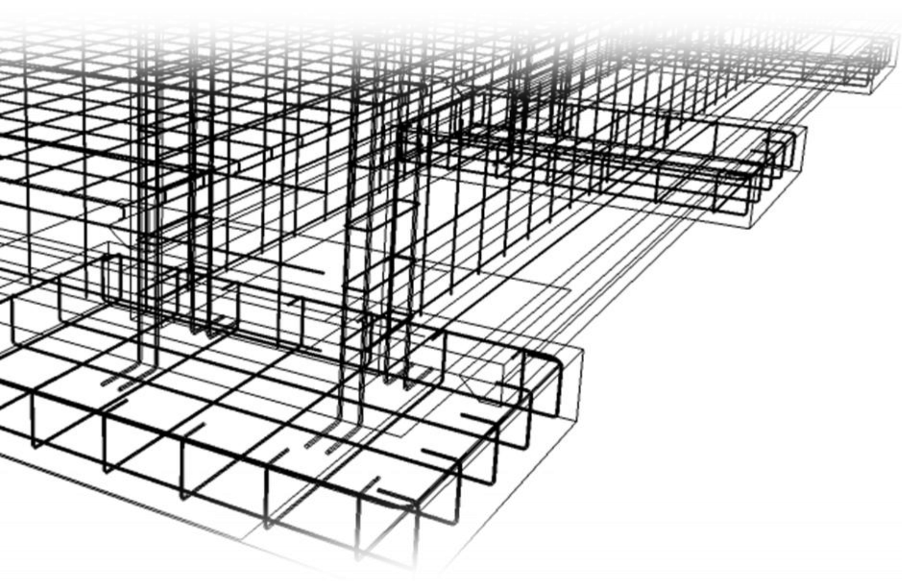
Assessment of 4D BIM applications for project management functions

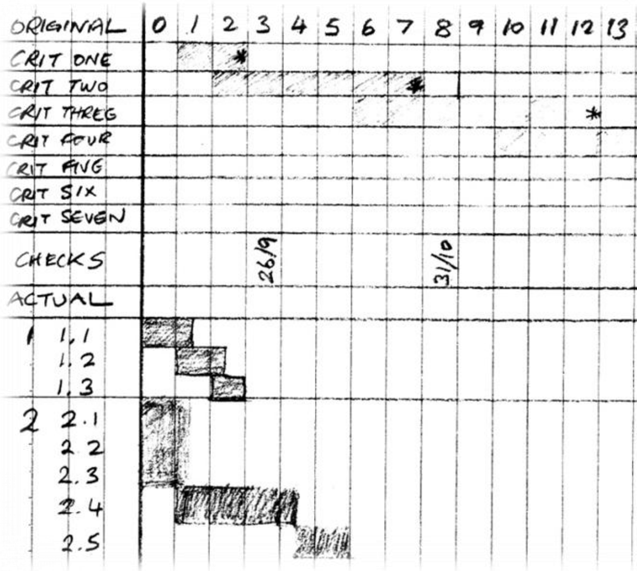
Master Thesis from the University of Cantabria conducted at the Polytechnic University of Valencia

by

ALBERTO URBINA VELASCO

EUROPEAN MASTER IN CONSTRUCTION ENGINEERING 2012-2013





UNIVERSITY OF CANTABRIA
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‘Nothing endures but change’
Ηράκλειτος (Heraclitus)

Abstract

The AEC sector is in decline in terms of productivity and performance during the last few decades if it is compared to the rest of industries. Projects are frequently faced with a high level of uncertainty and as a result, quality or scope, cost and time constraints are in continuous risk of being unfulfilled. On the one hand, there are many factors that seem to be causing this decay with respect to other industries, and they have to do with the actual organizational model and the information management. The low use of *Information and Communication Technologies* (ICT), the tendency to transfer rather than share risks among project stakeholders and the predominance of ineffective contracting methods are some of these factors. On the other hand, new emerging concepts try to put an end to this situation, such as the *Lean Construction* philosophy, the *Integrated Project Delivery* (IPD) method and the *Building Information Modelling* (BIM) working methodology. The integration of the also studied 4D technology (3D + time) in the BIM methodology for a better time management is the core of the present work. After analyzing their general theoretical requirements, the different possibilities of 4D BIM tools as well as the required workflow are assessed, paying special attention to the opportunities and limitations. The workflow from the practical part is completed with the use of the following software: Autodesk Revit ® 2013, Microsoft ® Office Project 2013 and Autodesk Navisworks Manage ® 2013. These tools, which allow implementing the BIM methodology, turn out to be really useful to satisfy and facilitate many of the project management functions, both in the planning and construction phase. Furthermore, they are a perfect platform for a collaborative and transparent environment. The opportunity to visualize and simulate the construction process is the key to reduce the aforementioned project risks. However, experience suggests that success on productivity improvement does not only depend upon the use of ICT, since their wrong manipulation could be counter-productive. At the same time, resistance to change is an important barrier to encounter in the adoption process. This is the reason why it is really important to understand the framework in which these tools must be implemented, because the combination of ideas incorporated by all these concepts could result essential. After all, all of them look towards a common goal: improving the construction sector.

Key words: *BIM, 4D, productivity, collaborative environment, simulation, visualization, IPD, Lean Construction*

Resumen

El sector de la construcción está experimentando un declive en las últimas décadas en lo que a rendimiento y productividad se refiere, si se compara con el resto de industrias. Los proyectos suelen afrontarse con un alto grado de incertidumbre que resulta en riesgos de proyecto que hacen que frecuentemente se incumplan las 3 restricciones principales: calidad o alcance, coste y plazo. Son muchos los factores que parecen estar provocando esta decadencia respecto a otras industrias, pero todo apunta a que la mayoría son de carácter organizacional y más concretamente están relacionados con la gestión de la información. El uso reducido de las Tecnologías de la Información y Comunicación (TIC), la tendencia a transferir el riesgo entre participantes en lugar de compartirlo y el empleo de métodos de contratación inefectivos son algunos de dichos factores. Por otro lado, muchos son también los nuevos conceptos que intentan hacer frente a esta situación, como la filosofía *'Lean Construction'*, el método de contratación *'Integrated Project Delivery'* (IPD) y la metodología de *'Modelado de Información para la Edificación'* (BIM). La integración de la también estudiada tecnología 4D (3D + tiempo) en la metodología BIM, que se denomina comúnmente 4D BIM, para una mejor gestión del tiempo es el núcleo de investigación del presente trabajo. Tras analizar sus requerimientos teóricos, se examinan las diferentes posibilidades de herramientas 4D BIM así como el flujo de trabajo requerido, haciendo hincapié tanto en las oportunidades como en las limitaciones. El flujo de trabajo para la parte práctica se completa mediante el empleo del siguiente software: Autodesk Revit ® 2013, Microsoft ® Office Project 2013 y Autodesk Navisworks Manage ® 2013. Estas herramientas permiten la implementación de la metodología BIM y resultan ser útiles para satisfacer y facilitar muchas de las funciones de la gestión de proyectos, tanto en la fase de planificación como durante la ejecución, además de poder ser aplicadas en un entorno colaborativo y transparente. La oportunidad para visualizar y simular el proceso constructivo es la clave principal para reducir los antes mencionados riesgos de proyecto. Aun así, la experiencia demuestra que el éxito en la mejora de la productividad no reside en el mero uso de las TIC, ya que su utilización errónea puede resultar contraproducente. Al mismo tiempo, la resistencia al cambio suele ser una barrera importante en el proceso de adopción. Es por ello importante comprender el marco en el que estas herramientas deben ser implementadas, ya que la combinación de ideas incorporadas por todos estos conceptos puede ser esencial. Al fin y al cabo, todos ellos parten hacia un objetivo común, que no es otro que el de mejorar el sector de la construcción.

Palabras clave: *BIM, 4D, productividad, entorno colaborativo, incertidumbre, simulación, visualización, IPD, Lean Construction*

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My most sincere gratefulness to all these people and organizations.

Acronyms

AEC = Architecture, Engineering and Construction

ALP = Average Labour Productivity

BIM = Building Information Modelling

BIMM = Building Information Modelling and Management

CAD = Computer Aided Design

CIC = Computer Integrated Construction

CIM = Computer Integrated Manufacturing

CM@R = Construction Management at Risk

CPM = Critical Path Method

DB = Design-Build

DBB = Design-Bid-Build

FM = Facility Management

H&S = Health and Safety

IFC = Industry Foundation Classes

IPD = Integrated Project Delivery

IT = Information Technologies

ICT = Information and Communication Technologies

JRM = Joint Risk Management

KPI = Key Performance Indicator

LOD = Level of Development

LPS = Last Planner System™

MEP = Mechanical, Electrical and Plumbing

PPC = Planned Percent Complete

RFI = Request for Information

SME = Small and Medium Enterprises

TFP = Total Factor Productivity

TPS = Toyota Production System

VDC = Virtual Design and Construction

WBS = Work Breakdown Structure

WIP = Work In Progress

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1
INTRODUCTION

1.1. Background

The present report is the result of my Master Thesis to complete the studies of the European Master in Construction Engineering from the University of Cantabria in Santander and it has been completed in the Polytechnic University of Valencia during the period from April 9th 2013 to August 26th 2013.

My motivation for studying this topic comes from late 2010 when I first heard of Building Information Modelling (BIM) during my Erasmus period in Horsens, Denmark. From the beginning I realized that there was something BIG involved in this methodology and that it might incorporate important changes in our sector, so I started to explore the Revit platform by myself. It was not until Prof. João Poças introduced BIM in one of the modules of the Master, though, when I decided to carry out my Master Thesis about something related to this topic. The courses on Revit received in Valencia as well as the people I was in contact with helped me understand the BIM methodology in general and the Revit platform in particular.

The scarce literature on BIM available in Spanish is a clear indicator of the poor influence of this methodology in the construction sector, in a national framework. However, during my stay in Valencia I realized that it is one of the areas within Spain in which BIM is starting to take its place. A clear evidence of it is the recently celebrated '1st National BIM Congress: EUBIM 2013'. Truly believing that a change is possible, and as a future construction professional, I would like to contribute with this report and future work in the adoption of the BIM working methodology in our country, for a better management of information in construction so as to add value to our activities.

1.2. Aims and Objectives

The main aim of this Master Thesis is to assess 4D BIM applications for their possible utility to address project management functions. First, it is intended to ascertain the general theoretical requirements to be fulfilled by 4D BIM applications. Secondly, by means of a specific selection of some of the available tools allowing this 4D environment of BIM, an effort to analyze whether these specific tools really accomplish the outlined requirements is to be made.

Apart from this principal aim, there are other no less important objectives. These are some of the research questions that this study also aims to give an answer to at the end:

- Which are the problems that the construction industry is facing?
- Which are some of the innovative concepts that could help solve these problems?
- What are the BIM methodology and 4D technology about?
- Is it possible to simulate the construction process before going on site? If yes, to what extent is it possible to use the selected tools for that purpose?
- How can 4D BIM help with project management functions?
- Are the analyzed 4D BIM applications valid for the construction stage and production management?

1.3. Research Methodology

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

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

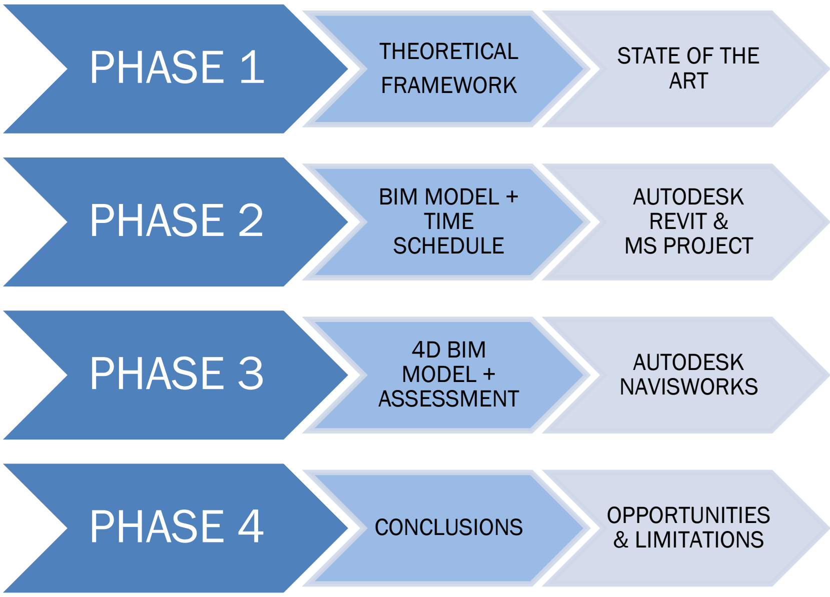

Figure 1.1 – Different phases of the Master Thesis

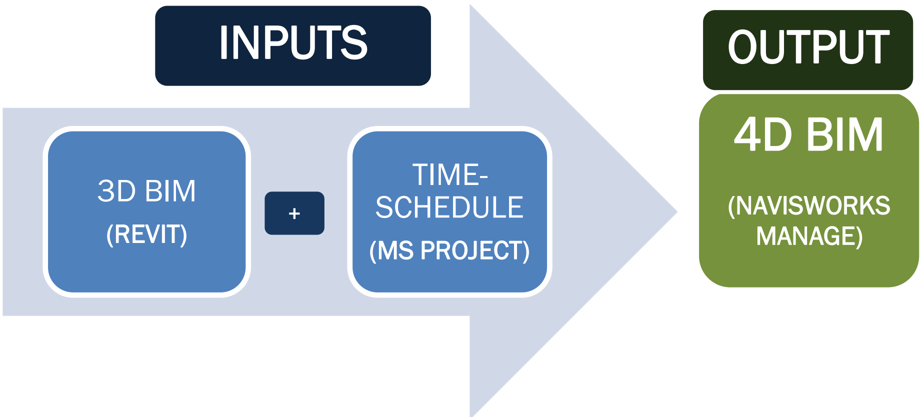

Figure 1.2 – Practical Part: From conventional BIM model to 4D BIM model

These phases are more or less reflected in the final chapter arrangement of the Master Thesis described in **Chapter 1.5**.

1.4. Limitations, Assumptions and other Considerations

Since it was carried out individually, one of the main limitations of the present study is that of not being able to simulate a collaborative environment in the practical part. However, due to the visual ingredient of the applications it is assumed that they at least serve for a better understanding of processes when several people are dealing with them at a time.

The model utilized in the assessment part is really simple and it does not represent the characteristics of a real project. Indeed, as it was not required to test the functionalities of Navisworks, no regulations, nor specific design rules have been followed for its creation. Thus, navigability behaviour of Navisworks for processing massive working files has not been proved, although it has been checked that the original file is compressed up to a 90%. The assumed level of development is LOD100 with the use of generic elements representing a very initial stage of a project.

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

1.5. Organization of the Thesis

This Master Thesis is divided into the following 4 chapters, including the present introduction: (1) Introduction, (2) State of the art, (3) Practical Part and (4) Conclusions. These chapters are complemented with a series of appendices included at the end of the work.

<u>Chapter 1:</u> In the introduction from the present chapter the main objectives are outlined and the methodology used to carry out the study is presented.

<u>Chapter 2:</u> The state-of-the-art represents the theoretical framework necessary to approach the main subject and to understand the rest of the study. It is organized in a way to facilitate its comprehension from the general to the specific: *problem > possible solutions (framework) > specific solution > functionality within the specific solution*. In other words, the starting point is the problems faced by the construction industry. The possible solutions represent a framework in which the specific solution has to be applied. The functionalities to be satisfied by the specific solution are those of project management practises.

<u>Chapter 3:</u> The practical part includes the assessment of functionalities of the applications chosen in order to compare theoretical requirements with their real possibilities.

<u>Chapter 4:</u> Finally, conclusions are divided into specific conclusions with regards to the assessment of the practical part and overall conclusions referring to the whole study.

2

STATE OF THE ART

2.1. The Construction Industry: What is wrong?

The construction activity has been a common practice since ancient times and for a long period considered one of the most important of all the existing industries and those to come. A good example of that is the endless list of historical buildings that our ancestors left behind in the form of valuable patrimony, such as the Pyramids in Egypt, astonishing medieval castles, cathedrals and other master pieces of architecture and engineering spread all over the world. Due to the magnitude of the projects and the huge amount of resources that such a practice involves, construction was for centuries considered to be a *high-tech* industry. However, this situation has changed to an extent that lately it has been considered a *low-tech* industry compared to others like the auto industry (Crowley, 1998).

Since the 2nd Industrial Revolution in the late 19th century, many industries emerged and started to evolve as decades went by. Although construction started to be considered as an industry it did not equally evolve in comparison to other industries, some of them even having started from scratch. It is true that many processes have been improved and industrialized with precast solutions and dry constructing methods, but construction still lies behind in many other aspects.

Due to the magnitude of construction projects the adaptation has not been as easy as for other industries. Many factors make of the construction industry a particular one and the features listed below are some of them:

- Construction projects are characterized by the ***large number of stakeholders*** and interested parties taking part in them.
- ***Combination of many trades*** or sectors during the realization of a unique project. Typically construction projects require of multidisciplinary teams.
- Construction takes place in a continuously ***changing environment*** in the form of a building site, instead of a factory in which the conditions are more controllable.

- Big share of ***small companies*** or small and medium-size enterprises (SME).
- ***Long production period*** for a unique product: the building.
- ***Large amount of resources*** are required to complete a unique project (labour, material and equipment) with the consequent management complexity.

Even so, construction by no means can be considered as the only industry dealing with complex projects. Others such as the aerospace industry carry out extremely difficult activities with a higher level of uncertainty, far more control over the operations and less space for improvisation. Therefore the question is: *What is happening in the construction industry?*

Many studies on different industries' performance clearly indicate that there is a problem in the current productive and organizational model of the construction sector. An introduction to the inefficient performance of construction is to be presented in this chapter in order to create an overview of the problems that are threatening the sector as well as to understand the proper way to deal with them.

2.1.1. Performance of the construction industry

It is a common practise to measure the performance of different industries and then compare the results so as to learn from them. These sorts of studies enable to obtain indicators and draw up conclusions on what could be wrong in a given industry. In the case of construction, many studies make clear that the actual productive as well as organizational model is lacking efficiency. The present section aims to reflect some of the problems that the construction industry is facing and create a framework of issues to be solved by innovative approaches that are to be presented in coming chapters.

Productivity

The construction sector is facing productivity problems in the form of a standstill or even decrease in its rates over time (Teicholz, 2004; Abdel-Wahab & Vogl, 2011; Glenigan & Constructing Excellence, 2012). Productivity is a Key Performance Indicator (KPI) aiming to measure the potential of inputs to obtain certain outputs in a production process, in terms of added value. It is the aim of every industry to improve productivity year after year.

Measuring productivity in the construction sector is not an easy task and many efforts have been made to address this issue. On the one hand, unreliability of data is considered by Abdel-Wahab & Vogl (2011) as one of the most important barriers for a clear productivity perception in construction. On the other hand, productivity can be measured in different ways and there are two general alternatives recognized by several authors: Average Labour Productivity (ALP) and Total Factor Productivity (TFP). According to Crawford and Vogl (2006), ALP considers just one of the inputs (labour), whereas TFP takes into account all the inputs of the process, not only the physical but also the intangible ones. Thus, although it is quite easy to measure ALP does not reflect accurately total productivity performance. That said, the same research suggests that ALP and TFP are closely correlated because they follow a very similar growth function. Therefore, regardless of their accuracy, both measurements can be considered significant evidences of productivity decrease and this is what really matters for the present study.

In an investigation conducted in the United States (US) comparing the progress of the labour productivity index of US construction and the rest of non-farm industries from 1964 to 2003, an important decrease of -0.59%/year (with some exceptions in between) is noticed in the first whereas the second experienced an increase of 1.77%/year (Teicholz, 2004). See *'Figure 2.1'*.

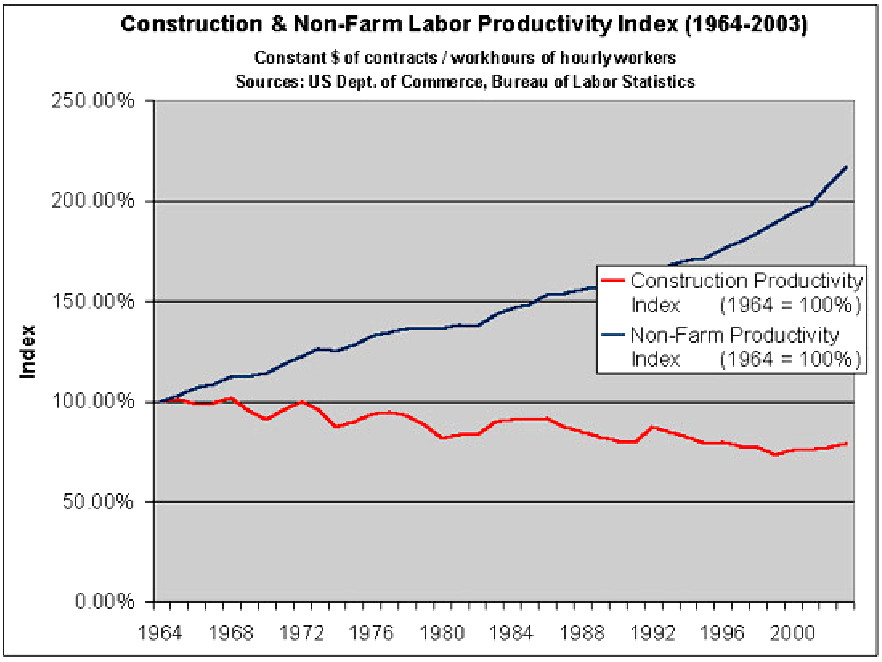

Figure 2.1 - Comparison of Labour Productivity Index between Construction and Non-Farm industries from 1964 to 2003 (Teicholz, 2004)

Another source of evidences is a reliable and recent report on the United Kingdom's (UK) Industry Performance based on the construction sector, which aims to reflect the actual situation in the UK by means of the use of KPIs (Glenigan & Constructing Excellence, 2012). Among many other things it clearly shows that the productivity increase has dropped significantly from 2011 and it is again in similar rates as in the period 2005-2008. Only a rise of 1.1% was experienced in the last year, as it can be seen in *'Figure 2.2'*. Being the UK considered a world exception in the mentioned productivity slowdown (Abdel-Wahab & Vogl, 2011), these figures confirm the bad state of the sector and the general nature of all these problems. Furthermore, this situation suggests that there is something beyond the present deep crisis having to do with this particular industry.

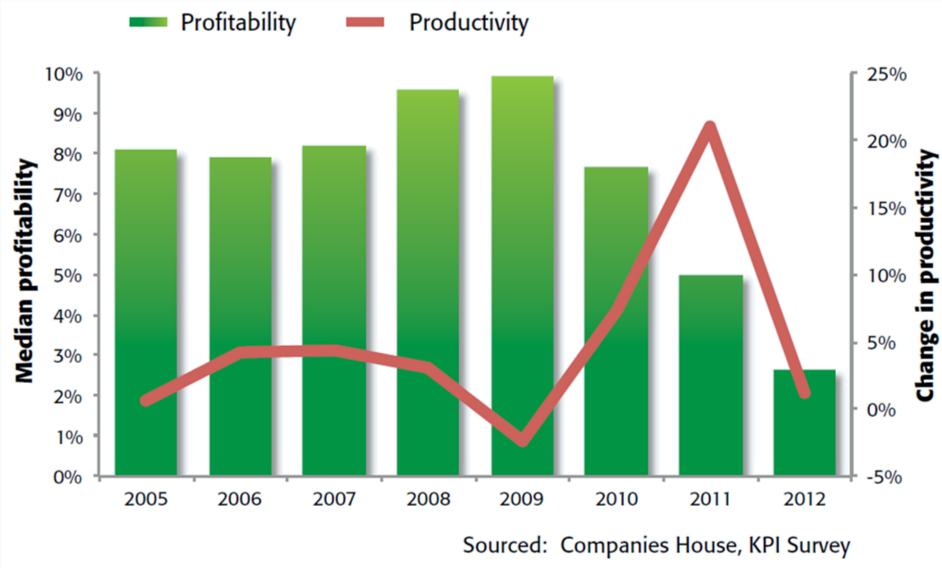

Figure 2.2 – Productivity and profitability variations in the UK construction industry from 2005 to 2012 (Glenigan & Constructing Excellence, 2012)

Among the general reasons that may be causing this productivity decrease, the following facts are suggested: (1) the low adoption rate of Information and Communication Technologies (ICT) in construction compared to other industries, (2) the predominant Design-Bid-Build (DBB) contracting method rather than a more collaborative approach (**Section 2.2.5**) and (3) the large percentage of SME taking part in the construction process that may be hampering the adoption of new technologies and investment in R&D (Teicholz, 2004).

The productivity decrease is also attributed to schedule pressure by Nepal et al. (2006), justifying that applied in an excessive manner it has negative effects on workers and their performance. Even though pressure in a proper measure is necessary for a successful schedule fulfilment, extreme levels of schedule pressure are likely to lead workers to commit errors and their motivation to be undermined. As a result, rework and consequently more time might be required to repair the originated defects. This is a clear indicator of how important the time constraint is in a construction project and how it is closely linked to productivity.

Time constraint

A project in its broadest sense is defined as *'a temporary endeavour undertaken to create a unique product, service or result'* (Project Management Institute, 2013). As the project management theory clearly states, projects are always tightly tied to three main constraints: scope, time and cost. All of these constraints are connected to each other, and any modification in one of them is likely to affect the other two. Fulfilling these constraints is the main duty of project management and is translated into getting the quality required by the client, complying with deadlines and achieving the prescribed cost.

However, these theoretical facts are far from being fulfilled in the reality since scope, time and cost constraints are not met in a large amount of projects. The true being is that construction projects are faced with a high level of uncertainty that jeopardizes the fulfilment of the aforementioned constraints. This low predictability is frequently translated in a reduction of the initial scope, non-compliance of deadlines and important over costs.

The focus of this work with regard to project constraints is time and it is after a better management of time. Nevertheless, every moment needs to be present the fact that the other two constraints, scope and cost, are in close relation with time and thus, they would surely be benefited from an adequate time management.

Time predictability is another important KPI to reflect to what extent deadlines are met and which level of uncertainty is present in construction projects. As it is shown in *'Figure 2.3'*, a study reflects that only 34% of the projects in the UK during 2012 were completed on time, being the lowest figure of the last 12 years. Dividing it by phases, design is slightly above construction in terms of time predictability, since in 42% of the projects construction was delivered on time, against 48% for design (Glenigan & Constructing Excellence, 2012). Being the UK a referent country within the European Union (EU), it could be taken as a clear indicator of performance failure of the AEC industry with regard to deadline compliance.

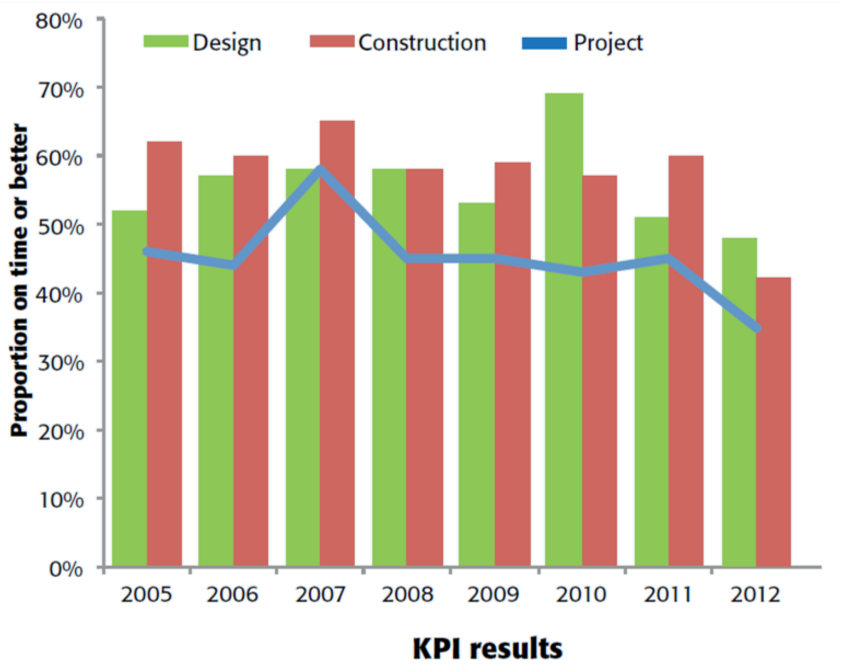

Figure 2.3 – Time predictability variations during design, construction and overall project in UK construction projects from 2005 to 2012 (Glenigan & Constructing Excellence, 2012)

Even though the research framework presented in Odeh & Battaineh (2002) is focused on construction practices of a developing country, the results are significant and display several causes of delays in construction projects using traditional contracts from the point of view of both contractors and consultants. Based on the results of a survey it was clarified that, although in a different order, contractors as much as consultants attribute project delays to factors having to do with labour, client and contractors. For contractors factors like low labour productivity and owner hampering are of vital importance, whereas consultants tend to relate delays more with contractor's lack of experience, client's way of payment and the role of subcontractors and outsourcing.

In order to reduce project uncertainty and all the risks it implies some measures have to be adopted. This practice of diminishing the level of uncertainty and risk reduction is commonly known as risk management technique (**Section 2.2.1**).

Organizational Model and Information Management

In addition to the stated deficiencies in productivity as well as poor accomplishment of project constraints there is something else that seems to be harming the performance of the construction industry. It has to do with several aspects of the current organizational model prevalent in the AEC sector, which is not able to overcome all of the mentioned issues.

