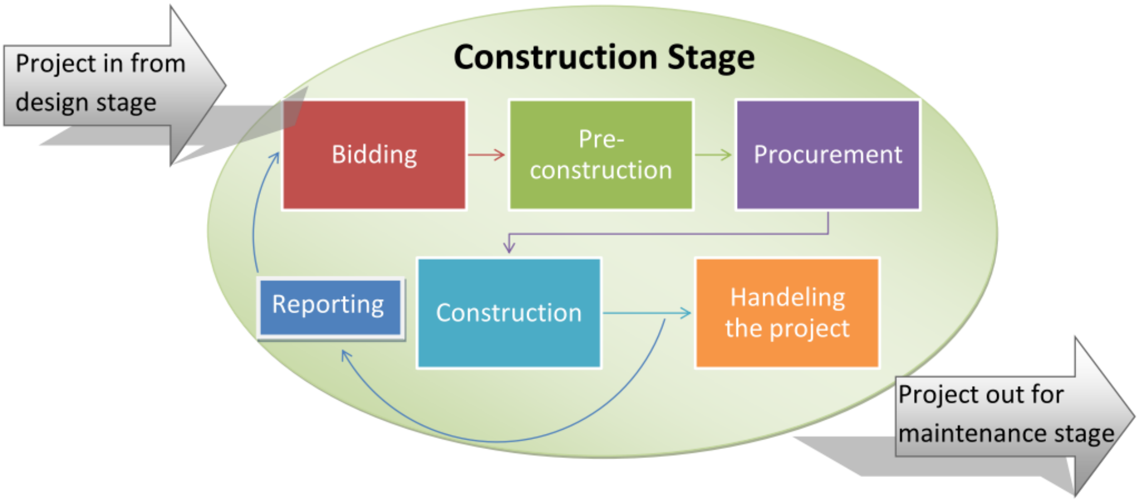


Figure 5.2 - Project cycle inside contractor organization.

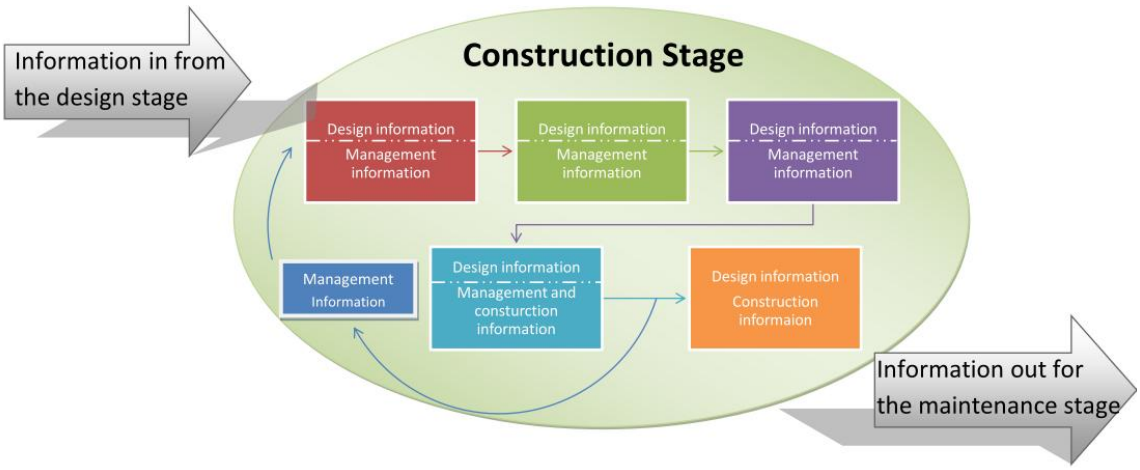


Figure 5.3 - Information flow inside the construction stage.

5.3 A real life example

5.3.1 Introduction

For supporting the analysis presented in this chapter, the author decided to use a project he worked with. The main reasons taken into consideration for choosing this project were:

- Being an infrastructure project;
- The works that constituted the project;
- The characteristics of the project;
- The possibility of giving a wide range of examples of work tasks;

The choice of an infrastructure project, was to meet the goal set, for analysing the applicability of BIM in these type of projects. The information available about BIM in infrastructure projects is very limited. The great majority of information available about BIM, is more focused for building construction projects. Infrastructure projects are also an area where the author have some experience working and feel some confidence to approach the topic. When choosing the project the author also wanted to cover as much situations as possible of being found into infrastructure projects. This can give a wider vision and perspective for what has to be taken into consideration when working in a project of this kind. Thus, for limitations of time, and since this is a first approach to the topic, only the most relevant works were taken into account. This will be better explained later on, when the project will be introduced.

When looking to the characteristics of the project, the author found interesting analysing a project which is not concentrated in a point. The idea is to see how the works can be managed in dispersed locations. Managing a project where the work tasks are dispersed can be challenging. Having different teams, with different productivities and facing different problems, can become an issue in the control and monitoring of the project. Due to these different locations, the resources needed to be carefully measured. This is important for not having the lack of resources, so some works are not possible to progress. But also, for not having excess of resources, so they will be in the site adding costs to the project. Due to these different locations, the available resources need to be adapted and distribute by the different locations of the project. So, no works will be waiting to be done. But, also there will be no teams on top of the others.

5.3.2 Presenting infrastructure projects features

Infrastructure projects, are projects which need to be handled carefully. For their characteristics, these are projects which are subjected to a wide range of factors. If looking into the characteristics and the types of works which comprise these type projects, especially the external factors will greatly influence their progress. Excavation works, asphalting, landfill, slopes, and so forth, may represent in average around ninety percent of the project. So, especially with adverse weather conditions, the productivity decreases drastically.

As presented in 3.5.9.4, infrastructure projects are projects in which the equipment and labour have the great majority for the weight in the influence of the project final results. The success of the project is almost depending on these two "elements". As seen in the "iron triangle" (3.5.9.4), these two elements are the responsible for all the three/four variables involving the project. The labour and the equipment will greatly influence the time, the costs and the quality.

The security and the environment will be affected as well, especially by the equipment.

Beside this high dependence on the labour and equipment, infrastructure projects are subjected to all the external factors. For their characteristics, all infrastructure projects are subjected to the weather factors along all the construction process. These are interferences which cannot be avoided or predicted. As well, these are constraints which have a huge influence in the progress of the works. The weather conditions can cause several delays in the works or even inhibiting the works to be executed. There are also situations where the work done is destroyed.

Other external factors, are those related with the conditions in the construction site. The soil conditions, surrounding conditions (the available space to work, the neighbouring facilities, etc...) the environmental conditions, will affect the progression of the works. Thus, again costs will be added and time consumption with low productivity will occur. However these factors can be controlled or faced easier then the weather conditions. Even thought, the overall costs (costs in its sense and time) may not be able to get totally back in track again, these can be reduced. These problems can be faced by reinforcing the construction teams, changing methodology or techniques.

Beside the mentioned external factors, also the human and equipment factor will have influence in the evolution of the works. Due to the high dependence of the equipment when performing the tasks, bad equipment, malfunctions, failures in the equipment will interfere with the progress of the works.

When handling with infrastructure projects an extra careful has to be taken. The estimation should be more accurate and done carefully. The considerations for the costs and the time need to be carefully measured and weighted. Is in this purpose, the information plays a very important role. A good quality in the information shared and transferred from the estimating department can help mitigating possible errors. The deviations can be found easier and faster, and thus, faster actions and correction measures can the taken. The same quality in the produced reports when closing the project should be considered. The information resulting from this process give a great help for estimating the future projects.

5.3.3 Presentation for the project A

In this section will be presented the project taken as base for this study. The purpose for presenting some features of the project is to fit the given examples. This will help also understanding the conceptual ideas and the to serve as foundation for analysing the problems.

The purpose of the project was to increase the water supply in a certain region. An extension for the already existing water supply system was build. This extension included three different sub-projects of pipelines. These sub-projects will be designated in this thesis as A1, A2 and A3. The distance between these sub-projects is shown in Figure 5.4. The representation in Figure 5.4, was taken with the real distance from the original location of the sub-projects. These points were transferred to random positions in Aalborg area, to help giving a better idea about the distance. The distance between A1 and A2 was around eight kilometres. A2 is spaced from A3 by around twenty eight kilometres. The main construction site where the offices for supporting the construction process were located in A2.

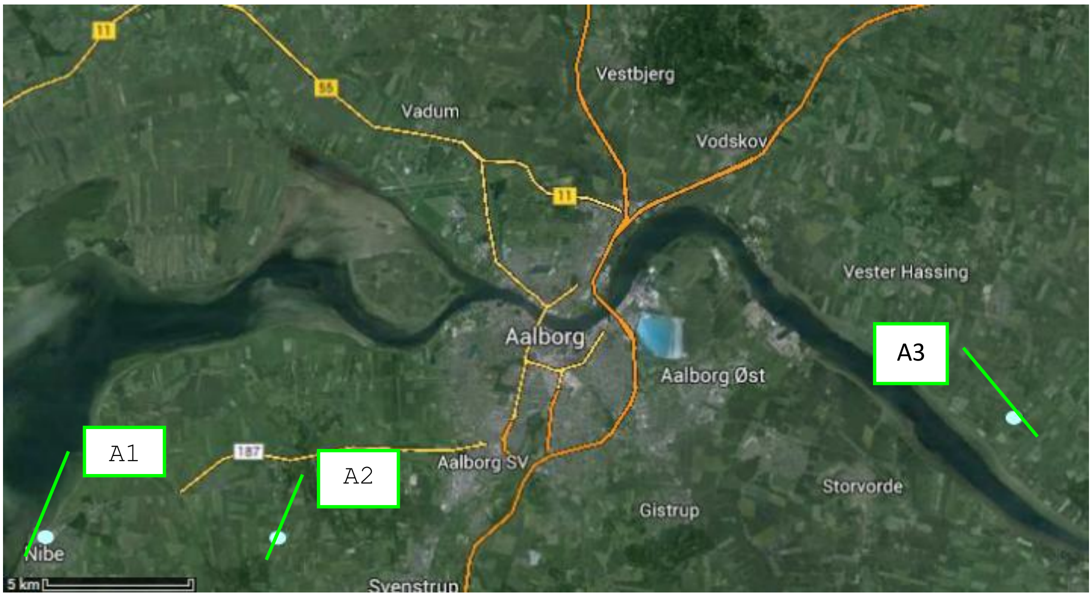


Figure 5.4 - Distance between the pipelines sub-projects A1, A2 and A3 (adapted from Google Maps).

Sub-project A1 will be the main focus of study in this chapter. In this sub-project was place a pipeline system with 800 meters of extension. Together with the pipes, were built in this sub-project a delivery station (Figure 5.5), two valves chambers (Figure 5.6) and it was placed a doghouse for air release valve (Figure 5.7). In Figure 5.8 is represented the implantation for sub-project A1. The sub-projects A2 and A3 had 3150 meters and 1070 meters.


Figure 5.5 - Delivery station.


Figure 5.6 - Valves chamber.


Figure 5.7 - Doghouse for air release valve

The project was built in joint venture by two contractors. The leading contractor was responsible for the construction works. The other contractor was a specialist in mechanical and electrical equipment. All the works related with the equipment were performed by this second contractor.

The delivery method used in this project was a DBB. The contract was done in mixed regime for type of contracts. For the construction works the contract was a unit price contract type. All the works related with the equipment and electrical installations were done under a lump sum contract type.

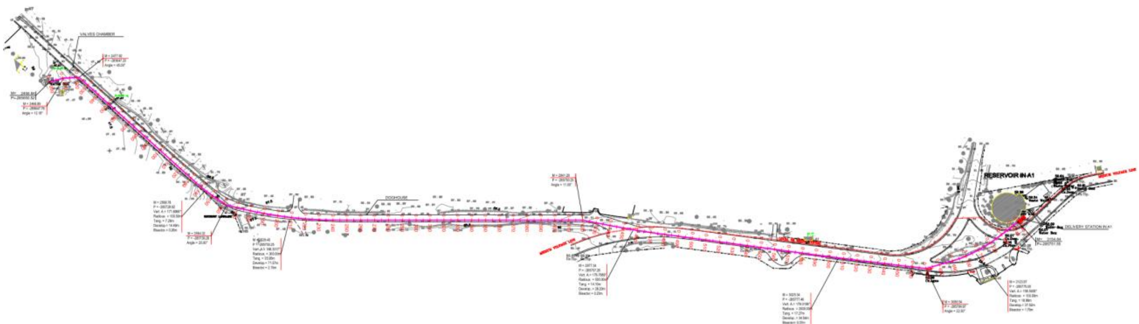


Figure 5.8 - Sub-project A1, implantation plan.

The project is categorized as being in the private sector. It is an infrastructure project type for environmental purpose.

The works involved in the project can be split into two types. For purpose of this thesis, the designation used for the type of works will be according their development. Following what was presented in subsection 3.5.1, the works will be called as "horizontal" and "vertical" works. The "horizontal" works will be all the works involved in placing the pipes. So, in the "horizontal" works are the earthworks, the pipelines, and the very small precast elements placement for water retention or water drainage. The "vertical" works will refer to all the supporting buildings for the equipment and electricity. Thus, the works were are included tasks for placing concrete, formwork, rebar work and so forth, will be considered as "vertical" works.

5.4 The Tools

The tools needed for working with infrastructure projects are in more quantity and specificity when comparing with building construction projects. Beside the difference in the way building construction projects and infrastructures projects develops, infrastructure projects may contain building construction works as well. Some examples of this two types of facilities can be seen in the project used as an example. Roads and highways also may contain similar situations. The bridges, for instance, even though their main functionality is on the horizontal, they grow into the vertical as well. Depending on their size and structure, the bridges can be analysed in the same way as a building. These features will force the contractor to have the modelling software. This software is for dealing with the works for the "vertical" and the "horizontal" facilities. Due to this double type of existing facilities, also requires specific needs for software and thus, a more quantity and variety. In this section will be presented some of the tools which can be used by the contractors. Most of the references and citations will be taken from the respective software websites. In this situation, the reference will be made in from of the first time the software is mentioned in this section. The main website will be posted between brackets after the designation of the software as for example DrawExpert (www.drawexpert.dk). In Eastman et *al.* (2011), in chapter two, sections 2.5 and 2.6, are presented the details, features and characteristics for BIM platforms. In this section, the author will make a short introduction and analysis to some of the available tools in the market.

Estimating and quantity takeoff tools

Associated to costs estimation the literature consider also the quantity takeoff software. Hardin (2009) and Eastman (2011) are two examples of this consideration. From the authors perspective, quantity takeoff can be associated either to the estimating and construction process. Quantity takeoff is also performed, when preparing, planning, scheduling and monitoring the project in the construction process.

For quantity takeoff two examples can be: Autodesk's QTO (http://usa.autodesk.com) and Vico Takeoff Manager (www.vicosoftware.com). However, REVIT and Navisworks for instance are also able to performing these tasks. Autodesk's QTO and Vico Takeoff Manager are presented by Eastman (2011) as being a specialized software for this task, being used in some specific situations. Autodesk's QTO is a takeoff tool for the models of the project. All the speciality models can be combined and the quantity takeoff done for all the specialities. Thus, the last version available to be seen in Autodesk's page, is from 2013. According to Eichenseer (2013), Autodesk stopped manufacturing this software and the potentialities of this software were introduced in Navisworks. Vico Takeoff Manager, performs a quantity takeoff from the models but also can include on it the locations. Vico Takeoff Manager allows for the users to integrate the information collected from the takeoff into the modules for estimating and scheduling.

For cost estimating some examples of software are Sigma Estimates (http://codegroup.eu/en/), Innovaya (www.innovaya.com) and Vico Estimator (www.vicosoftware.com). Looking into Sigma Estimator, the software allows creating from the beginning, estimating structures. The estimation for a task can be created from the zero point by adding all the items implicit into that task. The created task can also be reused, updated, copied and improved. This reuse can be done through previous worked projects or through libraries saved. With the libraries will be possible creating databases for the company. As presented in their webpage, "databases make it possible for the department's internal "experts" to share knowledge" (http://codegroup.eu/en/, seen in 29/05/2014). Sigma also allows for the connection between Bentley's software AECOsim and Autodesk's software Revit. This connection enables for the transference of quantities the information about the materials contained into the models. The connection between these software gives the possibility for the updates in Sigma, when made directly in the models. Sigma also allows for exporting to Microsoft Project. According to their website, Sigma can do information transferring according to shown in Figure 5.9. Also, videos about this topic are explained in the following WebPages:

- "http://codegroup.eu/en/news/revit-and-sigma-makes-it-possible-to-safely-steer-the-economy-from-idea-to-fabrication";

- "http://codegroup.eu/en/news/bentley-aecosim-and-sigma-connected-3d-to-5d-bim".

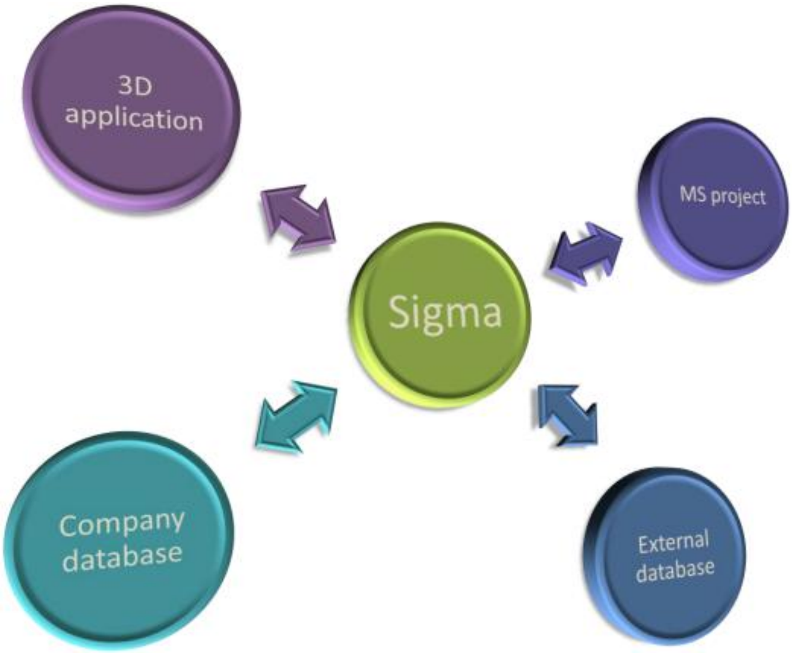


Figure 5.9 - Connections and their ways between Sigma, databases, MS Project and 3D modelling software (adapted from http://codegroup.eu).

In the presentation of these videos, it is mentioned also the transference for the hourly resources. From the author perspective, this transference cannot be done, at least with Revit and Navisworks. Revit have the chance for carrying costs information, but only a global price for the element, as it will be shown in 5.5. The same occurs with Navisworks. In Navisworks the task have the possibility for carrying the prices differentiated by materials, labour, equipment and subcontractors. But, again, these costs are the total costs for each resource type for the task. As already mentioned, for the subcontractors there is not a problem, if the prices are given by unit for the whole resources involved in the task. This perspective mentioned by the author can be seen in the demonstration videos in the following links:

- "www.youtube.com/watch?v=FM9-oAzP1Ow";
- "www.youtube.com/watch?v=aMB9_jsrXyY".

Modelling design tools

When the contractor receives the project, it can also occur, the different parts of the project being delivered into different technologies. For example the part related with the buildings project delivered into AutoCAD and the models for the infrastructures in Civil 3D. Then the contractor will need to bring them together into the Parametric Building Design technology. This is an issue which will tend to be dissipated over the time. With BIM's emergence and it's definitive implementation in the construction sector, all the parts of the project will be delivered in BIM software.

In this thesis was made the consideration, as if the contractor received the elements of the project in AutoCAD, needing then to do the models. Some of the models were made by the author to make this simulation. From the point the models were built, also the situation of receiving the models into a PBD software is implicit. So, the supporting facilities were created using REVIT 2014.

Further will be mentioned and perform an analysis to some of the available BIM's software in the market. Will be presented some of the tools which can be used by the designers and by the contractors. The presentation for the designer's tools is to make the connection to the contractor's tools and needs.

Taking a look first into the models for buildings, some examples of tools for buildings modelling are *REVIT*, *TEKLA and STAAD.PRO*. The models for the buildings, can then be split into architectural model, structural model, electrical model, mechanical model and so forth. These models can arrive into the contractor also in several ways. So, taking the example of the project mentioned into section 5.3, the supporting infrastructures for the water supply system contain; the architecture, structure, electricity and mechanic equipment. In the present project, these supporting facilities are not much complex, thus, the design for these four specialities is possible of being done by two design specialities organizations. If recalling what was said into chapter 3, when presenting the parties involved in a project, can be assumed, the architectural and structural models put together. These two models can then be made by the structural engineer. The same analysis can be done for the electrical and mechanical models, which can be done by the electromechanical engineer. Due to the wide variety of available software for doing these models, will be considered all the models to be done in REVIT. The models also can arrive to the contractor all-in-one model, or split. A possible scheme for three ways of delivering the "vertical" models can be seen into Figure 5.10.

Just to mention an example for bigger dimension projects, dams projects. These are projects which have a great component of structural elements. But, the electrical and mechanical component in these projects also represents a very significant presence in dam projects. Also, earth works with a significant weigh are a characteristic on these projects. The author do not have experience or background in these projects. Thus, it is possible to imagine that, these four branches of specialities will be designed independently. Within the design process, due to the particularity and specificity of the branches presented in the project, might be used software specifically produced for the role. This is being mentioned, because, for instance, Revit enables the designer of building the models for the architectural, structural and MEP components. However, the author have the opinion that, this software may not be the most suitable for these kind of projects.

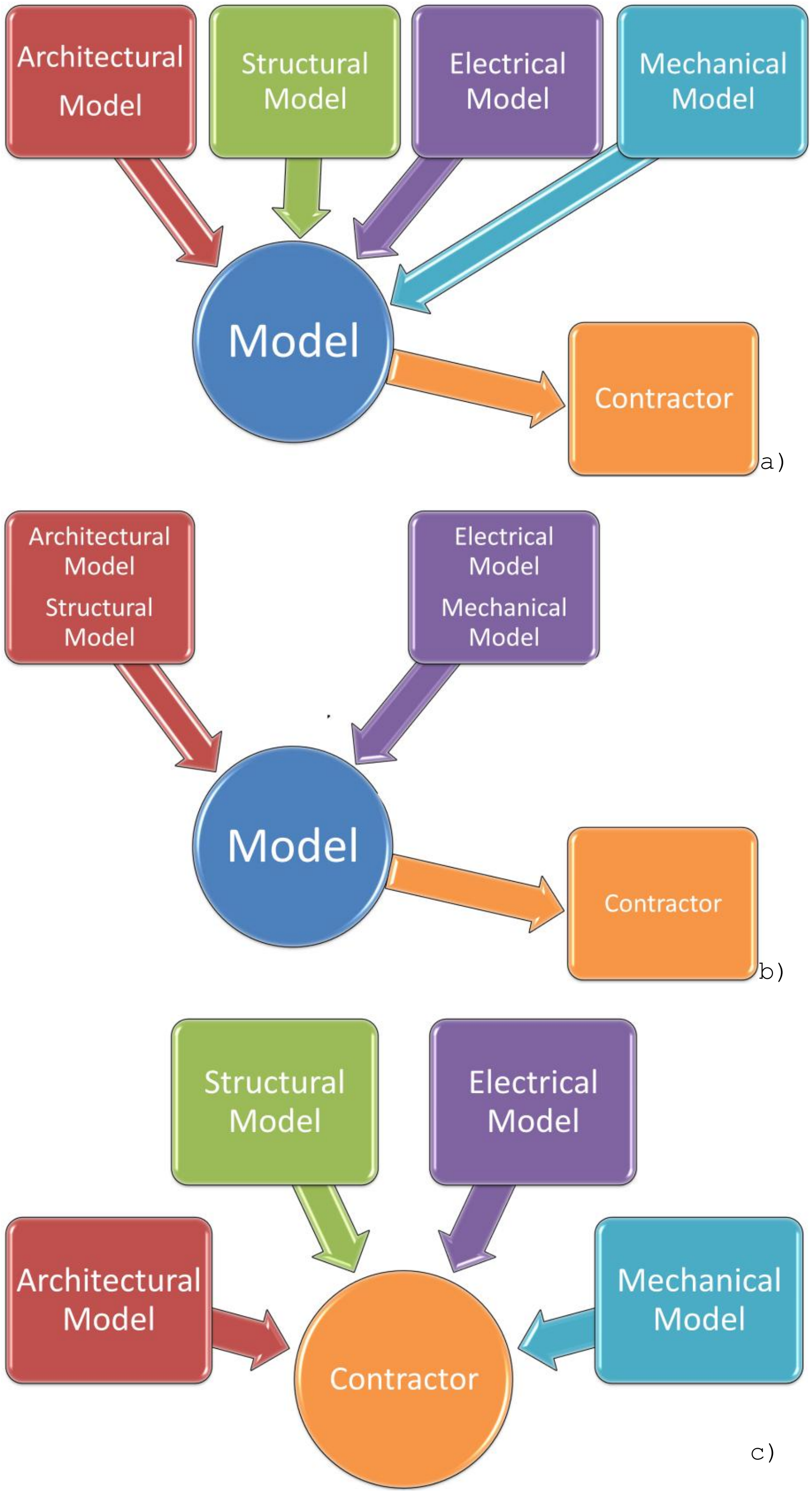


Figure 5.10 - Possible schemes for the way the models can reach the contractor: a) all the models specialities models are linked into one model, b) the structural/architectural and electrical/mechanical models linked into two models and c) all the models are delivered independently.

Revit is a tool which can be used either by designers and/or the contractors. Yet, Revit is considered more as an architecture tool (Eastman et *al*., 2011), the author sees Revit as a modelling tool. A comparison the author see, is with AutoCAD. Even though AutoCAD was a drawing tool for the projects, almost all the stakeholders involved in the project were using it. Revit enables for building the models from the objects which will compose the facility, e.g. walls, doors, windows, and so forth. Revit features and capabilities will be presented and discussed later on in section 5.5 when presenting the models for the project.

Tekla (www.tekla.com) is a tool similar to Revit. However this is a tool which is more targeted to structures projects or to the structural component of the project. The elements have the capacity to carry the information about their properties and roles in the model. Beside the design function, Tekla enables the users for planning. With Tekla, the delivery for the volume of concrete, for instance, can be planned and prepared. For preparing the works with reinforcement of the concrete, elements with specific characteristics/properties can be found and isolated. Know the location for these elements the plan for how to build these elements can be prepared. One example can be the length of the rebars in the project, with the length of the commercialized rebars. In terms of comparison, Tekla can be compared as if Revit and Navisworks into the same software.

For the infrastructures models, AutoCAD Civil 3D (www.autodesk.com), seems to be the most common software used. However Novapoint (www.vianovasystems.com), also offers the possibility for infrastructures design. For building these models, seems to exist a more restriction in choices of available software. Civil 3D for instance seems to be a more terrain modelling oriented tool.

Usually, the design organization involved in infrastructure projects is able to design all the all the facilities developing linearly. Looking into the example in the used project, the responsible for designing the main pipelines for the water, designs the drainage elements. The same occurs for a road or highway with the exception of the bridges. The bridges are a special case for the transportation infrastructures projects. The design of the bridge itself is done by a structural engineer. However, Civil 3D allows for the representation and modelling the bridges.

Model analysis tools

The model analysis tools, are tools which allow for putting the models together and performing conflicts checking between them. These tools enable also scheduling, planning, visualization and costs control. With the model analysis tools, the users can perform simulations over the time and look into how the costs evolve with the progress of the construction works. The users can also perform a walkthrough the models, to have a close visualisation to what will be the reality. The user can perform clash detections and collision checking.

Some examples of model analysis tools are Navisworks (www.autodesk.com) and Vico Office. These two tools have a wide range of application. Navisworks, for instance, can integrate the models for buildings with terrain models.

Navisworks is a tool which can be used in both types of projects, building construction and infrastructure projects. This can be visible by the example presented further into section 5.5 and subsection 5.6.4. Navisworks is a tool which gives the chance to the users for simulating the real environment of the project. The models from all the specialities can be brought together into a single "model". With this particularity, a real visualization of the final product can be seen. Using Navisworks incompatibilities between the specialities cab be checked and clash detections can be performed. The construction progress can be simulated by adding the variable time to 3D model(s). This way, Navisworks also enables scheduling of the project. The technique used in this software is the Gantt chart. Recalling the discussion in 3.5.9.1 about the definition for the Gantt chart and the designation used by, for instance Microsoft Project. Navisworks uses the Gantt chart in its definition, as presented into the construction/project management literature, i. e., the bars are not linked. A simulation for the evolution of the costs with the progress of the construction with this tool, is also possible to be done. Navisworks can be used together with the collaborative tools presented bellow. The features and some examples for Navisworks applications will be presented further into subsection 5.6.4.

DynaRoad is a construction software totally focused for infrastructures projects. This software enables planning, scheduling and control of the project along the construction phase. DynaRoads uses both ABM and LBM scheduling techniques. This enables for controlling the infrastructures and the buildings in the project. In the website, is made reference to a project for an airport. In the website, is made reference for using the Gantt chart in scheduling. The LSM is used for project control. Beside using ABM and LBM, it used also a "map" scheduling system for, visualising the progress over an area. This analysis for using both techniques will be done and presented in detail, further on into subsection 5.6.4.

The system used in the Gantt chart is very similar to the one used by Microsoft Project. With this feature, the resources can be tracked and controlled.

This tool presents a very important weakness. This tool do not works with BIM models. It can be said that this tool still working in the more "traditional" way.

Collaborative tools

With the advance of technology, there is the need for the tools adapt to the actual really. The new Operative Systems (OS) for portable IT equipment opened a new way for the collaborative work. The OS from Apple is a good example for this reality. Nowadays, the access to BIM through portable "pocket" equipment such as cell phones, iPad a iphone as become a reality. With the use of these portable equipment, the access to the elements of the project can be done from almost anywhere. Autodesk for instance offers a cloud based solution through

AUTODESK BIM 360 (www.autodeskbim360.com). The work principle for this collaborative tool is to serve as a pool, where all the information about the project is placed. All the participants have access to this pool, and thus all the information can be shared. Also, through will be through this pool the communication process will occur. Autodesk, for instance, offers two possibilities for this collaborative work process, BIM 360 Glue and BIM 360 Field. With a similar concept there is also available a software ArtrA (www.artra.co.uk).

BIM 360 Glue is a more focused tool for the design stage. the participants can work in a pool created for the project. The monitoring for the progress of the works can be easily done. In section 3.3 when presented the intervenients in the project, where mentioned the different branches specialties involved in the design process. With this tool, these specialities participating in the project can work in the models independently, but in converging to the project. Through the "pool" BIM 360 offers, the models can be put together, clash detection and collisions checking can be done. The errors and discrepancies can be corrected immediately. If adding the owner in this process, the "final product" can be seen and if needed, modified in collaboration by all the member of the design team. A very good explanatory video for the workflow with BIM 360 GLUE can be found in www.youtube.com in the video (www.youtube.com/watch?v=Vc6ehBJNtQQ, seen in 20/05/2014).

BIM 360 Field a tool more suitable for being used in the construction site. The work principle is the same as presented for BIM 360 Glue, although, the focus is more in the needs on the construction site. The purpose for this tool is to help with the management in the field. BIM 360 Field allows for visualizing the elements of the project, both in 3D and 2D. BIM 360 field gives the change for visualising the models and adding changes and information in a similar way as Navisworks.

5.5 The models

In the design stage of this project only engineering organizations took part on it. The buildings structures which were part of the project are quite simple in their overall perspective and requirements. Due to the characteristics of the project and to the functions these structures have in the overall context of the project, no special needs are required with the architecture. Also, this was an amplification project for something already exiting, so there were already facilities built. This means that, no space for creativity was left, once the already exiting pattern should be followed. For these presented reasons, the engineers were the only ones having a participation in the design process of the project. The specialities involved in the project were the structural engineers, hydraulic engineers and electromechanical engineers. However, to be able of presenting the possibility of architectural models, this branch was considered in this thesis. The architectural and structural models for the supporting building infrastructures were built independently. The work the contractor should need to do if the models were handed independently can be simulated as well with this approach. When building the models from the AutoCAD drawings, these were split into architectural models and structural models. Building this models from AutoCAD, gave the possibility for simulating the delivery in 2D formats. Assuming the contractor is already familiar with the BIM approach, but still receives the project into 2D format in AutoCAD files.

The models for the supporting buildings were built using Revit 2014. The author followed the drawings in AutoCAD and tried to produce a faithful model for the facilities. Figure 5.11 shows the model for the delivery station presented into Figure 5.5. This delivery station is located in sub-project A1. In Figure 5.11, the model was done with the structural and architectural elements together. Only the rebars were not included into the model. In Figure 5.12 is represented a cross section for this delivery station. It is possible to see in this cross section some of the elements which are part of this facility. This delivery station is mainly structural, only the upper walls are non-structural. The non-structural wall are made of bricks. This model is available in the Appendix A.4 a), Appendix A.4 b) and Appendix A.4 c) with several possible views. Also in Appendix A.3, Appendix A.4 and Appendix A.5, are presented the AutoCAD drawings, the models and the facilities built in the site. The possible architectural model for this facility is presented in Figure 5.13, showing Figure 5.14 the structural model. In Figure 5.15 is represented the respective cross section of this architectural model. As it is possible to be seen, this is a quite simple model. Thus, no special architectural details were need.

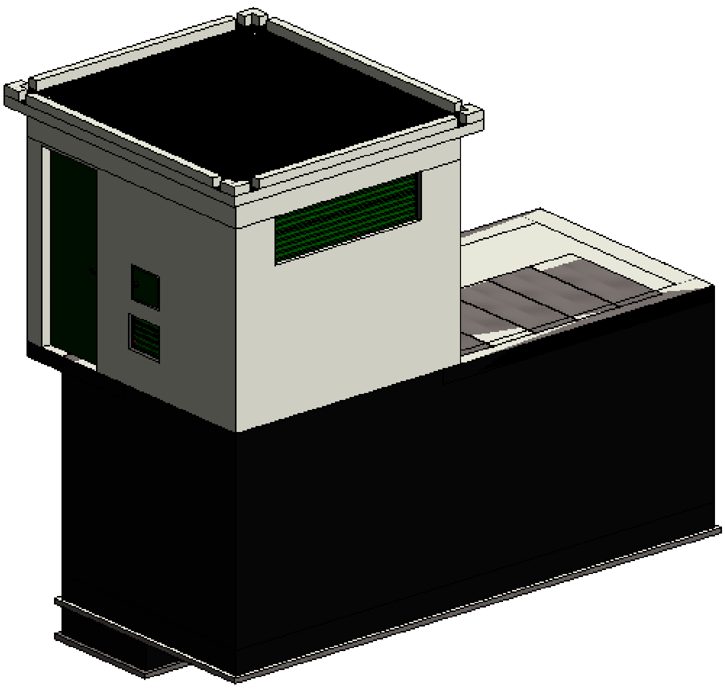


Figure 5.11 - Delivery station with all the elments.

Some of the objects presented in the models were built by the author. But there are also models which were downloaded from the internet. For instance, in Figure 5.12, the screws used in the ladder and in the railing, the bolts and anchor bolts used in the windows (Figure 5.15) were downloaded from Hilti's website http://hilti.cadclick.com/?mandant=IN&laid=203.

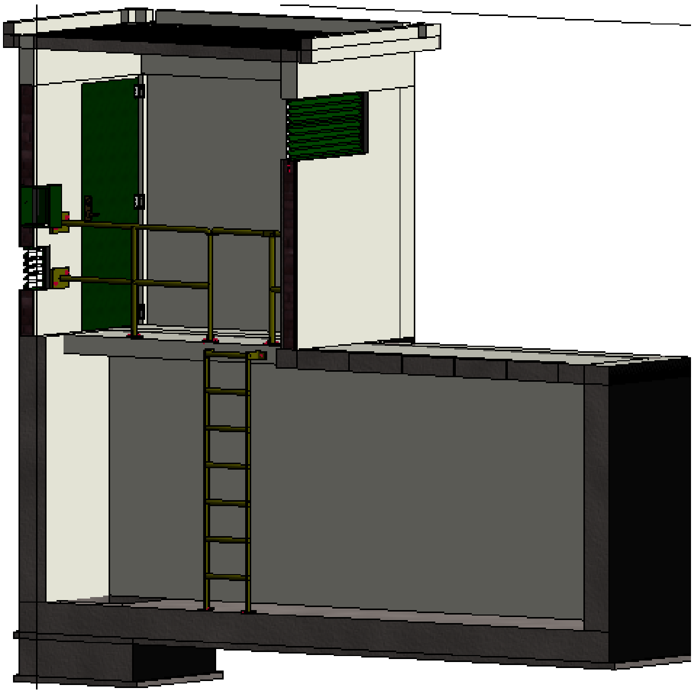


Figure 5.12 - Delivery station with all the elements - cross section.

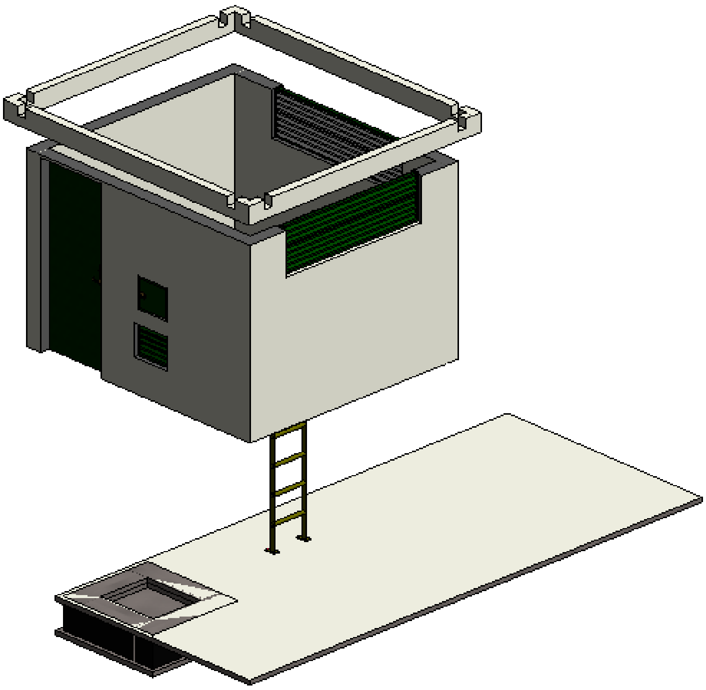


Figure 5.13 - Architectural model for the delivery station.

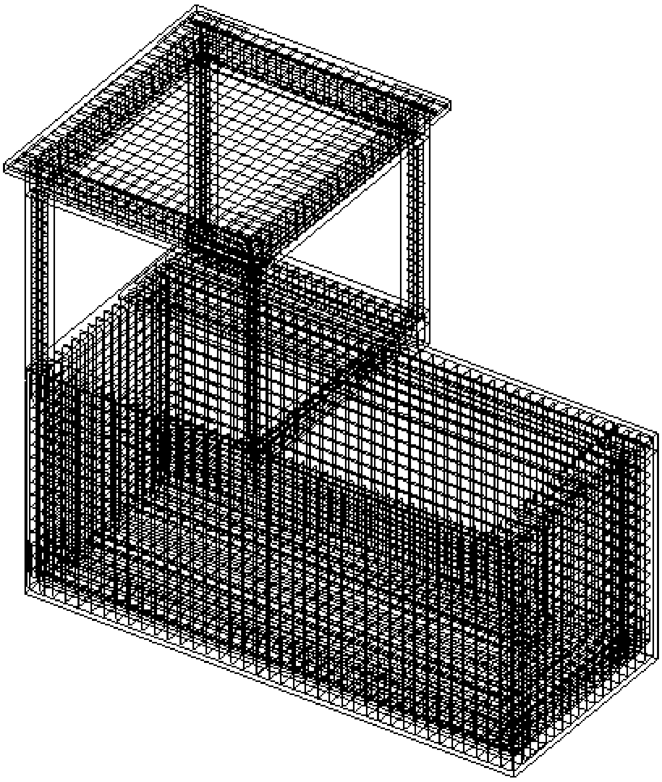


Figure 5.14 - Structural model for the delivery station.

For simulating the location of the facilities, it was built in Revit a very simple model for the terrain (Figure 5.16). This model was built from the implantation plan shown in Figure 5.8. This model will be used later on into 5.6.4 to serve as base for the simulations performed in Navisworks. Figure 5.16 also shows the location for the facilities included in this sub-project.

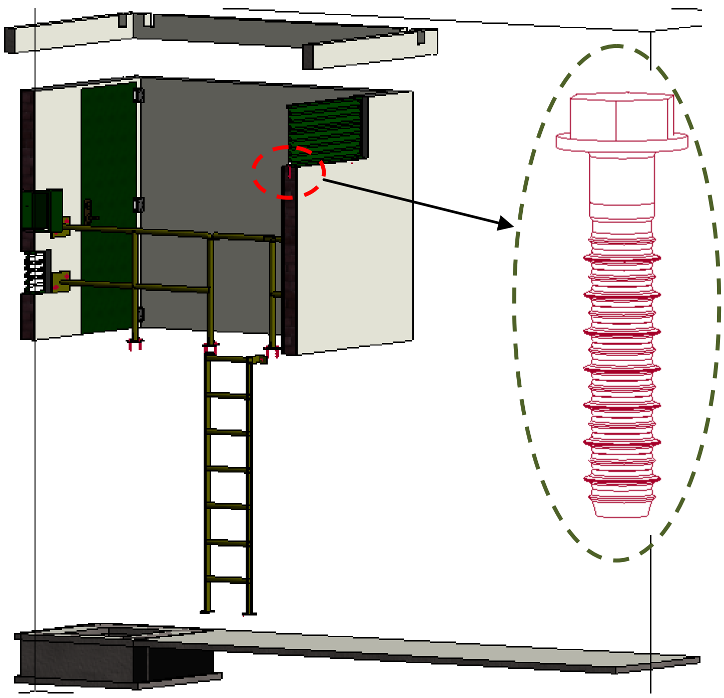


Figure 5.15 - Cross section for the architectural model for the delivery station.

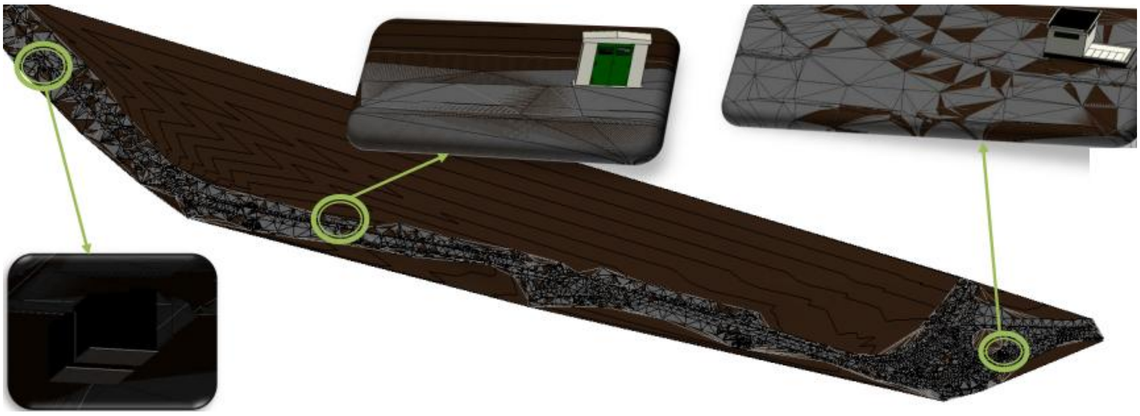


Figure 5.16 - Location for the supporting facilities in sub-project A1.

Following, some of the objects will be analysed, with the purpose of showing, BIM's objects characteristics and features, in the case for Revit. In Figure 5.17 is presented the model for the windows used in the delivery station. As it can be seen from Figure 5.17, the window "knows" what is the face that should be for the exterior and interior of the wall. The window "knows" as well that it should occupy the position in the middle of the wall, in this situation. When building these objects, several options exist for the different types of objects. The walls for building the doors or windows, the slabs for building the covers, and so forth.

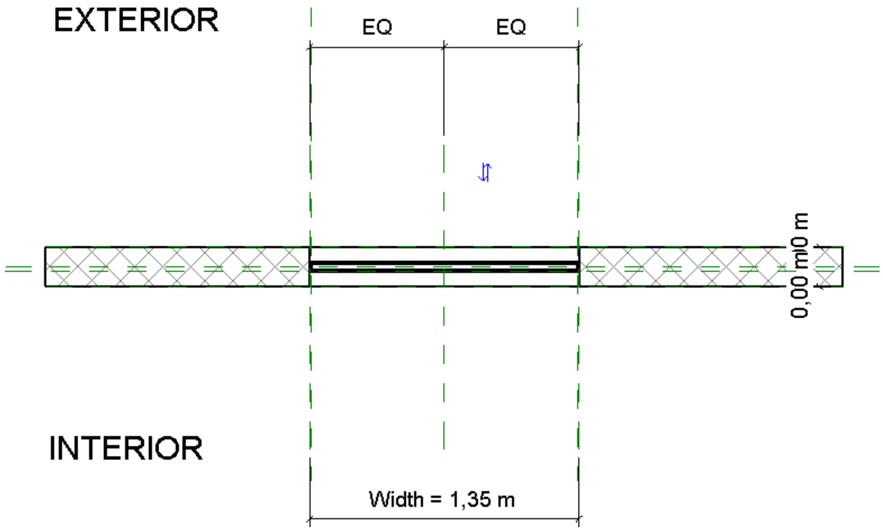


Figure 5.17 - Plant for the object window (used in the model for the delivery station).

When it comes to the properties of the object (Figure 5.18), it "knows" how to behave. If changing the dimensions of the window, all the elements for the window will automatically adjust to the size of the window. The opening in the wall where the window will be placed, will also adapt to the size of the window. The dimensions for the window are shown inside the red rectangle. The object can also carry the information about the material of which is made (inside the orange rectangle).In the material section is included all the information about its properties. Figure 5.19 shows the example of the physical properties for the high grade steel. Bellow the information about the dimensions in Figure 5.18, are presented some other informations the object can carry.

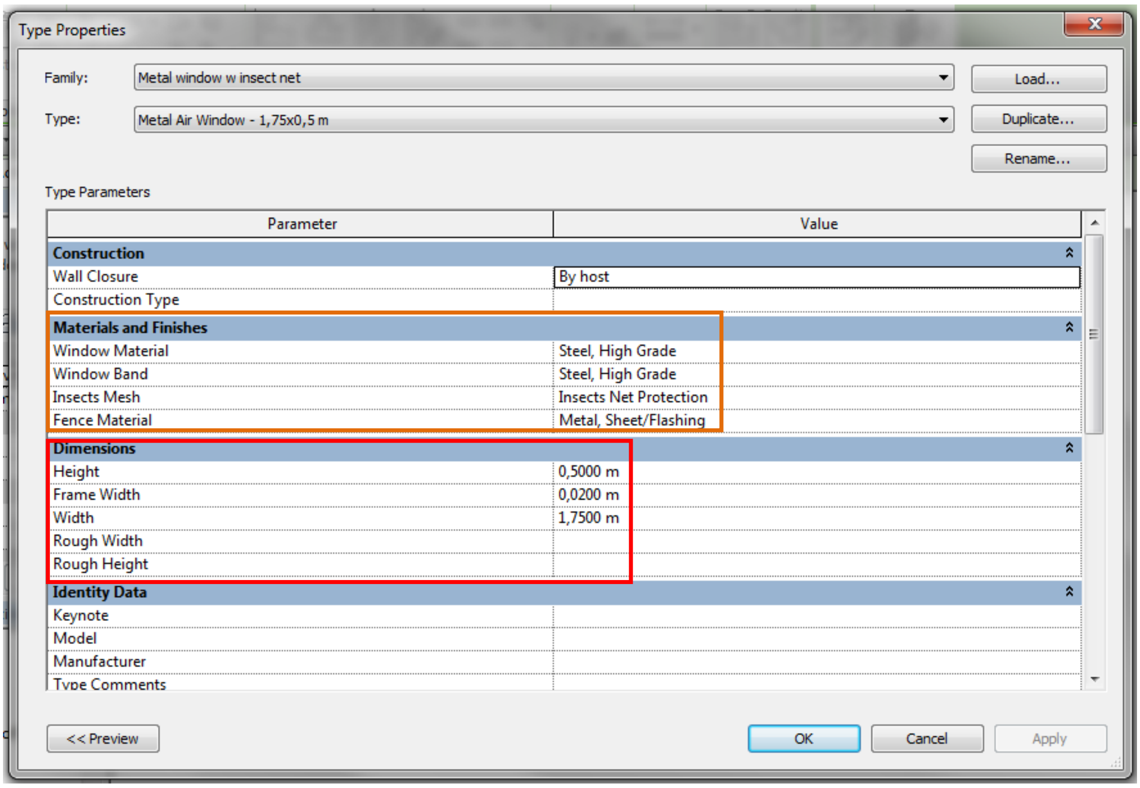


Figure 5.18 - Properties for the window.