Firstly, the construction practice requires an important degree of collaboration due to the multiple parties participating in a single project and there is a need for them to act as a whole. However, the true being is that many times the communication is ineffective and there is a lack of coordination among participants. Transferring knowledge in an appropriate manner is vital for a better understanding of the entire project by the team. Different disciplines counting with an expertise in their field need to share their knowledge by creating information. That being said, the way in which information is created and managed is not always adequate. For instance, even today it is common to have different team members working with different file versions instead of with the last updated one, which is a clear signal of existing communication and coordination shortages. This leads the whole team towards an unproductive and inefficient working way, many times involving re-work so as to amend the errors occasioned.

Secondly, due to the nature of prevalent construction contracts, this collaborative approach is not encouraged from the beginning. The most common contracting method is still awarding the lowest bidder (Odeh & Battaineh, 2002), encouraging contractors to carry out inaccurate estimations in order to win the contract. This fact obviously has its effects at more advanced stages and is likely to be detrimental to the project constraints and the client. Along the same lines, the contract relationships need to be reinforced from early stages of a project to encourage all participants to share risks and to facilitate every single party to go for a common goal.

Thirdly, it is worth mentioned that the organizational structure of construction firms is quite distinctive. By means of an extended survey Riley & Clare-Brown (2001) concluded that the construction industry is immersed in a project-based culture. The role of subcontractors is also pointed out as a major source of possible problems. Main contractors tend to outsource a vast amount of work to smaller specialized firms to carry out specific jobs. This means having another different team involved in the same project and therefore, an extra coordination effort to be made. In fact, taking into account that it is usual for these sorts of companies to appear on the scene and to leave it at intermediate stages of the project the coordination complexity grows considerably. Apart from all this, in the same study a vertical organizational section of a construction company was carried out and it showed an important lack of transparency between different organizational levels.

Another point to be considered, which is related to the first point, is the still generalized use of paper-based documentation (Crowley, 1998). Drawings play an important role in the AEC sector to represent with enough detail what is to be erected. Although being commonly employed and useful for certain tasks, paper-based documentation is static and its visualization opportunities are quite limited. Even if it is in an exaggerated manner, *'Figure 2.4'* evokes the information flow in a paper-based documentation environment**.** Besides being a time-consuming and error prone way of transmitting information, a lot of useful information is likely to be lost in the way. Besides, design is still completed using traditional CAD technology, which is an effective way to represent geometry but does not incorporate any information attached to that geometry and neither advanced features for parametric design.

Figure 2.4 – Representation of information flow in a paper-based documentation environment (Stephens, 2012)

It seems apparent that it is not only about finding a solution to one of the mentioned problems. This sector is sick and is crying out for a revolution to recover the position it one day enjoyed.

2.1.2. Conclusion Chapter 2.1

From the question *'What is wrong in the construction industry?'* not an only answer but many of them were obtained and therefore, the cause of the bad situation cannot be charged to a single factor. Clear sign of the concern surrounding the existing issue is the extensive work presented by various authors to solve all these problems during the most recent decades.

The uniqueness of the construction industry has hindered its logical evolution along the history compared to other non-farm industries. Productivity rates have maintained or even decreased over the last decades and project constraints agreed with the client are frequently being unfulfilled due to the uncertainty always present in projects before their start. There are many factors to be improved in organizational terms in order to drive collaboration and coordination in the construction industry. Poor communication, ineffective contract methods and old-fashioned means to generate and manage information are some of them.

As a result, it is obvious that poor performance in construction is threatening the sector. That being said, it is believed that changes should in part focus on the way information is managed and visualized during the entire life cycle of projects, driving a better project understanding by all participants. It can be clearly stated that the AEC sector is facing difficulties and that an immediate solution is needed to reinforce this industry at especially hard times by the introduction of new methodologies.

2.2. Possible measures to the mentioned problems

Once the situation of the construction industry has been briefly introduced, it is time to assess how to give a solution to the mentioned problems. In the present chapter risk management practices, the effect of manufacturing industry, ICT and innovative concepts such as Integrated Project Delivery (IPD) and Lean Construction are to be presented. Finally, the concepts of Building Information Modelling (BIM) and 4D technology are to be developed, first separately and in the end as a combination to introduce the 4D BIM environment, which is the main aim of this study.

2.2.1. Risk Management practices

Construction has long since been considered to be a risky business (Akintoye & McLeod, 1997). However, risks are not equally perceived by all project participants due to their different interests. The practice of dealing with these risks during the life cycle of a project is generally recognized as risk management and it is a relevant branch of project management. According to the Project Management Body of Knowledge (PMBOK), the main goal of risk management is to *'increase the likelihood and impact of positive* *events, and decrease the likelihood and impact of negative events in the project'* (Project Management Institute, 2013).

The term *'risk'* can many times create confusion because of its multiple uses. In the present framework the term risk should refer to uncertain events that in case they occur negatively affect project objectives. That is why in this case it is better to talk about uncertainty management rather than risk management (Ward & Chapman, 2003).

A scientific paper published by Akintoye and McLeod (1997) suggests that in a broad sense, contractor's perception of risks is related to probability of occurrence of unexpected factors affecting directly to their projects with regards to time, cost and scope or quality constraints. On the contrary, due to their consultant role watching over the client's objectives, project managers do not perceive risks as facts affecting their activity, but rather that of their client. Therefore, it is common to see how the different stakeholders watch over their own interests, sometimes at the expense of those of the client like in the case of contractors.

There are 4 different methods to manage risks in construction: risk retention, risk transfer, risk reduction and risk avoidance (Akintoye & McLeod, 1997). Risk avoidance, although desirable, is considered to be really difficult to achieve in construction as well as impractical because of the theoretically high costs and efforts required by this practise. Risk retention is used, for instance, in the form of insurances or risk premiums where risks are admitted and faced by means of overestimation. One of the most common methods consists in transferring risks to other stakeholders. This would not be a dangerous practise if risks would be transferred to those parties in best position to deal with them. In the typical case of contractors, they strategically tend to outsource a vast amount of their work to subcontractors as a particular way to reduce their own risk. Finally, risk reduction techniques intend to reduce the likelihood of occurrence of unforeseen events and are the focus of this work with the introduction of 4D simulations in a BIM environment as a tool to foresee these risks.

With regard to alternative risk management practices the term Joint Risk Management (JRM) is becoming popular as a management technique in which risks are shared rather than transferred among stakeholders. In fact, different parties usually tend to look after achieving their own organizational objectives more than project objectives (Osipova and Eriksson, 2013), far from collaborating. A scientific paper undertaken by Rahman and Kumaraswamy (2004) indicates that an early mobilization of project parties is recommended in order to manage more effectively some of the unexpected risks. Beyond relational contracting, JRM is proposed for a post-contract stage and its applicability for such stage was proved by means of a survey carried out in Hong Kong. It is also mentioned that trust between parties is essential and it allows having more flexible contract conditions. Due to the fact that knowledge from previous experiences and intuition has been traditionally used for managing risks (Akintoye & McLeod, 1997; Rahman and Kumaraswamy, 2004), a joint effort would definitely enhance such practise because in these cases the more opinions the better the chances to discover potential risks.

In relation with JRM, Osipova and Eriksson (2013) demonstrated in a recent paper how important both control and flexibility are when projects use a JRM approach, based on a case study of two Swedish construction companies. Even though certain control is essential, it was shown that a management system based on excessive levels of control undermine collaboration and it is not the most suitable way to manage risks. Flexibility to face unexpected events and introduce changes in the project is also required in construction. Consequently, finding the balance between control and flexibility in the management system employed is the key to success.

Another important issue is the concept of *'rehearsal'*, which is not introduced in a general way in the construction world. Trying to foresee as many factors as possible before carrying out any action would be a useful method to reduce risks. Otherwise, problems tend to arise at the construction stage, once it is late and difficult to properly deal with them. A previous simulation of the construction process would definitely help visualize the different stages in a better manner and reduce the uncertainty and risks by means of prevention. New technological advances are making these simulations attainable for a better risk management routine. Since this is one of the main lines of the present work, this concept is to be developed in coming sections, clarifying whether it is possible to simulate the construction sequence.

It is also worth mentioning the fact that nowadays risk management practices are more oriented towards Health and Safety (H&S) issues in construction sites, which is without any doubt another essential problem to be addressed in the sector. However, risks regarding constraints regretfully continue to be present and need to be improved in order to enhance project performance. After all, as in any other business, client satisfaction is one of the main goals to be achieved and therefore, projects have to be delivered in time, within budget and with the proper quality standards. It will be mentioned how these systems can also contribute to reduce risks in this particular field (**Section 2.4.5**).

Finally, JRM is in close relation with a new contracting method broadly known as IPD, and it is going to be presented in **Section 2.2.5**.

2.2.2. Focus on the Manufacturing Industry

In view of the poor performance of the construction industry and aiming to address some of the aforementioned problems, a search for a referent was launched shifting this way the focus on manufacturing models. As a result, an important effort to import new productivity and organizational approaches has been made during the last decades.

From this effort of concentrating in the manufacturing industry, the search for best practices has been many times connected to one specific sector: the automotive industry. In fact, it represents a good example of rapid productivity growth in an industry and in a short period of time. The focus on this particular industry inevitably brought researchers to the revolutionary as well as successful Lean Production approach adopted in the Japanese Toyota Production System (TPS) after World War II. This philosophy would later lead to an adaptation of its principles to construction, widely known by the name Lean Construction (**Section 2.2.4**).

Although many authors agree on the fact that concepts from the manufacturing industry cannot be duplicated and directly introduced to the construction industry (Crowley, 1998; Riley & Clare-Brown, 2001; Winch, 2003), it is possible to take ideas for then adapting them in a *“re-engineering”* process. Looking at what occurred in the manufacturing industry productivity gains can be achieved by means of improvements in organizational and management issues as well as those related to technology. Even though both of them are important and necessary, previous experience shows that basing this process solely in innovative technology uptake rather than organizational issues leads companies to maintain existing processes intact (Crowley, 1998). This fact indicates that technological advances are not enough by themselves, but are required to be accompanied by changes in business organization and processes.

Construction has attempted to be seen as a manufacturing process. However, due to the characteristics of its ‘products’, construction is a low-volume rather than a high-volume industry and the many times employed mass production model by manufacturing should not be of relevance for its productive model. In fact, it is still considered a craft-based industry (Crowley, 1998; Winch, 2003). On the other hand, standardization of certain parts of the building could be a solution so as to consider it as a *kit-of-parts*. Industrialization would also increase final quality, reduce production time and increase control over the final product. Although, buildings usually require of uniqueness and finding the balance between standardization of buildings and flexibility of production seems to be the key.

A good management of information becomes mandatory as product complexity grows. Computer Integrated Manufacturing (CIM) emerged in the manufacturing industry as a way to better deal with the more and more complex products that were being produced and in order to improve coordination of resources. This same concept brought to construction is known as Computer Integrated Construction (CIC). It was conceived with the aim of easing the communication of information between project participants. In other words: to *‘provide the right information to the right place at the right time’* (Crowley, 1998). This shows how efforts to introduce and extend the use of ICT in construction were already made in the 90’s.

Major importance was also given to the culture of a company by Riley & Clare-Brown (2001) in view of the attempts to transfer manufacturing best practises to construction, claiming that both industries have substantial differences in their cultures. The particularities mentioned at the beginning of this chapter define the culture of the construction sector and affect, for instance, to the non-uniform culture perception by the multiple parties like main contractor and subcontractors. The large amount of stakeholders force them to have a project-based culture more than a company culture.

This is clearly visible in a paper undertaken by Winch (2003), where the focus on manufacturing models as a way of *"re-engineering"* construction is analyzed, trying to verify whether it has been adequate for the characteristics of our sector. Hence, it advocates that the focus on the automotive industry does not fully represent the needs of construction. Furthermore, the research suggests that, being a discrete assembly industry, construction should have paid more attention to production of complex systems instead of mass production and Lean Production models. In other words, in terms of production strategies the construction and automotive industries are not comparable. Then the focus should be shifted on those industries utilizing Design-to-Order (DtO) and Concept-to-Order (CtO) production strategies, rather than Make-to-Forecast (MtF) and Make-to-Order strategies (MtO). The importance of project management in construction was one of the main conclusions of this author.

Among all of these conclusions drawn and lessons learnt by the fact of emphasizing on the performance of the manufacturing industry, one of them enjoys an especial significance: the relatively low use of Information and Communication Technologies (ICT) in the construction industry.

2.2.3. ICT in the Construction Industry

ICT are these technologies used to manage and transfer information in an enterprise, focusing not only on computers and software, but also on the networks in charge of connecting them to facilitate communication. It is an extension of the term Information Technologies (IT) and more proper within the construction framework, because communication is essential in this sector when it comes to dealing with information. These systems are considered as practical tools to raise productivity in the activity in which they are applied.

As it was mentioned in **Section 2.1.1**, the information management in the construction industry is not considered to be efficient in terms of knowledge transfer between different project phases (conceptual design, scheme design, detail design, construction, etc.) and parties. Actually, the use of ICT in construction is found to be scarce in comparison to other industries like manufacturing (Akintoye & McLeod, 1997; Teicholz, 2004). This is considered to be a weakness and a possible explanation to the poor performance of the AEC sector.

A study carried out in 2006 by an organism launched by the European Commission and called *e-Business W@tch* reflected the poor situation of the construction industry in terms of general ICT usage in comparison to other 9 industry sectors analyzed the same year (e-Business W@tch, 2006). This report was conducted by means of a survey to several European construction enterprises. The *'Figure 2.5'* shows on the yellow bar chart from the left the percentage of firms using ICT emphasizing the activity of small-size firms. Construction is situated in 8th position with a percentage of 46% of firms, barely followed by food and footwear industries. The blue bar chart on the right emphasizes the activity of larger firms and the results are weighted considering the number of employees. Construction is situated in 9th position with a percentage of 45% of firms, only followed by the footwear industry.

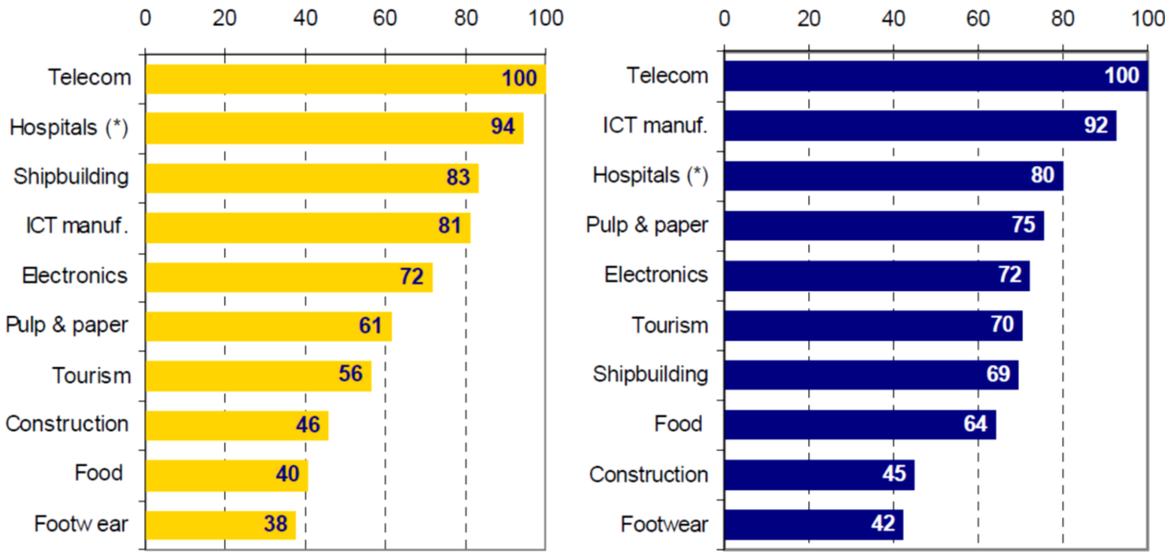

Figure 2.5 – Comparison of ICT adoption rates for 10 different industry sectors (e-Business W@tch, 2006)

'Figure 2.6' shows a radar chart including 16 component indicators listed on the right classified in the different branches of ICT: *ICT Networks (A)*, *e-Integrated Business Processes (B)*, *e-Sourcing and Procurement (C)* and *e-Marketing and Sales (D)*. In all of them the construction industry is way behind the maximum and average percentages of ICT adoption in the different industry sectors.

One of the main conclusions of the report in 2006 was that large construction enterprises were progressively increasing the use of ICT in their activities and that the SME were in a way more responsible for such a low rate of adoption of these technologies, due to the investment required to make it possible. It also reveals low adoption rates of ERP systems and e-procurement. Another important observation of the study was that 3D technology, being really appropriate for visualizing construction details and improving collaboration between project participants was not broadly used, because approximately only one out of twenty firms used it in a general basis for all their projects. Furthermore, it was shown that a great part of design communication was still done by means of 2D drawings.

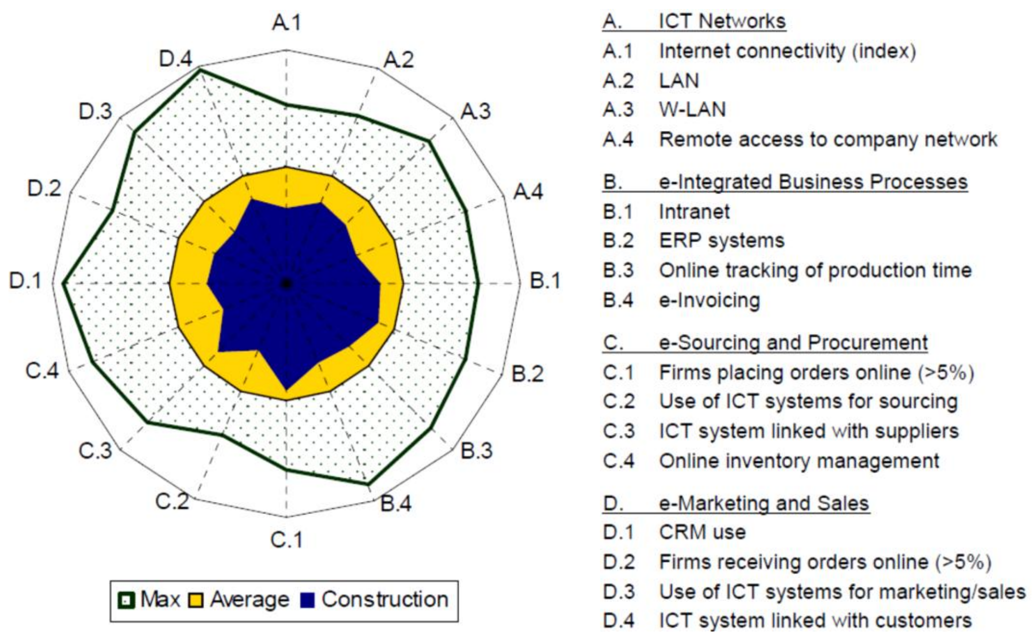

Figure 2.6 – Maximum, average and construction adoption of ICT by branches (e-Business W@tch, 2006)

With the aim of throwing a bit of light on the patent low use of these technologies Peansupap & Walker (2006) analyzed the possible barriers for ICT adoption in the construction industry. Adoption of ICT in any field is commonly characterized by the resistance to change because of the necessity to leave actual methodologies and adopt new ones. This resistance to change can be manifested by an entire organization, by a certain group of an organization or just by individuals. In a large scale, organizations may refuse to drive changes with regards to ICT because of the investment required, the need for standardization or even security issues. Groups within organizations could jeopardize the adoption because of diversified office location and lack of time to share ICT knowledge between colleagues. On the contrary, individuals' main reasons were found to be computer skill shortages, necessary learning process and lack of clear understanding of benefits. Lack of confidence as well as experience is generally the main problem present at all levels. In consequence, even though the main decision relies on the top management, people are also vital for any new ICT uptake to be successful and corroborating its tangible benefits is one of the greatest challenges (Peansupap & Walker, 2006; Bowden et al., 2006).

Another essential issue is the growing possibility to use mobile ICT on site, a thing that the construction industry was especially demanding because of its dynamic nature. Attainable innovative devices such as smartphones and tablets are allowing to have up to date information and to carry out real-time reporting and instant communication (Bowden et al., 2006). In addition, the tendency towards cloud-based storage goes hand in hand with the new form of accessible information anytime and anywhere.

During the last years BIM has emerged as a new methodology based on advanced ICT usage for a more appropriate project information management, among many other things (**Chapter 2.3**). It is true that some years have passed since the publication of the statistical figures from the *e-Business W@tch* report, and that the non use of ICT is rare nowadays. However, this late adoption can still be perceived with the BIM case.

As it was previously mentioned, it has to be kept in mind that technology is not able to overcome all the problems by itself. It rather provides an innovative working approach in which processes and people are likely to be affected. New organizational systems based on collaboration between parties are also being introduced in the construction sector.

2.2.4. Lean Construction

The term Lean Construction emerged in the 1990s and it is utilized to refer to the lean philosophy applied to construction (Howell, 1999). In general terms lean practises are about *'generating value to the client by means of optimized processes and applying the continuous improvement'* (EGLC, 2013). In this way, and following the new production philosophy adopted by the manufacturing industry, construction should be approached as a flow process, where value is the key, rather than just as a set of activities converting inputs into outputs (Koskela, 1992). The general principles of this philosophy are related to the improvement of project performance, productivity and reduction of times.

One of the most important concepts in Lean Construction is constituted by the term *'waste'*. Waste elimination consists in discarding those process activities that do not contribute to the output or do not add any value (Koskela, 1992). As it was mentioned in previous sections, great part of the wastes in construction are derived from an improper information management and Request for Information (RFI) among participants is a clear example of a non-value-adding task. Another essential concept is that of the *'internal client'* in construction projects. In fact, many times it is not clear where the end customer is, and there is a tendency to confuse the client with the final users of the building. However, construction projects are characterized by the net of internal clients that is generated as a result of collaboration, and a distinction between next customer and end customer has to be made. For instance, the main contractor would be an internal client of its subcontractors. Thus, generating value to the client throughout the whole process is the duty of everyone involved in a project.

The BIM methodology (**Chapter 2.3**) is considered to be helpful for lean practises. In a study developed by Sacks et al. (2010b) 56 interactions were found between Lean Construction principles and BIM functionalities. The results stated that 52 of these correlations were positive. Indeed, BIM is in close relation with some of the lean principles: reduces variation, reduces cycle-times, allows visualization and adds value in the design stage (Eastman et al., 2011). Furthermore, 4D visualizations and simulations (**Chapter 2.4**) were found to be another important Lean-BIM synergy because, among other things, they provide the required project transparency (Sacks et al., 2009 & 2010b). When it comes to monitor production, visualization of the Work In Progress (WIP) should be somehow enabled, which is much more difficult in construction than in manufacturing because of the changing nature of building sites. The information must also be presented in a structured and centralized manner in order it to be accessible to all members (Sacks et al., 2009).

There are many methods to implement Lean Construction but one of the most popular and relevant to this study is known as the Last Planner System™ (LPS).

Last Planner System™ (LPS)

In relation with the Lean Construction approach, the LPS is a tool ideated to aid production control in construction (Ballard, 2000). Traditionally, schedules are based on a *'push'* system in which deadlines are set before even knowing if they *can* be achieved, but rather maintaining that they *should* be achieved, no mattering if they are reasonable or not. The negative effects of schedule pressure and the aim of meeting unrealistic deadlines were previously described in **Section 2.1.1** (Nepal et al., 2006). In the LPS this *'push'* system is complemented with *'pull'* planning, and its fundament is the fact of being capable of really doing the planned work. Hence, planning could be seen as a *'should-can-will-did'* process. In other words, the LPS deals with uncertainty by means of meetings in which every agent sets reasonable deadlines by when their work *can* be completed.

In order to control the production, the Planned Percent Complete (PPC) has to be continuously measured, which indicates the % of assignments that are totally complete (Lean Construction Institute, 2013). Apart from that, the LPS is constituted by several meetings each of them having a specific purpose depending on the time frame (Croxley Construcciones, 2013). The first meeting is denominated *'pull session'* and the master schedule is outlined by all participants. Then, there are the *'look-ahead'* planning meetings, and even though they can be realized between an every 3-12 week period the most common is the *'6 Week-Look-Ahead Planning'* (6WLAP): a more detailed schedule for the following 6 weeks. As the name itself indicates, *'last planner'*, the *'pull'* planning is also implemented in a very short-term planning scheme, commonly in weekly periods. In this way *'weekly work plans'* are conceived in weekly meetings (*Figure 2.7*), typically at the beginning of the week, making sure that a realistic planning is performed once great part of the uncertainty has been reduced. The master schedule is to be continuously updated during all the process.

Figure 2.7 – LPS weekly meeting in a hospital project in Santa Rosa, California (Lean Construction Institute, 2013)

Along the same lines of Sacks et al. (2009) and trying to address some of the deficiencies of the LPS and to ease the real-time production control process, Sacks et al. (2010a) presented the *'KanBIM'* system for a smooth flow, which is an adaptation of the pull-based *'Kanban System'* from manufacturing with the BIM methodology. Simultaneously, they stated that despite of the advantages of up-to-date 4D CAD technologies, they were *'not appropriate for day-to-day production management'*.

Finally, 4D visualizations and simulations are considered to be a useful tool when it is integrated with the LPS, for instance in the weekly work plan meetings (Eastman et al., 2011).

2.2.5. Contracting methods

Traditional contracting methods utilized in construction are an additional brake to collaboration (Teicholz, 2004) and tend to cause disparity an interest conflicts between project stakeholders.

According to the practices in the US there are 3 different methods to award construction contracts (Eastman et al., 2011): (1) Design-Bid-Build (DBB), (2) Design-Build (DB) and (3) Construction Management at Risk (CM@R). The first one, DBB, is the most common approach used in the AEC sector, especially for contracts related to public buildings. After ordering the design to the designer, there is a call for contractors to present their bids and different firms present their offer to the client or owner. Finally, the owner selects the best offer for its interests, minimum cost being the most common selection criteria. The second one, DB, is a variation of the DBB method and it consists in introducing a unique design-builder contractor to carry out both the design and the construction. This method is considered more appropriate to achieve project constraints fulfilled, but is less flexible for the client to introduce changes in the design once it has been approved. However, counting with a better design from the beginning is likely to be less error prone and thus, to require fewer changes in the future. The third one, CM@R has the particularity of bringing the construction management before the construction starts to provide good advice during the design process. This way, the maximum cost of the project is also guaranteed. The diagrams of these 3 ways of contracting are represented in *'Figure 2.8'*.

As it was mentioned in **Section 2.1.1**, the DBB approach tends to award the lowest bidder (Odeh & Battaineh, 2002) rather than the most viable offer taking other factors than cost into account. Apart from that the main contractor has no say in the design process to assess constructability, since it enters the project in the construction phase.

Apart from these 3 methods the American Institute of Architects (AIA) quite recently came up with another one: Integrated Project Delivery (IPD). The main definition of IPD provided by the AIA 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 optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction'* (AIA, 2007).

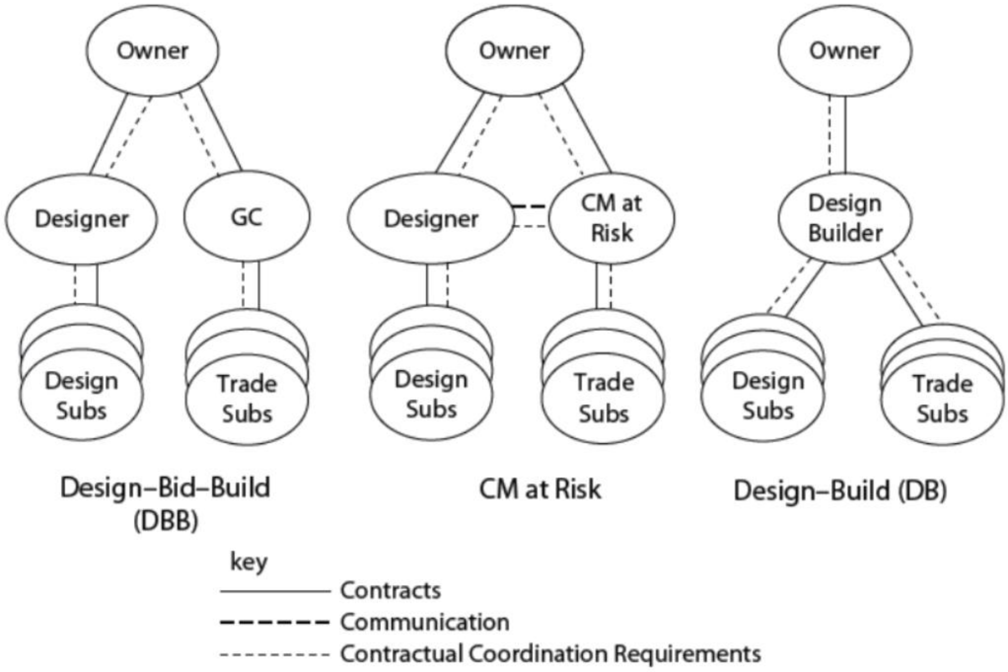

Figure 2.8 – Different contract methods utilized in the US construction industry (Eastman et al., 2011)

The 3 key features of IPD with regards to interaction between project parties are the following: (1) *early involvement*, (2) *shared risk and reward*, and (3) *agreement*. Sharing risks by the different parties is a way to implement JRM through a better project delivery. The implementation of relational contracting by means of a joint effort of all contract parties with more presence of flexibility rather than rigidity is assumed to be fundamental to address the problems of current contractual shortages (Rahman and Kumaraswamy, 2004).