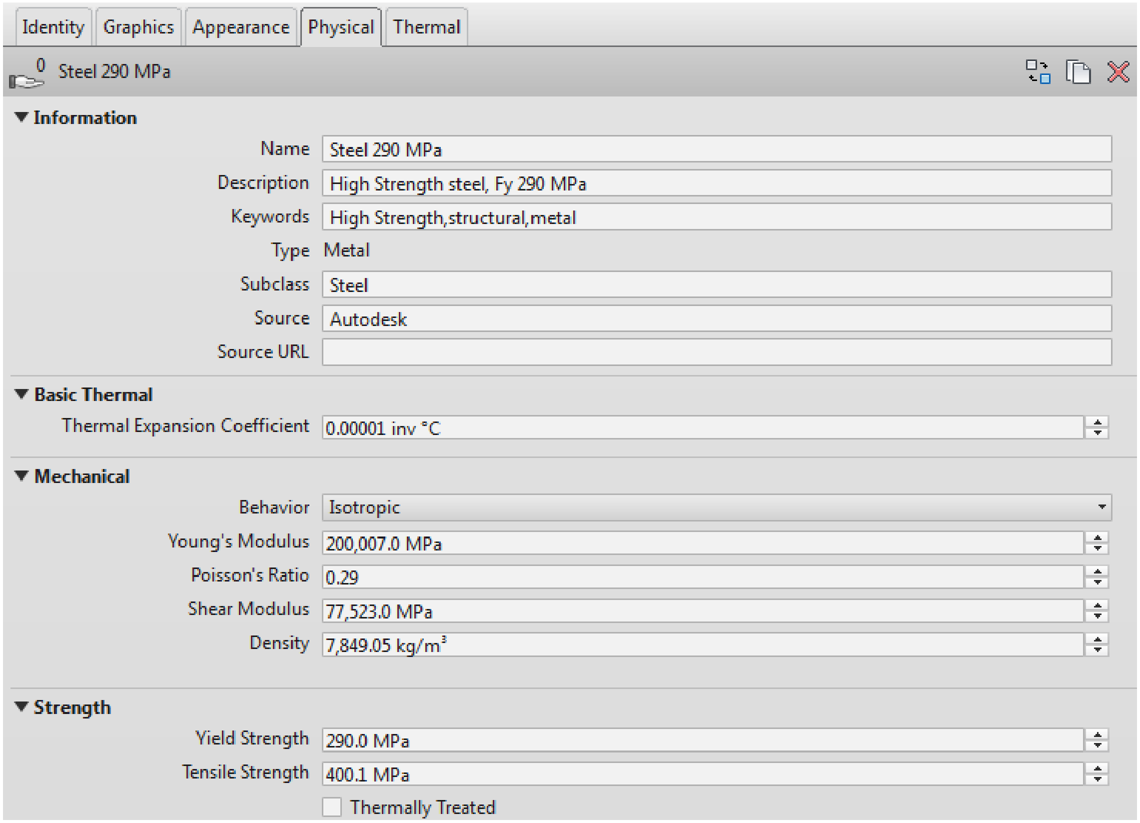


Figure 5.19 - Physical properties for high grade steel.

For presenting the other information, rather the material and dimensions will be used the model of a ladder. The reader should notice that, this ladder (downloaded from http://seek.autodesk.com) was not used in the models. This is just an example for demonstration purposes. As can be seen in Figure 5.20, several information can be added to the object. The website for the manufacturer, the characteristics for green building, the model series, and so forth.

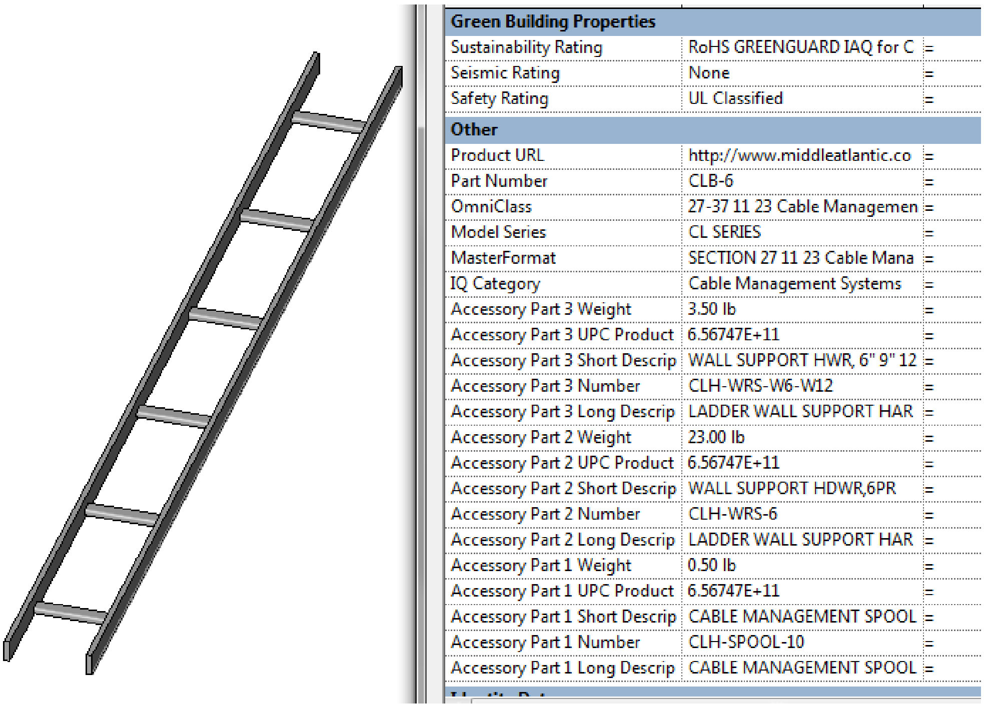


Figure 5.20 - Some information about the object.

The model may also carry with it the information about the costs (Figure 5.21). Thus the author wants to call the attention to this feature. The cost is the value for the whole object. Independently from the size or its constitution. The price should be included here is the total price for the object. For instance, in the price for the wall should be taken into account the all the resources which are part of the wall.

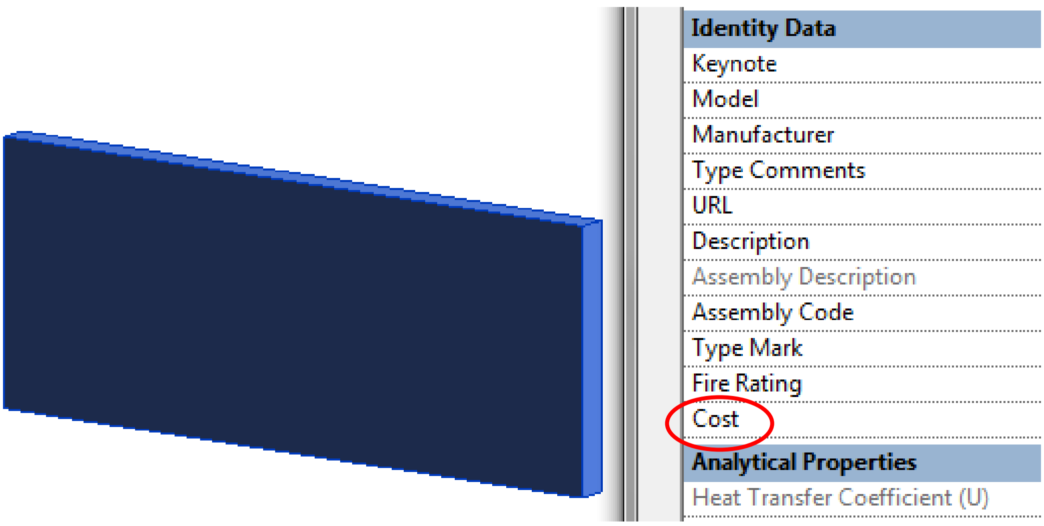


Figure 5.21 - Information for the wall object.

To learn more about the capabilities of Revit, the author modelled a facility which is located in sub-project A2. This facility was an existing valves chamber which needed to be expanded. So, some demolition works were planned for this facility. To learn and see how Revit deals with this problem the author built the model presented in Figure 5.22. In the well colored area, is the part to be built for the expansion. The region with duller colour represents the existing facility.

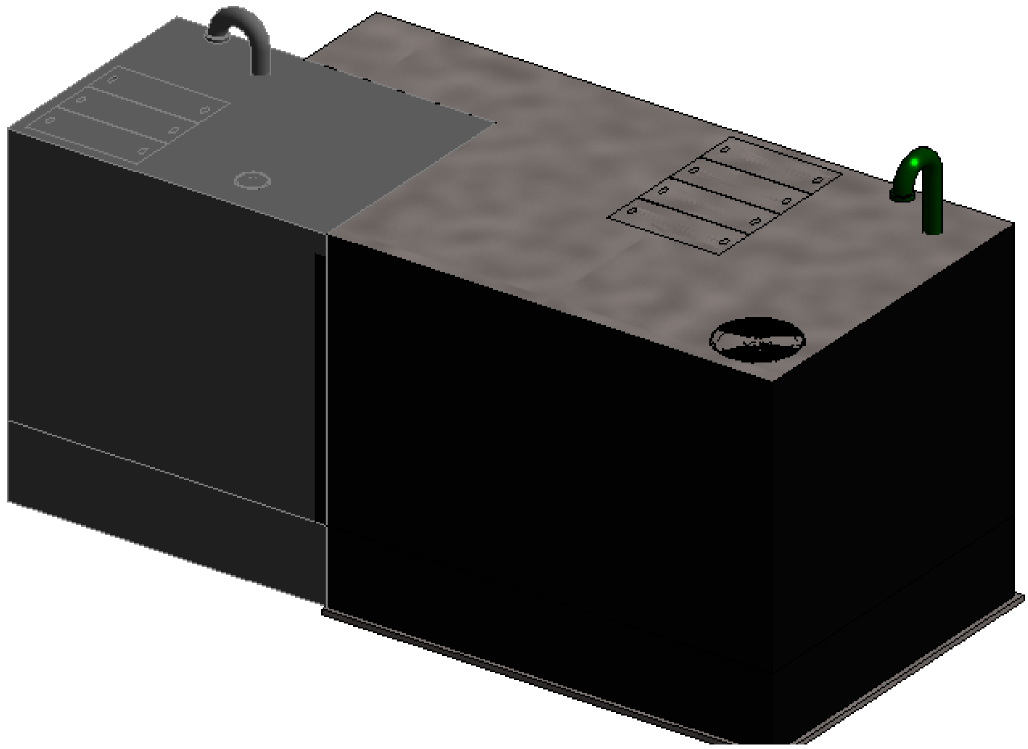


Figure 5.22 - Expanded valves chamber in sub-project A2.

In Figure 5.23 is represented a cross section for the final shape of the facility. Figure 5.24 and Figure 5.25 are showing the isolated existing and demolished phases, respectively, in cross section view.

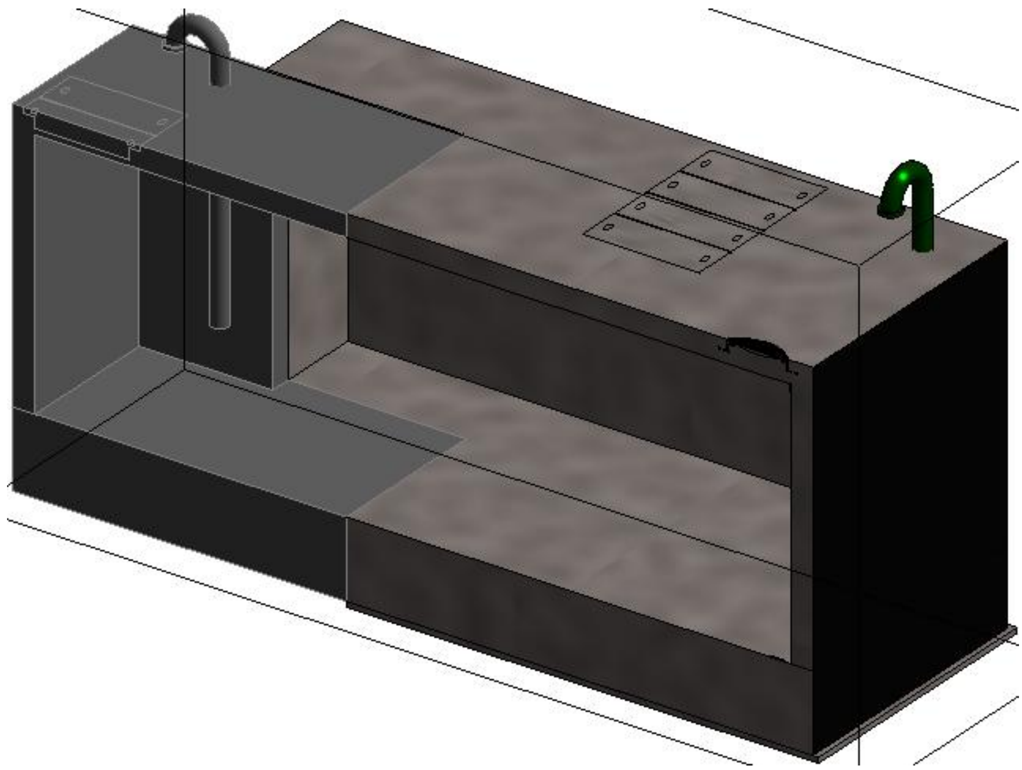


Figure 5.23 - Cross section view for the extended valves chamber in sub-project A2.

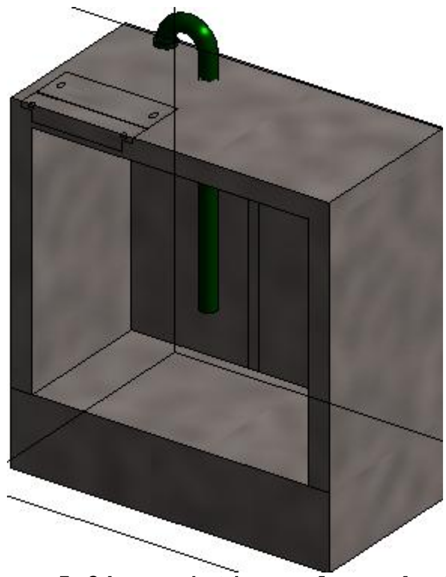


Figure 5.24 - Existing valves chamber in subproject A2.

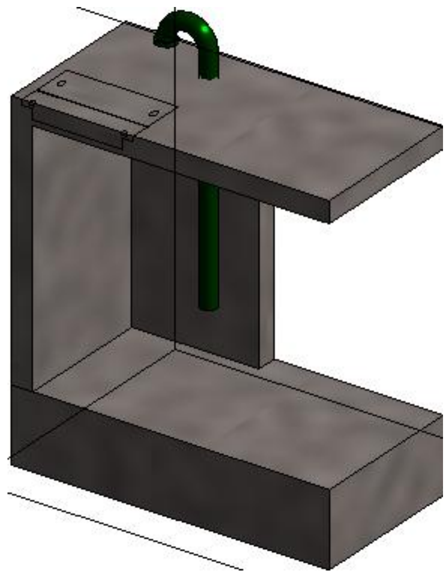


Figure 5.25 - Valves chamber in sub-project A2, after executed the planned demolition works.

Due to the simplicity of the building structures which were part of the project, the author also modelled the pumping station (Figure 5.26). This was the biggest building for the project. The reader should notice that, this model is not completed. The intention in building this model was to experience working with stairs, openings in the floors and foundations.

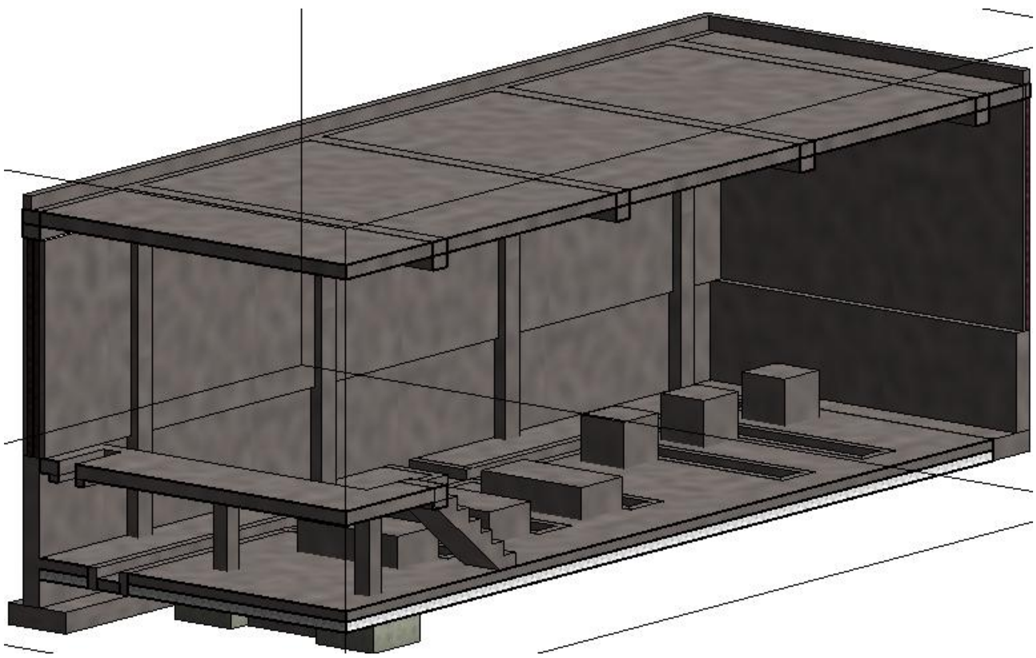


Figure 5.26 - Pumping station located in sub-project A2.

5.6 BIM in Infrastructure Projects and Information Flow

5.6.1 Adapting to this new reality

Along chapter 4 when presenting BIM, reference was made for this new approach and its concept. In section 4.4, when introducing the Disadvantages, was referred the need for adaptations to this new approach. A BIM expert will be needed to deal with the needs for using the software as well as all the surrounding environment. Thus, the need for specialized manpower, to work with this approach, will lead to the first change into the organization. The contractor can resort to companies having the right resources for working with BIM. One example can be, a consulting company specialized in working with BIM to make part of the team. Yet, this may not be the best approach for the future, once the tendency will be using BIM definitely in all the projects.

The structure and the organizational system of the company will need to adapt to this new reality. As seen along chapter 4, BIM is present along the entire project lifecycle. The same happens into the construction stage, in the phases. The information from the contractor starts being added when the contractor receives the documents for tendering. This information should be added to the project through BIM. Here starts the cycle for the information sharing and transferring inside the contractor organization. BIM will work as a pool of information, allowing to the participants in the project to view the information related with the project. Also, the workers in the company in general have the possibility for checking for updated information in projects they are working with. So, all the information about the projects will be available through BIM. Also the information will be able to "travel" along the construction process cycle. This way, the risk for loses of information in the project can get close to zero. In Figure 5.27 is shown this concept for sharing information inside the contractor company.

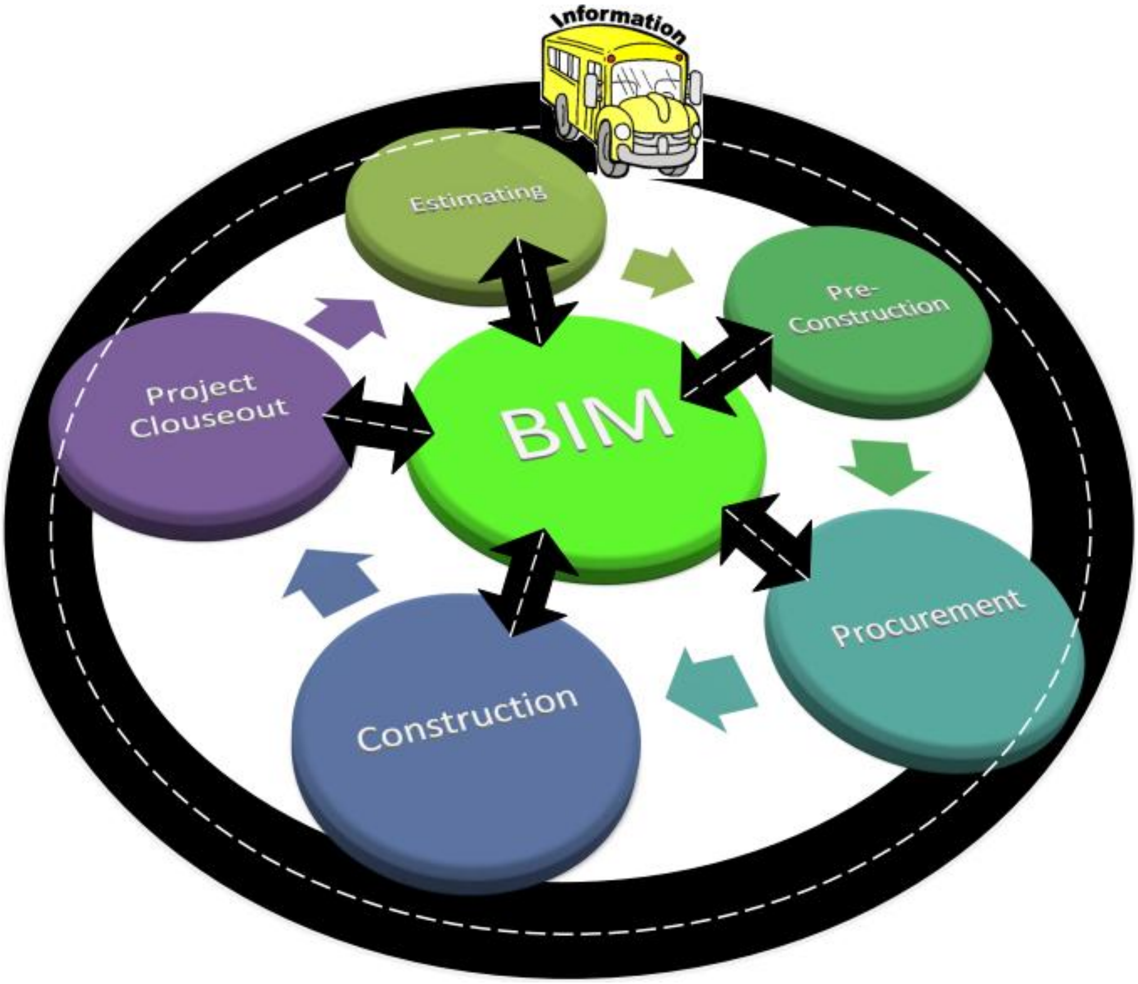


Figure 5.27 - Information path and availability for a project inside the contractor company.

During the estimating and tendering phase, the estimating department, the SHE department and quality department are the first departments working in the project. Further on, the information created in this phase needs to be available for the following phases. When the project is awarded to the contractor by the owner, the construction process and the time for the execution of the works starts immediately. For this reason, the pre-construction and procurement phases are most of the times inside the construction phase, not having a gap in time between them. Yet, they still existing and can be analysed independently. When the construction of the project is finished, all the information is collected and prepared for future projects. With this process, BIM will play the central role in the process. This means that the estimating department, the SHE department, the quality department and the construction department will be linked to BIM. But, these departments will be linked between themselves also through BIM, as shown into Figure 5.27.

To be able to have all these paths for the flow of information, the best solution, seems to pass by establishing a new department, the

BIM's department. Due to BIM's characteristics and features, will be through this department that all the phases of the project will pass. Is a suggestion that this department should be hierarchically above to the other mentioned departments. The idea is to allow the flow of information along the phases of the construction stage, through the related departments. The BIM department will then do the bridge between all the departments, by collecting and distributing the information in a two ways direction. With this central role of the BIM department, the close and continuous collaboration, as well as information flow will work better. This connection between the departments will also allow for help to the estimating department and SHE department with the construction methods, procedures, processes and other variables. Thus, better solutions, more accurate prices, for instance, can be prepared. The same is valid for the construction department, which will have the possibility of knowing how the project was approached and treated for tendering. As a result, less risks of deviations, an improvement into the performance and in the profits can be achieved.

In section 3.4, was presented the organization for the construction companies, by showing some standard organizational charts. Following, will be presented a possible organizational chart, for the introduction of BIM department. Recalling Figure 3.6, BIM department can be placed as seen into Figure 5.28. If the organization have a design department and can design also the projects for constructing, this department can be included inside BIM department. The advantage may arise from this, is the possibility of having the other departments related with the construction stage working in cooperation, and vice versa. The connection of BIM department with the director(s) also enables for the directors to have a view about the "events" of the projects. For the contractors working solely with infrastructure projects, the BIM department should have a person(s) to deal with the building models, since the concept can be quite different from the infrastructure models.

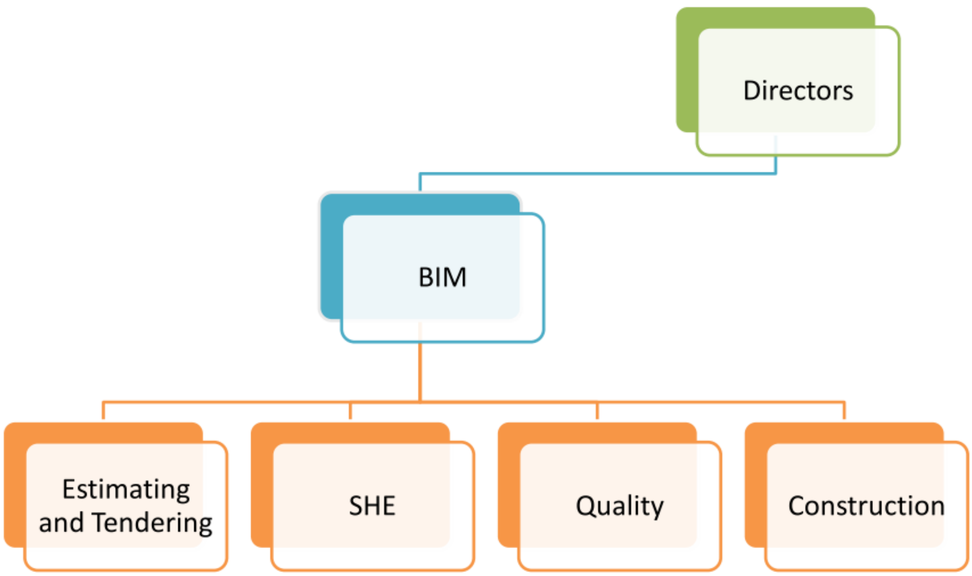


Figure 5.28 - Integration of BIM department inside the contractor organization.

5.6.2 The delivery methods

The initial information to be added by the contractor to the project and the way it is added, is dependent on the type of delivery method and the type of contract. The delivery method and contract type can play a very important role in the beginning of the construction stage. The approach by the contractor to the project will depend on these two parameters. The importance the delivery methods and the contract types have, are in distributing the responsibilities between the main parties involved in the project. In section 3.5.3 when presenting the delivery methods and the types of contracts (section 3.5.5), was mentioned their features. Now these methods will be analysed by the information content perspective, how they will influence the contractor approach and in which projects they are more suitable.

Mention is made along the literature about the delivery methods and their suitability when using BIM. The DBB and DB methods are not much suitable for making use of all the capabilities of BIM related to the collaborative work. From the author's perspective, the problem with the collaboration between the parties involved in the project should be treated separately for the private and public sector projects categories. Also the suitability for the contract types is closely related with the projects category. Eespecially within the public sector projects, the problem related with the collaborative work will be very difficult to solve, particularly between the designer(s) and the contractor(s).

Taking a look first into the private sector, the legal issues of interests, transparency, equality and competitiveness are not raised by stakeholders. In the private sector, the owner can resort to the organizations or persons of his/her preference. The projects don't need to be published and no explanations about the choices need to be given to the exterior of the owner "organization". The owner can invite the design organization(s) and the contractor(s) for working together since the beginning of the project lifecycle. Can even happens the designer(s) and contractor(s) be involved together with the owner in the conception of the idea for the project.

In the public sector, the collaborative work between the parties involved in the project, along the entire project lifecycle, seems to be a little utopian. The first question coming up is related to the legal issues. By legal issues, means that, the contractor (if there will be any) involved into the design stage of the project, is not allowed to construct the project. In this point is immediately a barrier for the collaborative work. The second problem, can be the information sharing between the design stage and the construction stage. Yet, this is a legal issue that can be overcome by the copyright clauses of contract and property rights. Again, from the author's perspective, is the owner paying the designer for the project, so, the owner will own the project. The owner sets the rules for the project and for what the owner wants. This issue can be seen with similarity, to the facility(ies) resulting from the construction of the project. The facilities will completely belong to the owner. So, the information still can be shared. Thus, instead being shared through collaboration along the project lifecycle, the owner will have to work as the bridge for this process. But, it is of all the interest for the owner to have the most information shared, so the problems with the project can be mitigated. This way, BIM can play a very important role and still being very suitable for these DBB and DB methods.

The DBB is a delivery method more suitable for the public construction sector. However it brings the issue especially about the collaborative work. The information will need to be shared through the owner, as already suggested. When working in a project with a DBB, the contractor, through BIM, have the opportunity of finding the possible errors in the project. This will allow for a better and a more accurate and competitive bid, thus, also the possibility for increasing the profit. If the project uses a DBB delivery method, the contractor for purposes of project quality, don't need to concern about the way the project is delivered. This method don't bring much responsibility to the contractor, for the errors contained in the design of the project. If there will be any errors in the project, these will be from the designer of owner responsibility. The contractor will have to work with the models the way they are delivered. Thus, the contractor will need to aware of the contract type. Because depending on the contract type, the way will the contractor need to study the project. Recalling the example already mentioned into 3.5.5, will be assumed the project to have two contract types. A lump sum contract type for the "vertical" facilities and a unit price for the "horizontal" facilities. When analysing the "vertical" facilities, the contractor will need to be careful with the errors and omissions and the quantities in the bill of quantities. in the drawing elements, and so forth. Considering the models shown into 5.5, for the delivery station, it should checked if all the windows have the "insects nets", the doors have the lockers, etc. Thus, if a door is in the wrong place, or a window is missing in the project documents, this may not be the contractor's responsibility. In this analysis process and information adding, BIM can be very useful. In addition, for the "horizontal" facilities, since is a unit price contract, the analysis don't need to be so precise for the quantities.

The DB can be either for the public and the private sector. However, in the public sector problems may arise if the project is started by the organization without a previous public advertisement with the base for the idea. But, once the project will be designed and constructed by "one" organization, the public opening can be done for the overall process of the project. The owner presents the idea and then the organizations present their solution for the idea. In this type of delivery method, problems with the collaboration may appear if the "organization" is made by two different designer and contractor organizations. However, is for the interest of both organizations, a good collaboration between them. BIM in the DB delivery method can help the "organization" by decreasing the errors of the project, and thus decreasing the errors for the contractor. Once the contractor and designer are working together, the models can be done how the contractor will request them. The contractor will be capable of presenting more accurate prices for the work. Also the prices can be lower, by presenting several alternatives for the materials and construction methods. The DB method will allow the contractor to approach the project the way that is most favourable.

Analysing BIM in the types of contracts, some similarities can be found when comparing to the delivery methods. If the contract is a lump sum type, the contractor should be careful when analysing the elements of the project. Errors in the estimating process can lead to losses for the contractor. Even though the literature refers that errors and omissions can lead to "change order", the owner always argues these could be detected when preparing the bid for the project. With BIM the feature of quantities take off will allow the contractor to verify these errors and omissions and help in preparing a more accurate bid. For the unit price contract type the approach of the contractor is similar to the one used for the lump sum contract. The difference here is the way the prices are given. Once the price is given for unit of work, the contractor will need to take a better look into the errors and omissions.

5.6.3 Estimating and tendering

Before going into the estimation process inside the construction process, as considered in this project, will be made a presentation about the overall scenario for reaching the prices in general. Everything starts with the intention of the owner in building certain(s) facility(ies). When requesting to the designer for the project for this/these facility(ies), the owner stipulates a certain maximum value for the project. When the designer is working on the project, beside the requirements for the facility(ies), should take into attention this cost requirement. So, the designer when building the elements which will be part of the project, will also made a estimate for the costs of the project. The estimation done by the designer is nothing more than a rough estimation for the total cost of the project. The designer don't takes into consideration the details about the construction processes and methods. Also, unless for very specific parts of the project, the designer do not make use of inquiries for asking prices. The estimation is done through by an approximation of averaged costs per meter, squared meter or cubic meter for the facility(ies). This process can be seen in the scheme presented in Figure 5.29. The owner asks for a project to the designer, by setting the rules which will follow the project along its lifecycle. The models for the project are then built and based on these models, the designer do an estimation for constructing costs. The project meets the first requirements, is then delivered to the owner. The information is then transferred for the contractors in a first approach for tendering.

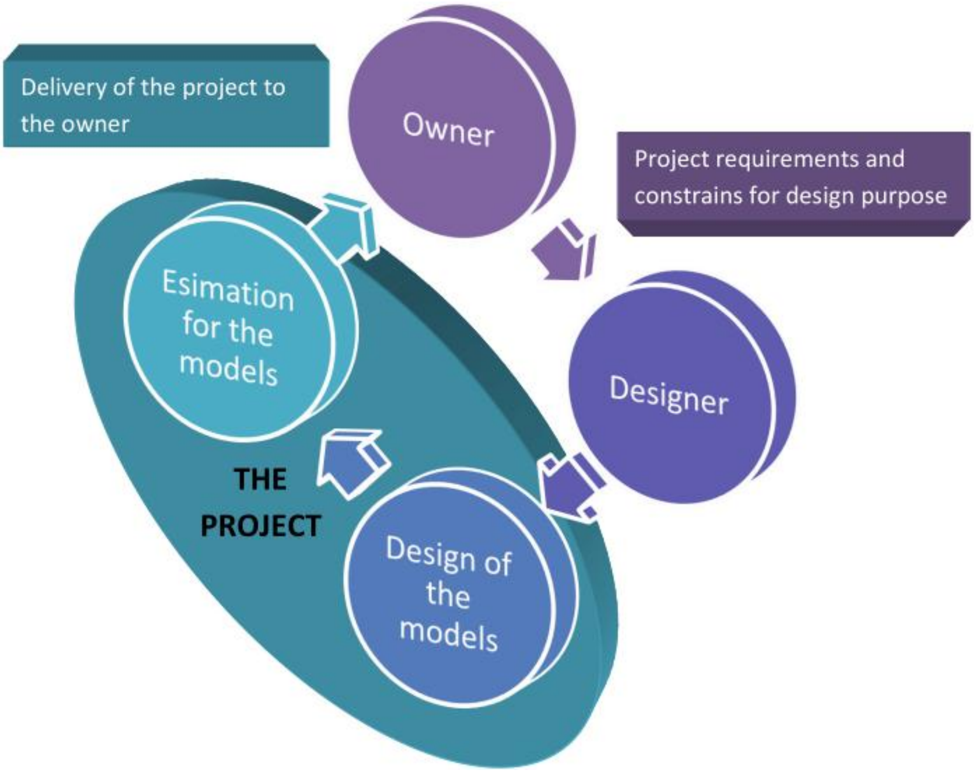


Figure 5.29 - The beginning of the estimation for the project.

In this transferring moment, no much information is lost. It can be said that all the information available for the project is transferred for the contractors. When presenting their tender, the contractors have to meet the requirement for the upper boundary for the cost estimated by the designer. So, the contractors should present a bid lower than the one the owner present as a upper limit.

Now, will be analysed the estimation process into the contractor's organization. The estimating process, as already mentioned is the most important and vital for the health of a contractor organization. It is from estimating and budgeting the construction process starts. The results from the estimation process, delivered to the owner, will be the base for the control and monitoring of the project progress. It is vital for the success of the project, to have a very accurate estimation and close to the reality. However, along the estimating process, only the information contained in the project and from the site visiting are available. So, the estimation is done taking into account some considerations and suppositions, based in previous experience, prices from enquiries to the subcontractors, materials suppliers, and so forth.

When estimating the productivities, resources in the teams and the times execution times for labour, are assumed for approximations. It can be said that, the estimation is done, based on some sort of a forecast about the way the construction process will be conduced. Jackson (2010) describes this very well, when stating that, "the estimate is an educated guess" (Jackson, 2010). From the author's perspective, some part is, some part not. The prices for the subcontractors, materials and equipment can be estimated with high accuracy. These are factors which don't need to be guessed. Unless no answers were received from the enquiries made, asking for these prices. Then, an "educated guess" should be done. However, this guess should be always based into projects of the same type. The reader should take into consideration that, many times, especially for the materials, variations in the prices may occur. However, this is an item usually taken into consideration in the contract. So, the factors which make the prices for the work tasks to vary from the estimated to those in the construction process are related to the productivity. The productivity is dependent on the teams (labour and equipment), the external factors (weather, site conditions, etc.). So the prices can be affected by either the time or the constitution of the team involved in the work task(s).

Opposite to the estimation done be the designer when checking if the project is within the requirements imposed by the project owner, the estimation done by the contractor, should be as detailed as possible. The contractor should be focused into including everything needed for the good execution of the works. When estimating the works for the project it should be taken into account:

- The resources need;
- The amount of resources needed;
- The unit costs for these resources.

For instance, when estimating the works for brick walls for the delivery station on the project used in this thesis, the following should be used:

- Bricks;
- Cement;
- Sand;
- Manpower (bricklayer and hodman, ...);
- Equipment (backhoe, cement mixer, ...).

The level of detail will be used when estimating and the amount of information will be transferred to the construction department, the better control and monitoring will be achieved. This detailed analysis is always done by the estimating department. So, if this information will be passed to the construction department, the analysis for the possible derails will be more accurate and precise. Thus, will allow for the construction team responsible for the project to find the source of the problem and proceed to the corrections in the best way.

The estimating department can be seen as a two ways information input and one way information output. As presented in Figure 5.30, the estimating department receives the information from the owner and should also receive the information from the construction department after the construction being concluded. But, the estimating department sends to the construction department the information worked with, along the estimating process. The big issue in this process is the amount, quality and utility of information transferred or shared inside the constructor organization. This problem was already introduced into 5.6.2 through Figure 5.27. Thus for simplicity of analysis, the construction process will be considered as if it was a single phase, the construction phase. The pre-construction and procurement phases will be considered as part of the construction phase. So, the path for the information inside the contractor will be as shown in Figure 5.31. The information created from the estimating department in the estimation process will pass to the construction department for the construction process. After concluded the constructed process the information returns updated to the estimating department. The return for the updated information to the estimation department will be treated later on in this thesis.

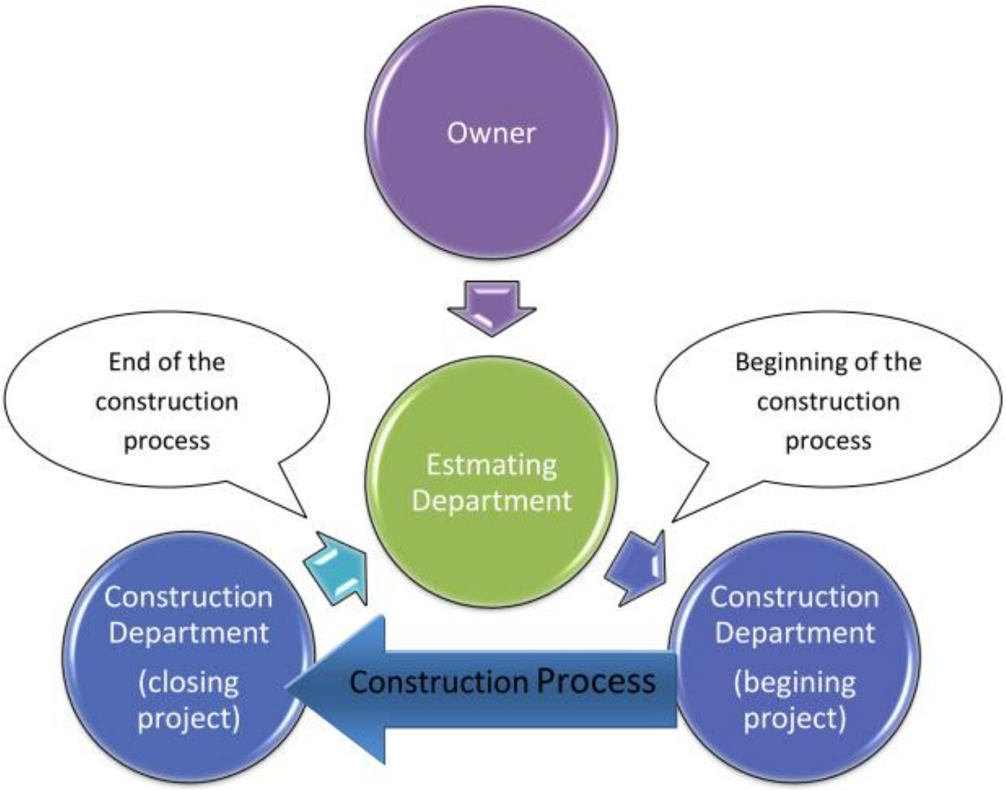


Figure 5.30 - Information ways around the estimating and budgeting department.

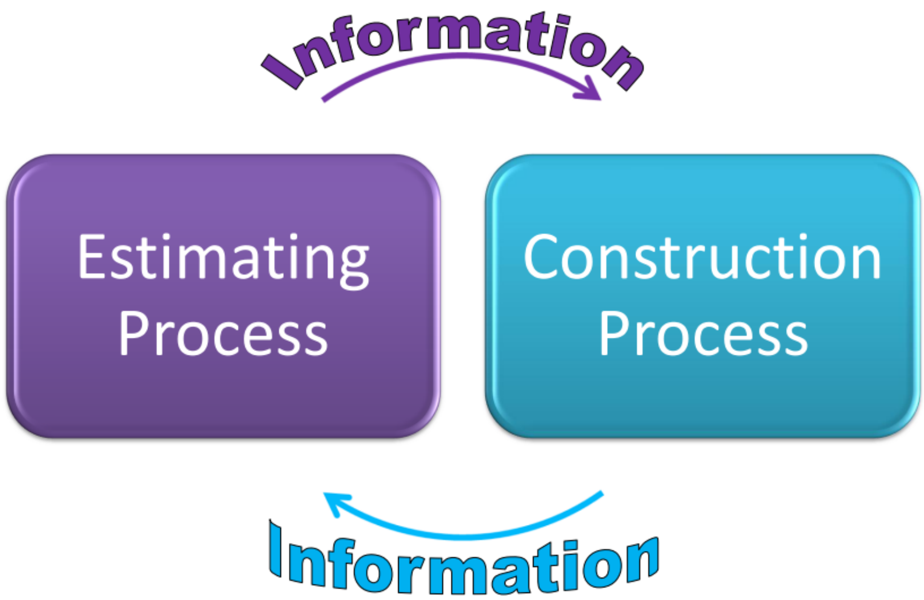


Figure 5.31 - Information cycle inside the contractor organization.

First will be analysed the amount of information usually is transferred and shared along the project cycle inside the contractor. As presented in Figure 5.30 the information of the project arrives at the contractor, following from the owner to the estimating department. This information is then treated and passed to the construction department. The reader should keep in mind that a consideration is being taken for the contractor who awards the construction of the project. Then, when the construction of the project is done, the updated information will be given to the estimating department. In this transferring process many information is lost, not shared or not transferred. Figure 5.32 shows this loss of information along the project cycle inside the contractor. When looking to Figure 5.32, the first impression it comes to mind is that, something is missing there, it is quite confusing, the image doesn't make much sense. This scenario can inserted in the contractors organization with the transference and sharing of information. The information either is lost, is not very explicit, and so forth. The reasons why this happens can be due to the used software, the system the company uses for sharing and transferring data, bad procedure when doing the estimating, and so forth.

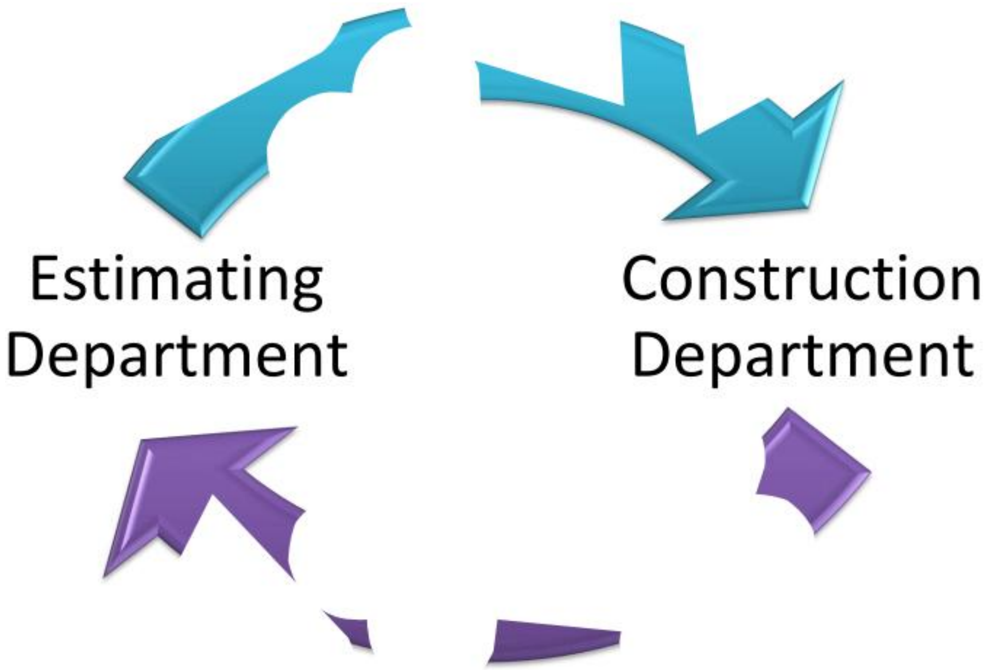


Figure 5.32 - Graphical demonstration for the quality, quantity and sense for the information shared or transferred through the path estimating department-construction department-estimating department.

From the author's experience, inside the organizations, usually the access to one department is restricted to all the others, or most of them. This brings some difficulties for the construction department, for instance, have access to the information inside the estimating department and vice-versa. The software used for estimating is not the same used for managing. This brings up the problem of information loss when transferring the data from the estimating to the construction. Even though the attempt is done, and careful is taken for transferring this information. One example can be seen between the importing the information contained in the project into estimating software. The same problem occurs when the information is taken out from the estimating software the construction of the project (usually exported to ECXEL). A great amount of information is lost in these two processes.

To solve the problem of losing information when transferring it between the departments, a common tool to both of them might be the solution. This idea can also decrease the costs for the company, avoiding the acquisition of more licences and the need for extra courses to the employers for leaning new software which they will almost not make use. So, when estimating the project for tending, in the documents making up the tender, a schedule for the distribution of the works should be included. For instance, traditionally, Microsoft Project is a common software used in both the estimating and construction department for scheduling. This same principle can be used with BIM software. By making use of the parametric feature of the objects, which enables carrying information with them (Figure 5.21), the information can be transferred through these objects.