It is also believed that IPD is, among the methods seen, the most suitable one for the implementation of the BIM methodology (Kent & Becerik-Gerber, 2010). As a matter of fact, the use of advanced tools for collaboration can be relevant to the success of this new approach (Eastman et al., 2011). As a result, it is not rare that IPD is gaining force as a new contracting method in those countries where the BIM uptake is growing up.

2.2.6. Conclusion Chapter 2.2

With the closure of this chapter a bunch of state-of-the-art innovative solutions have been separately presented. At this moment it is time to highlight the key points of each one of them and link everything to the specific purpose of this work.

On the one hand, new ways to reduce risk are rooted in collaboration and risk sharing among the interested parties. Moreover, the possibility to rehearse the construction process would also be a way to diminish uncertainty and allow taking early corrective actions. Contracts awarded using new contractual methods such as IPD is also one of the branches of action, remarking the importance of flexibility.

On the other hand, several things were learnt from the manufacturing industry: the lean philosophy from the TPS from which Lean Construction was conceived, the use of industrialized elements and above all the importance of a greater use of ICT. Due to the different cultures in manufacturing and construction industries, concepts need to pass through an adaptation process before transferring them from one to the other. In the case of ICT adoption, it is usually characterized by the entailed challenges and the resistance to change by practitioners. Furthermore, changes should not be solely based on technology uptake, but they should also include managerial issues.

The author considers this entire introduction essential to understand what is wrong and which problems a new methodology, in this case BIM, should address. Being aware of the framework in which BIM is expected to be implemented could strengthen the idea, and collaboration is a key ingredient in it. From this point on the work will be based on the use of methodologies and tools that allow this collaborative environment.

2.3. Building Information Modelling (BIM)

The present chapter is dedicated to briefly describe what BIM is about, the existing different levels, its current state in terms of adoption and some other important issues that need to be clarified before starting with the next chapter about 4D BIM.

2.3.1. What is BIM?

Building Information Modelling (BIM) is a revolutionary concept with a determined commitment to change from top to bottom the traditional practices of the AEC sector. There are a lot of different definitions of BIM and some of them are to be cited in the following paragraphs.

The authors of the 2nd Edition of the *'BIM Handbook'* state in their extensive work that *'BIM represents a paradigm change that will have far-reaching impacts and benefits, not only for those in the construction industry but for society at-large, as better buildings are built that consume fewer materials and require less labor and capital resources and that operate more efficiently"*. In view of what the appearance of BIM is supposing they also state that it is *"one of the most promising developments in the AEC industries'* (Eastman et al., 2011).

Considering all these definitions important, the author of the present work conceives BIM as *'a working methodology that aims to improve the way in which information is generated, managed, transferred and visualized throughout the entire life cycle of a building'.* Furthermore, it pursues to enhance communication between all the parties involved in every single phase of the project by locating the information in the centre (*Figure 2.10*). Therefore, it is obvious that the 'I' of information is the most important among the three letters of BIM. It can be seen as the methodology that makes possible everything seen up to this chapter, and could enable a significant boost for the productivity of the sector.

Consequently, it is clear that BIM is not a mere shift from Computer Aided Design (CAD) to a new modelling technique because it goes far beyond geometry. Unlike in 3D CAD solutions, the model is no longer conceived as a merely graphical representation of the building, but as a database containing all its information to be accessed during the entire life cycle. Indeed, object-based geometry is complemented with parameters including information at the element level, i.e., all the elements have an associated database describing their particular features, which is really useful for future stages. In addition, these elements can be considered smart because they closely represent the reality *'knowing'* how they must behave in the model: for instance, a window (guest element) in the model *'knows'* that it has to be accommodated in a wall (host element) and it would not be possible to place it with the non existence of such wall. This simple actions help professionals to take better decisions through a better design.

Naming issues are very often a product of an evolution of concepts. In this way, BIM has gathered many ideas that were long since around in the construction sector. Although it started to be known by this name in the last decade, the concept of CIC was present before BIM, and as it is suggested by Jung & Joo (2011), both terms are closely related and follow the same objective: to improve the effectiveness in construction by means of an integration of information systems, making a better use of them. Virtual Design and Construction (VDC) is another term in close relation with BIM which is lately being mentioned very frequently (Khanzode et al., 2008). In fact, BIM encompasses many concepts from VDC that have to do with the virtual environment applied to construction, such as 3D and 4D technologies. These capabilities are especially attractive for the construction stage and thus, are encouraging BIM adoption by contractors during the last 5-year period (McGraw-Hill Construction, 2012).

Another interesting point is the *'secondary effects'* of BIM. Since the workflow changes BIM implies other kind of transformations, like changes in the roles and responsibilities of the project members. The *'BIM Handbook'* mentions that *'BIM provides the basis for [...] changes in the roles and relationships among a project team'* (Eastman et al., 2011). As a result, new roles emerge as others may become obsolete (Gu & London, 2010). This is a reason why AEC sector practitioners need to adapt to these changes if they want to *survive*. At last, it is believed that BIM would have much more sense if it would be applied within a framework including IPD and principles from Lean Construction, creating a BIM+LEAN+IPD trident.

In order to summarize the BIM concept storm in a clear manner, these are some of the most important features of this methodology (Eastman et al., 2011):

- **Parametric design:** this design typology establishes relationships between elements in the model and between elements and the whole building by means of parametric objects (elements including parameters) and rules. In other words, parametric object-based design consists in having a model containing smart objects that behave as they are expected to: like real construction elements. This approach is more about constructing the model rather than representing it, this way achieving a really close approximation to the real building and facing problems early in the design. It also includes automation of certain functions as well as no space for discrepancies. Finally, parametric design is not only interesting to achieve a quicker design process, but also facilitates having information compiled at the element level making good use of these parameters.

- **3D graphics:** although 3D and BIM are not equivalent (3D CAD ≠ BIM), and it was clearly demonstrated to be one of the main concerns of misconception by the construction community (NBS, 2013), it is definitely one of the worthy features of BIM. It is unnecessary to explain that presented in 3D a construction project can be better understood by everyone. Project mistakes are at the same time more likely to be earlier detected. Apart from that, the owner who does not necessarily need to be a construction expert would be able to more easily comprehend the 'product' in 3D than in 2D.

- **Information at the element level:** apart from 3D geometry, each object or element settled in a BIM model contains valuable information. Having all this information stored allows having more control over every single element of the model as well as quickly obtaining quantities of any of them either individually or grouped. Furthermore, the conservation of these attributes is very useful for future phases of the project. It is not rare that sometimes BIM is referred to as *Building Information Management* or even *Building Information Modelling and Management (BIMM)* (BIM Task Group, 2011), because the term ‘modelling’ might lead to misunderstand the essence of this methodology.

- **Coordination:** this term can adopt different meanings within a BIM environment. On the one hand, it can refer to design coordination between project information and documentation. As the model is generated while changes in it are managed jointly, everything is reflected in all views all along the design process. It is no longer necessary to introduce all these changes manually in the different views, being the workflow this way less time-consuming and error-prone. Having a unique information repository or database (Gu & London, 2010) in the form of a virtual mock-up allows to have updated information and the last drawing version anytime. On the other hand, coordination may refer to advanced coordination possibilities between different participants and disciplines. For instance, combination between the architectural, structural and Mechanical, Electrical and Plumbing (MEP) models, as shown in *‘Figure 2.9’*. The introduction of VDC and clash-detection presents good improvements in this field and are especially useful in large construction projects, such as healthcare facilities (Khanzode et al., 2008).

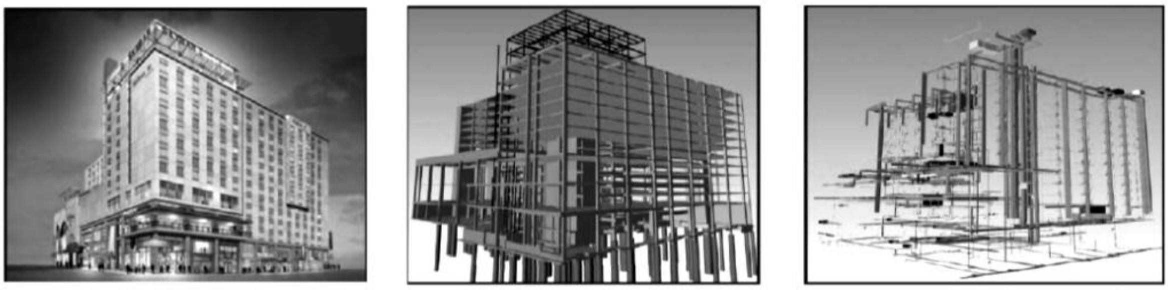
(a) Architectural Model (b) Structural Model (c) Plumbing Model

Figure 2.9 – Coordination between different disciplines models (Azhar, 2011)

- **Communication platform:** the importance of collaboration and communication was clearly emphasized in previous chapters and both are fairly improved with the use of BIM. As a methodology to be used in a collaborative environment, bringing the information to the centre is of vital significance (*Figure 2.10*). It means that every time a project participant requires certain information the transfer and RFI process is significantly simplified since usually he or she would directly request it to the model container of all this information. This does not mean that everything has to be visible for everyone, e.g., a structural engineer would not be interested in building carpentry. Providing the required information to each participant is one of the challenges so as they can use the model for their own purpose simultaneously and the available tools make it possible as long as they are well employed. The role of the BIM Manager, a figure already present in many construction firms, is relevant to the final success. At the same time, this improved way of communication also increases the transparency among all participants.

Figure 2.10 – BIM as a communication platform between different project stakeholders (Consortech Solutions Inc., 2011)

- **Visualization:** one of the major changes is the shift from representation to visualization. After the model has been *constructed*, views can be automatically generated to visualize the desired part of the building. In fact, as the information generated anytime is common and coordinated, the aim is no longer to represent every single element or groups of elements, but rather visualize any moment what is necessary and is already there. Furthermore, it is possible to hide and filter certain parts of the building as well as to change visualization settings for specific purposes in order to improve the output of the BIM model. Thus, visual mechanisms such as colours, transparencies and the like are a very appropriate tool for visualization.

- **Entire life cycle of the building:** BIM is conceived to be present throughout the entire life cycle of a building, from conception to maintenance or even demolition (*Figure 2.11*). Ideally, no relevant information lost should be experimented, since it is useful for future phases and even for future projects on the same building (inspections, refurbishments, demolition, etc.). In this way records of all the modifications in the building would be available. The BIM model acquires different purposes, satisfying the needs of all the participants and the construction phase is the most relevant for this study. Facility Management (FM) during the operation phase is another revolutionary utility of BIM which is nowadays in the spotlight.

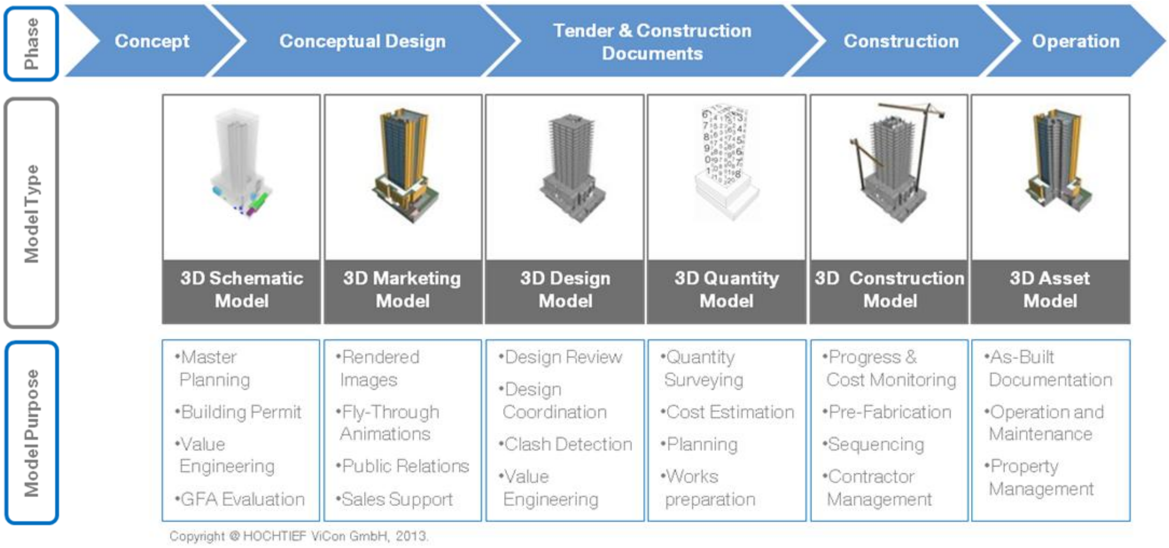

Figure 2.11 – Different purposes of the BIM model through the life cycle of a project (BIM Journal, 2013)

2.3.2. Different levels of BIM

When it comes to talk about BIM implementation levels, several definitions and classifications of different nature are available. First, the BIM maturity is characterized by the definition of 4 different levels in order to clarify the degree of collaboration, the data management/exchange medium and the working tools/processes utilized in each one of them. The diagram ideated by Bew & Richards in 2008 illustrated by *'Figure 2.12'* is the well known mean to communicate the maturity levels and these are their individual requirements (BIM Task Group, 2011):

- **Level 0:** the lowest maturity level would be based on basic 2D CAD with no specific collaboration requirements and having a paper-based (physical or electronic) documentation for data sharing.
- **Level 1:** 2D or even 3D CAD based design starting to use standards for a more effective and collaborative information production and data sharing. The graphical data is still likely to lack intelligence and there is no integration between drawings and other functions like scheduling and cost estimation.
- **Level 2:** the adoption of BIM enters in this level, where a 3D environment is also required. Information is attached to the graphical objects which can be used for other purposes. Library management, data structuring and some other common requirements are set to facilitate the data exchange. In this level integration

between different platforms could be achieved by means of proprietary applications but not in a fully *open* manner.

- **Level 3:** the highest BIM maturity level includes life cycle management of fully integrated interoperable data and a web-based model server for collaboration. Thus, team members can participate regardless of their location and the software used does no longer matter either. Everything would be integrated in a unique data repository or model.

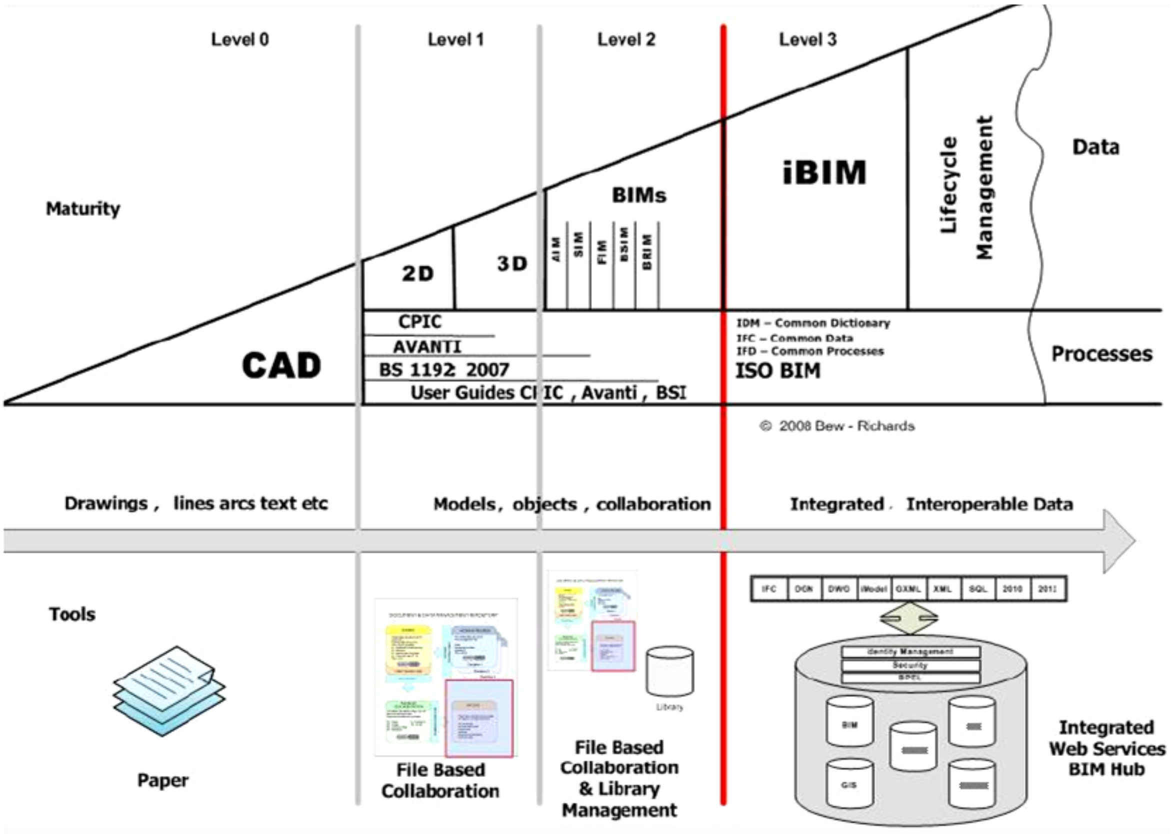

Figure 2.12 – BIM maturity levels (BIM Task Group, 2011)

Secondly, the concept of Level of Development (LOD) is also part of BIM. According to the American Institute of Architects (AIA), it *'describes the level of completeness to which a Model Element is developed'* (AIA, 2008). In other words, the content requirements for the elements in a BIM model are outlined in each of these levels, for a better information exchange between project members in a contractual environment. In this case, 5 different LOD are defined by the AIA: (1) LOD 100, (2) LOD 200, (3) LOD 300, (4) LOD 400 and (5) LOD 500. As the levels are accumulative they include their previous, e.g., LOD 200 includes LOD 100, etc. At the same time, each of them would correspond to a project stage: (1) conceptual design, (2) schematic design, (3) construction documents, (4) fabrication/assembly and (5) as-built conditions for FM. Thus, model objects get closer to the real construction products as projects advance on (Eastman et al., 2011).

Apart from maturity levels and LOD, the introduction of extra functionalities to the BIM methodology results in what are commonly recognized as BIM dimensions referring to areas of possible implementation. Far from being just a 3D modelling tool, BIM is rather a multidimensional (*nD*) approach integrating many business functions in the process of dealing with and conserving the information (Jung & Joo, 2011). This is in part achieved by the integration of graphical and non-graphical data. In this way, 4D, 5D, 6D,...,nD are taking a place beside the BIM acronym: 4D BIM for time management, 5D BIM for cost management, and so on.

At last, in order to represent a hierarchy, applications can also be levelled into: (1) BIM *environment*, (2) BIM *platforms* and (3) BIM *tools* (Eastman et al., 2011). The first refers to the integration of different BIM platforms and tools within an organization to optimize the data management and other company functions in systems like BIM servers. The second includes mainly design applications in which the original data model is created. The output from BIM platforms is typically exported to BIM tools, which are the third kind of applications where it is possible to carry out specific tasks.

2.3.3. Current status of BIM implementation

The implementation of BIM is by no means equal all over the world. There are specific countries in which this concept has been introduced some years ago and many others that are just starting to get *on board*. Moreover, *'the level of awareness, knowledge and interest varies within countries, from discipline to discipline and from client to client'* (Gu & London, 2010). Another fact is that not all the firms are implementing BIM at the same level of maturity, especially in those countries in a very initial stage of this methodology adoption.

There are some countries like the US, Canada, Australia, Singapore, UK and the European Nordic Countries (Finland, Denmark, Norway and Sweden) with remarkable levels of BIM implementation. Good evidence of it is the several guidelines for standardization that are available online as well as the publication of reports aiming to reflect the actual situation in these countries.

According to the SmartMarket Report 2012, the general BIM adoption of the construction industry in North America (US & Canada) has increased from a 28% in 2007 up to a 71% in 2012. Looking at figures by practitioner, another interesting fact reflected by this report is that contractors have overtaken architects, which is a clear sign of benefit perception by their part. Engineers are the less enrolled group but have experienced the largest growth since 2009. In addition, as it was mentioned in previous pages, the size of the firms is also important: 91% of large firms have adopted BIM in North America against only 49% of small firms *'Figure 2.13'*. The level to which BIM is adopted is also an important fact, i.e., the number of projects in which it has been employed *'Figure 2.14'*. Owners are the leaders at the light-user group, but this fact is set to change by 2014. With regards to 4D BIM taking up by contractors the report indicated that, although already adopted by a few large firms, it is still in early development stages (McGraw-Hill Construction, 2012).

Another recent National BIM Report from the UK revealed the implementation state by 2013 based on an extensive survey. It can clearly be seen that they still talk about 'awareness', which means that the use of BIM is not as extended as in the US. Only 6% of respondents were not aware of BIM in the UK, but only the 39% was aware and using BIM, the remaining 54% was just aware. In addition, the term CAD has substantial presence in the report because an important share of firms is yet to adopt BIM, besides the fact that many of them still mix it up with 3D. Actually, although the use of 3D (not BIM) is growing, among all the industry practitioners that took part in the survey 25% of them admitted that they were still using only 2D technology. Practitioners were asked about their confidence regarding BIM skills and only 35% of the respondents were confident, whereas 40% were not and the remaining 25% were somewhere in between (NBS, 2013).

The UK case is especially interesting in Europe due to the fact that by 2016 it will be compulsory for all public projects to be completed implementing BIM at least at *'Level 2'* (Cabinet Office, 2011). This is a clear sign of measures taken by governments and the importance of the introduction of new policies for BIM adoption by countries.

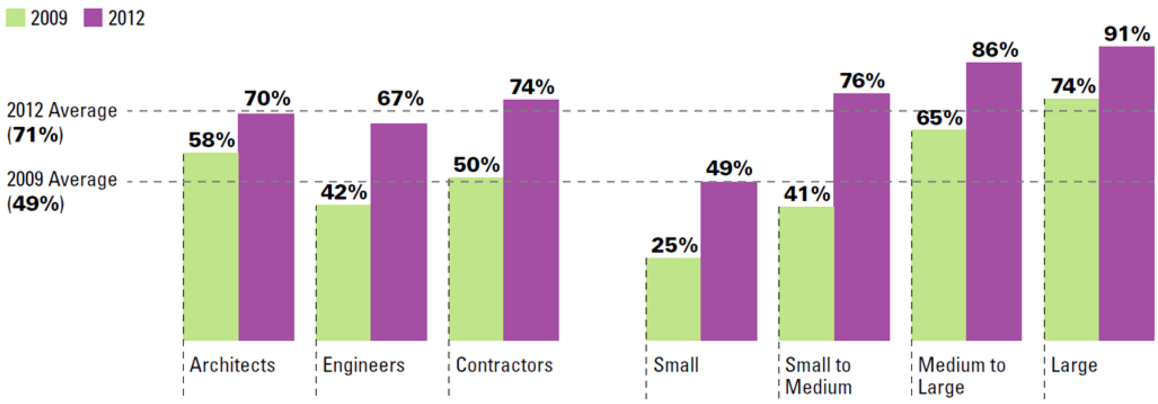

Figure 2.13 – Comparison between 2009 and 2012 BIM implementation in North America by player and firm size (McGraw-Hill Construction, 2012)

It is not easy to make this change, many practitioners telling their experiences agree on that. It does not imply immediate benefits; furthermore, they are yet to be contrasted. As it was seen in **Section 2.2.3** the construction industry is conservative and slow to adopt most new technologies (Peansupap & Walker, 2006). In part it is in close relation with software uptake, and it is another case of ICT adoption barriers.

A paper undertaken by Arayici et al. (2011) represents a good example on how SME can also experience the adoption and implementation of this methodology together with lean practises, for the particular case of a small architectural firm called John McCall

Architects, based in Liverpool. At the beginning there was an important resistance to change and this is why the process has to be gradual and progressive. It is also a good example of team motivation and *learning-by-doing*.

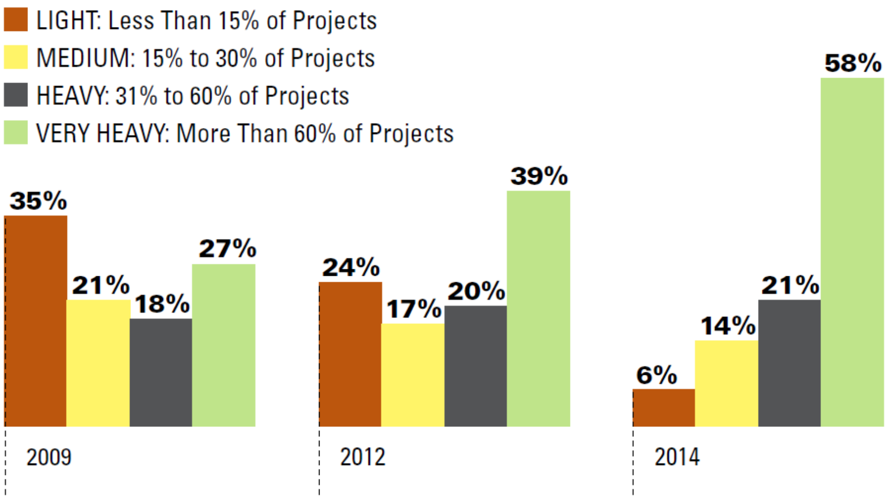

Figure 2.14 – Share of projects implementing BIM and predictions (McGraw-Hill Construction, 2012)

In the particular case of Spain, it can be said that BIM is only now gaining a bit of presence and thus, there are no figures available yet. In spite of everything, the 1st National BIM Congress, also known with the name "EUBIM 2013", has been recently celebrated with success which is a clear sign of adoption desire by practitioners. Further details of this event are presented in **'APPENDIX A'**.

Finally, it has to be mentioned that BIM adoption is a prerequisite for a further 4D BIM implementation.

2.3.4. Interoperability

Although interoperability is one of the main branches and challenges of BIM there is not an aim to go so much in depth because it is not vital for the present study. Nonetheless, understanding some notions is relevant for the practical part.

On the one hand, even though it would be optimum to have just one versatile application able to cover all the functions that the BIM working methodology includes, it is commonly not possible. As a result, the information needs to flow through different applications having also diverse format types as an output. In this way, the term interoperability refers to the *'ability to exchange data between different applications'* (Eastman et al., 2011). According to the hierarchical levelling of applications from **Section 2.3.2**, it may refer to either interoperability between *'platform-to-platform'*, *'platform-to-tool'* or *'tool-to-tool'*. The first one results to be the most challenging among the three of them.

On the other hand, there are many different software vendors that offer BIM platforms (**Section 2.3.5**). Consequently, not all the companies or practitioners decide to use the same software in their offices while they need to keep sharing and exchanging information as a form of collaboration. To summarize it in a simple manner, the thing is that each BIM platform establishes its own design rules to allow editing the model that is being generated, and also produces a proprietary format as an output. These differences in their rules cause problems when models generated in one platform are to be edited in another different one. In this way, the use of proprietary formats rather than open formats is an additional brake to interoperability, and makes *'Level 3'* BIM to be a sort of utopia nowadays.

There has been a continuous attempt to give a solution to this issue as well as to support standardization. The role of BuildingSMART, an international non-profit organization aspiring to make open BIM possible, during the last two decades has been especially remarkable. As a result of their effort, the most popular open data model broadly known with the name Industry Foundation Classes (IFC) was created for data exchange between different applications. IFC is also the acronym of an open exchange file format based on the mentioned data model. However, this file format still has limitations (Eastman et al., 2011).

Finally, *'platform-to-tool'* interoperability is the case to pay attention to in the practical part, since the output from one of the commercial platforms is utilized in a commercial tool for a specific purpose. Thus, synchronization and field mapping is required throughout the whole process.

2.3.5. BIM design platforms

The BIM working methodology requires of the adoption of design software platforms. Some of these applications available to date are listed in *'Table 2.1'* classified by company:

COMPANY	BIM PLATFORM	LOGO
Autodesk	Revit (Architecture, Structures, MEP) *Last Version: Revit 2014*	AUTODESK REVIT
Graphisoft	ArchiCAD *Last Version: ArchiCAD17*	GRAPHISOFT ARCHICAD
Bentley	Bentley Architecture *Last Version: Bentley Architecture V8i*	Bentley
Nemetschek	Allplan Architecture *Last Version: Allplan Architecture 2013*	NEMETSCHEK Allplan
Gehry Technologies	Digital Project *Last Version: Digital Project V1, R5*	Gehry Technologies
Tekla	Tekla Structures* *Last Version: Tekla Structures 19*	TEKLA Structures

*Only for the creation of structural BIM models

Table 2.1 – Main BIM design platforms and last versions available in the market (Eastman et. al, 2011)

2.3.6. Conclusion Chapter 2.3

The BIM methodology, which combines parametric design, 3D graphics, information at the element level, coordination, communication and visualization throughout the entire life cycle of the building, is completely changing the information management in construction. It gathers many of the required ingredients to make of construction a more effective and productive sector.

Although its adoption is heterogeneous in many aspects, BIM is a reality in many countries being the US a referent in the world. The UK case is also interesting because it represents a clear example of the strong say of Governments and their policies as far as public projects are concerned. In addition, statistics suggest that BIM is starting to be interesting for contractors since many of their processes are being covered and they can obtain benefits from it.

Unresolved interoperability issues are considered to be one of the barriers for a broader BIM adoption, at least up to its full extent, since there is a long way to walk before going beyond maturity *'Level 2'*. Data exchange between different BIM applications is concurrently hampered by the existing conflict of interests between different software vendors and the forced use of their proprietary output formats. *'Platform-to-tool'* interoperability is the most relevant for the practical part of this study in **Chapter 3**.

Leaving these issues aside for the moment, the next step is to analyze the actual possibilities of 4D BIM.

2.4. 4D BIM

This study aims to shift the focus on the opportunities of BIM for its use in project management functions and to consequently improve the fulfilment of the time constraint. Hence, a separate section is considered necessary to cover all the related issues. This chapter provides the basis for the 'Practical Part' of the present work regarding the 4D environment of BIM.