The information is added to the models through the modelling software. Then, the "compatibility check" software and/or the software for estimating can be used to import the information into the estimation process. Some information can be added to the scheduling software, and then, no needs for importing/exporting will be needed. One example for this, is the information about the materials be transported through REVIT. The information about the equipment, labour for each task together with the calculation for the productivity which will determine the costs for that task, can be transported through NAVISWORKS. This introduction for the teams and their constitution will be approached further on into subsection 5.6.4. With this suggestion, the needed tools to be used by the contractor in the entire cycle of the project will work also as means of transportation for the information. With this process also the considerations and assumptions taken into account when estimating the project will be shared and transferred.

With the mentioned possibility of introducing the resources with their working productivity in the models, a closer perspective of the reality can be achieved. This will then reduce the level of guess in this estimating process. The estimating and budgeting of the project can be done by simulating the construction process with almost all the variables found "*in situ*". With this analysis, all the parties can take advantage and benefits from the project. The owner will maybe have lower values for the construction of project with more accurate prices. So, some disputes and problems may be avoided. Also, the contractor will be able to reduce the risk when estimating and thus, increasing the profits percentage. The estimation process can be done faster since there will be created a pool of information from the previous projects (by the concept shown in Figure 5.27). The contractor will be able to get more time for a more careful analysis of the project. As a result of this a better quality in the "final product" can be achieved. When the estimating and budgeting is being done, the concept for the "iron triangle" presented into 3.5.9.4 can be also taken into account. BIM will allow for the simulation of the variables present on the project, so the manager of the department can take the decision of which variable he/she wants to sacrifice. With the information contained into the models, the construction department can then follow the approach taken into account when the estimation of the project. With the return of the information from the construction site, the estimating department can then analyse the decisions and approaches taken. So, the estimating department will be able to improve the methods for estimating and budgeting. By this, it can be stated that, the estimating department will be a department in constant evolution.

In small projects, the quality and quantity for the information transferred and shared may play a vital role in the success for achieving the goals for the company. Small projects usually have approximately the same time big projects have for estimating, thus the amount of elements to analyse is smaller. This allow for a more detailed and careful study of the project. As it will be seen in subsection 5.6.4, this will have a great impact when dealing with these types of projects, due to the time for preparing and planning the project. Usually the replying time for the enquiries made for the prices in the small projects is also approximately the same as the time for the big projects. The importance of the information transferred in small projects is due to the limited time usually these cause in the preparatory works. In small projects the amount of work and procedures needed is the same as for big projects. The issue is that in big projects, whole project don't need to be prepared from the begging. The works in advanced can be prepared later in the course of the project. In small projects all the works need to be prepared in the very beginning of the process. Usually the suppliers and contractors, take more time replying to the enquiries for the prices for the construction. This happens because there might be no much interest in these small projects. Thus, they are put into second plan. If all the information about the source of the prices will be transferred for the construction, the same organizations will be asked for the prices again. This will allow the contractor receiving the prices faster, once the project was already studied previously by these organizations. This will also help with the subcontractors and suppliers portfolio management.

5.6.4 Construction process

Along this subsection when analysing the construction process, the pre-construction, procurement and the construction itself will be seen as a whole phase. The reason for this consideration is due to, these three phases can be done by the construction team responsible for the project "*in situ*". For the analysis of information sharing and transference, the main focus will be in the "bridge" between the estimating and the construction process, as presented in Figure 5.9. But, should be kept in mind that, information sharing and transference inside the construction team is very important as well. If analysing the information inside the construction team, then these stages should be taken into account. To be more precise, the division should be even more detailed. The "departments" which constitute the team "*in situ*" should be well distinguished.

Scheduling analysis

Above in section 5.4, when presenting the tools, the "vertical" and "horizontal" models were mentioned. When presenting the planning and scheduling tools into 3.5.8, were introduced the features for the ABM and LBM. Recalling what was presented into 3.5.8, the LBM are better suitable for complex projects and with repetitive work tasks. The project used can be inserted into this "group". Also, it was seen that, the LOB is more appropriated for building construction projects and the LSM for infrastructures projects. In the example used, there are some supporting infrastructures and small buildings (Figure 5.5 and Figure 5.7, respectively) for the water supply pipeline system. These are present in all the three sub-projects (A1, A2 and A3). Thus, these structures/supporting infrastructures, for purposes of project planning and scheduling, cannot be considered as being buildings. There are no repetitive works along their development. Their size and materials quantities are also of small amount and they have a low building complexity level. For this reason, these elements will need to be analysed independently, and get together in the scheduling with the "horizontal" elements after.

Starting the analysis with the pipelines infrastructure, the LSM can be used for the works related with these elements. With the LSM, it is possible of analysing the progress of the works through their extension. In addition, the overall view for the location of the "vertical" elements, and their construction time can be also seen. Recalling Figure 3.36 together with Figure 3.37, for example, the lines can be used for representing the pipelines development. The supporting buildings/infrastructures can be represented with the bars. This is expressed into Figure 5.33, where the works related with the application of the pipelines, are represented by the lines. In the bars are represented the supporting facilities. Recalling the example given in Table 3.2, the work tasks in this table are represented in the schedule from Figure 5.33. Again, the reader should notice that the table is not completed. In Figure 5.33 are included the doghouse and the valves chambers, not mentioned into Table 3.2 The given example corresponds to sub-project A1 presented into Figure 5.8. This sub-project is presented into Figure 5.16, where the location for the elements in Figure 5.5, Figure 5.6 and Figure 5.7 is also shown. The consideration for the 50% of rock and soil mentioned in Table 3.2 is not taken into account in the chart of Figure 5.33. The idea is to show some of the works involved and how can the information be used. If considering the percentages mentioned, the sections where the line representing the excavation is steeper should develop through the same distance as the gentle section.

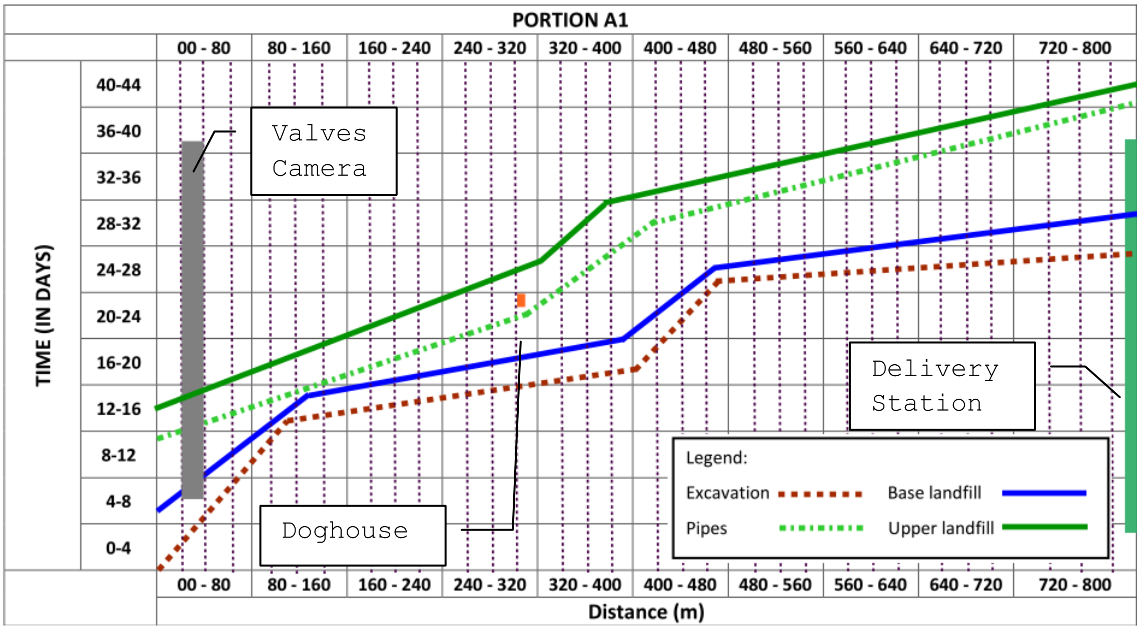


Figure 5.33- LSM example for sub-project A1.

The supporting infrastructure, the doghouse, presented in Figure 5.7 can be represented as a bar. This is a quite simple activity of being executed and thus, no special requirements for the team working on this task are needed. This is also an activity not consuming much time. The possibility for being placed into the schedule is quite flexible. As it can be seen from Figure 5.34, these are precast elements, thus, they just need to be settled in the right place. Thus, if looking into the delivery station from Figure 5.11 and valves chamber (Appendix A.4 e)), the way the bars are presented, may not be the best choice for representing the work progress. The bar can give the idea about the time consumption for these structures. However, with the bar, the work done is still not known. The same happens for the location where the works are being executed. Recalling that, these are elements which develop along their "hight", the location is an important information. If looking in a more generalized perspective, the "vertical" facilities may interfere with the progress of the "horizontal" facilities. Thus, it is important to know when the works for these two elements of the project collide with the pipes.

Since the works are not complex and have small quantities, one team can be doing the works in the supporting structures. The information for the location of the team is not available only with the information given by the bars. Considering the example in Figure 5.33, the team for the steel, for instance can be at the 15th day in the location 20-40 meters. But this same team can be working on other structure in the same sub-project, but at the distance 800 meters. Can also occur, the team be in other sub-project which is not available through these bars and this chart.

Figure 5.34 - Doghouse's air release valve: a) base, b) wall, c) cover and d) the completed element.

In chapter 3, when presenting the LBM, was mentioned in 3.5.8 the lack of suitability for the LSM when applied in buildings. This non suitability can be visible in the example given above. Since there will be a problem in representing the works for these supporting structures through the LSM, other procedure is needed to be found. It was mentioned into 3.5.8 that, LOB for building construction projects is the most suitable. However, despite LOB being possible to be applied, may not be most appropriated for the present situation, due to the simplicity of the facilities. This can be seen from Figure 5.35, where is shown a possible LOB chart for the delivery station (Figure 5.11) and the valves chamber (Appendix A.4 e)).

The author wants to call the attention for one particularity which might bring into a limitation for these types of projects and facilities. In Figure 5.35, for the delivery stations, if the activity "walls painting" was immediately bellow the activity "columns", could give the idea of no existing interference between these two tasks. It can be seen that, these two tasks occur into different levels. However, due to the size and simplicity of the facility (Figure 5.11), the conflict between these two tasks may exist. This is due to, as can be seen from Figure 5.5, there is a small area where the works can be developed.

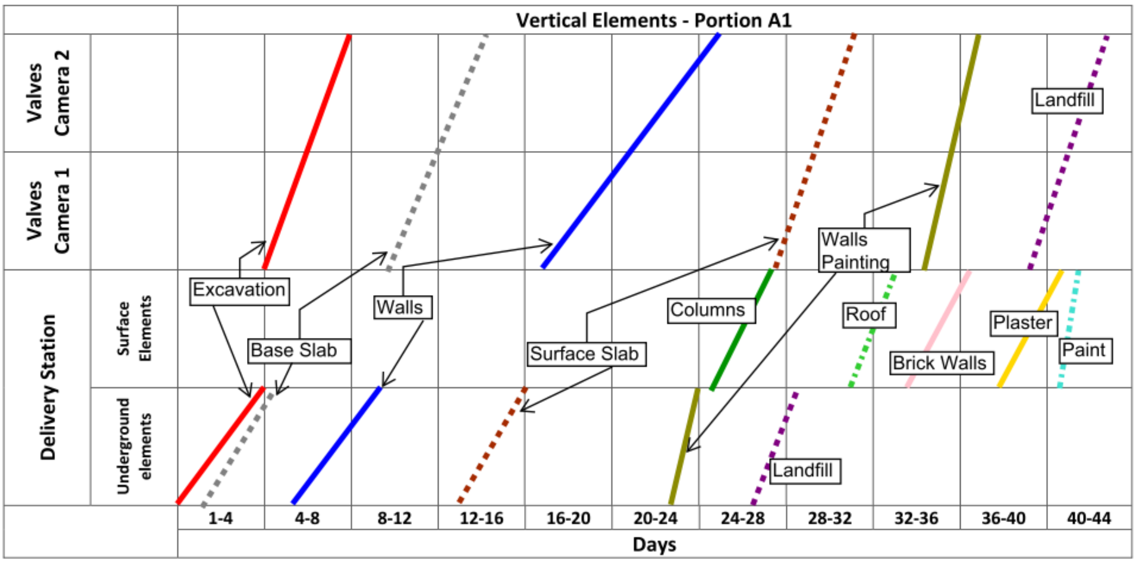
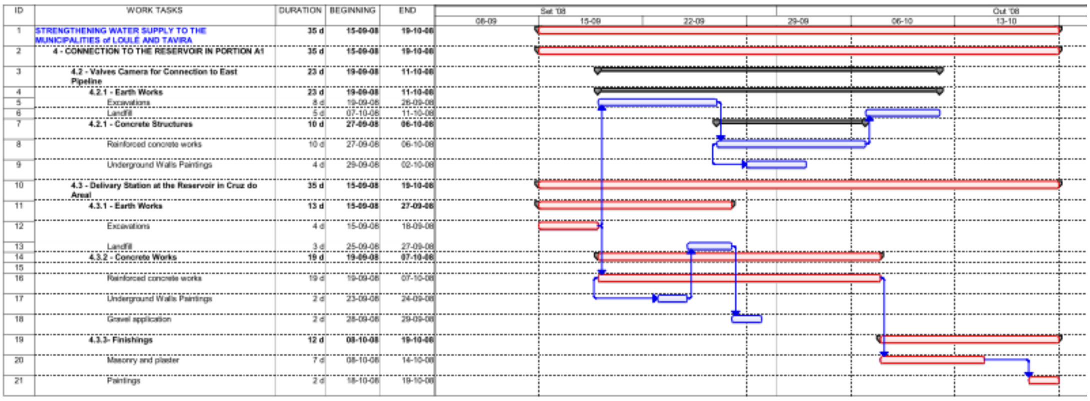


Figure 5.35 - LOB for the supporting infrastructures.

As it can be seen, these "vertical" facilities can be constructed completely independent from the pipeline structure. This allows for programming the construction of these "vertical" elements to occur in different sequences and positions. Taking again the example from Figure 5.33, the foundation slab for the delivery station can be started at the third day. Four days after, for instance, the concrete is placed. The same team responsible for these works can then go to the valves chambers to start the foundation slabs. This example is shown into Figure 5.35, where the team changes between the facilities according to development of the works. In this situation, from Figure 5.33, the information given was that, the works were occurring in both places. If comparing the development of the LOB with the LSM, as presented in 3.5.8, the LOB have a development for the locations along the vertical (the y-axis) and the LSM through the horizontal (x-axis). From the author's perspective, one attempt for getting these together in one chart. This topic will be treated later on in this subsection.

Another possibility, is the use of the ABM. So, maybe the solution of the "Gantt chart" (Microsoft Project uses for example) reveals to be a good option. But, the Gantt chart as presented into Figure 5.36 does not shows the gaps between the different positions for the facilities. It shows a continuous flow of the works, by giving the idea of two teams working in different positions at the same time. For representing these gaps in the works between the structures, the concrete task, for instance, should be split into the components which constitute the concrete works. So, the WBS would look something like:

- Foundation slab;
- Basement walls;
- Floor;
- Columns;
- Beams;
- Roof;
- and so forth.



ID	WORK TASKS	DURATION	BEGINNING	END
1	STRENGTHENING WATER SUPPLY TO THE MUNICIPALITIES of LOULÉ AND TAVIRA	35 d	15-09-08	19-10-08
2	4 - CONNECTION TO THE RESERVOIR IN PORTION A1	35 d	15-09-08	19-10-08
3	4.2 - Valves Camera for Connection to East Pipeline	23 d	19-09-08	11-10-08
4	4.2.1 - Earth Works	23 d	19-09-08	11-10-08
5	Excavations	8 d	19-09-08	26-09-08
6	Landfill	5 d	07-10-08	11-10-08
7	4.2.1 - Concrete Structures	10 d	27-09-08	06-10-08
8	Reinforced concrete works	10 d	27-09-08	06-10-08
9	Underground Walls Paintings	4 d	29-09-08	02-10-08
10	4.3 - Delivary Station at the Reservoir in Cruz do Areal	35 d	15-09-08	19-10-08
11	4.3.1 - Earth Works	13 d	15-09-08	27-09-08
12	Excavations	4 d	15-09-08	18-09-08
13	Landfill	3 d	25-09-08	27-09-08
14	4.3.2 - Concrete Works	19 d	19-09-08	07-10-08
15				
16	Reinforced concrete works	19 d	19-09-08	07-10-08
17	Underground Walls Paintings	2 d	23-09-08	24-09-08
18	Gravel application	2 d	28-09-08	29-09-08
19	4.3.3- Finishings	12 d	08-10-08	19-10-08
20	Masonry and plaster	7 d	08-10-08	14-10-08
21	Paintings	2 d	18-10-08	19-10-08

Figure 5.36 - Microsoft Project schedulle for the "vertical" elements.

The same approach would be needed for representing the valves chambers. For simple structures like the ones presented in this thesis, this may be suitable. However, in an industrial project, for a plant which requires complex buildings and great extensions of pipes, this solution may not be the best one. The best solution for this problem will be the use of 4D planning and scheduling. The example used in this thesis was done by using Navisworks.

Navisworks allows the simulation for the construction along the path of the project. In Figure 5.37 is shown the model for the terrain presented in Figure 5.8. In Figure 5.38 are represented the models for the facilities related with the supporting structures built in this sub-project. These three models were built in Revit and then exported to Navisworks. The model for the terrain and the models for the facilities were get together, so the real location can be seen (Figure 5.39). This link was made making use of Revit, by linking the models for the facilities into the model for the terrain. Thus, the same can be done directly in Navisworks.

For purpose of simulation, was modelled a completely random terrain in Revit and then used this terrain in Navisworks where the facilities were placed (Figure 5.40). This allows for seeing the evolution of the works with the time, as already presented into section 4.3. So, one of the issues is already solved. With this possibility allows for seeing the task in its position and it evolution with the time. It can be said that, the LSM gives the information in 2D, which is the progress of the works along their horizontal development with the time. With this possibility the variable for the height/location is added. The progress of the works can be seen along their positions, through their horizontal and vertical path.

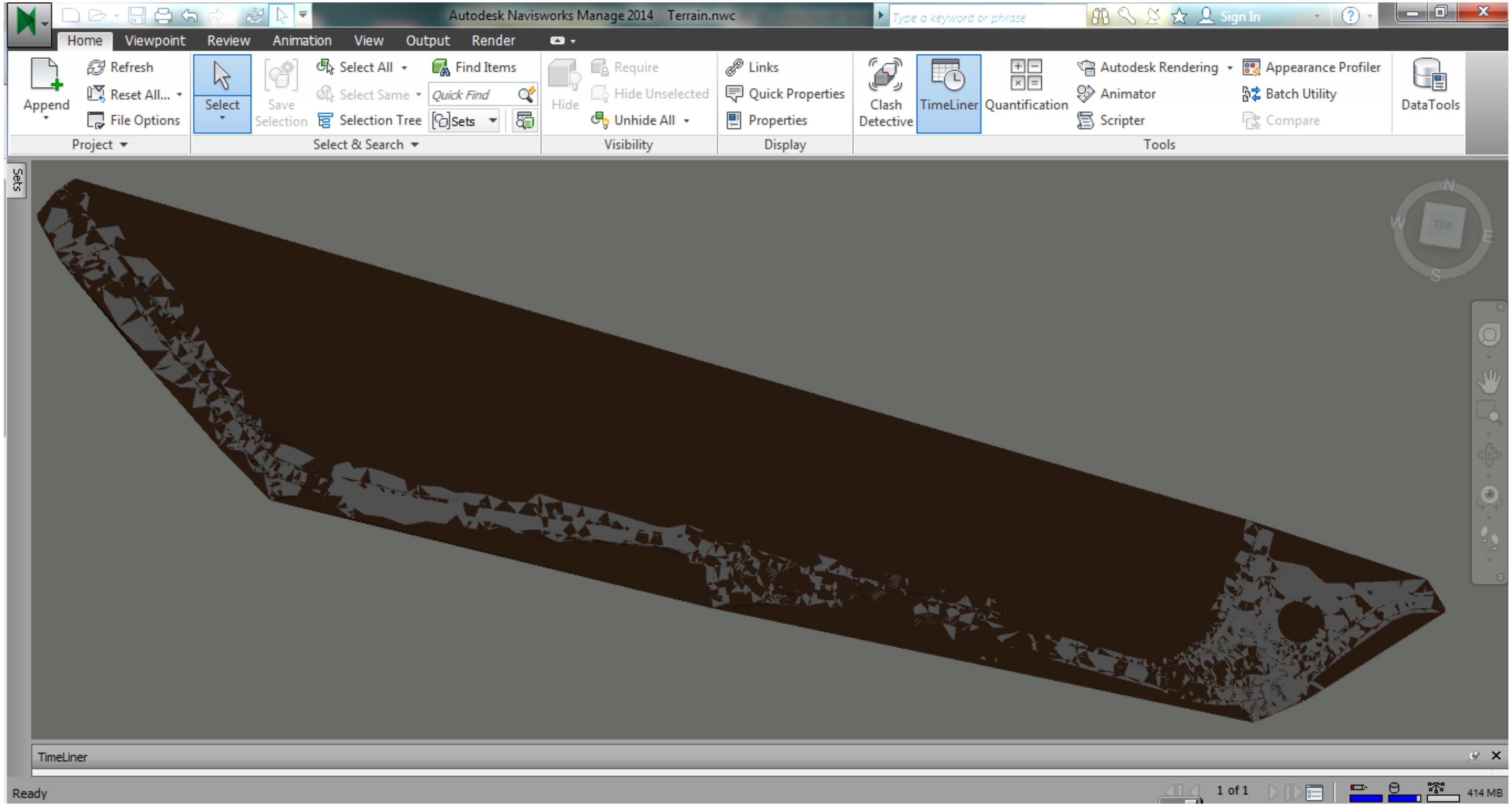


Figure 5.37 - Terrain model for the sub-project A1 into Navisworks.

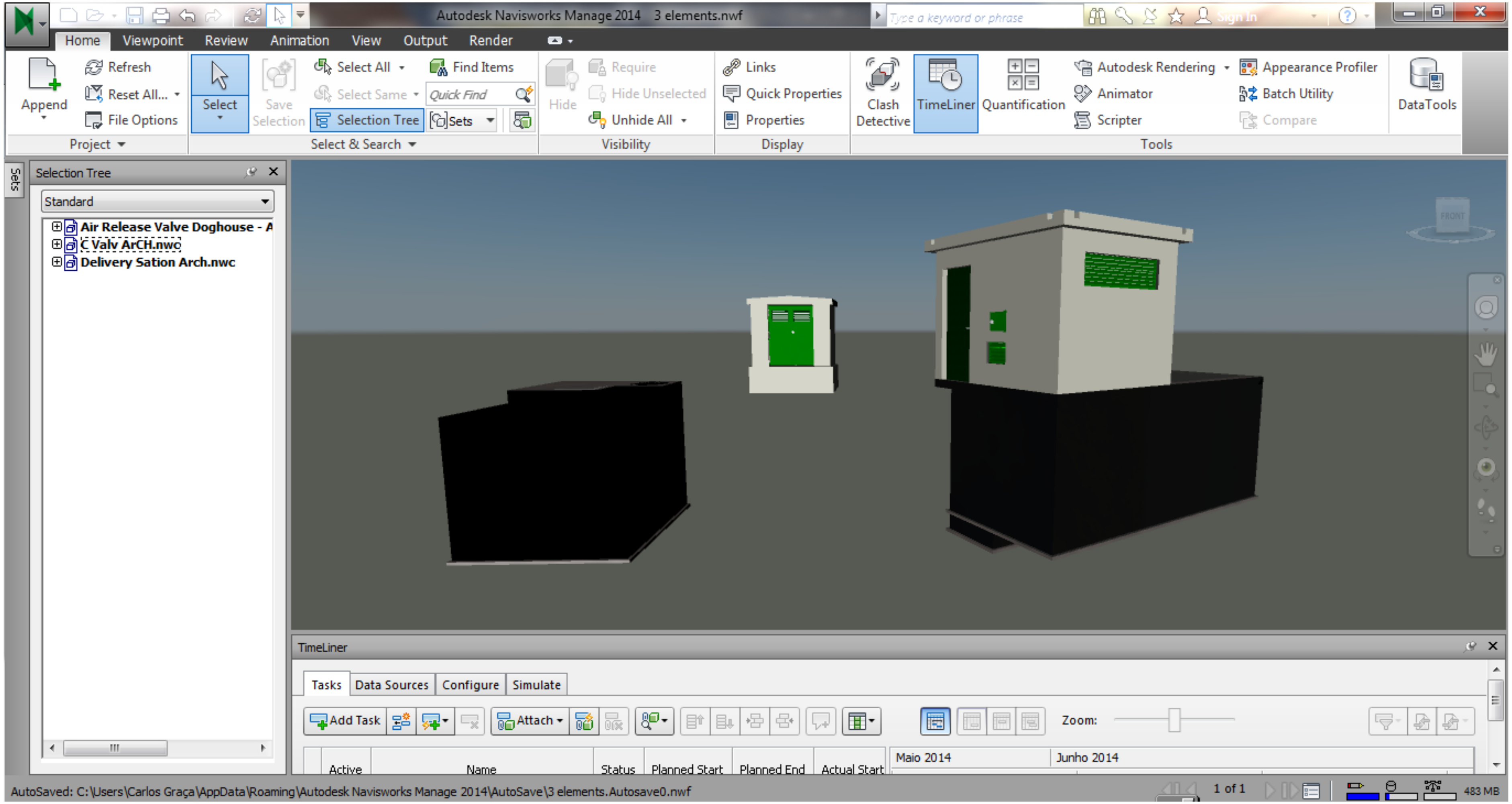


Figure 5.38 - Supporting facilities models for sub-project A1 into Navisworks.

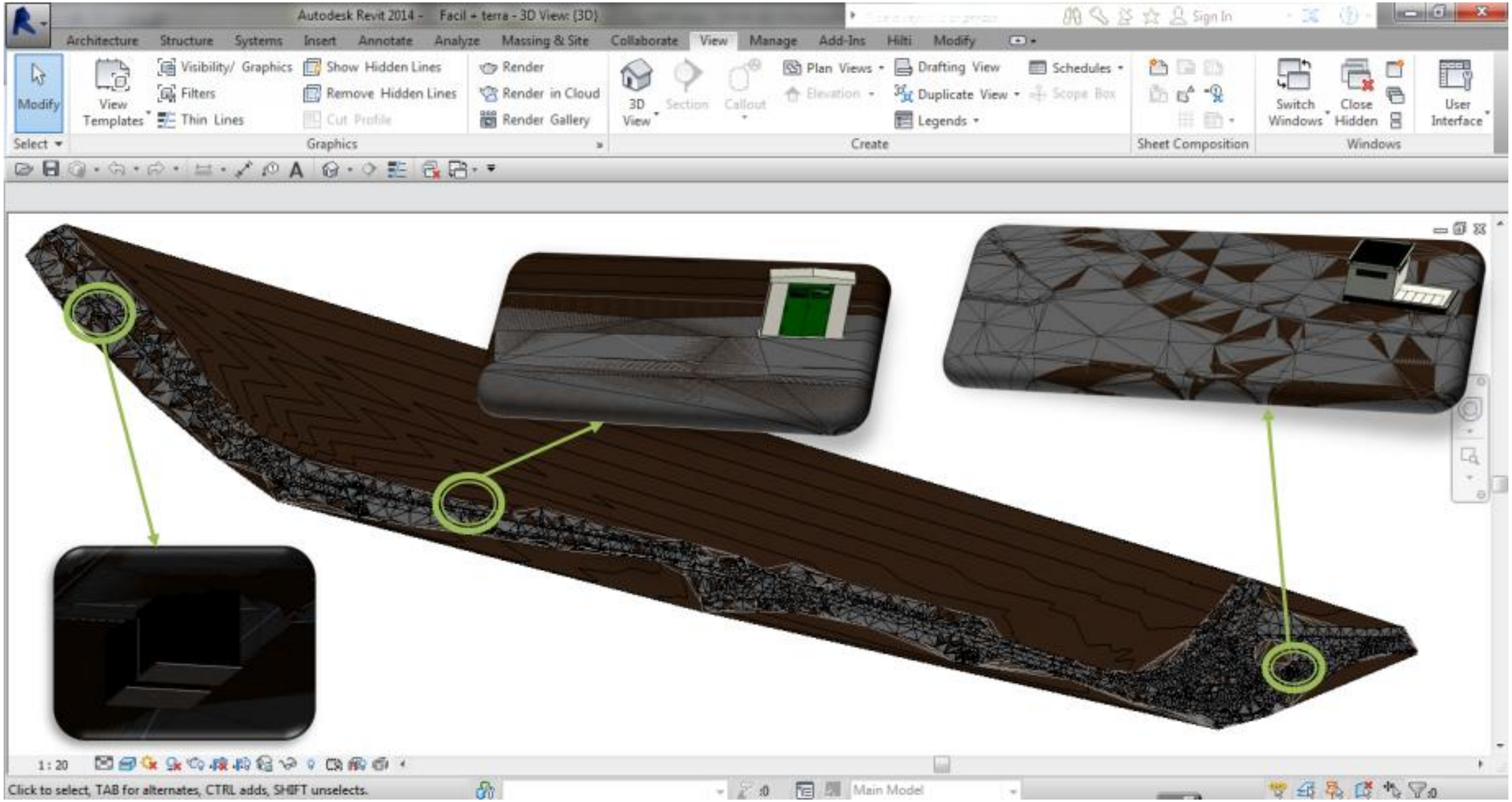


Figure 5.39 - Location for the "vertical" facilities in sub-project A1.

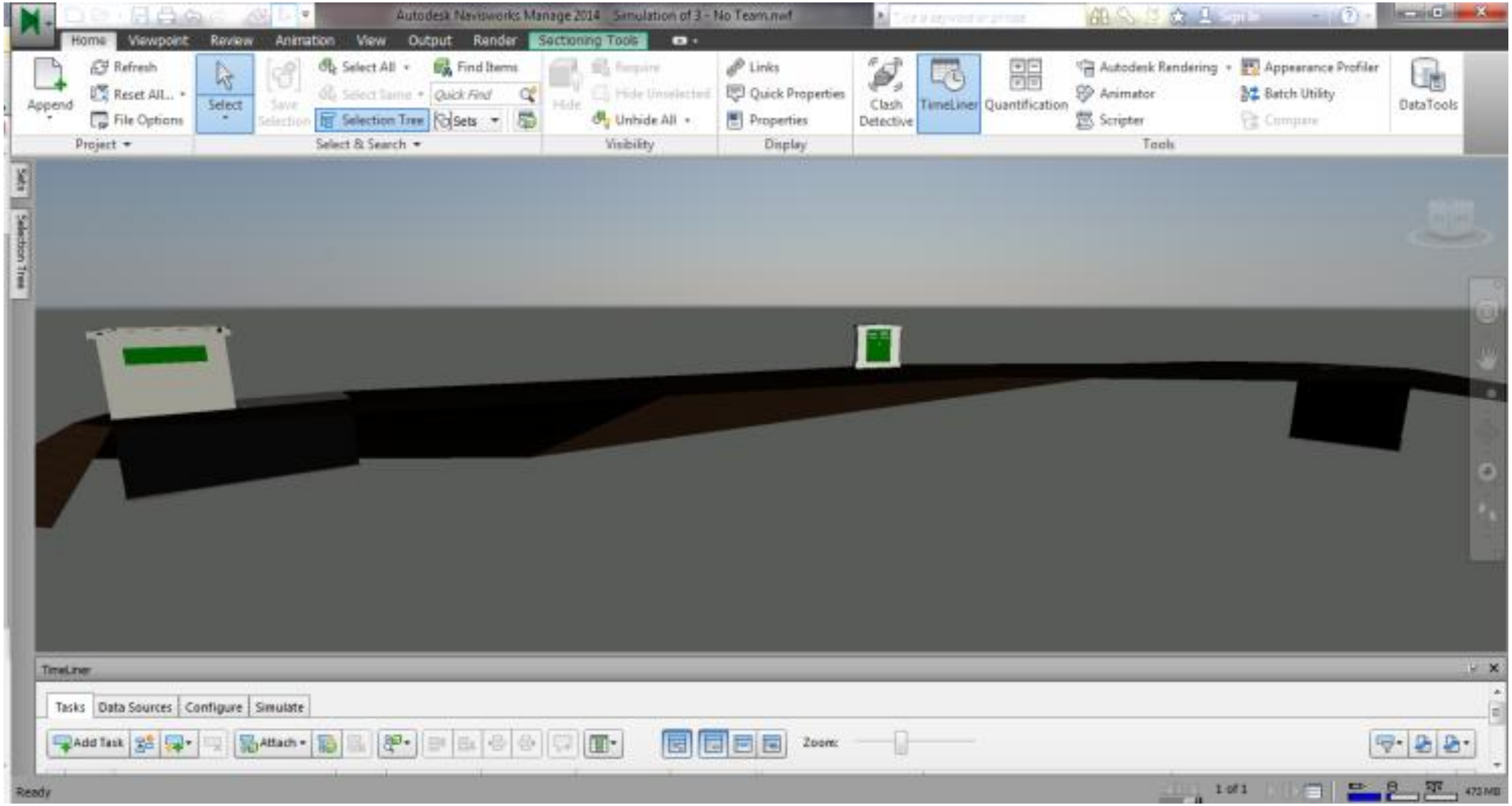


Figure 5.40 - Model of a random terrain with the facilities in Navisworks.

A good example for the application of this concept, are the projects for constructing urbanizations. These projects usually involve the two types of projects mentioned into 3.5.1, i.e., infrastructures and buildings. In the urbanization projects exists the infrastructures for the roads, water supply and waste water, electricity, telecommunications, and so forth. But there are also the construction for single-family houses, small buildings, etc. These are projects which have their main development around that point, i.e., no straight lines are developed for kilometres, as for example roads or pipelines. But, they also have an horizontal development, for the expansion of the area where the urbanization will develop. Figure 5.41 shows an example of an urbanization developed based on a point without horizontal extension but with a considerable amount of "horizontal" works. Again, several scenarios can occur. The first one. the construction for the urbanization is split into the infrastructures project for one contractor and the buildings project for another contractor. The second scenario is, the same contractor be responsible for the whole project. Other possibility is the construction be split into several phases, and more scenarios can occur. Thus, for the first scenario, the problem can solved through using the LSM for the infrastructures and the LOB is used for the scheduling of the buildings. The second scenario will fall into the analysis being done here.

Coming back again to the project used as example in this thesis. By making use of Navisworks, the problem of seeing the position where the tasks for buildings are being executed was solved. However, the second issue, related with the progress of the works by distributing the resources needed for constructing these elements, still needed to be solved. Navisworks do not give the information about the position for the resources Again, two possible scenarios can arise when distributing the recourses. The first one is by using two different teams working independently for the two locations. In this situation, the problem with the conflict between the teams and the non continuous development of the works in the two positions is solved. The works will develop independently and once these are independent facilities, the works can be done simultaneously. But, the use of two teams may not be the best solution. If analysing the costs and the availability of resources, this might lead to conflicts with the plans of the contractor related with the other projects. Also, due to the simplicity of the facilities and the time between the place of the concrete and the cure of the concrete for allowing proceeding the works, gaps in the development of the works will inevitably occur. This situation may lead to the teams responsible for the works to leave this project to work in another one. If the teams will be on the site, this will add costs to the project without any work progress. In the situation the works will be done by a subcontractor, the subcontractor will not allow to have his resources without working. In the most cases, the team(s) are removed from the project, which may bring delays into the project and thereby will increase the costs of the project. Or if the team(s) will stay in the construction site, no work will be produced and thus again, costs will be added to the construction process.

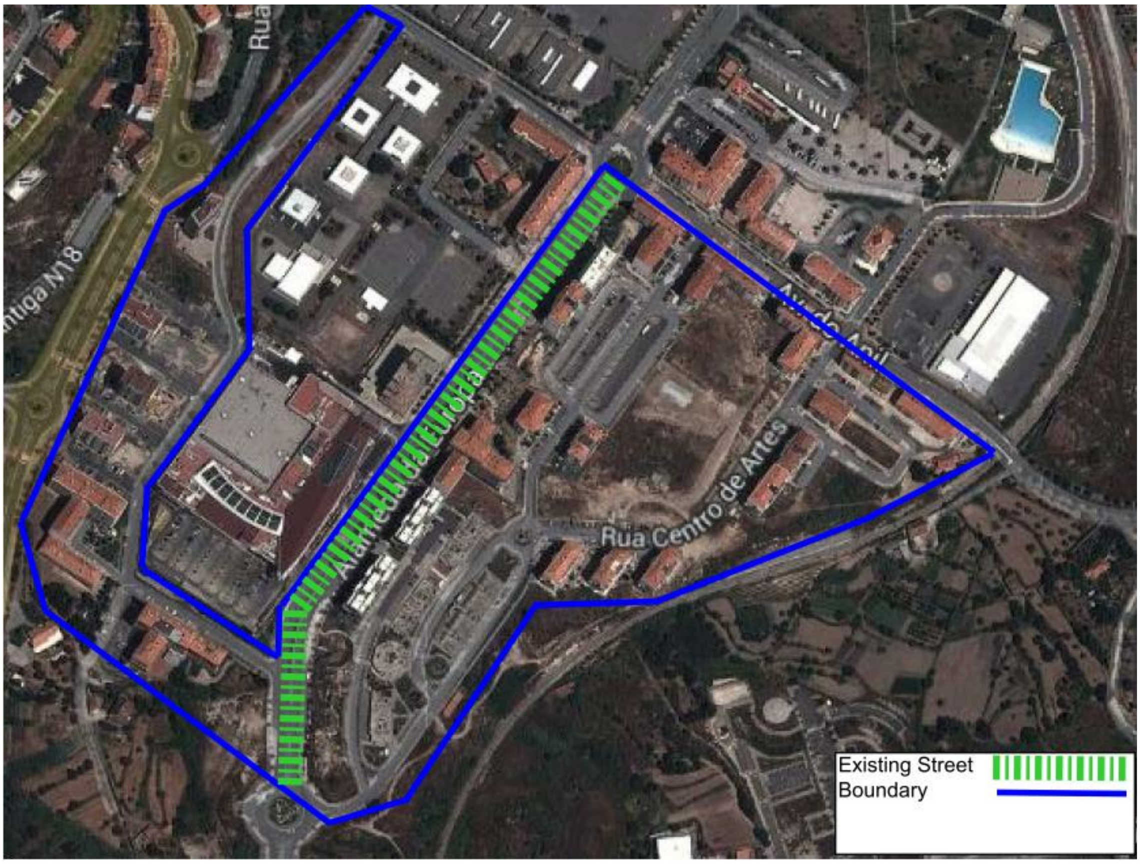


Figure 5.41 - Urbanization with "horizontal" and "vertical" facilities.

The solution of having only one team doing the works for both "structures" seems the most reliable and suitable for this example. Thus, it will become crucial having a good scheduling and planning of the works and the teams, so there will be no delays in the construction time. For this purpose, becomes of extreme importance to, similarly with the variable time and costs added to the 3D model(s), add the distribution of the teams. This "team variable" will add another dimension to the project, allowing to observe and distribute the resources into the facility(ies), with the time and the locations of the project. One example, can be seen through Figure 5.42, Figure 5.43, Figure 5.44.

Figure 5.42 shows the excavation works for placing the doghouse. The E on the top of the location is referring to the excavation team working in that specific location executing the excavation task. It is possible also to be seen from Figure 5.42 that, the excavation works are being done on the fourth day of the first week. The configuration for the visualisation of the time progress can be adjusted according to the needs for the visualization purpose or the way the observer may want.

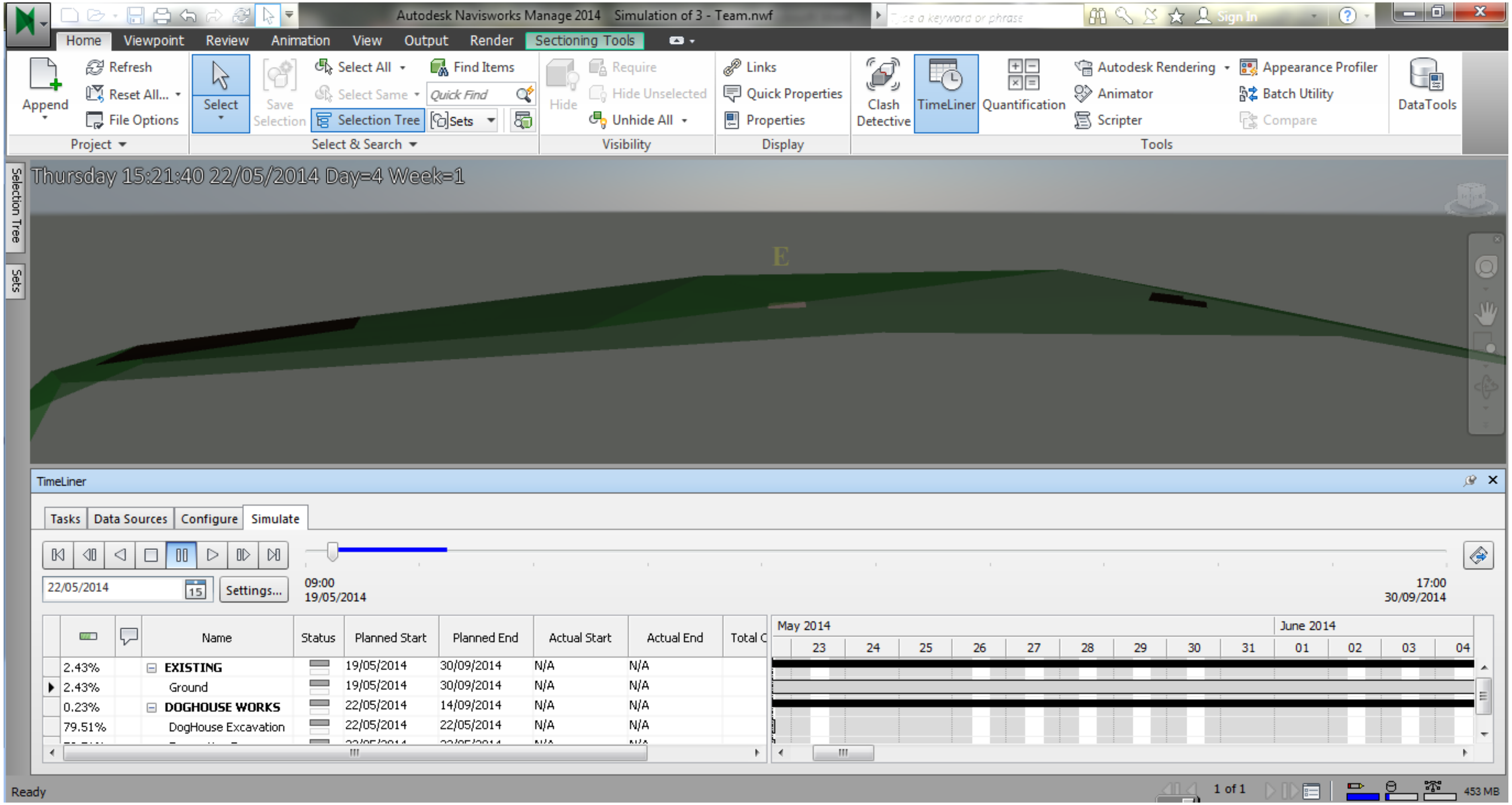


Figure 5.42 - Point in time, in space and with the team executing the excavation works for the doghouse facility.

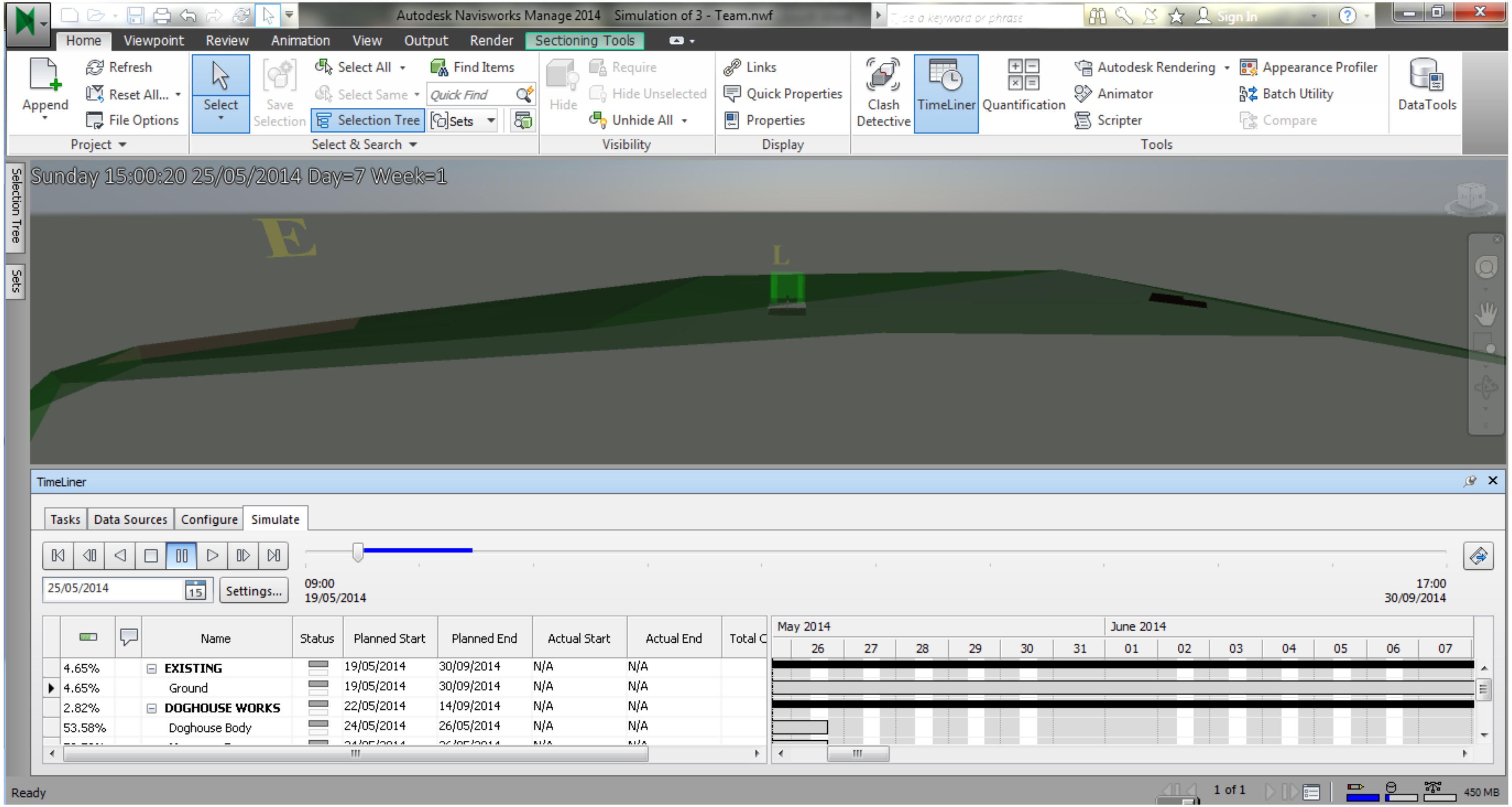


Figure 5.43 - Point in time, in space and with the teams executing the excavation works for the delivery station and placing the body of the doghouse facilities.