2.4.1. Time: The 4th dimension

The addition of the time attribute to a *3D (x,y,z)* environment results in what it is broadly known as *4D (x,y,z,t)* environment. This extra feature provides the model with more dynamism in terms of representing the behaviour of the building elements along time, extending in this way its usage for other purposes. Introducing time in the BIM environment is seen by the author as a way to make the time constraint more likely to be fulfilled and at the same time to address some of the problems previously mentioned in **Chapter 2.1**.

In principle, BIM and 4D technology are separate concepts and have had different progression from their conception. Nevertheless, it is believed that their combination in the same working methodology could help enhance certain processes and it seems especially interesting for contractors (Eastman et al., 2011).

It is believed that advanced ICT are able to ease the on time delivery of projects to the project team by the introduction of geometry in traditional construction schedules. In the following section, the application of 4D technologies to the AEC sector is to be analyzed.

2.4.2. 4D Technology in construction

At the time of representing a building, traditional design tools usually present its final and completed state without paying attention to its variation over time (McKinney & Fischer, 1998). As a result, one of the main limitations of 3D models is their incapability to display the precise status of the construction progress (Wang et al., 2004). However, planners require of a more dynamic view of the sequence in order to be able to visualize intermediate stages. Apart from that, the traditional tools employed for planning, such as bar-charts and diagrams do not facilitate the visualization of the process because they do not display spatial features and require of a high level of abstraction to create a mental representation (Koo & Fischer, 2000; Chau et al., 2003 & 2004). Even though experience is a strong point for planning there is a need to reduce risks by leaving less space to improvisation and consequently to possible inadequate interpretations. 4D technology came to light in order to address all the aforementioned problems, leading static models towards a more dynamic context by the introduction of the time variable: 3D + time.

4D models have several uses throughout the whole project life cycle and they offer opportunities within different project phases. 4 different stages can be distinguished regarding possible utilization of 4D models to assist construction projects (GSA, 2009): (1) pre-design stage, (2) design development, (3) tendering phase and (4) construction stage.

- **Pre-design stage:** at very early design or drafting stages, 4D technology is useful for the analysis of possible construction alternatives. It allows comparing several solutions with the interaction between the basic construction schedule and very general parts of the building, such as levels and spaces, but not at the element level yet.

- **Design development:** as the design advances on and more details are to be included, this technology is valuable to carry out constructability analysis. Whilst project planning attains importance, 4D models are truly helpful to check whether the planned schedule and construction sequence make sense. Apart from that, they are of good use to compare and select construction methods and processes.

- **Tendering phase:** 4D models can be used by contractors to communicate the different construction phases to the client, as well as the way in which the building is to be constructed. In part it could serve to convince the client about the ability of the general contractor to carry out the project. Simultaneously, they are also mentioned by the U.S. General Services Administration (GSA) to be useful to optimize the bidding process in requests for proposals. Therefore, 4D technology would not only work as a selling tool, but also to gain accuracy in the estimations by means of a better understanding of the construction sequence.

- **Construction stage:** during the construction stage one of the challenges for contractors is to coordinate trades or subcontractors on site so as to avoid time-space conflicts. This is another capability of 4D models along with the help they provide for visual site management. Another utility for this stage would be the *'as-built vs. as-planned'* comparisons for project monitoring functions. This is also the phase where it can be combined with the LPS seen in **Section 2.2.4** for short-term look-ahead meetings (Eastman et al., 2011), since the time for meetings can be reduced up to a 30% by the use of 4D technologies (Dawood & Sikka, 2009). Hence, the use of 4D can be extended to work as a tool to improve field productivity through an enhanced coordination and communication between disciplines and project participants. Especial attention is to be paid to these functionalities since this is the most relevant phase for the present research.

Regardless of the project phase, there is no doubt that these 4D models enhance project understanding, particularly in those large-scale projects with especially high complexity. Logically, the requirements of the model would significantly vary depending upon its purpose. If the model is to be used as a mere visualization tool, for instance, to show a construction sequence to the client in an animated manner the information and scheduling criteria used for such animation would not be vital. Nevertheless, if it is going to be used for management purposes by contractors and project managers, the model would be much more demanding in order to satisfy the flexibility needs of planners. This is the key factor where BIM has something new to offer. In this work more attention is to be paid to the opportunities of these tools for management at advanced stages, since it is when they are lacking more applicability and can be extended to their full potential.

2.4.3. Evolution of 4D technologies: From 4D CAD to 4D BIM

From the conception of 4D technology and until these days, many studies have attempted to improve the quality and visualization of the construction process, as well as diminish the effort required by the user to make it possible. Therefore, this technology has experienced an evolution during the last two decades, leaving a bunch of different generations of tools in the form of both commercial and prototypical applications. With a view to better understand this evolution it is necessary to pay attention to the existing literature on 4D CAD so as to be aware of the problems and questions that first researchers on these topics dealt with. This will help comprehend what kind of requirements these tools need to address. Hence, the present chapter is dedicated to perform a chronological literature review on 4D technology.

The term 4D CAD emerged as a medium to represent time and space for graphic simulation of a process. The CIFE (Center for Integrated Facility Engineering) from the Stanford University is an academic research centre committed to investigate on VDC (Stanford University, 2013) that was already dealing with 4D CAD in the 1990s. They focused on the power of 4D tools for time planning, allowing the consideration of construction and scheduling alternatives. As a result of their investigations, a tool called *'CIFE 4D-CAD'* was created. In other words, this tool was conceived for schedule visualization as well as decision-making in a single platform. At the very beginning the method of linking CAD components to tasks was almost purely manual and two wishes were stated for future works in McKinney et al. (1996) to address these shortcomings: (1) introduce further automation for the creation of the 4D model and (2) adapt this tool for a collaborative use.

A number of deficiencies of 4D CAD tools available in those times along with several requirements were presented by McKinney & Fischer (1998). A desirable *4D+x* environment was also mentioned, which was likely to include extra information apart from time and space, such as cost analysis. They also demonstrated how these tools can be used not only during the design phase, but also as an extension for the construction phase, by means of an example showing how it helped in the re-planning and decision-making for the construction of a roof. Collaboration was pointed out again in this paper referring to 4D CAD as a tool to be used by project teams, and remarking the level of detail as a key issue to be addressed within this particular field.

In 2000, some of the benefits of 4D CAD were proved as it was verified that 4D models are a useful tool for visualization, integration and analysis (Koo & Fischer, 2000). By applying this technology to a real case the model allowed a group of researchers face common problems that traditional scheduling systems might lead to, such as inappropriate level of detail and illogical schedule sequence in addition to time-space and accessibility conflicts. However, some weaknesses were still detected in 4D models, for instance they do not transmit all the necessary planning information. They were not able to show temporary elements neither their space requirements, not to mention other nonphysical constraints like resource availability.

Akinci et al. (2002) presented a system called *'4D WorkPlanner Space Generator'*, also known as *'4D SpaceGen'*, for automated generation of workspaces in an attempt to make 4D CAD simulations more enlightening. It was created so as to enable the user to visualize in the model not only the elements but also the space required for carrying out the activities. By these means it is possible to automatically detect time-space conflicts of four types of workspaces: labour crew, equipment, hazardous or dangerous and protected. Apart from that it also allows sharing the IFC-based output with other programs in order to conduct 4D CAD simulations or even automated modification of schedules.

Chau et al., (2003) elaborated another 4D tool for *'Graphical Construction Planning and Site Utilization'*, which platform was also known with the acronym *'4D-GCPSU'* and having an output model named *'4D Site Management Model'* (*4DSMM*). In view of the still component-based nature of 4D CAD models, it incorporated extra site management techniques such as resource allocation as well as a bi-directional information exchange, i.e., there was a possibility to switch from one application to another in order to introduce changes either from the 3D model or the schedule. In spite of everything, some of the manifested weaknesses were the slow processing of large files and the rigidity for model updating.

In 2004, a new enhanced 4D model called '*4D Site Management Model +'* (*4DSMM+*) was proposed under the system platform *'Management for Construction Planning and Resource Utilization'* (*4D-MCPRU*) (Wang et al., 2004). It permitted a dynamic resource planning as well as site utilization among other new functions. It means that, apart from adding schedule information it was also possible to include resource information, visibly structured in a work breakdown structure (WBS) and making possible to carry out resource plans by means of predefined templates for element types. This way the 4D model was extended towards other construction management fields. As it is indicated, an improved flexibility for re-planning is one of the key characteristics of the system, a vital feature for site management.

Along the same lines of site management tools for construction managers, Chau et al. (2004) presented a new prototype introducing annotations of the required resources (labour, material and equipment) for each of the activities of the schedule. It was validated as a useful tool for short-term site re-planning in a real case consisting in a warehouse erection in Hong Kong.

Due to the fact that 4D technologies had not experienced a broad adoption by construction practitioners, Mahalingam et al. (2010) made an effort to increase the understanding of the concept for a better acceptance via a practical application and several surveys carried out within the Indian construction sector. They analyzed the applicability of 4D CAD for different project types, stages and users, concluding that all of them can obtain, in one way or another, benefits from this technology. Despite great benefits can be achieved from 4D for contractor-client communication purposes, the lack of integration of these technologies with existing project management tools was addressed as an important future trend in case its applicability pretends to be further extended to project management functions.

With the progressive irruption of BIM in the AEC sector, 4D technology started to be integrated in the BIM process due to the several advantages, to be mentioned later, this new methodology incorporates. The barriers that 4D technology has been facing for its adoption are similar to those typically confronted by ICT in general and by BIM more specifically. In fact, a full understanding of BIM is required to implement 4D BIM. There is one particularity, though, the time required to prepare and link the model for simulations. Many problems faced by the use of 4D CAD were resolved simply by the new conception of a model at the element level, as it is going to be explained in the following subsection.

2.4.4. Differences between 4D CAD and 4D BIM

After the review of existing literature on 4D technologies it is vital to understand the differences that this methodology change entails and how it contributes to the 4D technology in construction. The main distinguishing factors of 4D CAD and 4D BIM are the following:

- **Information:** this is the most important difference among all the listed ones. Elements from a BIM model, unlike 3D CAD objects, contain valuable information and parameters. This is translated into a tight control over every single element from both the 3D and 4D models. The information is already attached to them from the beginning, and it does not have to be manually added. Furthermore, extra parameters can be included in the BIM model with view to facilitate the generation of the 4D model. However, to a large extent this fact relies on the quality of the imported BIM model.

- **Layers vs. Elements:** 3D CAD models are mainly composed of graphical layers that represent object's geometry. As a result, in a 4D CAD model layers are linked to tasks, whereas in a 4D BIM model tasks are mapped directly to elements in the model. In that respect the second methodology supposes a great advantage over the first.

- **3D model generation:** since one of the inputs for a 4D model is a 3D model, in a BIM-based workflow the 3D model is generated automatically and therefore one of the inputs is achieved without significant time consumption. On the contrary, in a typical CAD-based workflow, the 3D model would have to be created from 2D drawings with the consequent time loss for its production. As a result of all these differences the workflow also varies significantly from CAD to BIM as illustrated by *'Figure 2.15'* and *'Figure 2.16'* respectively.

- **Flexibility for re-planning:** the advantage of rapid generation and flexibility on introducing changes in a coordinated manner makes of BIM a really suitable environment for 4D as a managing tool. In case more than one application is used, coordination between different platforms becomes a really important issue and that is why synchronization options are really powerful. Automation, which was denoted to be a problematic issue of 4D CAD (McKinney et al., 1996), is also strongly reinforced in the process. After all, when the time available is quite reduced, as in the case of site management, the time-consuming 4D CAD workflow does not make much sense.

- **Advanced linking options:** the information included in the 3D objects is very valuable when it comes to link geometry to tasks (**Section 3.2.3**), and it is only possible as long as BIM is utilized. The use of rules to make reference to certain parameters contained in the elements accelerates the arduous manual linking process. This is usually anticipated inside the BIM design tool by the inclusion of additional parameters that are to be used later in a 4D BIM tool.

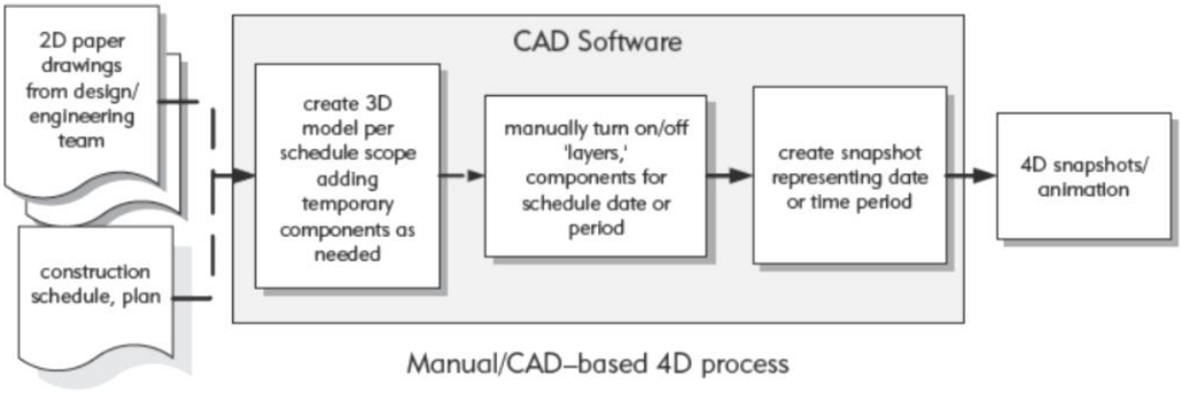

Figure 2.15 – Typical process steps for a 4D CAD-based workflow (Eastman et al., 2011)

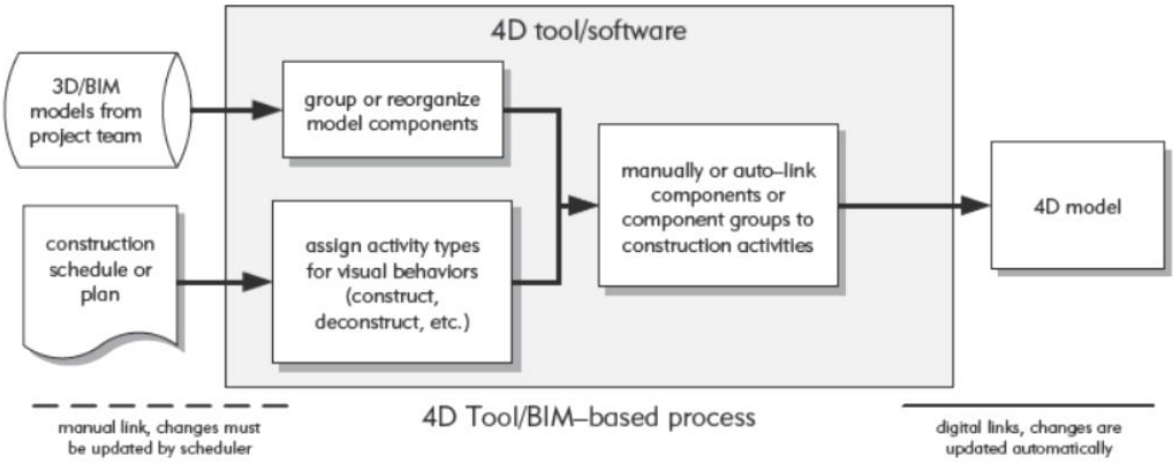

Figure 2.16 – Typical process steps for a 4D BIM-based workflow (Eastman et al., 2011)

2.4.5. Utilities of 4D models

After reviewing the existing literature on the evolution of 4D applications one can expect several functions to be covered by up-to-date 4D technology. The real value of 4D planning is an issue aim of debate among practitioners, since the client is several times considered to be the only beneficiary of all this, rather than planners. Nevertheless, this is not what literature suggests, because 4D BIM is referred to as a new dimension set to achieve more ambitious objectives. Briefly summarizing the content, these are some of the theoretical utilities of 4D models when they are to be used as an aid for project management functions (*Figure 2.19*):

- **Schedule visualization:** one of the most common utilities of 4D models is their implementation for visualizing construction sequences (McKinney et al., 1996; McKinney & Fischer, 1998; Chau et al., 2003). As an extra attribute introduced to 3D models, time visualization can considerably facilitate the understanding of schedules, not only to planners, but also to the rest of the team or stakeholders. This feature encourages the collaboration of all the participants, achieving a high level of transparency, which is demonstrated to be vital (Riley & Clare-Brown, 2001; Sacks et al., 2009). Schedule visualization is not limited to the design stage, but it also serves during the construction stage, for instance, for visualizing the changes introduced in a construction schedule. Time schedules can be visualized by means of either snapshots or simulation clips. Finally, real-time navigation at any construction stage via *3D walk-through* or *fly-through* is another possibility of 4D models.

- **4D simulations:** simulating the construction process is a visual way to assess constructability and to get close to the real conditions in the building site prior the start of site works. In other words, 4D simulations could serve as a sort of construction *rehearsal* to reduce uncertainty and anticipate project risks. They are applicable to entire projects or to a certain period of time, e.g., structural works phase. Sometimes creating a clip can be more effective than having snapshots in order to more evidently reflect the dynamism of a building site. Actually, animations can be included to make even more visual for everyone.

- **Integration and communication of project participants:** 4D technologies are also proper to be used in project meetings as a perfect mean for collaboration. It has been mentioned that effective communication between different trades and disciplines is vital during the construction phase. At the time of visualizing traditional construction schedules it is not rare to obtain different interpretations by different project members (Koo & Fischer, 2000). Thus, the addition of a visual component to the schedule is likely to help clarify any possible doubt as much as achieve a better communication and coordination among participants.

- **Decision-making:** the construction practice involves constantly making decisions during design, planning and construction stages of a project. However, the solution is not always clear and sometimes quick decisions are taken blindly without being completely sure of the best and most suitable option. 4D models are a mean to assist decision-making of practitioners whenever they need a clear picture to discard or approve different options. It is known that those decisions taken early have the largest impact on the project (Koo & Fischer, 2000). Analyzing construction or schedule alternatives are some of the main decision utilities of these systems. Many scientific papers agree on the fact that 4D is above all a tool to make proper decisions (McKinney et al., 1996; McKinney & Fischer, 1998; Chau et al., 2003).

- **Re-planning:** as they can be used for planning, 4D models can also be utilized for changing the schedule whenever it is required, in order to redirect the project towards the proper target. Flexibility to introduce these changes is vital so as to have a smooth flow and not to have to spend excessive time doing so (Chau et al., 2003 & 2004). Otherwise, if every time a change is to be made large amount of time would be required, 4D technologies would not have much sense. After all, neither the geometry nor the schedule is definitive from the beginning to the end. Consequently, the idea is rather to continuously be able to change and update the model until the end of the project.

- **Time monitoring:** control over completed tasks as well as those tasks under development is another important function of project management practises. Tracking the progress of the planned activities is imperative to know whether the plan is being accomplished and, in case it is not, to adopt proper measures to successfully confront the situation. Comparison of the *'as-planned'* against *'as-built'* conditions is the key aspect of time monitoring. The use of visual mechanisms like colours can serve as a temporary tool to help monitor the time constraint in a more visible way.

- **Analysis:** finally, 4D models can be used for carrying out analysis of different nature, all of them being related to project management activities. These are some of the alternative uses of these technologies:

    - <u>Conflict detections:</u> improper activity sequencing can originate time-space conflicts (McKinney & Fischer, 1998; Koo & Fischer, 2000) while carrying out construction works. This is usual because of the lack of visual content of time schedules. Foreseeing possible conflicts would avoid problems in the building site, such as, waiting time and waste. The automated generation of workspaces to anticipate time-space conflicts or *bottlenecks* is another function that can be added to 4D models (Akinci et al., 2002).

    - <u>Site utilization:</u> 4D models can provide a dynamic picture of the space required in the building site during the different construction phases (Chau et al., 2003 & 2004). Visualizing the location of resources like machinery, temporary equipment and installations or even possible spaces with stacked material of the utilization of the building site. Furthermore, the behaviour of mobile equipment could be foreseen. For instance, a common usage in this field would be the anticipation of crane activities (Al-Hussein et al., 2006) so as to analyze their manoeuvrability beforehand, as it can be seen in *'Figure 2.17'*. Site layout including machinery and temporary equipment (*Figure 2.18*).

    - <u>Resource allocation:</u> in order to know the resources (labour, material and equipment) required per activity 4D models can integrate functions to ease their optimum allocation (Chau et al., 2003 & 2004; Wang et al., 2004). As studies analyzing these possibilities suggest, this would be obtained by means of a database providing such information.

- <u>Health & Safety management:</u> since health and safety measures are also part of the scheduled activities, 4D BIM can be useful for safety management (Kiviniemi et al., 2011). It would consist in the integration of these kinds of elements and activities in the model and simulations, as illustrated in *'Figure 2.18'*.

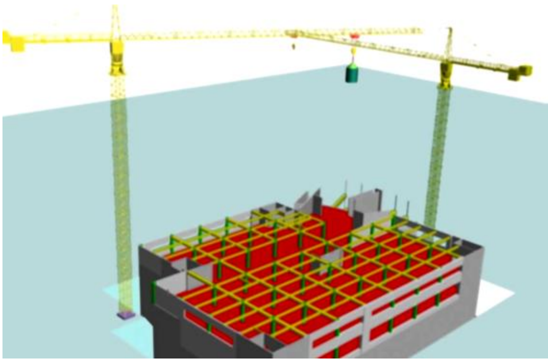
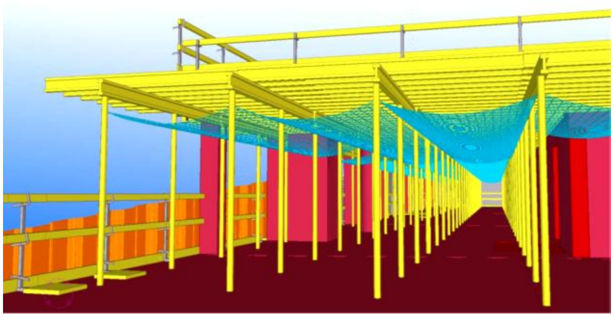

Figure 2.17 *(left)* – Model to analyze tower crane operations (Al-Hussein et al., 2006)
Figure 2.18 *(right)* – Health and safety measures and temporary support elements in a 4D model (Kiviniemi et al., 2011)

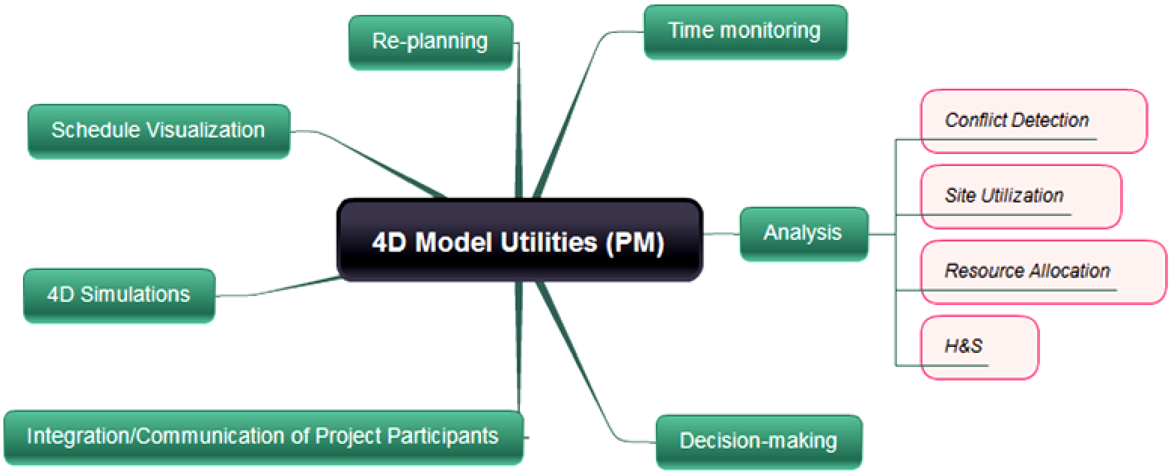

Figure 2.19 – 4D Model Utilities for Project Management (PM) Functions

The integration of cost analysis and management into the 4D environment is known as the 5th dimension of BIM: 5D (x,y,x,t,€). Even though it is another very important project management function, cost is out of scope of this study.

<u>Level of Detail</u>

The level of detail is an essential concept to take into account in 4D models. This depends both on the imported BIM model and the time schedule. On the one hand, having a homogeneous level of detail for all the activities in a model is very important to understand the construction process (Koo & Fischer, 2000). I.e., schedules have to count with a consistent WBS in which all the activities are broken down to the same level. On the other hand, the elements in a BIM model have to behave in accordance with the schedule and in the different project stages (from conceptual design to construction) they might be used to represent different aspects. This is why the LOD described in **Section 2.3.2** may also vary, increasing as the project advances on. 4D models should equally support different levels of detail as long as there is harmony between the schedule and the BIM model.

2.4.6. 4D BIM Tools

At the time to select a 4D BIM tool there are several aspects to be taken into account. In this section, the requirements for, different ways to build a model as well as the available software are to be explained.

Requirements of 4D BIM tools

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

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

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

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

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

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

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

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

Apart from these general issues mentioned in the *'BIM Handbook'*, there are also other factors to consider when selecting a 4D BIM tool. For instance:

- **Size of the file:** the resulting size of the output file would dictate the computer requirements for data processing. This is another really important fact to consider (Chau et al., 2003 & 2004) especially in large-scale projects entailing massive working files.

- **Bi-directional data exchange:** another no less important point to look at in those cases when multiple applications are used is whether the 4D tool is able to exchange data in a bi-directional way, i.e., if data can be introduced and changed in any of the platforms and if it is possible to reflect it in the others.

- **Stand-alone application:** some 4D BIM tools may integrate all these functions in a unique platform. This fact is considered important by practitioners (Mahalingam et al., 2010).

Available 4D BIM software

As these working methodologies entered the construction scene the market of 4D BIM applications has experienced a gradual growth and diverse software has been developed. The following *'Table 2.2'* displays a list of different commercial applications available to date for 4D BIM purposes:

COMPANY	4D BIM TOOL	LOGO
Autodesk	Navisworks* *Last Version: Navisworks 2014*	AUTODESK NAVISWORKS
Synchro Ltd.	Synchro Professional *Last Version: Synchro Professional 4.7.2*	Synchro Explore options. Manage solutions.
Vico Software	Virtual Office 4D Manager *Last Version: ---*	VICO SOFTWARE Integrating Construction
Tekla	Tekla Structures** *Last Version: Tekla Structures 19*	TEKLA Structures
Bentley	Bentley Navigator *Last Version: Bentley Navigator V8i*	Bentley
Innovaya	Visual Simulation *Last Version: ---*	innovaya
Gehry Technologies	Digital Project Extensions *Last Version: V1, R5*	Gehry Technologies

*2 different versions: Manage & Simulate
**Only for dealing with structural BIM models

Table 2.2 – Main BIM tools and last versions available in the market (Eastman et. al, 2011)

2.4.7. Future and innovative trends

The technological progress experienced in the last few years is presenting important advances for production management in the building sites. Mobile devices such as smartphones, tablets and the like offer the opportunity to have real-time responds from outside the office, making possible to track the WIP of project activities or work packages in a considerably more rapid manner (*Figure 2.20* and *2.21*). This fact could also accelerate the replacement of physical paper by electronic documentation once and for all in construction. At the same time, this shift from static documents towards a more dynamic and visual representation of buildings is likely to force a change in the perception of construction documentation.

Figure 2.20 *(left)* – Team using mobile devices in the building site (CITEWORLD, 2013)
Figure 2.21 *(right)* – Autodesk Navisworks for iPad (Autodesk, 2013)

With regards to other possible innovations, laser-scanning techniques are starting to be used to represent the *'as built'* state of buildings by means of point clouds. The application of augmented reality is also emerging in construction allowing overlapping virtual elements with the real environment through screens. Therefore, complemented with the previously mentioned mobile devices it could be a powerful tool for the future. Both are providing advanced possibilities for a more automated project monitoring with the integration of 4D technologies in the construction stage. For instance, Golparvar-Fard et al. (2009) proposed the combination of 4D technologies with time-lapse techniques, laser-scanning and augmented reality to compare *'as-planned'* against *'as-built'* conditions in an effort to automate progress tracking.

Although it is difficult to predict the future, these emerging technologies as well as promising research areas might be beneficial for 4D BIM and are likely to contribute with the continuous change of the industry.

2.4.8. Conclusion Chapter 2.4

Although they were devised separately, 4D (3D + time) technologies and the BIM methodology can be benefited the one from the other by their combination resulting in the 4D BIM environment. It can have several uses but its validity for project management functions is to be checked in the present study. From an extensive literature review on 4D CAD it was learnt some of the functions expected from 4D tools. In this way, the main requirements of 4D BIM tools for project management functions are outlined for the assessment part of the study. Some other extra features are also recommendable to be included by the same tools. Among the different 4D BIM applications available, the one provided by Autodesk is going to be used for the practical part: Navisworks Manage 2013.

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

Finally, innovative solutions may arise in a not too distant future to help obtaining more *'active'* functionalities by the incorporation of more automation in all the process.

3
PRACTICAL PART

3.1. Description of the Software Used

For the development of the practical part of this work 3 different computer programs were used: Autodesk Revit ® 2013, Microsoft ® Office Project 2010 and Autodesk Navisworks Manage ® 2013.

3.1.1. Autodesk Revit ® 2013

Autodesk Revit ® 2013 is one of the BIM design software platforms available in the market (**Section 2.3.5**). It makes possible implementing the BIM methodology and it has been used to create the BIM model for the practical part of this study. In this case, Revit has served as a design tool to create a simple 3D model for later exporting it to Autodesk Navisworks Manage ® 2013, including all the information at the element level.