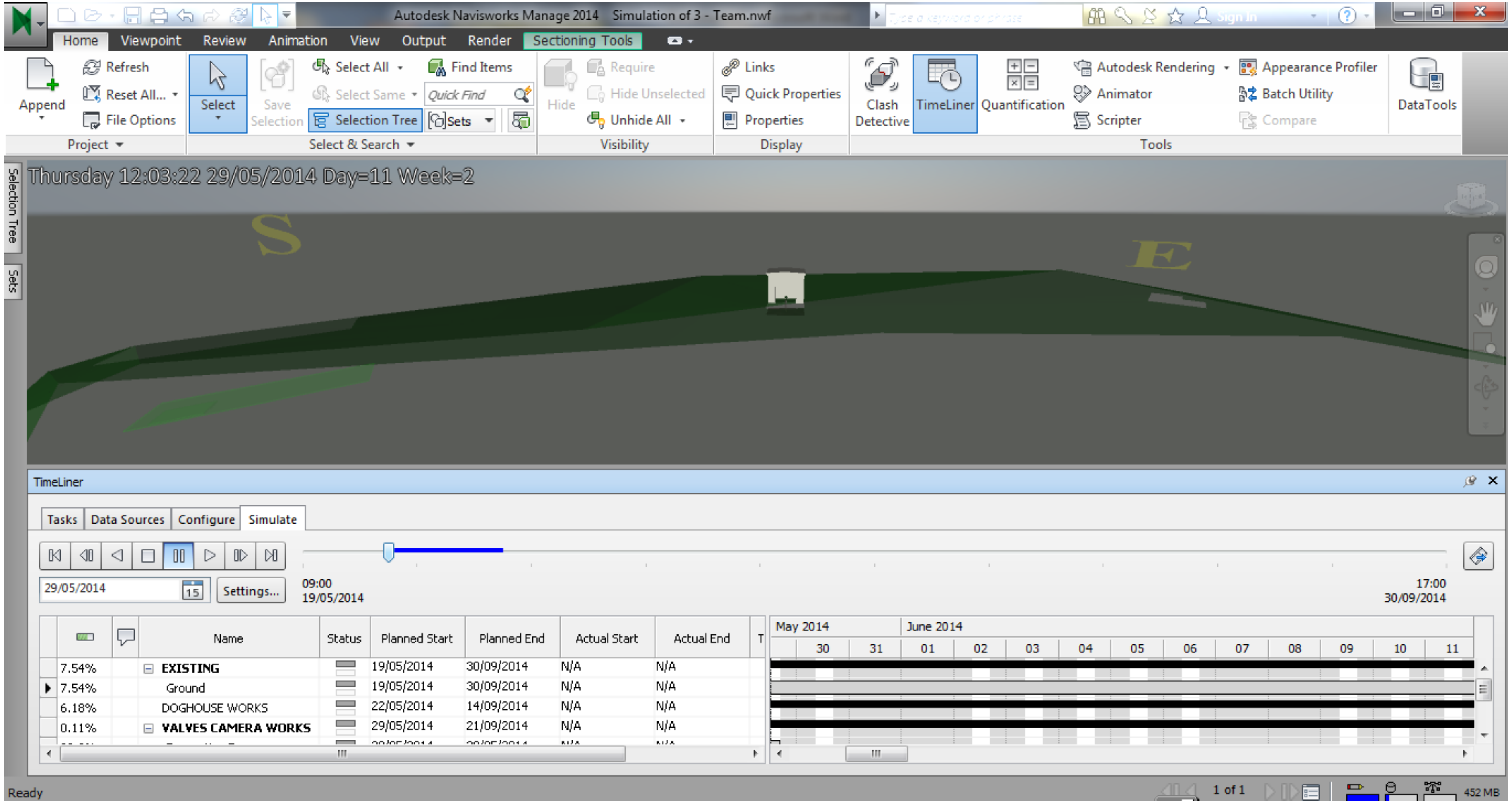


Figure 5.44 - Point in time, in space and with the teams executing the excavation works for the valves chamber and executing the foundation slab for the delivery station facilities.

The author wants to call the attention for the detail into the doghouse, which appears already as if the works were already finished. The idea was to make the painting appear sequentially for the three facilities. Showing the sequence of this works as if was the subcontractor responsible for the paintings. Thus, due to some issues with the models in Revit and the sequence for visualizing in Navisworks, it was not possible to do such contrast.

This visualisation will grant also to the construction manager and all the team involved in the project for planning and managing the contractor's own resources, the subcontractors, equipment and the material placement and distribution.

The analysis with the resources included, will enable the integration of the "iron triangle", presented in 3.5.9.4, helping with the decision making and the risk analysis. This approach, will give the opportunity to the construction/project manager, for simulating and having the control of the three/four variables of the project. It was seen in the "iron triangle" the way costs, quality and time are related between themselves. It was also shown that, the costs are highly related with the materials, subcontractors, equipment, labour and with the productivity. But, the materials are a factor which have the costs fixed after the agreement with the supplier. There is nothing in the project that will affected by the costs of the materials, after its price has been decided. Thus, no changes are possible to be done in the costs or in time by "playing" with the materials.

To control the time, the productivity needs to be changed. The way the productivity can change, is changing the constitution of the teams and their distribution over the project. The introduction of the teams may allow for this simulation by placing the teams, defining the teams and checking their productivity. The construction/project manager will have the chance for simulating how the variables into the "iron triangle" will be affected. This will help in the decision making, once the construction/project manager will be able to see how these variables will be affected. For instance, imagining the project is going out of the rail in the time and the costs. The construction/project manager can simulate several scenarios. This will help to find the one which may reveal to be more favourable for getting the project again back into the rail. How much it will cost and the way the teams are needed to be built for increasing the productivity.

As it has been presented, LSM and LOB charts by their own, do not give the best perspective on the overall planning and schedule for these type of projects. It is missing the coordination between the teams for the infrastructures facilities and the buildings. If looking into how these charts provide the information, it is possible to see that, both of them give the progress of the works with the time. These charts also give a similar visualisation as BIM's software for scheduling. For instance, as presented, Navisworks provide a visualization of the works progress, for the work tasks, with the time, in a certain location. LSM and LOB give exactly the same information, for the work progress with time. For the LSM, it can be seen the work tasks represented by the lines, developing over the time (in the y-axis) and with the distance (the x-axis). The same is valid for the LOB, thus, the time is represented by the x-axis and the location in the y-axis. To be able of seeing the development of these two types of facilities the possibility for merging these two charts ,may be a solution. Since the axis for the time is common to both of them, the LSM and the LOB can form a 3D chart by sharing the axis for the time. A suggestion is given in Figure 5.45. As it can be seen, if looking into the plane Location *vs.* Time (LT), the LOB can be analysed alone. The same happens if looking for the plane Distance *vs.* Time (DT). The LSM chart is also visible, being the time-axis in the opposite direction to the presented in Figure 5.33. The bases for the example in Figure 5.33, are the examples given into Figure 5.16 and Figure 5.35. The legend for the colours is the same as for the mentioned examples. When looking to the chart in Figure 5.45, the reader should keep in mind that, this is a simple sketch for presenting a first solution and for a first approach as well. The visualization, and presentation needs to be treated and worked, to improve the perception.

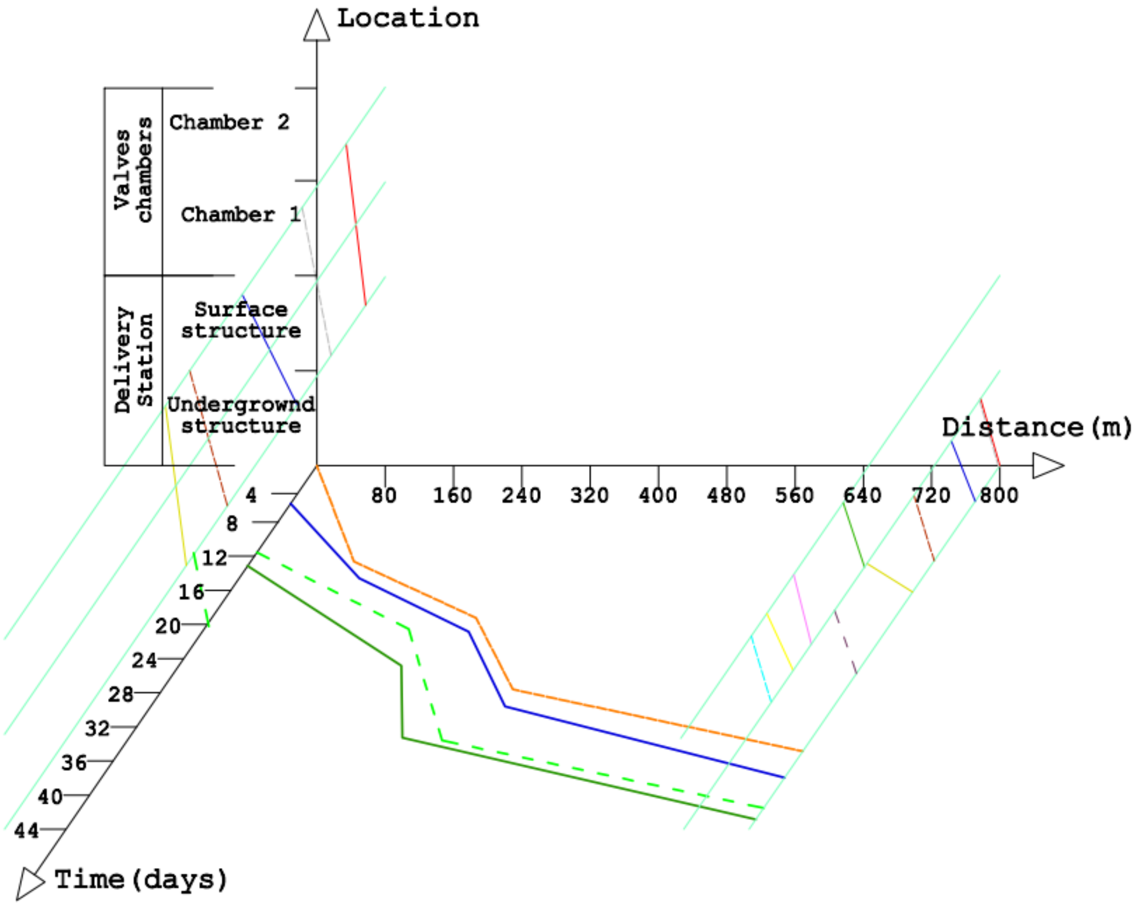


Figure 5.45 - 3D visualization for the LOB and LSM in sub-project A1.

The 3D scheduling chart will provide the project/construction manager the independent analysis for both types of projects. To check the collisions between teams working in the buildings, the LT place can be used. The same can be done for the infrastructures, in the DT plane the development of the works can be studied. For checking possible incompatibilities between the two "types of projects", the 3D chart can be used. If looking into Figure 5.46, it is possible to be seen the excavations for the valves chambers do not collide with any of the works for the pipelines. Thus, the base slab will interfere with the works for the placement of the pipes and it's landfill. The same analysis can be done for the delivery station. The plaster and the paintings for the delivery station may interfere with the works for placement of the pipelines.

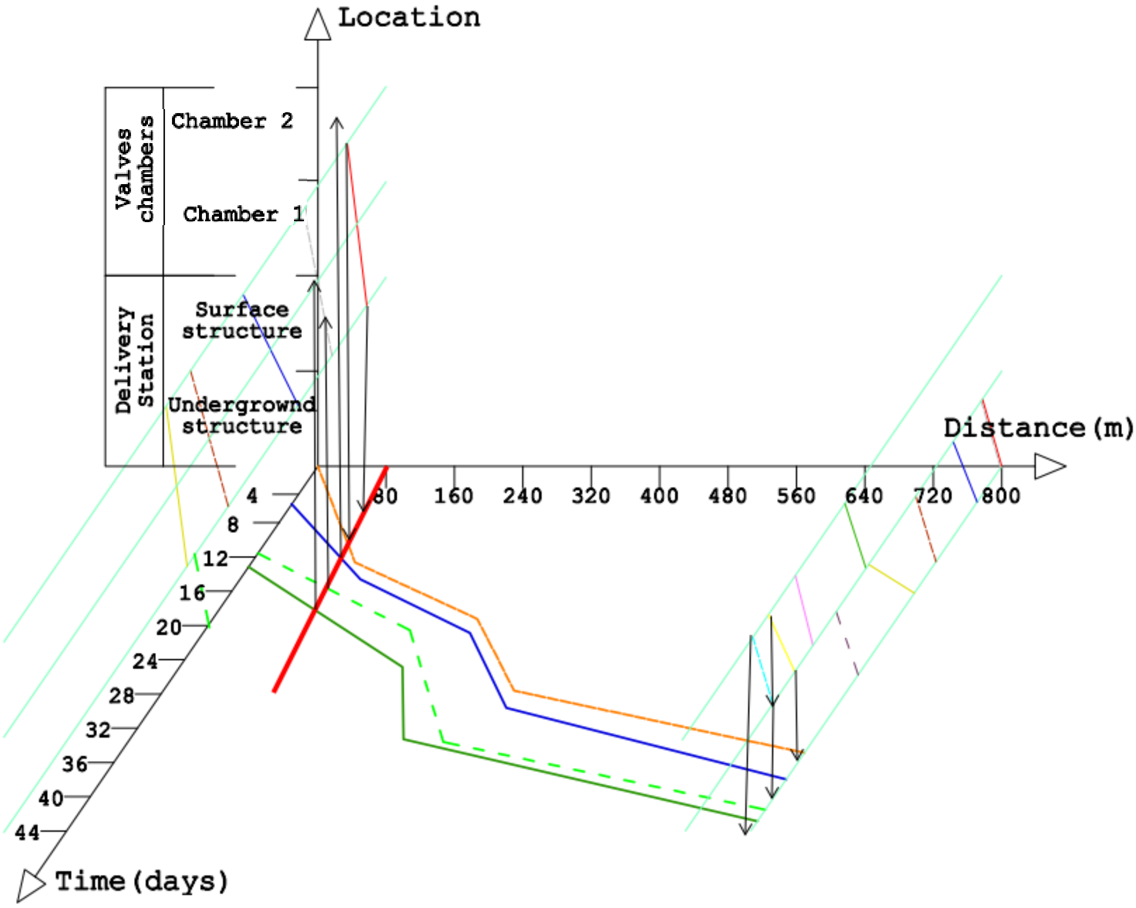


Figure 5.46 - Chart analysis for superposition of the works involved in the project.

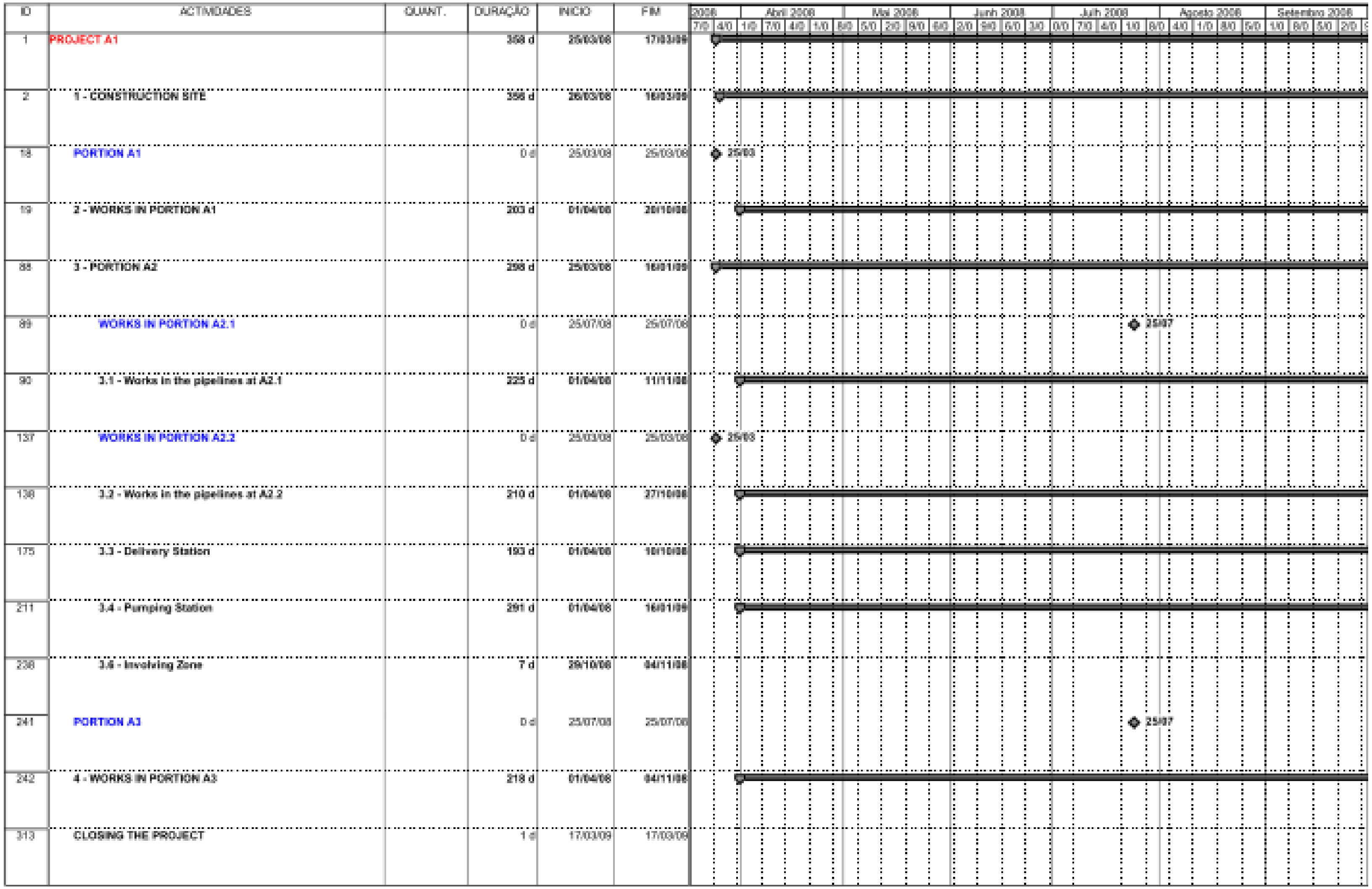
So far, the analysis done was only considering that there is only one pipeline. But, from the author's experience, in these type of projects there are usually more than one sub-project. Also for example in roads/highways projects there are some sections or parts which may follow other directions. Some examples of this are the exits connecting to the existing infrastructures or the intersections. Into the industrial projects, may also occur having different subprojects, for the distribution of the pipelines. So, there is the need to analyse the sub-projects existing in the project together. With the use of the software as Navisworks for instance, this issue might be easy to be solved. As presented previously, the 4D BIM software enables for the simulation in several different places at the same time. However, if the information needed to be analysed is too big, there might be an issue in putting the parts of the project together into Navisworks. This might be a limitation of the software.

The analysis for two pipelines in different locations is not possible to be done using the LBM scheduling charts. The Gantt chart can give the possibility for visualising the different subprojects contained into the project. This analysis becomes quite easy once they can be put together into the same chart. In Figure 5.47 is presented a small part of the scheduling from the project used, with the summary tasks. As can be seen, all the sub-projects are represented in the Gantt chart. Thus, the Gantt chart presents the limitations already mentioned before. Next, will be presented some ideas for solving this issue though the LBM.

The LOB chart allows for the same type of analysis as the Gantt chart presented in Figure 5.47. With the LOB it is possible of observing the schedule for several buildings at the same time in a unique chart. Thus, a simultaneous analysis can be done for all the buildings. As can be seen into the examples Figure 3.38 and Figure 5.35, two and three facilities, respectively, are being analysed into the same chart. This brings the possibility for organizing the teams for all the buildings of the project. The chart is built in a way, the buildings share the same axis for the time and being represented in the axis for the locations, the levels of the buildings.

To see the progress of the works for more than one sub-project of infrastructure facilities, the same consideration, as in the LOB, can be used. The idea is to insert the several subprojects of infrastructures into the same LSM chart. One idea for this approach can be building the chart in a similar way to the LOB chart. The several sub-projects can share the same axis for the distances. A simplified scheme for this approach is presented in Figure 5.48. With the chart presented in Figure 5.48, it is possible to see the development of the works for all the pipelines at the same time. The project/construction manager can see which of the sub-projects is late in the progress or in advance. This can give a very important help in choosing the measures to get the project back on time again. For instance, knowing what is the sub-project with problems, the recourses can be directed to that sub-project, from other position.

If including the all the sub-projects of the project into one LSM chart, as presented in Figure 5.48, a similar analysis can be done for all the infrastructures sections.



ID	ACTIVIDADES	QUANT.	DURAÇÃO	INICIO	FIM
1	PROJECT A1		358 d	25/03/08	17/03/09
2	1 - CONSTRUCTION SITE		356 d	26/03/08	16/03/09
18	PORTION A1		0 d	25/03/08	25/03/08
19	2 - WORKS IN PORTION A1		203 d	01/04/08	20/10/08
88	3 - PORTION A2		298 d	25/03/08	16/01/09
89	WORKS IN PORTION A2.1		0 d	25/07/08	25/07/08
90	3.1 - Works in the pipelines at A2.1		225 d	01/04/08	11/11/08
137	WORKS IN PORTION A2.2		0 d	25/03/08	25/03/08
138	3.2 - Works in the pipelines at A2.2		210 d	01/04/08	27/10/08
175	3.3 - Delivery Station		193 d	01/04/08	10/10/08
211	3.4 - Pumping Station		291 d	01/04/08	16/01/09
238	3.6 - Involving Zone		7 d	29/10/08	04/11/08
241	PORTION A3		0 d	25/07/08	25/07/08
242	4 - WORKS IN PORTION A3		218 d	01/04/08	04/11/08
313	CLOSING THE PROJECT		1 d	17/03/09	17/03/09

Figure 5.47 - Part of the total schedule for Project A.

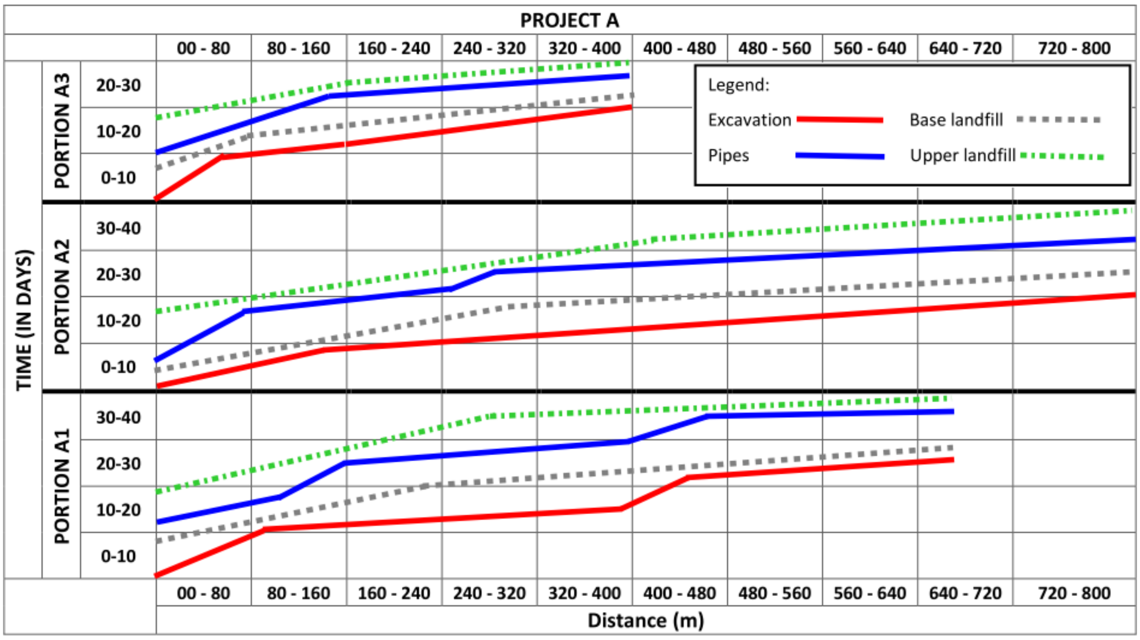


Figure 5.48 - LOB for the three sub-projects of the project A.