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

The system requirements for the use of this software are specified in **'APPENDIX B'**.

3.1.2. Microsoft ® Office Project 2010

Microsoft ® Office Project 2010 is a project management software application for construction planning. It has been used to complete the time schedule, defining the activities, their duration and the sequential relationships. The final schedule has been imported in Autodesk Navisworks Manage ® 2013 in order to create the 4D model.

The system requirements for the use of this software are specified in **'APPENDIX B'**.

3.1.3. Autodesk Navisworks Manage ® 2013

The Autodesk Navisworks product family provides 3 different versions, each of them including more or less features: (1) Autodesk Navisworks Freedom, (2) Autodesk Navisworks Simulate and (3) Autodesk Navisworks Manage. The version used to implement the practical part is Autodesk Navisworks Manage ® 2013 since it includes all the features, although the Simulate version would be enough for 4D BIM purposes.

Autodesk Navisworks Manage ® 2013 is a BIM design review tool with 4D BIM capabilities thanks to the integration of the *'Timeliner'* function. It has other useful functions, such as, clash detection for project coordination. Navisworks was not conceived to provide the opportunity to modify a model, but it is rather a review, coordination and simulation tool. None of the actions in Navisworks modifies the original file and neither the model data contained in it.

The function within Navisworks that is going to be used most often is the *'Timeliner'*. It has a built-in scheduling application to manage tasks, although as it has been mentioned a more powerful tool will be used to that end: Microsoft ® Office Project 2010. In order to deal with external data sources, there is a dialog to add, delete and refresh them. Furthermore, Navisworks *'Timeliner'* allows visualizing the model status over different dates thanks to the *'Simulate'* tab. Even though *'Clash detective'* is a powerful functionality of Navisworks, it is not going to be explored in this study.

The system requirements for the use of this software are specified in **'APPENDIX B'**.

3.2. Process Description

It was stated in previous chapters that, as several studies confirm, there is a possibility to simulate the construction process over time. The question now is: to what extent is it possible? With the help of the tools described in **Chapter 3.1**, the aim is to prove what these studies suggest assessing by means of a practical example what is possible and what is not. At the same time, especial attention is to be paid to the workflow.

In order to complete this practical part, first a BIM model and a time schedule are to be produced, so as to merge them afterwards and generate the 4D BIM model. This is the analysis of a quite common workflow: merge a model from Revit with a time schedule from MS Project into Navisworks for 4D modelling.

3.2.1. Description and realization of the BIM Model

Since there is a time limitation and due to the fact that the author considers it as unnecessary to validate the requirements and capabilities of these tools, it is not the aim of this work to create and manipulate an extremely complex model. In any case, the exercise could be further extended to the wished level of complexity. However, it has to be kept in mind that as the model grows in size the requirements of the equipment used increase considerably.

No specific design criteria has been considered for the creation of the model, the main idea has been to have a building composed of different elements in order to carry out a logical analysis of the possibilities offered by the applications. The model of the building generated in Revit consists of 4 floors and a simple topography is included in order to represent excavation works. The elements used to compose the model are generic, assuming a level of development LOD 100, representing a very initial stage of the project. In the construction stage, the LOD would vary for a greater definition of each of the elements. The model as it was first generated for its exportation to Navisworks is further described in **'APPENDIX C'**.

In order to ease the visualization of the 4D model in Navisworks, there are some requirements for the output of the Revit model to be taken into account while creating it. The process consists in adding project parameters to the elements in the model. 2 advanced options are going to be explored: (1) the division of elements into parts and zones and (2) the assignment of a Task ID to the elements.

- **Parts and zones:** while elements with a pre-established geometry such as doors and windows do not require of any preparation, some others like floors and walls may need to be split into parts to better represent their construction sequence. For instance, floors can be divided into zones representing concrete pours (*Figure 3.1*). Grids and levels play an important role in this process, since those elements to be split need to be converted into parts in the BIM model. Grids can mark up horizontal and vertical zones that can be assigned to elements. For example: *'A-2'*. This has to be done prior the model exportation to Navisworks.

- **Assignment of Task ID to elements:** there is an interesting possibility to include a parameter to the elements in the model so as to make reference to tasks in the construction schedule and ease the mapping process in the future. For example, the ID or code for the columns contained in Level 0 is in this case "C02" (*Figure 3.2*).This has to be done prior the model exportation to Navisworks.

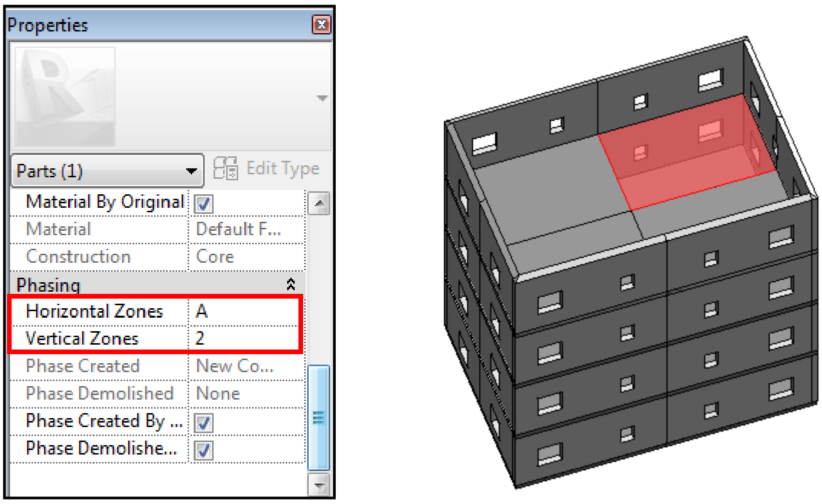

Figure 3.1 – Division of a slab into parts representing concrete pours: *'A-2 Zone'* (Revit 2013)

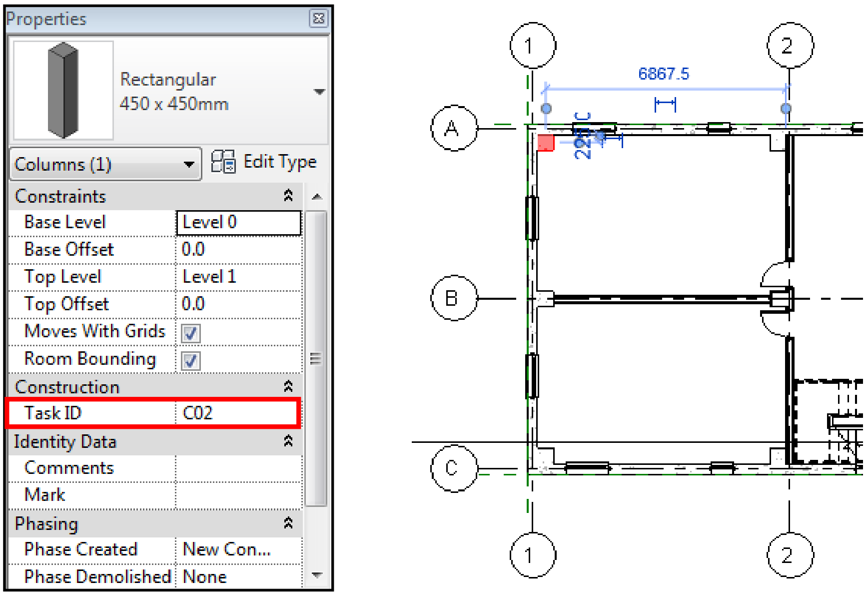

Figure 3.2 – Task ID parameter of a rectangular column: *'C02'* (Revit 2013)

In this case a simple model has been created and the size of the RVT file in its raw state was quite small: 6820 KB. This does by no means represent the reality of a large-scale project where it would be normal to run large files with the consequent need for a computer with a higher capacity.

'Figure 3.3' shows the original BIM model generated in Revit. The next step would be to import it into Navisworks as well as to create the construction schedule.

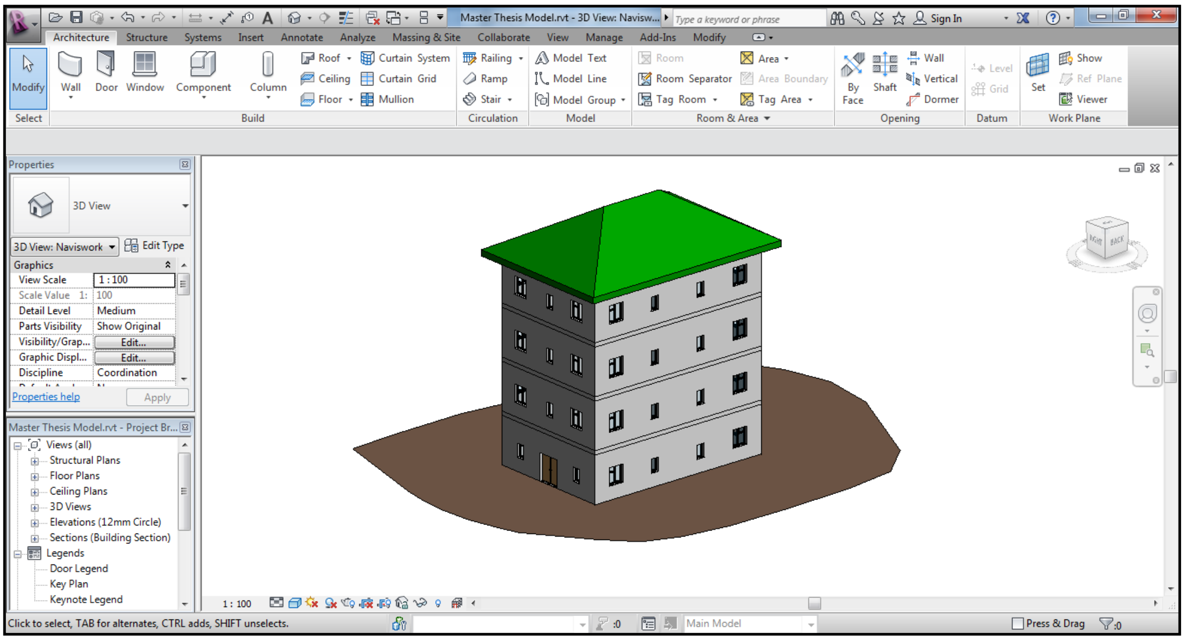

Figure 3.3 – Original BIM model created in Revit 2013

3.2.2. Description and realization of the Time Schedule

When it comes to realize the time schedule there are many different methods to arrive to the same point, but some of them are more time-consuming than others. As it has been mentioned before, Navisworks counts with a built-in scheduling application for introducing activities and several features of them. Nevertheless, due to the synchronization options of Navisworks with more appropriate and powerful project management software like Microsoft ® Office Project 2010, the schedule is to be completed in MS Project in order to later import it in Navisworks.

A simple construction sequence was prepared based on the BIM model. Approximated durations were given and relationships were added to all tasks. The different ways to create the time schedule will be further described later in **Section 3.2.3**. In this case the grouping of elements in activities has been generally made gathering the elements by level.

If the schedule is going to be created directly in MS Project, it is of great importance to include two extra columns: *"Task ID"* (if the Task ID method is to be used, **Section 3.2.1**) and *"Task Type"* (Text 1). The Task ID consists of a code given to each task (*Table 3.1*) and the Task Type is introduced with the aim of distinguishing between *temporary* elements, elements to be *constructed*, and elements to be *demolished 'Figure 3.4'*. The figure shows activities categorized under *'construct'* task type. However, activities under categories *'demolish'* and *'temporary'* could also be added.

Task ID	Task Name	Task ID	Task Name
T01	INITIAL SURFACE	**RF01**	ROOF
T02	EXCAVATED SURFACE	**EW01**	EXTERNAL WALLS L0
F01	FOUNDATIONS	**EW02**	EXTERNAL WALLS L1
C01	COLUMNS L-1	**EW03**	EXTERNAL WALLS L2
C02	COLUMNS L0	**EW04**	EXTERNAL WALLS L3
C03	COLUMNS L1	**IW01**	INTERNAL WALLS L0
C04	COLUMNS L2	**IW02**	INTERNAL WALLS L1
C05	COLUMNS L3	**IW03**	INTERNAL WALLS L2
F01	FLOOR L0	**IW04**	INTERNAL WALLS L3
F02	FLOOR L1	**D01**	DOORS L0
F03	FLOOR L2	**D02**	DOORS L1
F04	FLOOR L3	**D03**	DOORS L2
S01	STAIRS L0-1	**D04**	DOORS L3
S02	STAIRS L1-2	**W01**	WINDOWS L0
S03	STAIRS L2-3	**W02**	WINDOWS L1
R01	RAILING STAIRS L0-1	**W03**	WINDOWS L2
R02	RAILING STAIRS L1-2	**W04**	WINDOWS L3
R03	RAILING STAIRS L2-3	**---**	---

Table 3.1 – Tasks and ID of the elements in the model

There may be activities that do not represent any object in the model but are equally consuming time. They are irrelevant for the 4D simulation but have to be considered in the schedule, representing either a waiting period or a milestone. No actual dates are introduced at this step because it is to be analyzed in the section about time monitoring within the project management functionalities.

	Task Mode	Task ID	Task Name	Duration	Start	Finish	Actual Start	Actual Finish	Text1
1			**TOTAL PROJECT**	**194,25 days**	**Mon 01/07/13**	**Fri 28/03/14**	**NA**	**NA**	
2			**00 TOPOGRAPHY**	**8,88 days**	**Mon 01/07/13**	**Thu 11/07/13**	**NA**	**NA**	
3		T01	INITIAL SURFACE	0 days	Mon 01/07/13	Mon 01/07/13	NA	NA	Construct
4		T02	EXCAVATED SURFACE	8,88 days	Mon 01/07/13	Thu 11/07/13	NA	NA	Construct
5			**01 FOUNDATIONS**	**12 days**	**Thu 11/07/13**	**Mon 29/07/13**	**NA**	**NA**	
6		F01	FOUNDATIONS	11,13 days	Thu 11/07/13	Mon 29/07/13	NA	NA	Construct
7			**02 COLUMNS**	**78,5 days**	**Mon 29/07/13**	**Fri 15/11/13**	**NA**	**NA**	
8		C01	COLUMNS L-1	7,88 days	Mon 29/07/13	Thu 08/08/13	NA	NA	Construct
9		C02	COLUMNS L0	5,88 days	Wed 21/08/13	Thu 29/08/13	NA	NA	Construct
10		C03	COLUMNS L1	4,88 days	Tue 17/09/13	Tue 24/09/13	NA	NA	Construct
11		C04	COLUMNS L2	5,88 days	Thu 10/10/13	Fri 18/10/13	NA	NA	Construct
12		C05	COLUMNS L3	6,88 days	Wed 06/11/13	Fri 15/11/13	NA	NA	Construct
13			**03 FLOORS**	**59,88 days**	**Thu 08/08/13**	**Thu 31/10/13**	**NA**	**NA**	
14		F01	FLOOR L0	8,88 days	Thu 08/08/13	Wed 21/08/13	NA	NA	Construct
15		F02	FLOOR L1	8,88 days	Thu 29/08/13	Wed 11/09/13	NA	NA	Construct
16		F03	FLOOR L2	8,88 days	Tue 24/09/13	Fri 04/10/13	NA	NA	Construct
17		F04	FLOOR L3	8,88 days	Fri 18/10/13	Thu 31/10/13	NA	NA	Construct

Figure 3.4 – Task ID parameter of rectangular columns from Level 0 in the time schedule (MS Project 2010)

'Figure 3.5' shows the original time schedule generated in MS Project. The next step would be to import it into Navisworks to start creating the 4D BIM model.

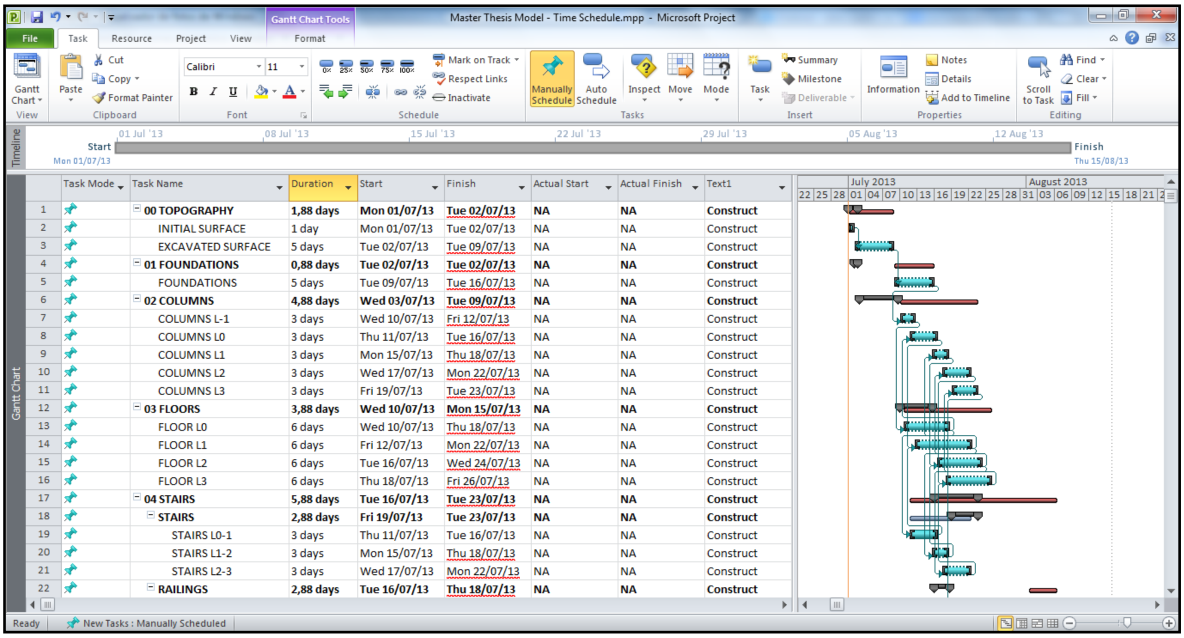

Figure 3.5 - Original time schedule created in MS Project

3.2.3. 4D Model

Once both the BIM model and the time schedule have been generated, it is time to bring the graphical and non-graphical data to Navisworks in order to merge them through a linking process and finally create the 4D model. As it is going to be shown, the preparation of the 4D model as well as the fact of dealing with changes are some of the most important issues. Hence, the workflow required for those purposes needs to remain clear throughout the whole process. Since the workflow aim of investigation is based on the use of several applications, the ability to switch from one platform to another as well as the export/import capabilities play an important role in all this.

It is worth mentioning that the better the quality of the BIM model and the time schedule the more refined the result will be. Therefore, great part of the job is to be done out of Navisworks.

Bringing the model from Revit to Navisworks

It is important to understand how to deal with different Navisworks file formats before starting to work. There are three different Navisworks file formats (*Figure 3.6*) (Autodesk, 2013):

- ***NWC** (Navisworks Cache File):* this is the default Navisworks format and it is linked to the original appended file (in this case RVT). This format compresses the model up to a 90% of its original size, and allows publishing NWF files. Although, this is not typically the workable file and the following 2 formats are more used.

- ***NWF*** *(Navisworks File Set)*: this is a reference file including external reference to the original appended file. No geometry is saved and it relies on the data from the main files, either NWC or RVT. This is commonly the file to work with. It is also linked to the original file (in this case RVT) and any change in it can be reflected. From an NWF it is possible to publish files with NWD format.

- ***NWD*** *(Navisworks Document File)*: this is typically the file to be shared with different team members for revision. It is a snapshot of the model in a specific moment, in which annotations can be included to communicate possible corrections.

Figure 3.6 – Different Autodesk Navisworks file formats (Autodesk, 2013)

As in many other similar applications there are two possibilities to bring the model created in Revit to Navisworks: (1) to import the model once the user is running Navisworks or (2) to export the model from Revit to a NWC file. The result is identical because in the first option a NWC file is created when the model is first saved. If the NWC file is opened again, there is a possibility to save the model as a NWF or NWD file.

The aforementioned different file formats vary in size for the same representation of the model. The size of the NWC is considerably smaller than the main RVT file (105 KB) because of the aforementioned reasons. At the same time, the NWF file is further compressed taking up a size of just 19 KB, whereas the NWD file is 99 KB. This is conceived this way so as to assure a smooth navigability of the model.

Once the model is in one of the Navisworks workable files it is ready as far as model graphical and non-graphical data is concerned. *'Figure 3.7'* shows the BIM model opened in Navisworks. For the purpose of this study NWF is the file format to be continuously used. The next step would be to import the time schedule in order to add the time attribute to the model.

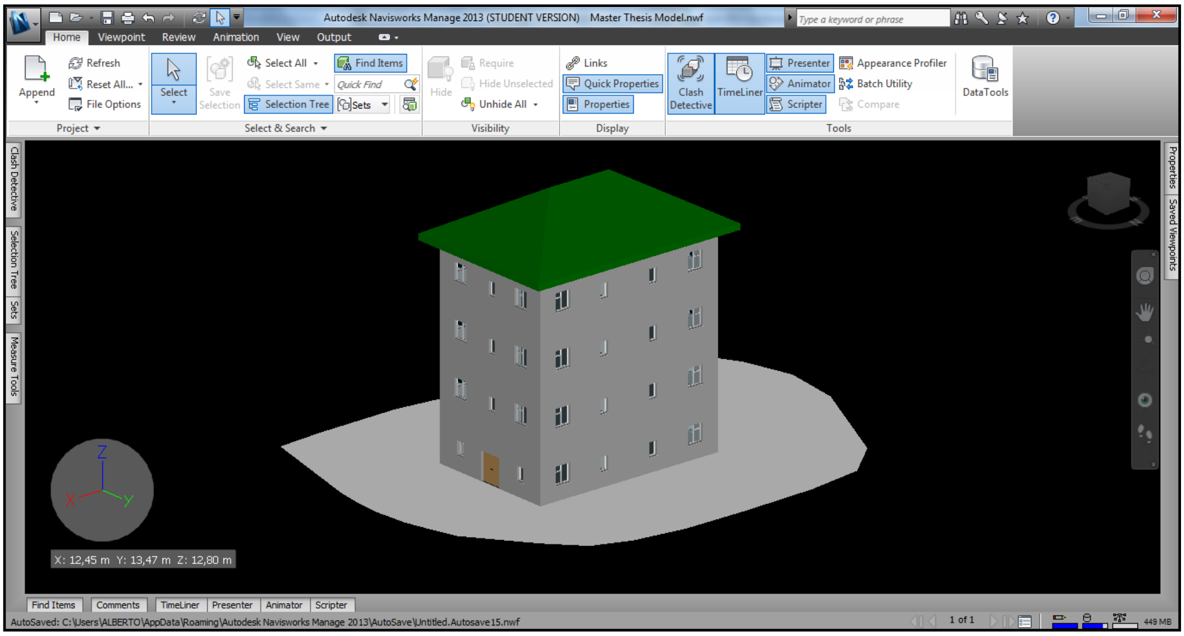

Figure 3.7 – BIM model opened in Navisworks Manage 2013

Preparing the model: Selection Sets

Before starting to analyze the different functionalities of the presented workflow, a description on how to prepare the model is to be given. One of the most important steps comes right after importing the BIM model to Navisworks. This process consists in creating selection sets of all the elements contained in the model based on the way it is aimed to represent the time schedule, e.g., amount of elements linked to a certain activity. As many selection sets as necessary have to be generated in this step with a view to facilitate the manipulation of groups of elements from the model.

In this case, as in the time-schedule, elements have been grouped by level. For example, all the columns from the Level 0 have been classified in one single activity. These sets are essential for the linking process that comes right after importing the schedule. The *'Selection Tree'* is also very useful for creating sets since it automatically organizes all the elements contained in the model so as to make it is easier to select any particular item. Furthermore, in case more than one model has been appended, all of them are visible in the selection tree. The hierarchy is maintained as per in Revit: *Category* > *Family* > *Typology*. For instance: *'Column > Rectangular > 450x450 mm'*. All the information from the original model is hence well preserved.

Once the selection sets have been created, every time they are selected the elements included in them are highlighted in the model (*Figure 3.8*) and are ready to be linked to schedule data. Furthermore, every single element or selection set can be isolated from the model hiding the rest of the elements (*Figure 3.9*). This helps considerably in the process of creating and checking the selection sets as well as visualizing internal parts of the model.

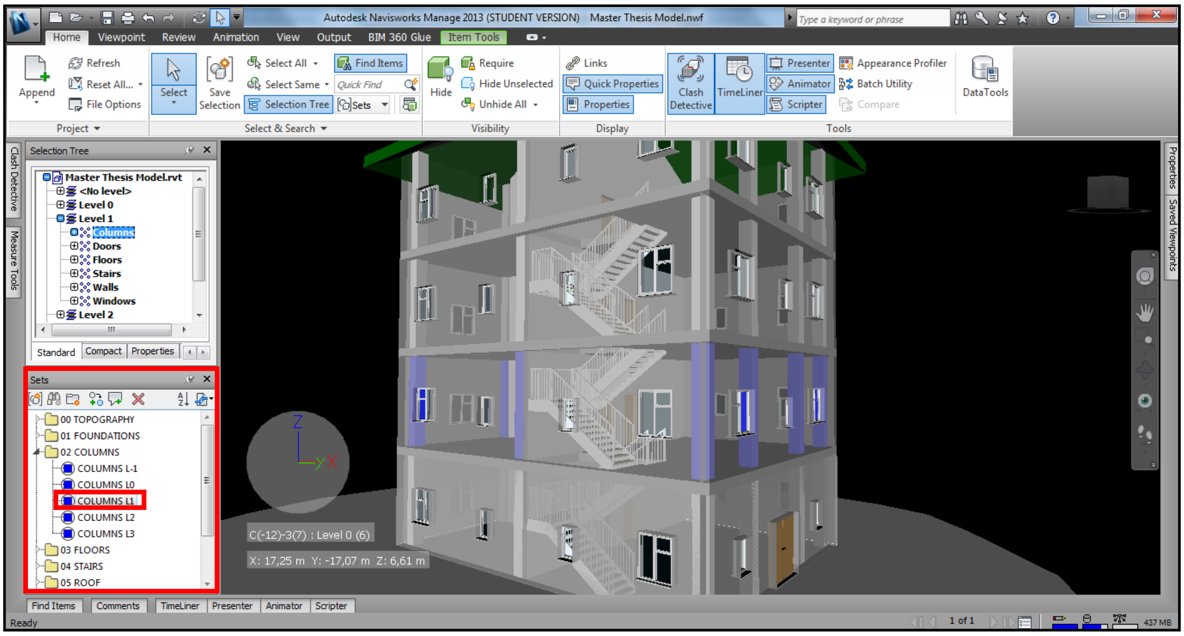

Figure 3.8 – Selection sets: *'Columns L1'* highlighted in blue (Navisworks Manage 2013)

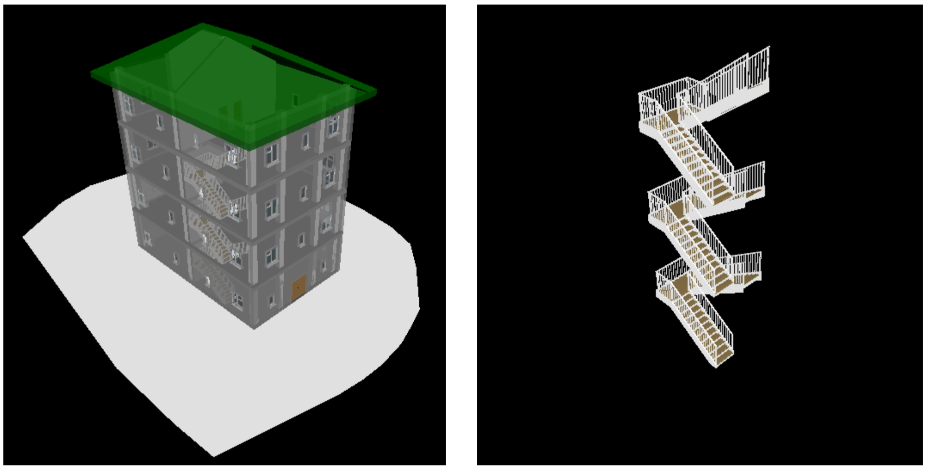

Figure 3.9 – Stairs and railings isolated from the model using the command *'Hide Unselected'* (Navisworks Manage 2013)

Another useful feature is the *'Find Items'* tool since it allows a further exploration of the model by the introduction of several searching criteria, which is especially useful in complex models.

Bringing the time schedule from MS Project to Navisworks

Navisworks has a built-in alternative to create activities in a similar way to other scheduling tools but this option has been discarded for the aforementioned reasons. Hence, the method of bringing the time schedule generated using external planning software (MS Project) to Navisworks is to be explained in this section.

Under the *'Data Sources'* tab in the *'Timeliner'* it is possible to add several file types and *'Microsoft Project 2007-2010'* is one of the options. At the time of adding a MPP file, there is a need to re-map the fields or columns from MS Project to associate the information to the *'Timeliner'* in Navisworks. This is done by means of the field selector, which pops-up each time a schedule is to be loaded. In this case, only the fields shown in *'Figure 3.10'* are mapped. Depending on the method used this mapping process will be required more or less times. Since it acts as a data source, every time a change is made in the linked schedule it has to be refreshed using the *'Rebuild Task Hierarchy'* or *'Synchronize'* option. The first one overwrites the whole existing schedule according to the linked one, whereas the second option only updates the changes introduced to different tasks' data.