Cost analysis

When coming to the cost analysis, having the variable for the teams, as presented above, gains even more importance. As seen before, the productivity depends on the constitution of the teams. Thus, the teams will have influence in the time when executing the tasks and consequently in the costs. Scheduling software gives the change to follow the costs of the project with the time. Navisworks, for instance, allows for the visualization of the costs over the time, with the progression of the works. In Figure 5.49 and Figure 5.50 are presented two examples for the costs with the project progression. As can be seen in these figures, the total costs can be presented. Also the costs for the groups of the recourses can be seen. Thus, the costs presented for the resources are related with the total costs. This is a good tool for checking if the costs meet the initially estimated. For the owner for instance, gives the opportunity for checking how the costs will vary with the time. Thus, the payment plan can be prepared. The same can be said for the contractor. However, if the costs are running out of the rail, there is no possibility for checking the source. With this format, gives the idea of being a software more suitable for checking the costs in a primary stage. When it comes for a more detailed analysis, may not be such a powerful tool.

With the introduction for the variable of the teams a more close and accurate control can be done. For instance, when looking into the schedule, Navisworks allows for checking the initial schedule with the actual progress of the works (Figure 5.51). The same idea could be implemented for the costs.

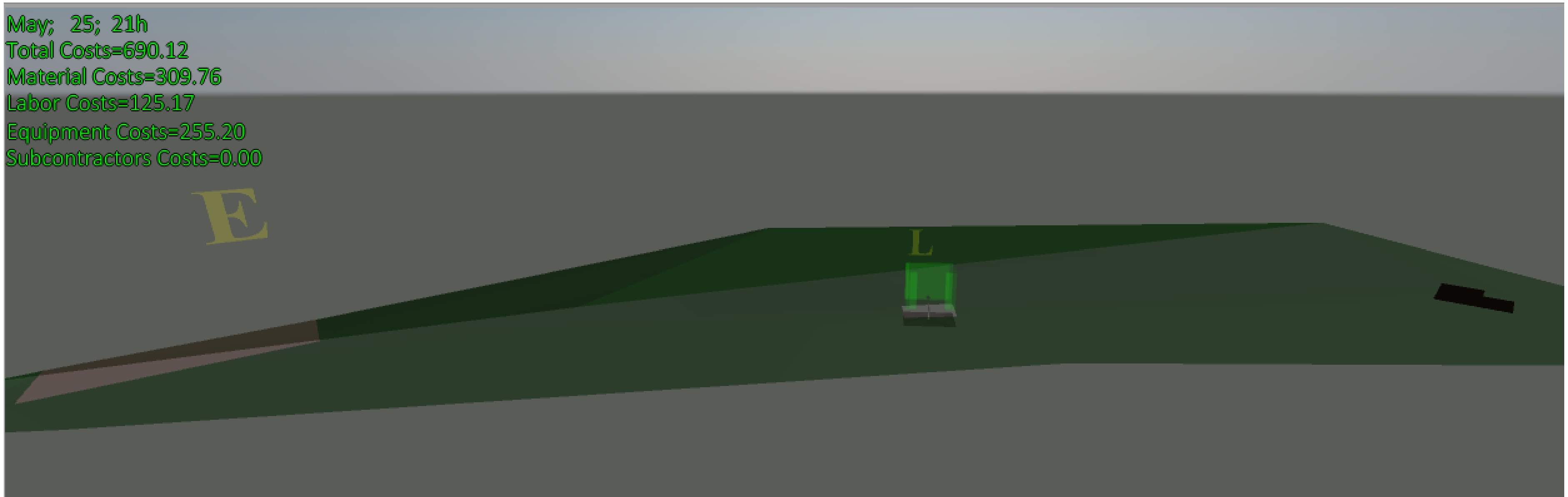


Figure 5.49 - Construction costs in 25th May.

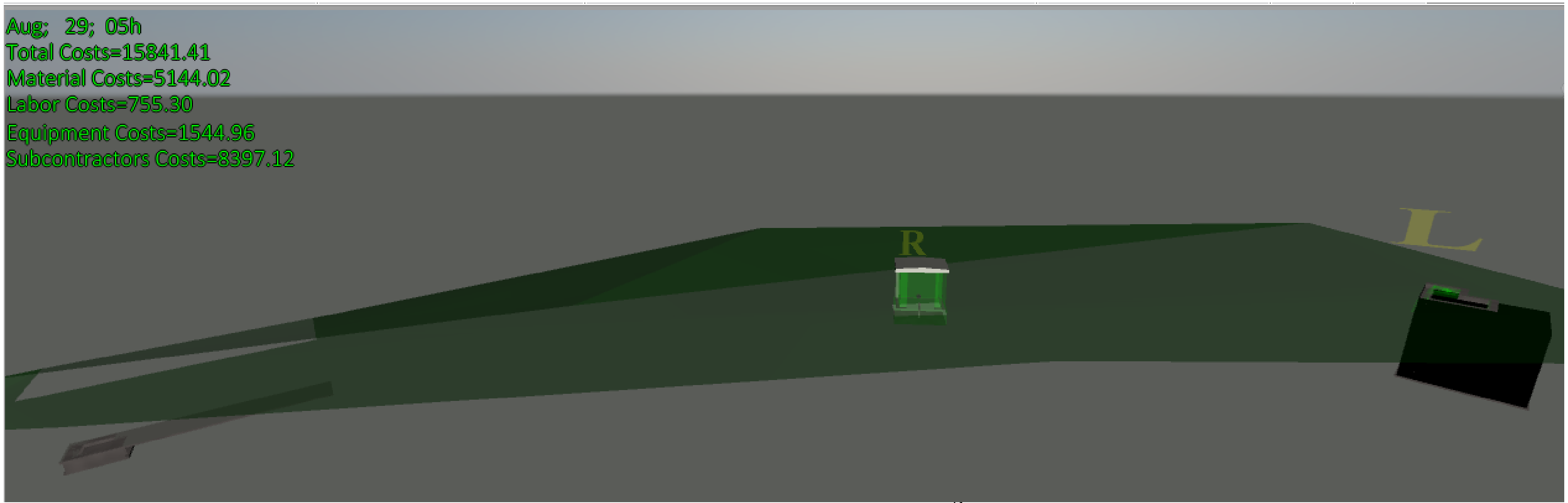


Figure 5.50 - Construction costs in 29th August.

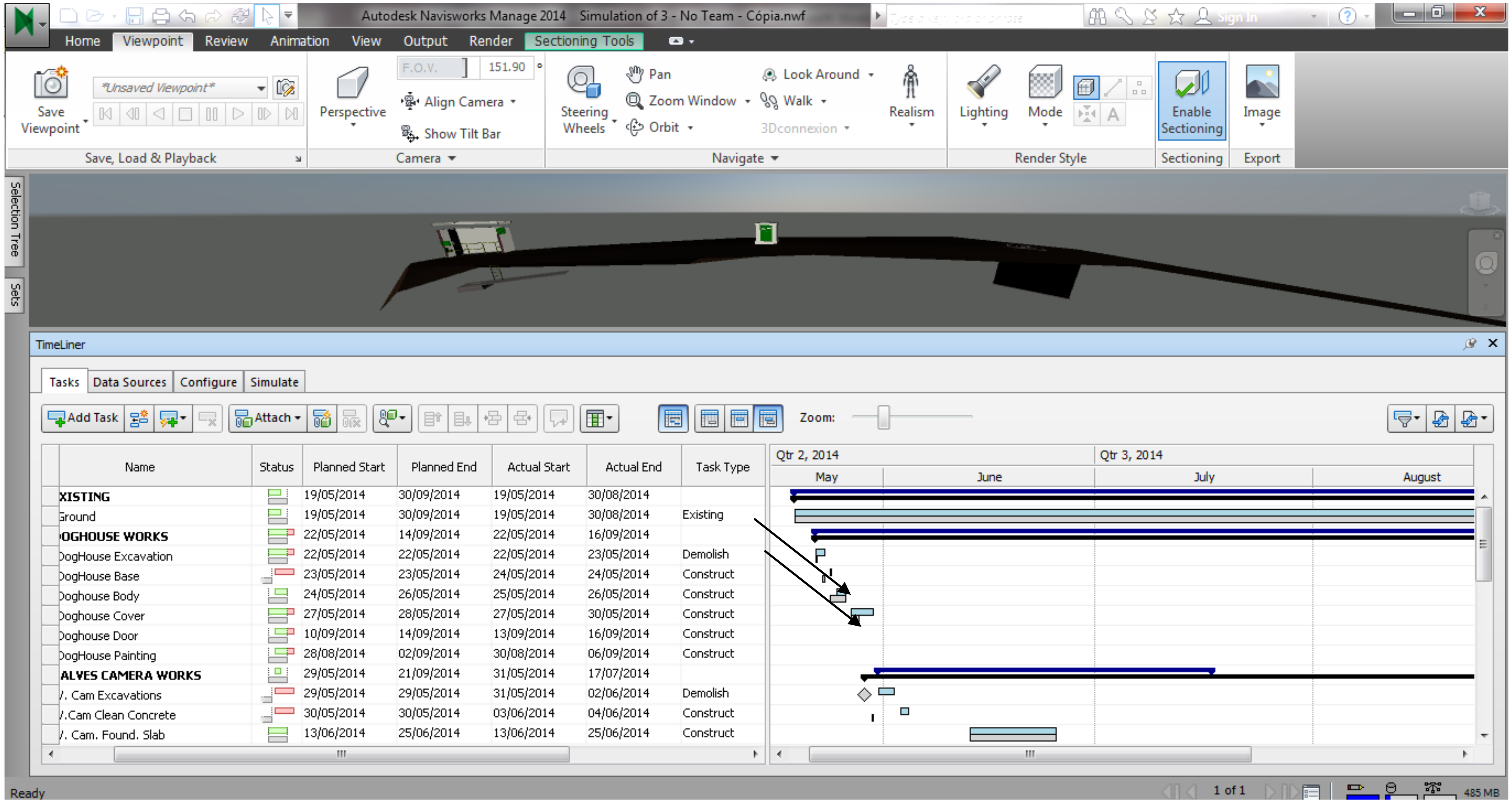


Figure 5.51 - Scheduling comparison for the initial and actual schedule.

Closing the project and the reports

When all the works are finished, and the contractor closes the project, should the produced a report about the project. This report should contain all the information about the progress of the works during the construction process. For instance, information about the subcontractors, suppliers, teams, problems, and so forth. BIM can give a useful help in producing these reports. Along the construction process, the changes of the project will be automatically "recorded". As mentioned earlier, BIM will for itself transport the information.

From the author's opinion, the importance for these reports has two purposes. The first and most important, to serve as "real" database for the estimating department. The second one for the work file and future references. The database for the estimating department can help producing more accurate estimations and with better quality. In 5.6.3 was mentioned a statement made by Jackson (2010) which refers to estimating the project as "an educated guess". The question can be made now is: "And if this "educated guess" can be transformed into a more "precise estimation". The solution for this problem, may rely in the information returning to the estimating department.

In Table 3.2 is mentioned the excavation for trenches in rock and in soil. Also in the same table, in the item 2.1 and 2.2 is mentioned the automatic joints and locked joints respectively. In these two pair of parameters will occur different productivities. The excavation in rock will be slower than the excavation in soil. The same happens for the pipes, being slower the application in the locked joints, then for the automatic joints. This can be visible, for instance, into Figure 5.33. In the distances 0-120 and 400-460, there might be the location for the excavation in rock and for the pipes with locked joints. Just to mention, the location for the rocks is totally independent from the location for the locked joints. From the charts it is possible of knowing the productivity in these four conditions.

The information for the productivity together with the constitution of the teams can be used to adjust the prices for the same type of projects/tasks. This information can be also used when deciding the prices, based on the "iron triangle". Knowing the "real" data, the decisions can be taken based in fundamental and concrete information. So, the risk when deciding some prices decreases as well. Another advantage is, in the absence of given prices, a more real source of information can be used. Instead of using information from previous estimated projects, the information for the real prices "*in situ*" from a finished project can be used. The uncertainty for the accuracy of the previous estimated prices will be smaller. Once the result from these previous estimated prices is unknown, the risk for being used bad prices again is greater.

The costs, when estimated through the "individual" resources, the labour, equipment, etc, the productivity and resources allocated play a very important role. With an updated report in BIM, also the costs for the resources can be updated.

So far, only big projects were taken into account. Thus, a good sharing and transferring of information can be the major part in the success for small projects. If considering projects with durations less than six months, the time for correction possible errors, mistakes or deviations is almost inexistent. Also, the time for preparing the works "*in situ*" is very short, once all the works of the project should to be prepared when the construction "*in situ*" begins.

The success for these tasks is dependent from the information which arises from the estimating department. But, this quality for this information, as it has been saw, is dependent on the feedback coming from the construction site.

6 Discussions, Conclusions and Future Perspectives

*In this chapter will be discussed the study and analysis made into the chapter 5-"*BIM Technology in Project Management and Construction Management"*. The conclusions will be taken by having the discussions as support. After the be presented the future perspectives. These will serve as a reflection about the current situation. Some suggestions for possible studies will be presented, together some final ideas for the future.*

6.1 Discussions and conclusions

BIM is a new approach that promises to revolutionize the methods, procedures the way the construction industry approaches the project. BIM is described by many as a tool which enables collaborative work and is capable of carrying all the information of the project in it. It is known that information sharing inside the contractors is not very well done. Is this lack and bad collaboration and sharing of information, the responsible in some part of the losses in the contractors. This project intended to study how BIM can contribute for improving this process. The organizational aspects for the construction organizations were also seen in this work.

When searching for information about BIM, it is possible to be found a great amount of information. However, very few or none information can be found for infrastructure projects. Thus, a first approach was taken here for applying BIM to infrastructure projects. From the existing information about BIM and respective tools, it was the intention to see how the existing tools can be used in infrastructure projects. What are the needs and how can BIM be improved for infrastructure projects.

Adapting to BIM

BIM is highly praised and known for being a collaborative tool. This is one of the references used when referring to BIM. A new delivery method (IPD) was developed to boost this feature. Thus, for the public construction sector, the collaborative feature may never become possible of being used. Due to the legal issues, especially between the designer and contractor this collaboration may not become possible. However, inside the companies or organizations involved in the same process, this feature might be valuable.

Introducing BIM into the organization will lead to internal changes and adaptations. A new department should be created, the BIM department. This department has to work as the connection between the company's departments. All the departments involved in the projects, should be linked to BIM department. The structure, organization, methods and procedures inside the company will have to change to adapt to this new reality.

The adaptation process may bring some problems to the employees, due the new methods and processes of working. One of the solutions to face the problem may be the integrating BIM gradually in the projects.

This may help the integration in the processes, through a more smooth transition. Other option, can be working in close cooperation with the universities. This can help giving the first steps for the integration in this new system. Open minds, with fresh ideas and no work processes or methods acquired may be easier to help in the changing process.

Managing the project

When the contractor make the decision of tendering a project, the goals for the project are defined. This is where the information for the contractor starts being build. In this phase, also begins the management process of the project by the contractor.

When managing the project inside the contractor company exists two crucial moments for achieving a successful project. These moments are when the information is shared and transferred between the two main phases of the construction stage. The estimating department giving the project to the construction department is the first moment. The construction department closing the project and returning the information to the estimation department, is the second moment. The information in when closing the project, should never be left, but used as knowledge source for future projects. The information should flow like a continuous cycle.

The estimating and construction department previously worked in a more vertical "hierarchy". The information was created in the estimating phase and left for the construction phase. Finished the construction works the information was left and lost. With BIM, the estimating and construction departments will work in a horizontal "hierarchy". Being linked through BIM department will enable the departments to work in collaboration. The information will be added, updated and shared through BIM. This collaborative work will help preparing more accurate estimations.

Producing information for data query to be used, would result in a great amount of paper. With the information in paper difficulties can occur in finding the information needed. This can reveal to be extremely time consuming. BIM can give a significant help in reducing the amount of paper, thus the amount of waste. Since all the information is kept, a better approach to the construction process can be done. Thus, may be possible to increase the work efficiency and quality, so, profits may be achieved.

Estimating the project

When tendering, the contractor should take into account the type of contract. The type of contract will have influence in the final results. The strategy considered when tendering should be defined based on the contract type and delivery method. This is an information should be passed to the construction department. With the possibility for BIM collecting and transporting the information, the approach to the project for tendering can be easily added and be shared.

The process of estimating the project for tendering should be elaborated with a high level of detail. All the resources and productivities should be featured and presented. The same should be done in the construction process when controlling and monitoring the project. This level of detail is very important for the success of the project(s). The way, the quality and the level of detail are shared and transferred between the departments may be the key for the success of the project.

For estimating, it seems to exist good software which can import the information from the models. Then, the estimating process can be done in high level of detail. However, when exporting the information created along the tendering process, there is a lack in resources to collect the information with the same level of detail.

Construction process

Along the construction process all the information added will be kept in BIM's pool. A constant updated and accurate information about the changes in the site is obtained. When closing the project, colleting the information becomes an easy task. Thus more complete and accurate reports about the construction process can be built. The quality and accuracy of this reports should be used when estimating the next projects. Making use of the information contained in these reports, may enable increasing the competitive edge. The profits may also increase, due to the better accuracy of the tenders.

The entire process of information sharing may bring higher quality to construction companies. Their technical capacity, organization and team work may lead to a more cohesive structure. Using BIM's pool of information will give to the company a capacity to acquire new information. The information can be kept updated. Companies that have the best ability to collect information, organize and analyzes it will be highlighted. This may lead to the need of innovating methods and techniques. Thus, as a result, the quality for the final product may also be improved.

The possibility of greater competitiveness and lower prices is of great interest for the owners. This might lead to the owner setting as a rule, using BIM. Thus, one of the barriers for implementing BIM might be overcome.

When it comes to infrastructure projects, these should be handled carefully. These projects are subjected to all the external factors along the entire construction process. They also highly depend on the labour and equipment. The productivity is dependent on these two types of resources. So, these will be the resources which should have the focus of attention.

When estimating, are considered amounts of resources and productivities for these resources. Labour and equipment are the resources which can cause the most significant deviations. Labour and equipment will have a direct affect the time. The costs will be affected by the time and/or by the resources. From this, arises the need of software capable of handling with the information created when estimating the project.

A bad estimation for productivity, equipment and labour and recourses in the infrastructures projects may lead to irretrievable damages. The same applies to the construction process when monitoring these three elements. So, it is important to produce simulations how the costs and the time will vary depending on the resources used for executing the works

In infrastructures projects, it is very important to analyze the productivity. The costs can have their deviation from the estimated in the negotiations or due to productivity. Higher prices with high productivity may bring to profits. Thus, prices below the estimated, with low productivity can lead to losses. To monitor and have the control of the project in the rail, it is important to manage the costs with the productivity. So, construction management tools should be able to handle with the detail used when estimating the project.

Analysing the tools and methods

Navisworks is a good tool for simulating the development of the project. To study the construction process and visualize schedule for the tasks, Navisworks seems to be efficient. Thus, to study the productivity and analyze particular situations in the same task, reveals to be inefficient. The example can be seen in the pipes with automatic joints and locked joints. The same task, different productivities. Navisworks cannot distinguish these two particularities.

Location Based Methods showed to be the best choice for having the information about the productivity. LBM enable a close knowledge about the productivity. Linear Scheduling Method seems to be suitable for isolated infrastructure projects. Line Of Balance seems to fit better only in building construction projects. Thus for infrastructures projects with the "horizontal" and "vertical" facilities the individual chart might not work very well. One of the possibilities is by combining both of them.

To have a better insight into the constraints of the project, should be possible of adding information in the LSM charts into the distances axis. For example, distances with rock, with automatic joints, with locked joints, and so forth. With this feature becomes possible to analyze the constraints and determining their productivity. If comparing the LSM with the LOB, adding the information in the LSM charts makes once in buildings there are no physical external factors affecting the development of the works. With the information added, it is also possible do determine the productivity for certain conditions. Thus, a more accurate estimation and scheduling can be made in the future.

The LOB enables to view the schedule and progress of the works for several "vertical" facilities in the same chart. With the "standard" LSM chart is only possible to view the schedule and progress for a project/sub-project. In the present study was visible the need for visualizing all the sub-projects. The solution may lies into grouping the LSM charts into a single one.

4D simulating and analysis tools, give information about the progress with the time, in a location for the tasks. LBM give the same information in a chart shape. Thus, LBM seems to be more appropriated for using in BIM. With BIM's implementation and emergence, making use of LBM, the Activity Based Methods might tend to disappear.

DynaRoad seems to be a very good software for infrastructures projects. In a first impression looks very complete. It enables scheduling and visualization in the Gantt chart, LSM and in map based planning and control. Thus, this software don't allows working with BIM.

Estimating software enables the detailed analysis about costs, resources, productivity. Construction management software isn't capable for this detailed analysis. The studied tools show an overall perspective of the final costs and how they progress over the time

BIM software in general is touted as a tool capable of analyzing costs. Thus, only the total costs are possible to be analyzed and simulated. So, the cost analysis is made for a low level of detail.

This can be a good feature for the design phase. In the construction phase can be good to give a general idea about the progress of the cost. Thus for construction management purposed, it seems to be a very limited feature.

The existing software is very specialized for the branches designing the project. The tools are split into infrastructures and buildings software. Thus, this software is more focused for the design process. The contractor will be forced to have a great amount of software. There is a need for a software containing both infrastructures and building tools. There is also a lack in software more focused into the contractors.

From the analysed software, the modelling one seems to be the most complete for its purpose. There is also a great amount of available software for modelling, most eespecially for buildings. Thus, when it comes to construction management, there are only few available tools which can perform close to the needed. The existing tools categorized as this, are more for project management in the design stage. The contractor still needing to make much use from the "traditional" tools for construction management purpose.

One of the main reasons for information losses in the construction stage may be due to the "non compatibility" between the estimating software and construction management software. The construction software is not capable of receiving the information as the estimating software builds it. When the construction process, the monitoring and control has to be done "manually" through the "traditional" methods. This may be other reason for the losses in the information.

The "mobile" software close to the works

From the author's experience, construction managers tend to spend 90/95% of their time in the office. The opinion the author have is, this is one of the biggest mistake that can be done. The problems occur in the site, and this, should be solved in the site. BIM 360 for instance may give a great contribute in solving this office problem.

The possibility for BIM 360 allowing adding information to the models, might also help building the reports. The information about what happens in the construction site can be shared. Thus, the knowledge about the issues can be shared as well. Making use of this feature, photos, descriptions, solutions and so forth, can be added and shared. This information can be very important in future projects.

BIM 360, for instance, enables to keep the information constantly updated. With this tool is possible to add the information to the precise objects and location. Thus the task of finding the information , gets easier and simplified.

The lack of tools for construction management in the contractor may be working as a barrier to BIM's implementation into the construction sector.

The small construction projects

In small construction projects the quality of the information is very important. With a good quality the construction process will have a great help in preparing the project. This will reduce the risk for all the works not being prepared. Thus the changes of profit may become greater.

6.2 Future perspectives

The author felt a great need of information about BIM in infrastructures projects. This is an area where very few or none information is available. It seem to be field with a great space to be developed and explored.

This thesis was some sort of a first approach to BIM implementation in infrastructures projects. The author believe to be possible to be created and developed a great amount of ideas. Many cases and needs can be studied in these types of projects. The author hopes that, this work will spark interest in exploring and studying of the topic of BIM in infrastructures projects.

For a better implementation of BIM in the contractors working with infrastructures projects a better study should be made about the LBM. Since the LOB and LSM are specifically for building construction and infrastructure projects, respectively, the hypothesis of combining both methods may help solving some issues.

Considering software which allows for a more detailed analysis of the project during the construction process. The possibility for this software to support receiving the information from the estimating software in its "original" shape. The author felt a great need of software which can handle the construction management in detail.

The possibility for including the concept of the "iron triangle" into the construction and project management software. Due to the high dependence of labour and equipment in infrastructures projects, to consider the possibility for the software to include a higher level of detail for analysing these two elements. This concept may allow for helping in estimating and managing the construction process.

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Appendix