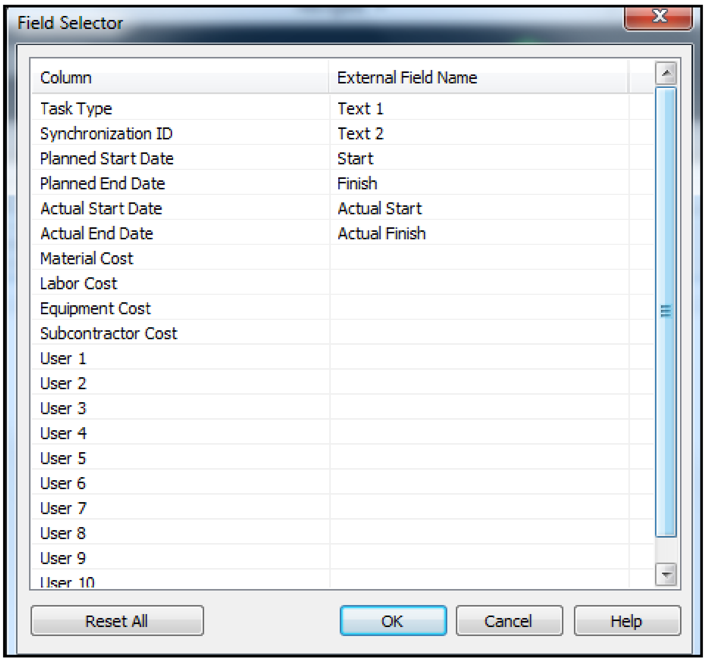

Figure 3.10 – Fields mapped in the field selector (Navisworks Manage 2013)

Finally, it is possible to include more than one construction schedule as a data source.

Merging geometry and tasks: Linking process

This is one of the keys of 4D modelling, the ability of the program to link elements to activities. It can be done manually, but in a model with a vast amount of elements it would be frustrating as well as time-consuming to attach all of them one by one. This is why automatic linking options gain so much importance.

A very useful tool for automating the linking of elements to tasks in Navisworks is the *'Auto-Attach Using Rules'* option. The choice *'mapping by selection sets with the same name'* is the most suitable in those cases when sets were created with that purpose, but it is also possible to do it by layers or elements. The set to which the task has been linked can be seen under the *'Attached'* tab (*Figure 3.11*).

Another powerful option is to create specific rules to map elements by category and property. This is suitable for making use of any of the properties of the elements such as

'Task ID'. This way it is not even necessary to create selection sets and the linking process is totally automatic, thanks to the information coming from the design tool. In this case, beside every activity being mapped the attachment is indicated as an *'Explicit Selection'* instead of a selection set (*Figure 3.12*).

Regardless of the linking method used, once an object has been linked to a task the information regarding such task in the *'Timeliner'* is displayed in the element properties. It is a good practise to check whether all the elements have been properly linked with the command find *'Attached Items'* and then hiding the selection.

Active	Name	Status	Planned Start	Planned End	Actual Start	Actual End	Task Type	Attached
☑	INITIAL SURFACE		01/07/2013	01/07/2013	N/A	N/A	Construct	Sets->00 TOPOGRAPHY->INITIAL ...
☑	EXCAVATED SURFACE		01/07/2013	11/07/2013	N/A	N/A	Construct	Sets->00 TOPOGRAPHY->EXCAVAT ...
☑	⊟ **01 FOUNDATIONS**		11/07/2013	29/07/2013	N/A	N/A		
☑	FOUNDATIONS		11/07/2013	29/07/2013	N/A	N/A	Construct	Sets->01 FOUNDATIONS->FOUND ...
☑	⊟ **02 COLUMNS**		29/07/2013	15/11/2013	N/A	N/A		
☑	COLUMNS L-1		29/07/2013	08/08/2013	N/A	N/A	Construct	Sets->02 COLUMNS->COLUMNS L-1
☑	COLUMNS L0		21/08/2013	29/08/2013	N/A	N/A	Construct	Sets->02 COLUMNS->COLUMNS L0
☑	COLUMNS L1		17/09/2013	24/09/2013	N/A	N/A	Construct	Sets->02 COLUMNS->COLUMNS L1
☑	COLUMNS L2		10/10/2013	18/10/2013	N/A	N/A	Construct	Sets->02 COLUMNS->COLUMNS L2
☑	COLUMNS L3		06/11/2013	15/11/2013	N/A	N/A	Construct	Sets->02 COLUMNS->COLUMNS L3
☑	⊟ **03 FLOORS**		08/08/2013	31/10/2013	N/A	N/A		
☑	FLOOR L0		08/08/2013	21/08/2013	N/A	N/A	Construct	Sets->03 FLOORS->FLOOR L0
☑	FLOOR L1		29/08/2013	11/09/2013	N/A	N/A	Construct	Sets->03 FLOORS->FLOOR L1
☑	FLOOR L2		24/09/2013	04/10/2013	N/A	N/A	Construct	Sets->03 FLOORS->FLOOR L2
☑	FLOOR L3		18/10/2013	31/10/2013	N/A	N/A	Construct	Sets->03 FLOORS->FLOOR L3

Figure 3.11 – Auto-Attachment of elements to tasks Using Rules by selection sets (Navisworks Manage 2013)

Active	Name	Status	Planned Start	Planned End	Actual Start	Actual End	Task Type	Attached
☑	INITIAL SURFACE		01/07/2013	01/07/2013	N/A	N/A	Construct	Explicit Selection
☑	EXCAVATED SURFACE		01/07/2013	11/07/2013	N/A	N/A	Construct	Explicit Selection
☑	⊟ **01 FOUNDATIONS**		11/07/2013	29/07/2013	N/A	N/A		
☑	FOUNDATIONS		11/07/2013	29/07/2013	N/A	N/A	Construct	Explicit Selection
☑	⊟ **02 COLUMNS**		29/07/2013	15/11/2013	N/A	N/A		
☑	COLUMNS L-1		29/07/2013	08/08/2013	N/A	N/A	Construct	Explicit Selection
☑	COLUMNS L0		21/08/2013	29/08/2013	N/A	N/A	Construct	Explicit Selection
☑	COLUMNS L1		17/09/2013	24/09/2013	N/A	N/A	Construct	Explicit Selection
☑	COLUMNS L2		10/10/2013	18/10/2013	N/A	N/A	Construct	Explicit Selection
☑	COLUMNS L3		06/11/2013	15/11/2013	N/A	N/A	Construct	Explicit Selection
☑	⊟ **03 FLOORS**		08/08/2013	31/10/2013	N/A	N/A		
☑	FLOOR L0		08/08/2013	21/08/2013	N/A	N/A	Construct	Explicit Selection
☑	FLOOR L1		29/08/2013	11/09/2013	N/A	N/A	Construct	Explicit Selection
☑	FLOOR L2		24/09/2013	04/10/2013	N/A	N/A	Construct	Explicit Selection
☑	FLOOR L3		18/10/2013	31/10/2013	N/A	N/A	Construct	Explicit Selection

Figure 3.12 – Auto-Attachment of elements to tasks Using Rules by Task ID (Navisworks Manage 2013)

The secret for a fast and effective linking lies in making use of the right option in any case, since all the cases are not equal. However, for companies dealing with many similar projects it would be really helpful to have all these processes standardized and to count with a defined workflow for all of them.

Possible workflows

3 different methods to bring the time schedule into Navisworks are to be mentioned, depending upon the way in which it has been created:

- ***METHOD Nº1:*** the first method consists in manually creating the time schedule in MS Project and then separately carrying out all the linking process with selection sets. This involves re-entering all the names of the selection sets based on the activities and therefore, it is rather time-consuming (*Figure 3.13*).

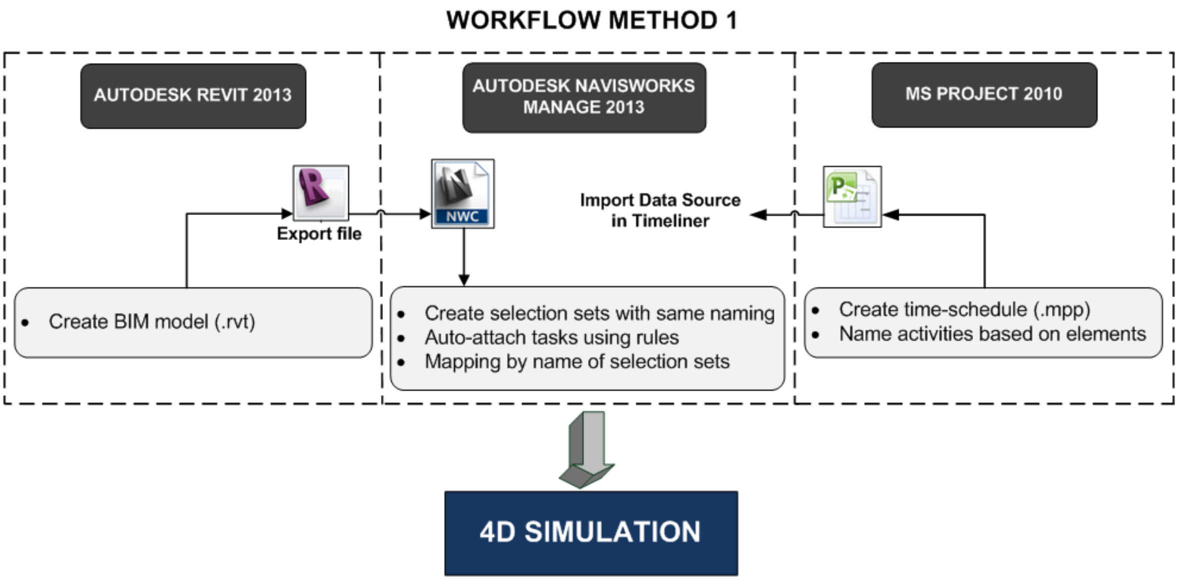

Figure 3.13 – Workflow for Method 1: Manual Time Schedule creation and automatic linking

- ***METHOD Nº2:*** in the second method selection sets are first created in Navisworks. Using the *'Auto-Add Tasks'* for *'Every Selection Set'* option the tasks are then automatically generated in Navisworks. After that, a CSV file is exported to MS Project for further task organization and management as well as to count with more advanced options. Finally, the optimized time schedule can be added again as an external source into Navisworks (*Figure 3.14*). This is probably the fastest method among the 3 presented, but also the less adapted to the way things are done nowadays.

- ***METHOD Nº3:*** the last method consists in using an ID for every activity as it was shown in **Sections 3.2.1** & **3.2.2**. Associating an ID to tasks in the time schedule (MS Project) and elements in the model considerably simplifies the mapping process in Navisworks. Otherwise, in the first 2 methods shown, activity names would be dependent upon the names of the selection sets, or vice versa, which could not be effective in many cases. The ID is another field or parameter to be added in Revit beforehand. This method or workflow could result a bit more time-consuming at the beginning, but once in Navisworks it is totally automatic. At the same time, it is a very useful and organized way to sort elements by activity as well as a way to extend the use of these tools as it goes hand in hand with the BIM philosophy (*Figure 3.15*).

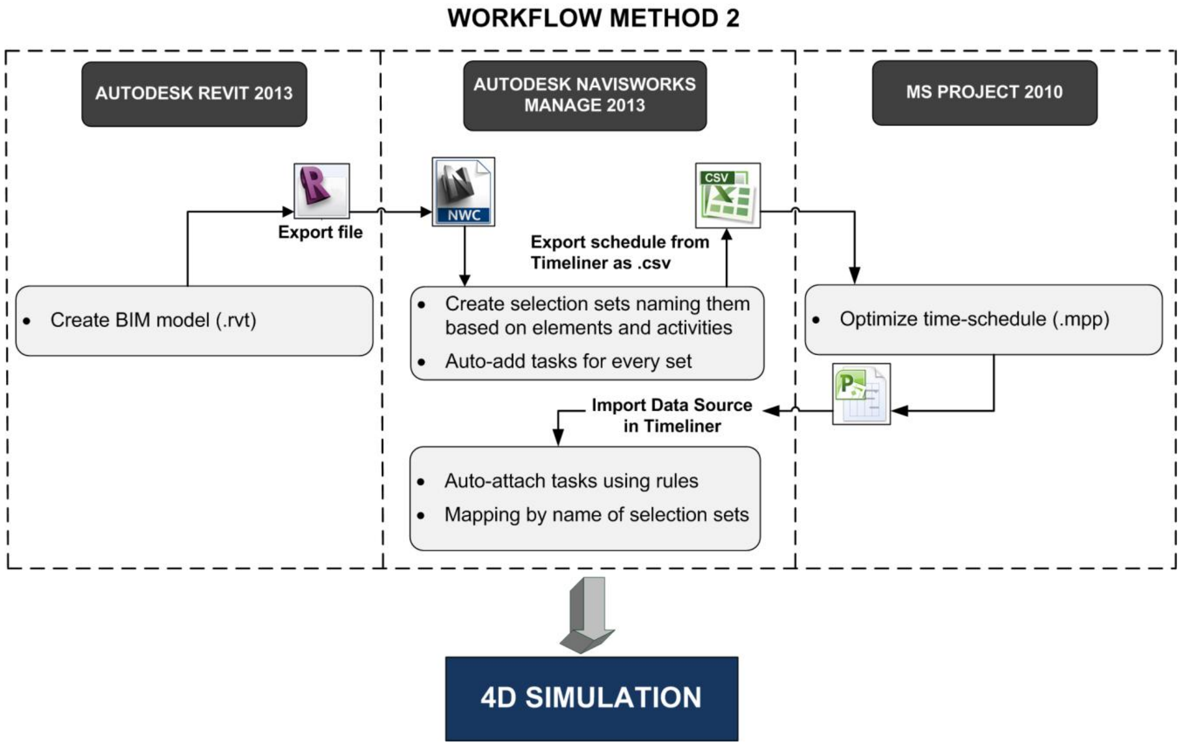

Figure 3.14 – Workflow for Method 2: Selection sets based Time Schedule and automatic linking

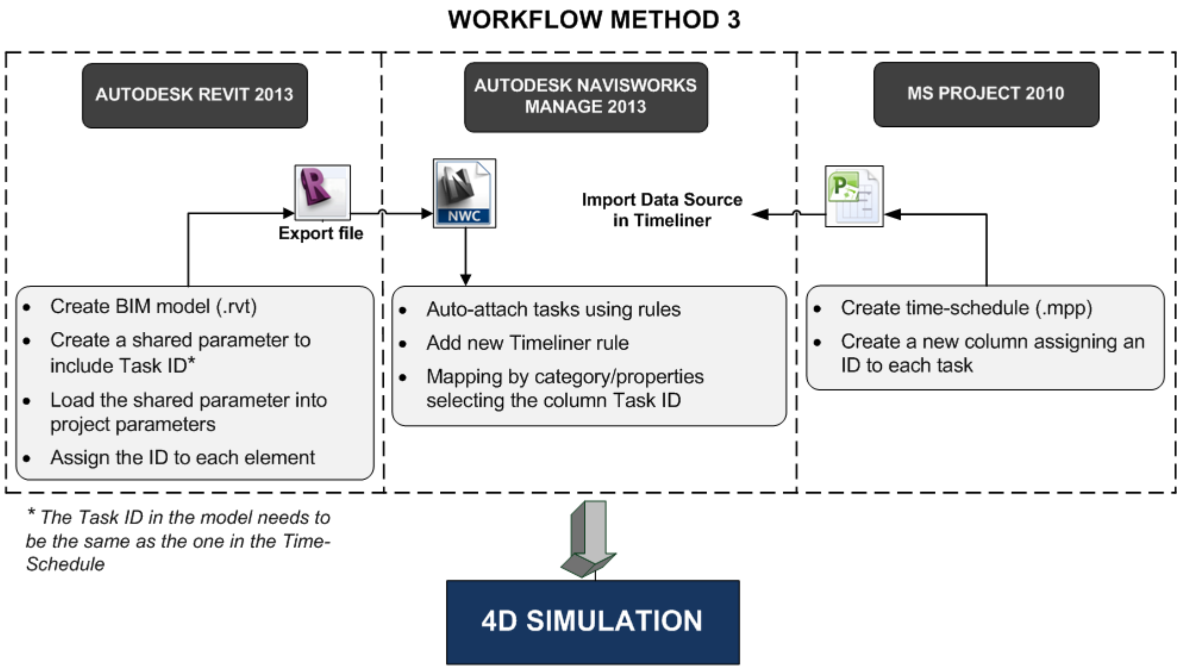

Figure 3.15 – Workflow for Method 3: Manual Time Schedule creation with task ID and automatic linking

As it was shown in *'Figure 3.10'*, if the *METHOD 3* is to be used, the *'Synchronization ID'* field has to be mapped with *'Text 2'* column, which is the one referring to *'Task ID'* in MS Project. The rule that was introduced and the *'Task ID'* property in the *'Selection Tree'* can be seen in *'Figure 3.16'*.

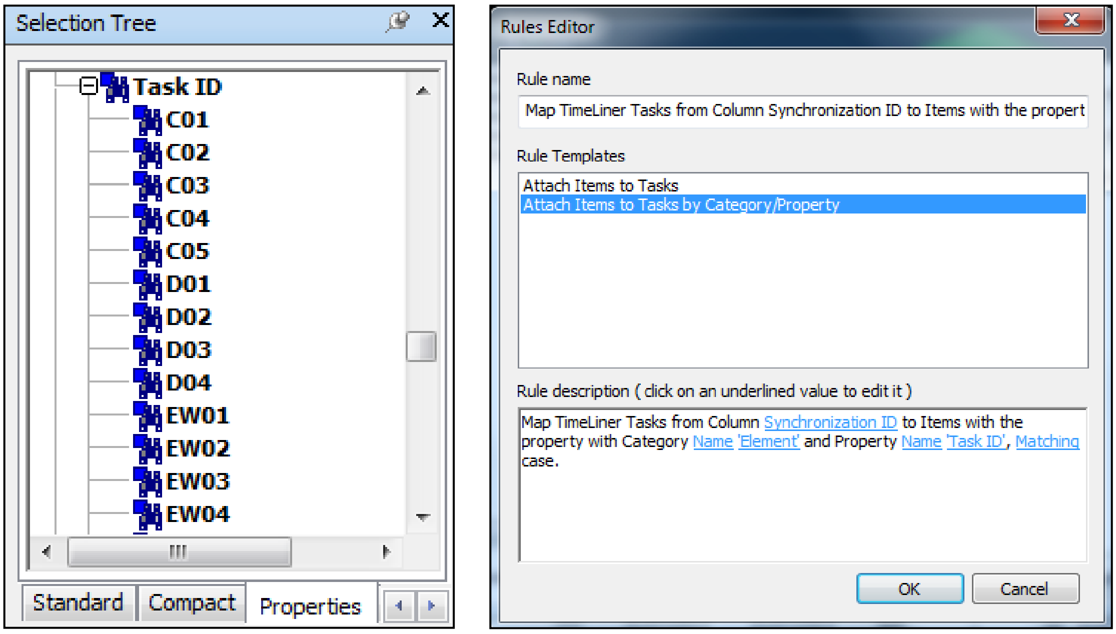

Figure 3.16 – Task ID property and addition of a new rule (Navisworks Manage 2013)

As soon as the 4D model is ready after using one of the workflows mentioned above, the model is ready to test its functionalities as a project management tool.

3.3. Analysis of possible functionalities

All the possibilities of 4D technology for project management functionalities mentioned in the state-of-the-art are to be analyzed one by one in this section. In this manner a clear picture of what can and cannot be done using the proposed workflow will be created, and will allow drawing up conclusions on the utility of these tools.

3.3.1. Visualization

It is clear that visualization is one of the most important general contributions of 4D technology. Navisworks offers several functions to ease visualization of the construction sequence, as well as the model in general terms.

On the one hand, in order to visualize the construction schedule it is possible to position the *'Timeliner'* in any of the activity period. In consequence, the planned work progress can be visualized at any period contained in the schedule. The activities being completed at that exact moment in time are highlighted and displayed in a different colour (*Figure 3.17*). Schedule visualization and simulations are very closely related.

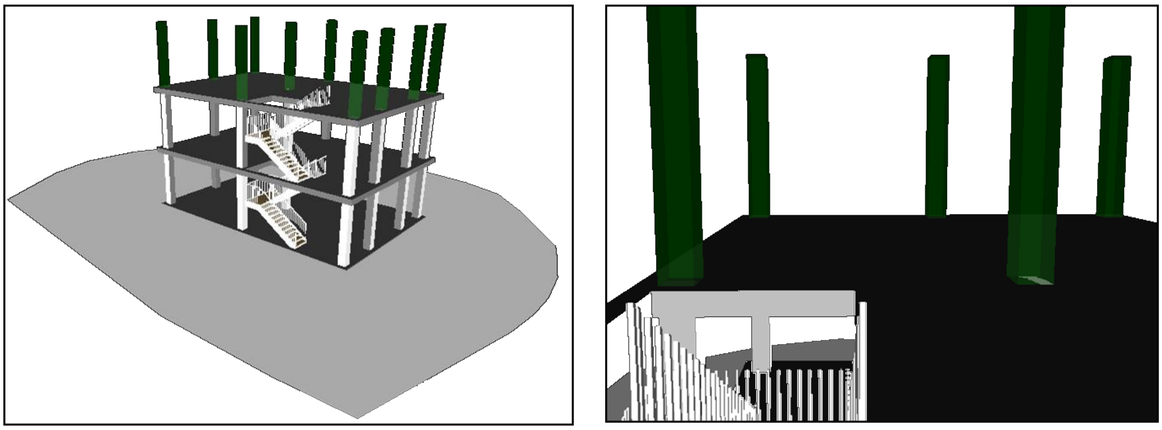

Figure 3.17 – Construction of the columns in Level 2 (green) from different viewpoints (Navisworks Manage 2013)

On the other hand, some of the virtual factors that VDC refers to can be appreciated in Navisworks. The model can be reviewed from every single point and *'Viewpoints'* can be saved for future use. Real-time navigation through the virtual mock-up of the building is also possible with the *'Walkthrough'* and *'Flythrough'* options. Furthermore, these functions are available for any of the construction stage, which means that the 4D model can be analyzed from any position and in any day contained in the time schedule period. It is even possible to use an avatar to add up more realism to the model, as it can be seen in *'Figure 3.18'*. It is important to be aware of the fact that this can help detect design errors as much as reduce uncertainty.

Figure 3.18 – Model real-time navigation with an avatar and potential design error detection (Navisworks Manage 2013)

In the *'Timeliner'*, under the *'Configure'* tab it is possible to control the visualization settings according to the specific needs of the user. These settings are useful for colour scheming and applying transparencies to components. Time monitoring is a function that can be benefited from them as it is shown in **Section 3.3.4**. Thus, the way in which the elements of the model are displayed in the construction sequence simulation can be easily manipulated.

3.3.2. 4D Simulation of the construction process

Navisworks allows simulating the construction process of the BIM model imported from Revit. The output would consist of either a clip or several snapshots of the building to visually anticipate the state of the construction progress over the planned period. It also helps envision possible conditions that are likely to be faced during construction to reduce uncertainty before or even during the construction stage. Apart from that, it serves as a communication tool to coordinate site works.

The simulation can be freely navigated backwards and forwards and it can be paused or even adjusted to a specific date in the schedule. The simulation period can be limited by dates if desired, as well as the total duration of it set in seconds. In addition, the simulation can be viewed from different angles and points of view and it is possible to orbit and zoom in and out the view while the sequence is being displayed. These options facilitate the visualization of possible critical parts of the model at a certain moment in time.

Simulations are the basis for the rest of project management functions since they are the tool to be used every time something needs to be analyzed, clarified or discussed. *'Figure 3.19'* presents the planned state of the building by *'Thursday 26/09/2013'* (marked in red). As it can be seen, the building would be completed up to the second floor slab at that specific date.

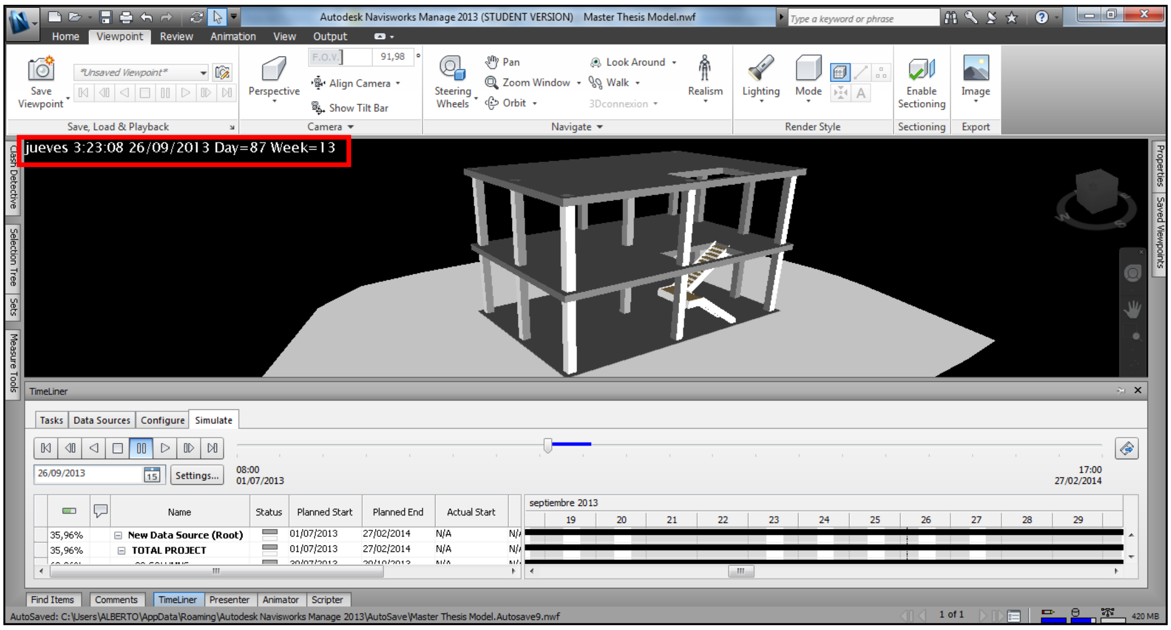

Figure 3.19 – Navisworks *'Timeliner'* simulator showing an intermediate stage of the construction sequence. *Date: Thursday 26/09/2013*

It is worth mentioning that a paper-based delivery of the present work does not facilitate the envisioning of the 4D simulation. In consequence, screen snapshots are the only way to show it in the written report, although the full potential of this tool is not tangible. A short clip is included together with this paper, and a more detailed construction sequence of the model is shown in '**APPENDIX D**'.

3.3.3. Introducing changes: Re-planning

As it has been mentioned in previous chapters, flexibility is an important factor to take into account when using a 4D tool. In fact, sometimes it is necessary to adapt the 4D model, because there is a need of either redirecting the plan and re-scheduling activities or modifying design constructive solutions. In this chapter some of the features for introducing changes in the schedule as well as in the model are going to be analyzed by means of a simple example.

It is common to detect design errors while a 4D model is being reviewed and it would be ideal to be able to correct them straight away. Since the original model cannot be modified in Navisworks, it is mandatory to go back to the design platform if any change has to be made. However, there is a tool to help in all this process: *'Switchback'* (*Figure 3.21*). This option can be enabled in Revit and it works as a communication tool between both platforms. Those elements selected in Navisworks are reflected in the original model by means of a view that is opened up in Revit with the name 'Navisworks'. This function fairly improves the Revit-Navisworks connection.

In the previous **Section 3.3.1** a design error was detected by means of the *'Walkthrough'* functionality: there was a missing railing in the perimeter of the staircase hole in every level. Once the change is made in Revit it is recommendable to include the *'Task ID'*, if this method is being employed. In this case, as the added railing is to be represented together with the rest of the railings, the ID from *'Table 3.1'* has to be introduced in the railing of each level: R01, R02 and R03. This way the changes will be reflected in the 4D model and it will be ready for the simulation after refreshing the introduced rule (*Figure 3.20*).

As it was a notorious error the *'Switchback'* option would not be so necessary to solve the problem because it is known that the railing is missing in every level. Although, it is very useful to change specific elements like doors, windows, etc. as in the example shown in *'Figure 3.22'*. The typology of one of the windows and the position of one of the doors is quickly modified by means of the *'Switchback'* option. This tool is also commonly utilized in clash detection, to correct collisions between ducts/pipes and beams in a rapid manner, for instance.

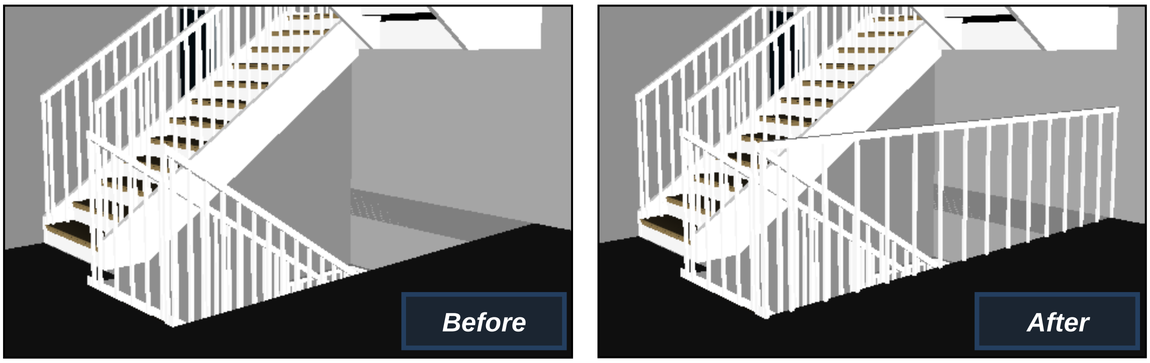

Figure 3.20 – Railing added to the model and ready for the simulation (Navisworks Manage 2013)

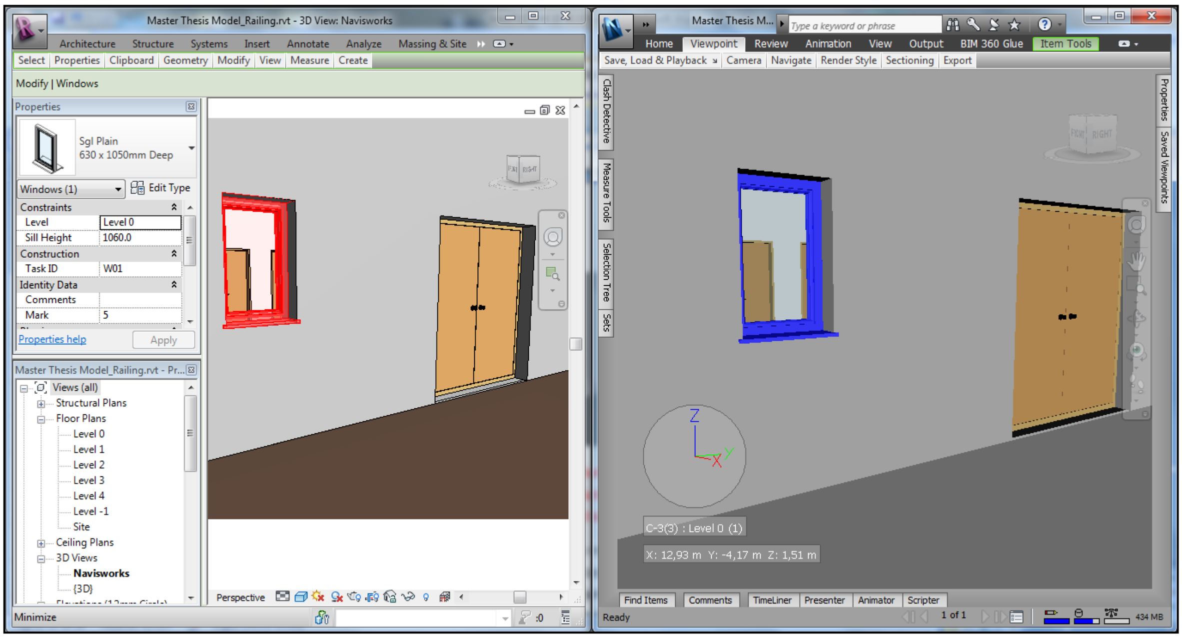

Figure 3.21 – 'Switchback' function: Revit (left) and Navisworks (right)

The change must be saved in Revit and then synchronized in Navisworks. In these kinds of changes there would not be a need to modify the schedule and the ID of the elements is conserved. Consequently, the only thing to do would be to *'Clear Attachment'* and re-apply the linking rule. For *METHOD Nº1* and *METHOD Nº2* this process is more complicated and cumbersome, because selection sets have to be continuously re-created.

With regards to the time-schedule, there is no option to change the model and automatically update the schedule. It has to be updated independently in MS Project.

Adaptations in the time schedule and the model are continuously necessary and 4D BIM tools have to satisfy these needs. In this case, since different platforms are employed, it is also very important to have clear how to jump from one to another. *'Figure 3.23'* explains the typical procedure for changes and re-planning. Finally, the 4D simulation could be carried out again with the new arrangement of the 4D model.

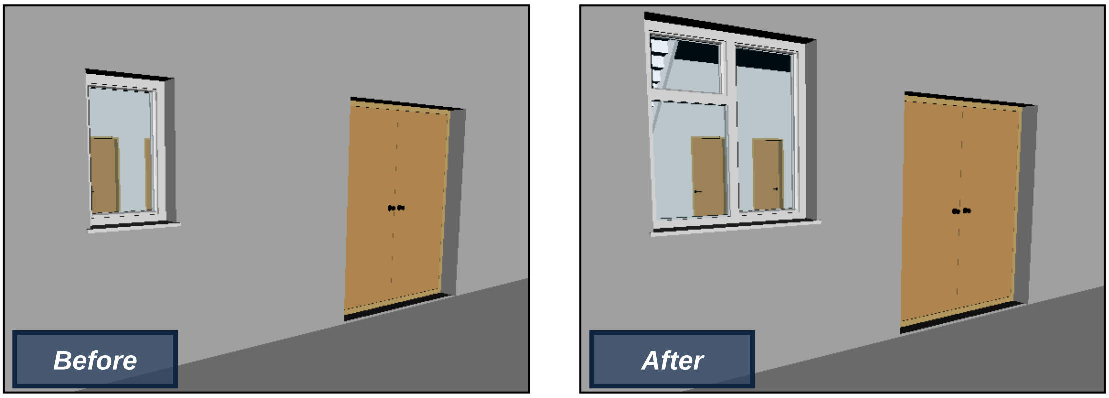

Figure 3.22 – Change refreshed: modification of the window typology and the door position (Navisworks Manage 2013)

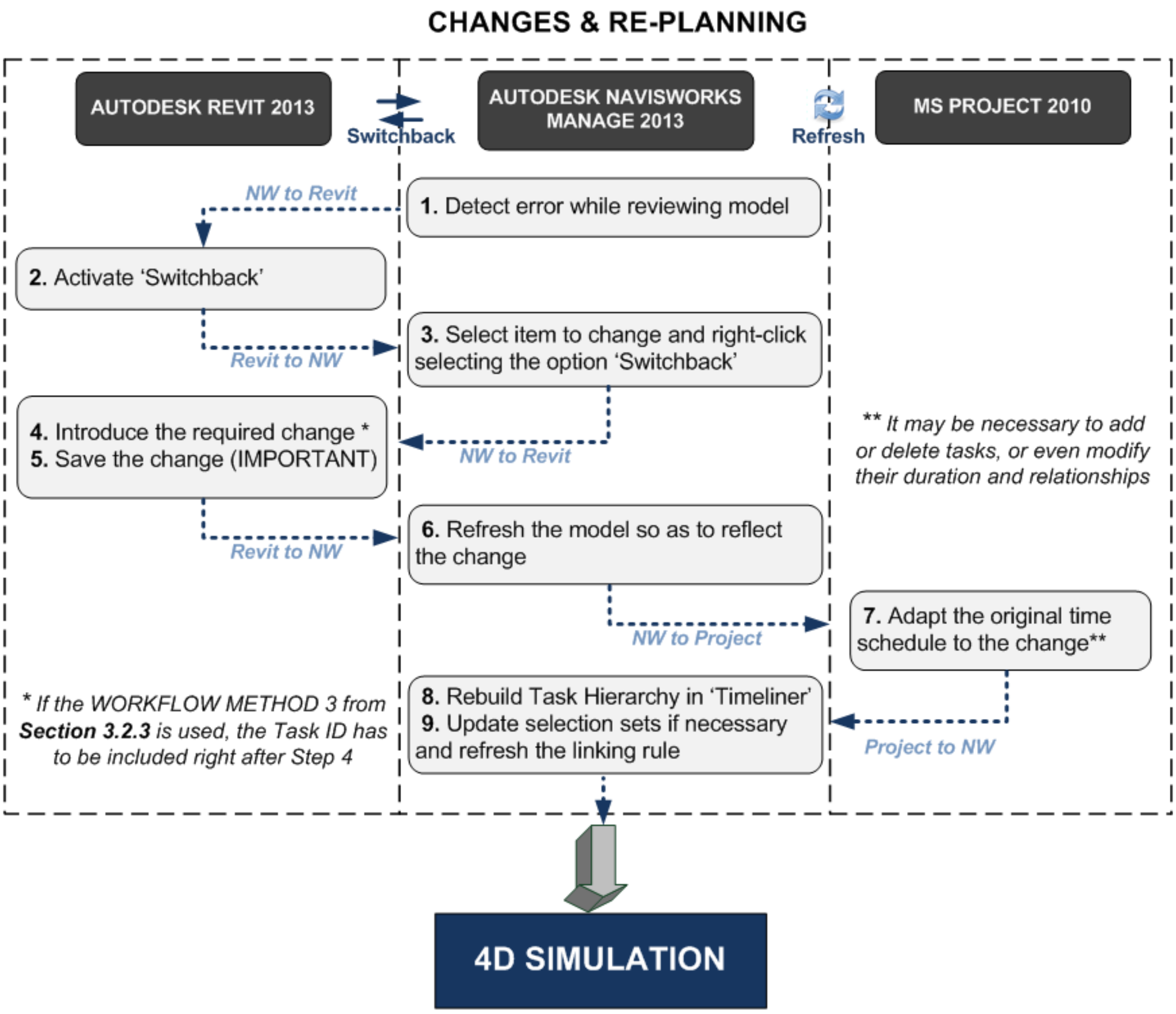

Figure 3.23 – Steps to follow among different platforms for re-planning

The process of introducing a single change can appear to be complicated and time-consuming, but it can be easily systematized as long as the process is clear. However, as it can be appreciated in this section, integrating the scheduling engine within the 4D BIM tool would be of great help. Above all, the value of the *METHOD Nº3* is reinforced against the two others for re-planning.

3.3.4. Time monitoring: Planned vs. Actual

Since plans are created to be fulfilled in the reality, it is very important to have control over them in order to anytime be aware of whether the deadlines set are being accomplished or not. In fact, usually one thing is what it is planned and another different thing is the actual state of the work over the planned schedule. Thus, start and finish dates of each of the tasks can be delayed or anticipated. The relationships and status of tasks are represented by a set of symbols in Navisworks *'Timeliner'* as illustrated by *'Figure 3.24'*. Hence, a quick overview is provided as concerns comparison between planned and actual status for each task, group of tasks or the entire project.

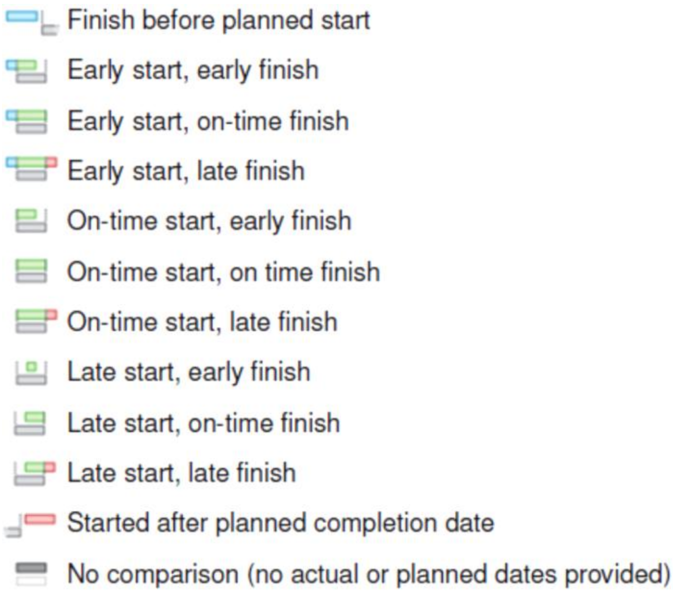

Figure 3.24 – Symbols representing Planned vs. Actual status of tasks, group of tasks or entire projects (Autodesk, 2013)

This, though, is what one can expect from any traditional planning software to imagine what may go wrong having a first glance at the diagram, but it does not help much by itself in terms of visualization. In Navisworks, if any of the tasks suffers a variation in the start or finish dates it can be also represented in a visual way. Therefore, it can be seen how each change affects the development of the entire project. As a matter of fact, it is possible to compare the planned versus the actual state of tasks so as to see which activities are behind or ahead of schedule, both in space and time by means of the 4D simulation. There are several visualization options with regards to schedule simulation:

- **Planned:** only the *'as-planned'* schedule is displayed. This is the option to be used during the planning phase.
- **Planned (Actual Differences):** the differences between the *'as-planned'* and *'actual'* schedules are displayed over the planned activities, i.e., only taking into account the *'Planned Start'* and *'Planned Finish'* dates period. This is typically useful to visually detect tasks with a *'Late Start'* and *'Early Finish'*.

- **Planned against Actual:** the *'as-planned'* and *'actual'* schedules are displayed at the same time. This is typically useful to visually detect tasks with all kinds of deviations (delays or fast completions): *'Early Start'*, *'Late Start'*, *'Early Finish'* and *'Late Finish'*.
- **Actual:** only the *'actual'* schedule is displayed representing the completed work and real dates.
- **Actual (Planned Differences):** the differences between the *'as-planned'* and *'actual'* schedules are displayed over the actual activities, i.e., only taking into account the *'Actual Start'* and *'Actual Finish'* dates period. This is typically useful to visually detect tasks with an *'Early Start'* and *'Late Finish'*.

The instrument used by Navisworks to visualize these delays or fast completions are the colouring settings. Those elements contained in tasks which have been delayed or early completed are displayed in a different way than those completed on time. By default, those tasks completed on time are displayed in green as shown before in *'Figure 3.17'*. If the schedule counts with actual dates and there are deviations between *'as-planned'* and *'actual'* dates, early appearance and late appearance are highlighted with different colours, the first in yellow and the second in red (*Figure 3.25*). In order to assess the monitoring opportunities actual dates have been included in the *'Timeliner'* in a way to interpret possible deviations given in a project.

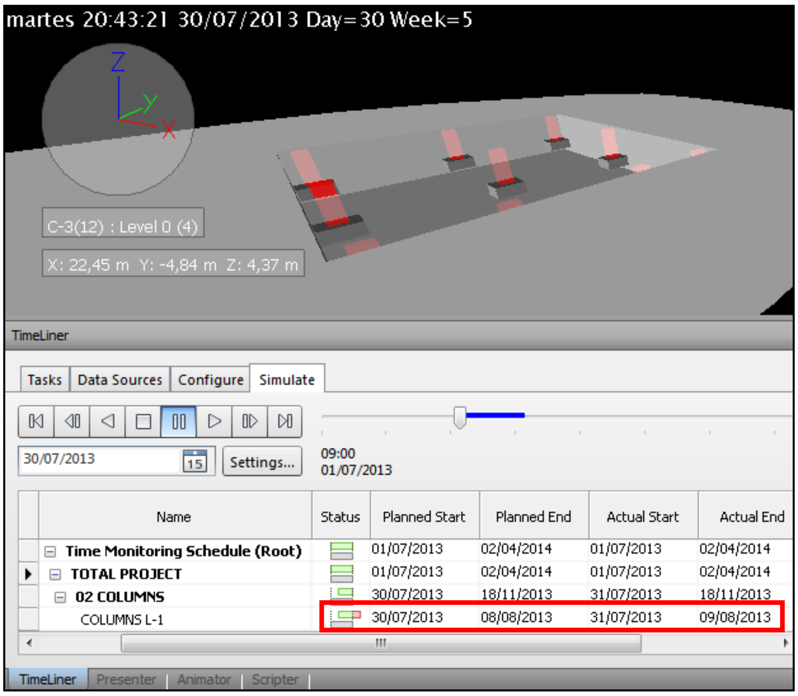

Figure 3.25 – Comparison between 'As-planned' and 'Actual' dates: 'COLUMNS L-1' Late Start in *red* (Navisworks Manage 2013)

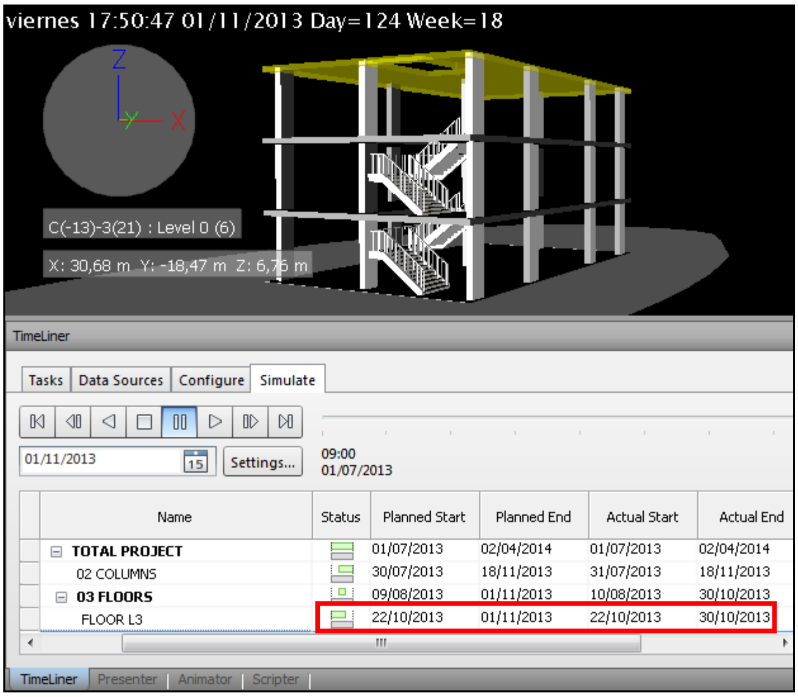

Figure 3.26 – Comparison between 'As-planned' and 'Actual' dates: 'FLOOR L3' Early Finish in *yellow* (Navisworks Manage 2013)

The WIP can be visualized but not as in the *'KanBIM system'* (Sacks et al., 2010a). While running a simulation, the % of completion is shown for every task, group of tasks and the entire project but it by no means represents the real PPC measurement. Then, it is not very useful as a production control and monitoring method.

3.3.5. Site utilization

Equipment and temporary elements can be appended in Navisworks as separate RVT or even SKP (Sketchup) files (*Figure 3.27*). The space occupied by these temporary elements has to be taken into account in when planning site logistics. Equipment such as trucks and cranes can be animated and the building site and its dynamism can be better represented. This demonstrates also the possibility to merge different models in Navisworks.

These kinds of elements would be attached to tasks as though they were normal model objects, but classifying them under *'Temporary'* task type, instead of *'Construct'*. Every extra element appended in Navisworks would involve another model in the *'Selection Tree'*.

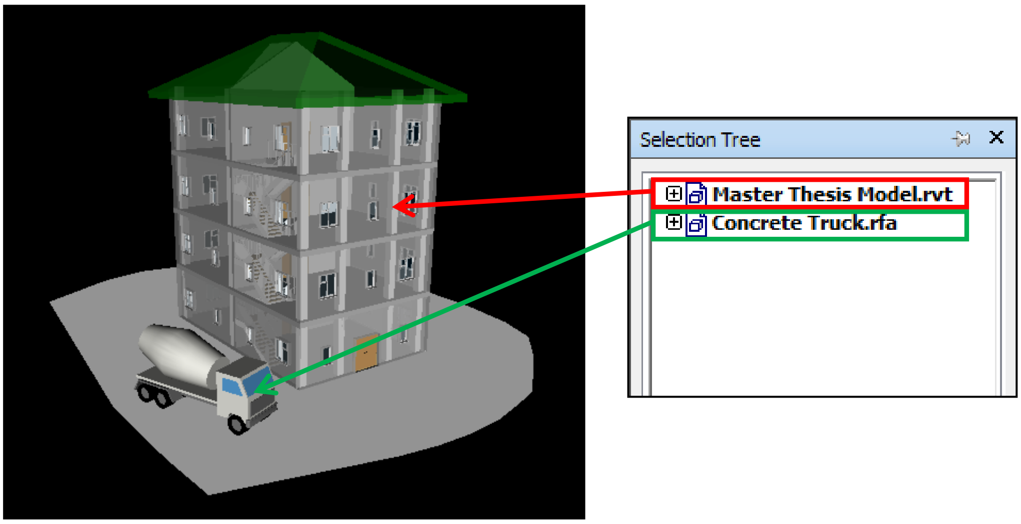

Figure 3.27 – Appending equipment for site utilization as a separate model (Navisworks Manage 2013)

3.3.6. Resource allocation

The capability of Navisworks for resource allocation relies upon the opportunities that MS Project offers for that purpose. This information has to be included in the different tasks in the planning software.

3.3.7. H&S

With regards to H&S management, conditions are improved thanks to visualization by including temporary safety measures as elements. Although, there is nothing to automatically detect risks and it is a *'passive'* use rather than an *'active'* use of 4D BIM (Jung & Joo, 2011).

4
CONCLUSIONS

4.1. Analysis of the Results

This part of the final conclusions is a specific conclusion about the practical part of the study seen in **Chapter 3**, based on the results of the analysis. The extent to which the theoretical requirements have been fulfilled as well as the opportunities and limitations encountered during the assessment process are presented in the following sections. This is the assessment of Navisworks Manage 2013 as a 4D BIM tool.

4.1.1. Fulfilment degree of the requirements

In the state-of-the-art from **Chapter 2** a set of requirements for the applications where outlined both with regards to their capabilities as a 4D BIM tool (**Section 2.4.6**) and their validity for project management functionalities (**Section 2.4.5**). Now it is time to verify to what extent Navisworks fulfils the requirements comparing the expected capabilities with the real ones.

Even though the model used to analyze the selected application was very simple, it served to verify many of its possible utilities like schedule visualization, 4D simulations, flexible re-planning, time monitoring and carrying out analyses like conflict detections. At the end, some of these functions were better accomplished than others, and some were not fulfilled at all. The following tables summarize the capabilities of Navisworks regarding project management functionalities (*Table 4.1*) and some other useful features (*Table 4.2*). The workflow aim of analysis was *'Revit - MS Project - Navisworks'* but only the features of the last one are to be assessed in the mentioned tables.

It can be said that 4 out of 10 project management functionalities (*Table 4.1*) that can be theoretically benefited by 4D BIM are fully supported by Navisworks. These are schedule visualization, 4D simulation, integration and communication of project participants and decision-making.

PROJECT MANAGEMENT FUNCTIONALITIES				
Does Navisworks 2013 fulfil the following project management functionalities?		YES	NO	Comments
Schedule Visualization		X		The schedule imported from MS Project can be visualized. This functionality is fully supported.
4D Simulation		X		The *'Simulate'* option included in the *'Timeliner'* allows simulating the construction process at different levels of detail. This functionality is fully supported.
Integration and communication of project participants		X		The previous 2 functionalities facilitate collaboration in a project team (transparency). This functionality is fully supported.
Decision-making		X		It continuously supports the process of making decisions in the different examples through an optimized visualization. This functionality is fully supported.
Re-planning (flexible)		X		Synchronization options and the *'Switchback'* function can result very helpful here, despite not having a fully integrated scheduling functionality.
Time monitoring		X		Comparison between Planned and Actual schedules is supported by means of colours.
Analysis	*Conflict detections*	X		Real-time navigation of the 4D model can fairly improve the detection of design inconsistencies. Time-based clashing also.
	Site utilization	X		Building site can be overviewed by the inclusion of temporary elements and machinery. Even dynamism could be visualized.
	Resource allocation		X	Limited to the capabilities of MS Project. No additional help appears to be included by Navisworks for resource allocation.
	H & S management		X	Cannot be supported actively for automatic risk detection, but rather to improve visualization. Passive way.

Table 4.1 – Opportunities and limitations of Navisworks Manage 2013 for project management functionalities

About the remaining 6 functionalities, they have been fulfilled to a less extent although 4 of them have been classified under the 'YES' column. It can be said that re-planning is quite flexible despite of having to continuously jump through 3 different applications. The *'Switchback'* option as well as the possibility to use the *'Task ID method'* for linking elements to tasks accelerates the re-planning process. This could be even more flexible, though, if the time schedule would be more effectively integrated within the 4D BIM tool. Something similar happens with the time monitoring: it is possible to visually compare *'As-planned'* and *'As-built'* conditions using colours with the introduction of the actual dates, but the process is hampered by the lack of bi-directionality between Navisworks and MS Project.

The other 2 functionalities were categorized under the 'NO' columns indicating that they are not covered. On the one hand, resource allocation relies upon and as far as it was studied there is not much that this tool can incorporate compared to traditional MS Project schedules. On the other hand, the use of this tool for H&S management cannot be contemplated, apart from the possibility to add temporary safety elements to the model and detect inconsistencies through real-time navigation. In any ways, its use would be totally passive helping only for visualization and not for risk detection and the like. In fact, it is thought that this is other branch to be covered by BIM.

REST OF 4D CAPABILITIES				
Does Navisworks 2013 include the following features among its capabilities?		YES	NO	Comments
Import capabilities	*BIM model import*	X		Data is perfectly conserved and usable when using an RVT file.
	Time schedule import	X		Schedules from planning software such as MS Project or Primavera can be imported. It worked well for the MPP files from MS Project.
	IFC import	X		Although the quality of the imported model from alternative BIM platforms has not being tested using the IFC format, at least there is an option to import these kinds of files.
Export capabilities/ Output	*File formats*	X		The 3 different file formats within Navisworks (NWC, NWF & NWD) are conceived to assure a proper use and to support collaboration.
	Reduced file size	X		NWF files have a really reduced file size (up to 90% of compression) for smooth navigability.
	Snapshots	X		Image formats such as JPEG or PNG can be exported as snapshots of the different construction phases.
	Movie	X		Animated clips can be exported to AVI format to create simulation clips.
Bi-directional data exchange			X	The data exchange is generally made in one direction by synchronizing. The original imported files are not modifiable in Navisworks, though. This is in a way compensated with the *'Switchback'* option as far as re-planning is concerned.
Model merging options		X		Multiple models can be merged in the same 4D model.
Data reorganization		X		Selection sets are a good way to reorganize the model. However,

			Navisworks does not allow the reorganization of the elements in the model, for example in parts or zones.
Automatic task-geometry linking	X		It counts with automatic linking options based on rules. The possibility to use the *'Task ID method'* is one of the strengths.
Temporary elements and equipment	X		These kinds of elements can also be appended from Revit or Sketchup files to visualize the site utilization.
Animation	X		Although this function has not been explored, elements can be animated to better represent reality.
Stand-alone application		X	*'Timeliner'* is by no means enough to complex schedules. This fact sort of converts Navisworks into a non-stand-alone application since it needs support from more advanced planning software.

Table 4.2 – Rest of capabilities of Navisworks Manage 2013

12 out of 14 of the extra expected capabilities listed in *'Table 4.2'* are covered by Navisworks. Concerning import capabilities, Navisworks is able to append BIM models generated in Revit as well as time schedules from advanced planning software. There is an option to import IFC and CIS/2 formats for interoperable data exchange. It is also able to export several output formats to share the 4D model and produce snapshots or even animated simulations. The huge reduction of the original file size is also a good point in its favour, since navigability is considerably improved. The possibility to merge different models in a single 4D model, the opportunity to reorganize data and automatically link elements in the BIM model to tasks in the schedule using rules are essential capabilities also covered. Finally, temporary elements and equipment can be included in 4D models for site management and they can be animated the rest of elements adding more dynamism and realism to construction simulations.

The remaining 2 capabilities not covered are true *'bi-directional data exchange'* and *'stand-alone application'*. Despite of the inclusion of a very useful *'Switchback'* function to facilitate changing the original model in its original platform, the data exchange is not fully bi-directional. Any change in the original file can be synchronized, but changes are compulsorily introduced in their original application. This can result cumbersome in advanced stages of the project like construction. The same conceptualization of the application makes it not to be stand-alone.

Consequently, even though Navisworks is a really powerful tool, and many of its functionalities have not even been explored, it also has some weaknesses as a 4D BIM tool despite of its numerous possibilities. Those fields categorized under the *'YES'* column are contemplated as opportunities, whereas those under the *'NO'* column are considered to be limitations in comparison to the expected 4D BIM capabilities. The main opportunities as well as limitations will be further remarked in the following sections.

4.1.2. Opportunities

Navisworks has many strong points that represent opportunities, being the following considered to be the most significant ones:

1. Thanks to the schedule visualization and 4D simulation opportunities Navisworks can be a good tool to support project planning in a collaborative environment. In fact, the schedule can be continuously visualized as it is being generated and re-planned quite flexibly. Therefore, many of the project management functions are covered.
2. As both are Autodesk products, the *'platform-tool'* interoperability between Revit and Navisworks is really good. All the data from the BIM model is available in Navisworks and ready to be utilized for sophisticated purposes. Furthermore, the *'Switchback'* and synchronization options offered work very well with the tested workflow.
3. The workflow based on the *METHOD Nº3* presented in the practical part with the inclusion of a *'Task ID'* to each element in the BIM model is very interesting and evidences the advantage of BIM over CAD for 4D modelling.
4. Navisworks offers really advanced possibilities for model manipulation due to the fact that it allows analyzing every single corner of it and every single element or groups of elements separately. Thus, this control over the elements leaves less space for inconsistencies. This is mainly because, among other things, it is a design review application and real-time navigation is one of its strong features.
5. Navisworks incorporates almost all the features that can be expected from a 4D BIM tool, as it was shown in *'Table 4.2'*.

4.1.3. Limitations

As well as opportunities, Navisworks has some weaknesses that represent limitations, being the following considered to be the most significant ones:

1. The main limitation of Navisworks comes from its conception of not being able to modify the original files. This is more a design-review-like feature, but it is not as helpful for a 4D BIM environment. Indeed, 4D BIM is not the main utility that it was conceived for, but the *'Timeliner'* is rather an additional tool included in its set of tools. Counting with more options for bi-directional data exchange between the model and the schedule would be interesting.

2. In the same lines, planning of re-scheduling operations cannot be processed in the 3D environment. It is necessary to go back to the external scheduling tool and synchronize the *'Timeliner'* hierarchy.

3. Parts and zones have to be created beforehand in Revit, which can be considered a weakness, since having elements divided in parts is not handy in the original BIM model. A 4D BIM tool should include a function to split elements like slabs, walls, etc. without modifying the model contained in the original file.

4. Although in one way or another Navisworks covers the most of the outlined project management functionalities (*Table 4.1*), some of them are covered in what it is considered a *'passive'* way rather than in an *'active'* way (Jung & Joo, 2011). This means that these functionalities are supported by 4D technologies only due to the fact that they improve visualization. Consequently, a more active role of these tools would be also useful. This is commonly achieved by additional automation.

4.1.4. Future challenges

The future challenges for these applications will consist in conserving the opportunities and giving an answer to the limitations presented in the previous sections. The evolution should go towards the integration of the workflow in a single application if possible, as long as these tools are aimed to be used for project management at advanced project stages. In this way, including a more sophisticated schedule engine in the 4D BIM tool would permit to have more interaction between task data and objects.

The construction stage would be benefited by these optimizations, speeding up the 4D model re-generation process in order to adapt to possible unexpected events. For time monitoring, apart from colour differentiation, it would also be helpful to be able to visualize 2 simultaneous simulations in order to better compare the actual and planned state of the construction process. If possible, they should as well enable the visualization of the workflow and the WIP if they are to be used for production monitoring.

As far as personal future goals are concerned, after exploring Navisworks by Autodesk, the author would like to test other 4D BIM applications such as those provided by Synchro Ltd. and Vico Software, which seem to be conceived as more integrated and 4D-specific tools.

4.2. Overall Conclusion

As a closure for the present Master Thesis, the most important ideas are to be recalled for the last time.

The cure for the recovery of the construction industry appears to rely on many different and innovative concepts that are continuously emerging. In fact, important changes are required to improve construction performance because despite of its ancient character, nowadays it lags behind many other industries.

The working methodology presented in this work, which pretends to totally change the information management in construction and is broadly known as BIM, involves the adoption of ICT with its consequent changes in many processes as they were known to date. As a result, it is experiencing a severe resistance to change by construction practitioners although it seems to be finally imposing, at least in some parts of the world. It is believed that BIM can be further optimized if it is accompanied by contracting methods based on IPD and some of the Lean Construction concepts, since all of them look forward to improving the construction sector and encouraging a collaborative environment that has been once and again mentioned throughout the whole study.

Focusing on a branch within BIM, the study was redirected towards 4D BIM for a better management of time, and it was found to be valid for project management functions as a way to mitigate project risks by means of one of the available commercial applications: Navisworks Manage 2013. This tool requires of the use of 2 other platforms to make 4D modelling possible: Revit 2013 and MS Project 2010. This workflow was analyzed and it was concluded that it is able to satisfy many of the theoretical functionalities expected from it. However, apart from opportunities some limitations already mentioned in the previous section were also detected.

In terms of 4D modelling, the quality of the imported BIM model is critical for the success of the process. Furthermore, as the mapping techniques rely pretty much on the activity name or code, standardization plays an essential role to accelerate the process. Using an adequate naming or coding criterion and its standardization for coming projects could be a very important thing to consider. One of the most important factors is the flexibility offered by the application to adapt to probable changes or project needs. This is vital for its possible use as a management tool in advanced project stages.

At last, construction, as the world, is continuously changing and evolving. Technological advances are once again offering support to this adaptation process, but history has shown that it is not all about technology uptake. This time the combination seems to be consistent, but in the end, human beings are the final judges who will dictate whether these innovative as well as promising approaches are either adopted or discarded.

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List of Tables and Figures

All those tables and figures with no reference beside have been self-elaborated.

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Front/Back Cover Figure 2:
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Chapter 1: INTRODUCTION

Chapter 2: STATE OF THE ART

<u>Chapter 3: PRACTICAL PART</u>

Chapter 4: CONCLUSIONS

APPENDICES

APPENDICES

APPENDIX A: EUBIM 2013 VALENCIA

As the author had the opportunity to attend to the *1st National BIM Congress* celebrated in Valencia, also known as *EUBIM 2013*, it is considered that it deserves a brief Appendix. In fact, due to the relevance and success obtained it is called to have a considerable impact on the near future of the BIM methodology in Spain. It was celebrated between the 24th and 25th of May 2013 and was organized by the Polytechnic University of Valencia and with the collaboration of the members of the local group of Revit users called GURV (*Grupo de Usuarios de Revit de Valencia*: http://www.gurv.es/). In part, it was organized as a continuation of the *1st Meeting of BIM Users* celebrated also at the Polytechnic University of Valencia in 2012. The EUBIM 2013 was for two days the gathering place for AEC practitioners, members from the University, software vendors, members from the Spanish Chapter of BuildingSMART, researchers, students, etc.

It is clear that the BIM implementation in Spain is scarce and way behind other countries of the European Union and the rest of the world (**Section 2.3.3**). This congress helped the author understand the real state of implementation in Spain as well as identify companies and exchange ideas with individuals dealing with this topic. The aim and willingness of representatives from different trades to collaborate with this urgent BIM adoption process was manifested. As stated by an AEC practitioner representing an important firm that deals with international projects: *'There is no choice if you want to survive in this sector'*. Indeed, nowadays it is starting to be possible for companies to lose important contracts if BIM is not adopted. This sooner or later is set to happen in the national framework.

People from different specializations and disciplines within the industry talked about the wide range of possibilities offered by BIM: structures, heritage, measurement and costing, etc. Almost all the speakers agreed on the fact that it is time for changing the AEC sector in Spain and that a quick and effective reaction is required. The need for standards for a better implementation was also one of the main topics developed. As a result of the topics discussed during the congress, the *'uBIM'* initiative was created in order to organize AEC practitioners and start the BIM adoption strategy. The necessity to deal with common data (common dictionary, common and generic library of BIM element families, etc.) is vital to be able to start with the implementation in Spain, and the aforementioned initiative was born as a particular way of standardization.

4D simulations were present in many of the talks offered by the presenters, and even some practical examples were shown by a consulting firm of name *'Avatar BIM'*.

In conclusion, the congress was a successful event that is called to become an annual meeting for those interested in the application of the BIM methodology in Spain.

Figure AP.1 – 1st National BIM Congress: EUBIM 2013 (Valencia) (UPV-GURV, 2013)

APPENDIX B: MINIMUM SYSTEM REQUIREMENTS

The minimum system requirements to run Autodesk Revit ® 2013 are the following according to the software company:

Description	Requirement
Operating System	Microsoft® Windows®7 32-bit • Enterprise • Ultimate • Professional • Home Premium Microsoft® Windows® XP SP2 (or later) • Professional • Home
Browser	Microsoft® Internet Explorer® 7.0 (or later)
CPU Type	Single- or Multi-Core Intel® Pentium®, Xeon®, or i-Series processor or AMD® equivalent with SSE2 technology. Highest affordable CPU speed rating recommended. Autodesk® Revit® software products will use multiple cores for many tasks, using up to 16 cores for near-photorealistic rendering operations.
Memory	4 GB RAM • Usually sufficient for a typical editing session for a single model up to approximately 100 MB on disk. This estimate is based on internal testing and customer reports. Individual models will vary in their use of computer resources and performance characteristics. • Models created in previous versions of Revit software products may require more available memory for the one-time upgrade process. • /3GB RAM switch not recommended. Revit software and system stability can be affected by memory conflicts with video drivers when the /3GB switch is active.
Video Display	1,280 x 1,024 with true color
Video Adapter	Basic Graphics: Display adapter capable of 24-bit color Advanced Graphics: DirectX® 10 capable graphics card with Shader Model 3 as recommended by Autodesk.
Hard Disk	5 GB free disk space
Pointing Device	MS-Mouse or 3Dconnexion® compliant device
Media	Download or installation from DVD9 or USB key
Connectivity	Internet connection for license registration and prerequisite component download

Table AP.1 - Minimum requirements for Autodesk Revit 2013 (Autodesk, 2013)

The minimum system requirements to run Autodesk Navisworks Manage ® 2013 are the following according to the software company:

Requirements
• Microsoft® Windows® 7 Home Basic, Home Premium, Professional, Enterprise, or Ultimate (recommended); Microsoft® Windows Vista® Enterprise, Business, Ultimate, or Home Premium (SP2); Microsoft® Windows® XP Professional, Home Edition 32 bit (SP3); or Microsoft® Windows® XP Professional x64 Edition (SP2)
• Intel® Pentium® 4 or AMD Athlon™ 3.0 GHz (or higher) with SSE2 technology
• 512 MB RAM (minimum); 2 GB or greater RAM (recommended)
• 18.5 GB free disk space for installation
• Direct3D 9® and OpenGL® capable graphics card with Shader Model 2
• 1,280 x 800 VGA display with true color (1,920 x 1,080 monitor and 32-bit video display adapter recommended)
• Microsoft Mouse-compliant pointing device
• Microsoft® Internet Explorer® 7.0 or later

Table AP.2 – Minimum requirements for Autodesk Navisworks Manage ® 2013 (Autodesk, 2013)

The minimum system requirements to run Microsoft ® Office Project 2010 are the following according to the software company:

Requirements
• 700-megahertz (MHz) processor or higher
• 512 megabytes (MB) RAM or higher
• 2 gigabyte (GB) available disk space
• 1024 × 768 or higher resolution monitor
• Windows XP with Service Pack (SP) 3 (32-bit), Windows Vista with SP1, Windows Server 2003 R2 with MSXML 6.0, Windows Server 2008 or later (32-bit or 64-bit), Windows 7 or later operating systems.

Table AP.3 – Minimum requirements for Microsoft ® Office Project 2010 (Microsoft, 2010)

APPENDIX C: DESCRIPTION OF THE BIM MODEL

These are some of the views from the BIM model generated in Revit. Note that, despite of the fact that only windows are presented, quantities of every element typologies can be automatically obtained. The RVT containing the BIM model is presented together with the written work.

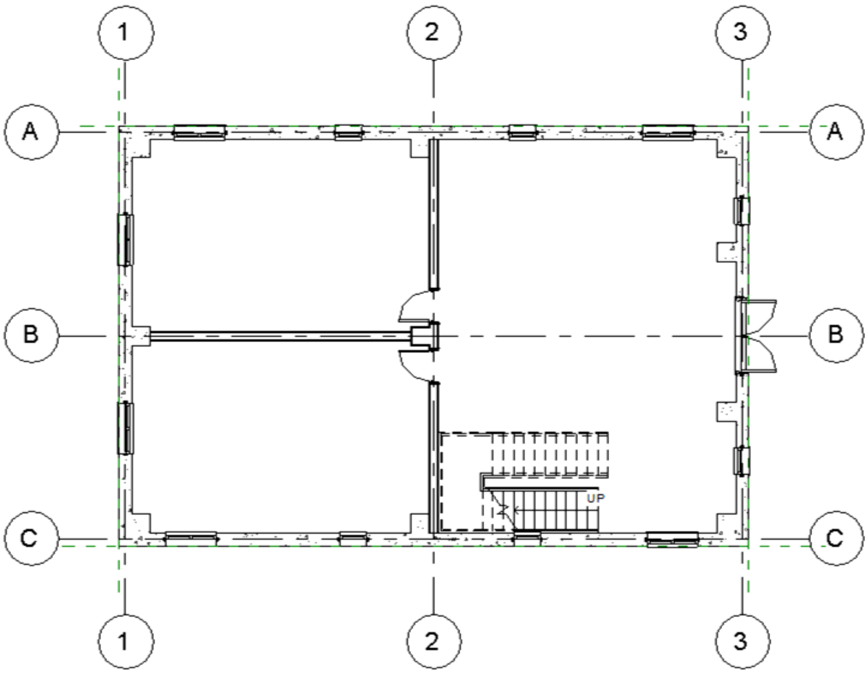


Figure AP.2 – Typical floor plan: Ground Floor (Revit 2013)

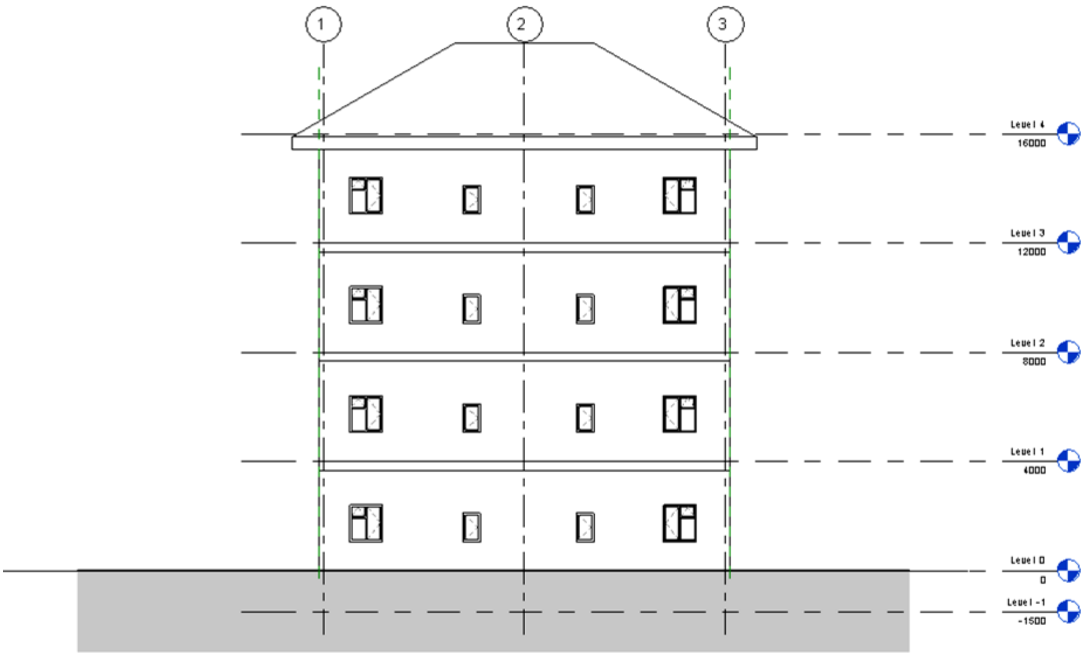


Figure AP.3 – South Elevation (Revit 2013)

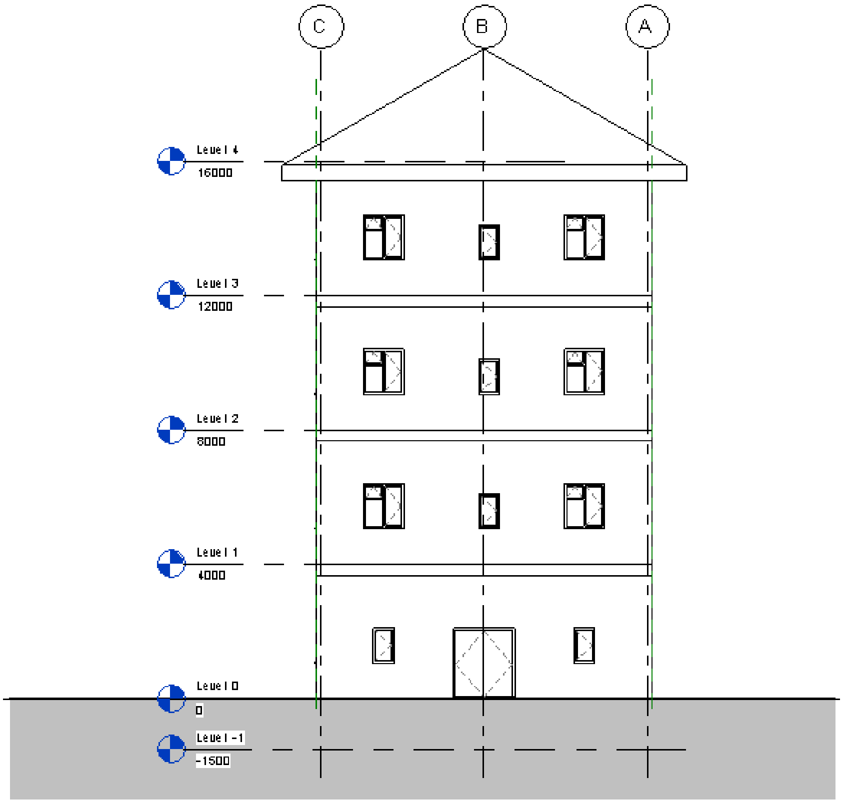


Figure AP.4 - East elevation (Revit 2013)

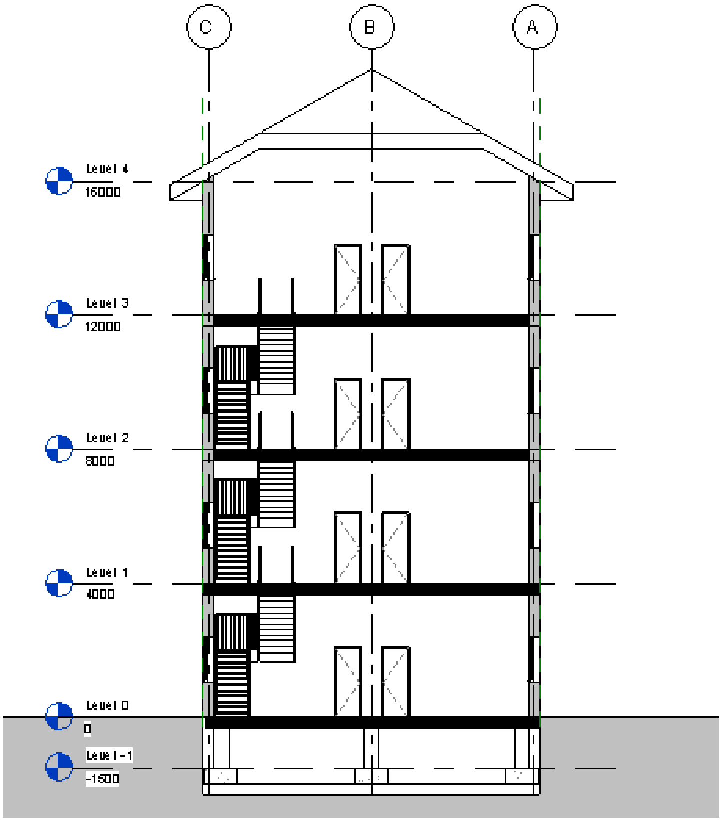


Figure AP.5 - Cross Section (Revit 2013)

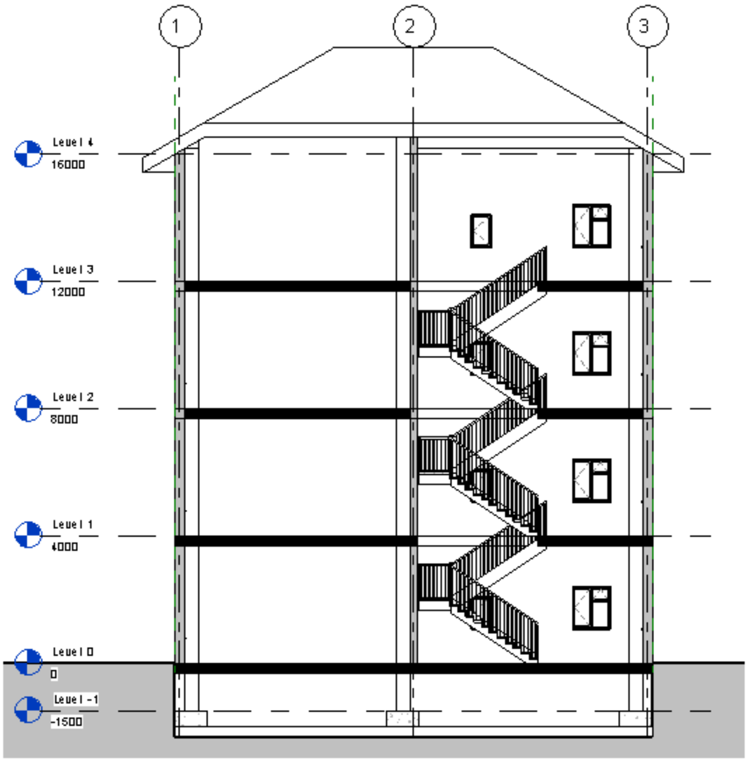


Figure AP.6 - Longitudinal Section (Revit 2013)

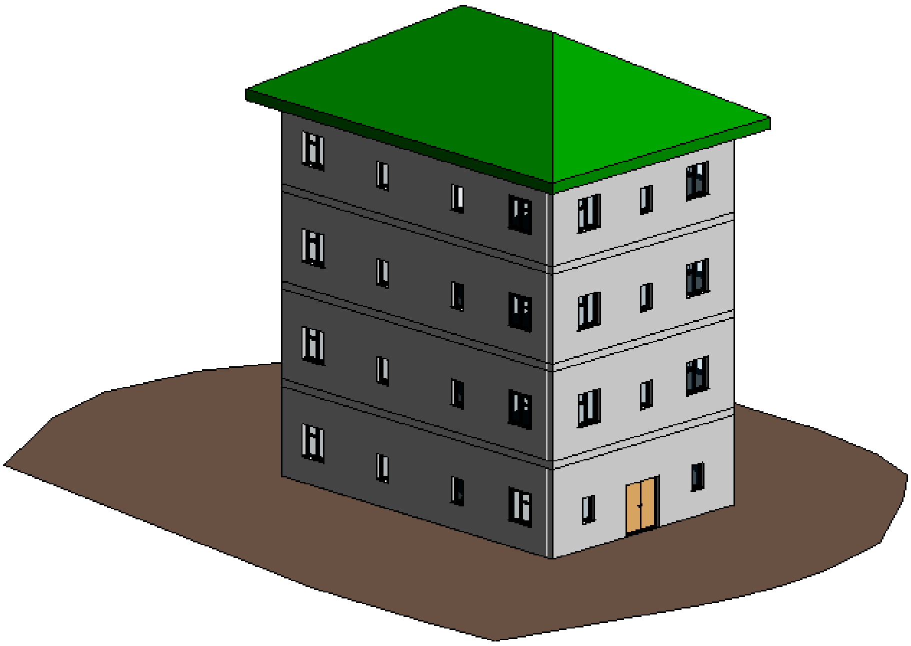


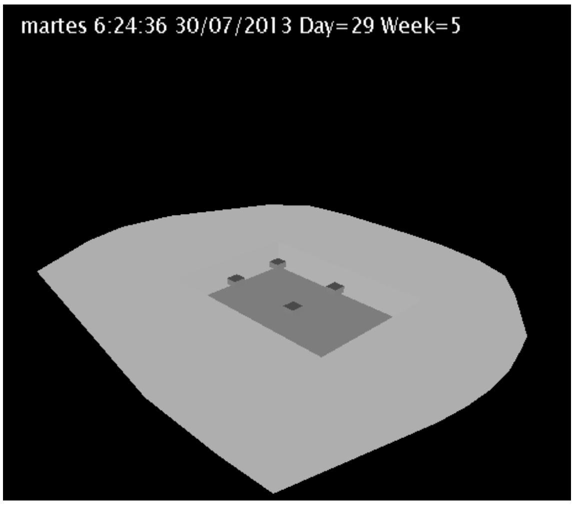
Figure AP.7 – 3D Model (Revit 2013)

Window Table					
Family	Type	Height	Width	Head Height	Count
Level 0					
Dbl Case	Dbl Case	1350	1200		6
Sgl Plain	630 x 105	1050	630	2110	6
					12
Level 1					
Dbl Case	Dbl Case	1350	1200		8
Sgl Plain	630 x 105	1050	630	2110	5
					13
Level 2					
Dbl Case	Dbl Case	1350	1200		8
Sgl Plain	630 x 105	1050	630	2110	5
					13
Level 3					
Dbl Case	Dbl Case	1350	1200		8
Sgl Plain	630 x 105	1050	630	2110	5
					13
Grand total: 51					51

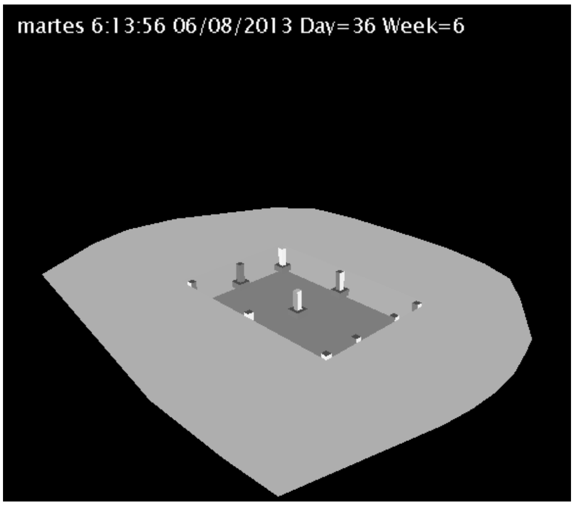
Figure AP.8 - Window quantity table (Revit 2013)

APPENDIX D: 4D CONSTRUCTION SEQUENCE SIMULATION

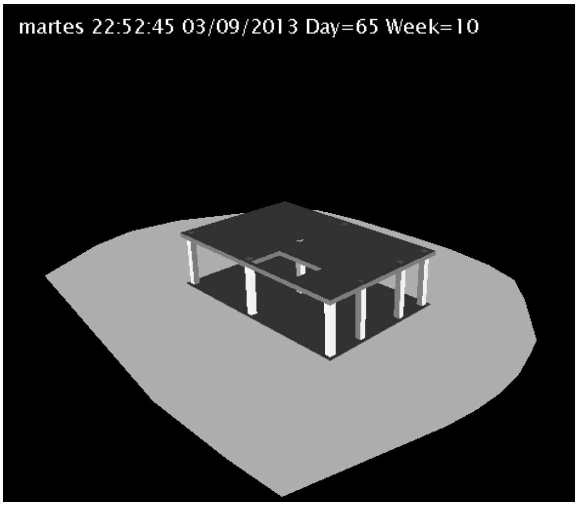
The following snapshots show the construction sequence of the building in the 4D model:



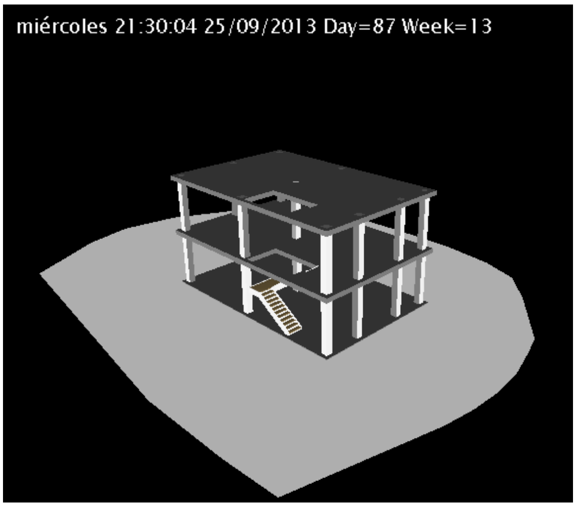
1. Foundation works: *Tuesday, 30 July 2013*



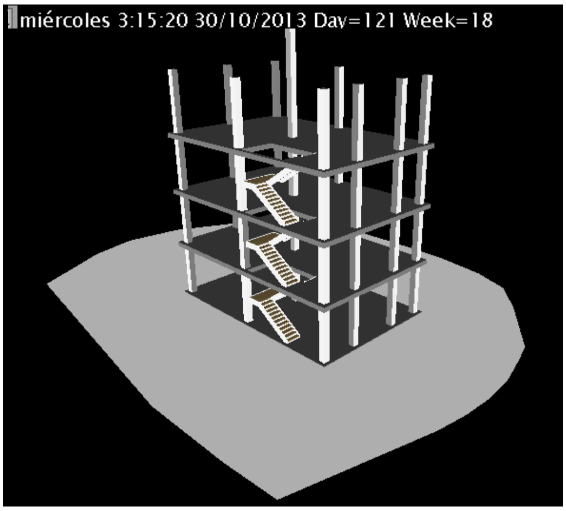
2. Column erection: *Tuesday, 06 August 2013*



3. First floor structure: *Tuesday, 03 September 2013*

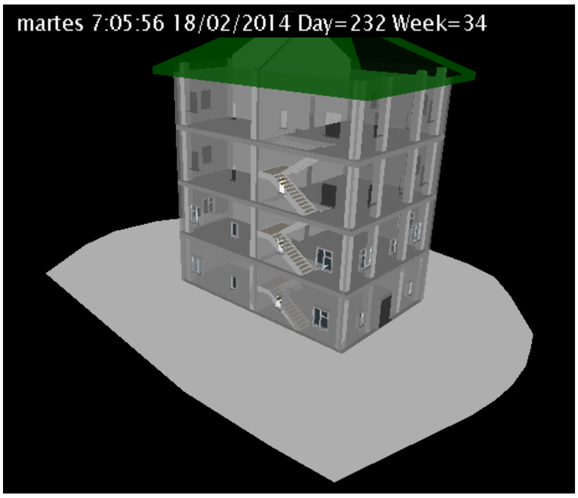


4. Second level: *Wednesday, 25 September 2013*

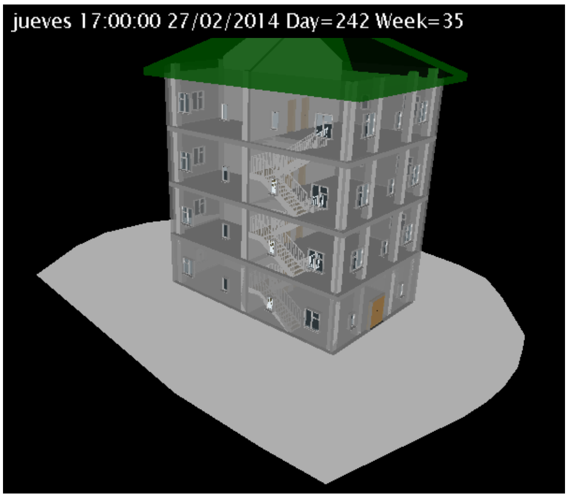


5. Whole structure: *Wednesday, 30 October 2013*

6. Building envelope: *Thursday, 09 January 2014*



7. Carpentry setting: *Tuesday, 18 February 2014*



8. Completed building: *Thursday, 27 February 2014*

A short clip (AVI file) is included together with the written work to better appreciate the whole 4D simulation.

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