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

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.

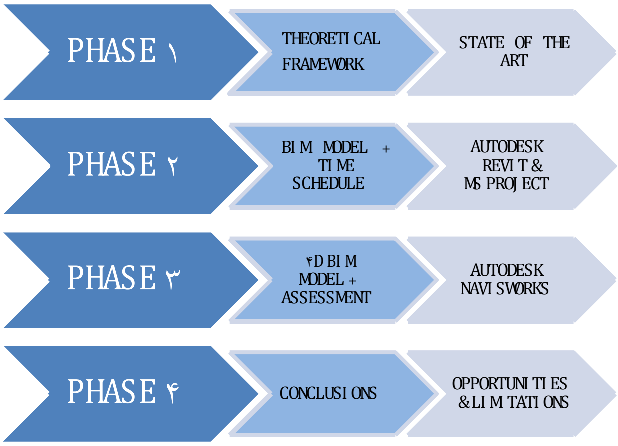

Figure 1.1 - Different phases of the Master Thesis

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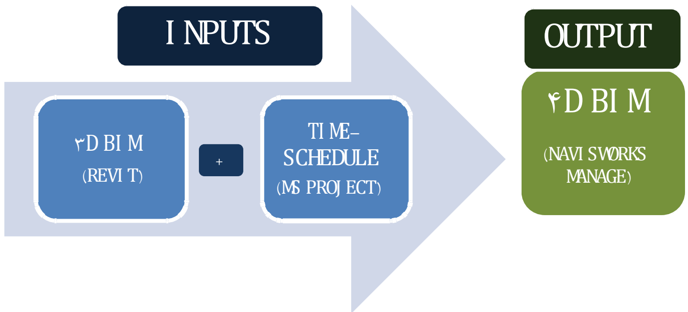

Figure 1.2 - Practical Part: From conventional BIM model to 4D BIM model

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.

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

Chapter 2: 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.

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

Chapter 4: 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'.

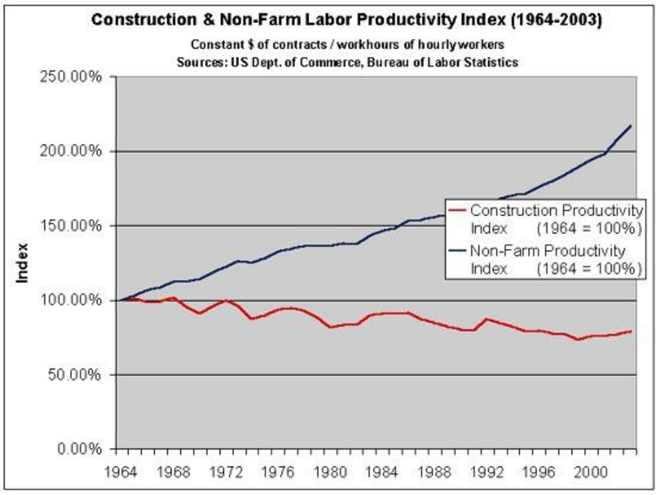

Figure 2.1 - Comparison of Labour Productivity Index between Construction and Non-Farm industries from 1964 to 2003 (Teicholz, 2004)

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.

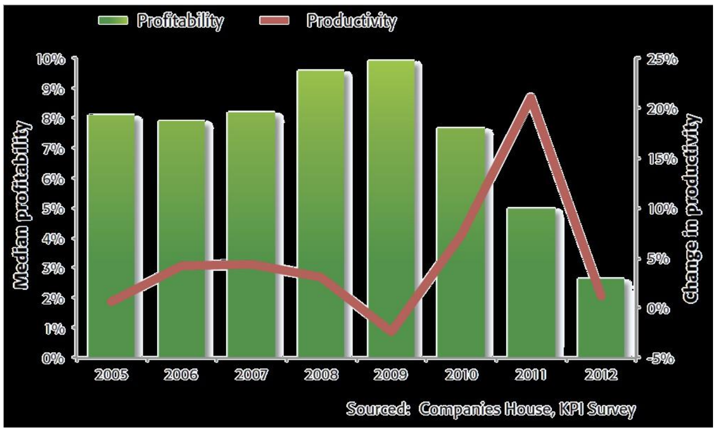

Figure 2.2 - Productivity and profitability variations in the UK construction industry from 2005 to 2012 (Glenigan & Constructing Excellence, 2012)

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.

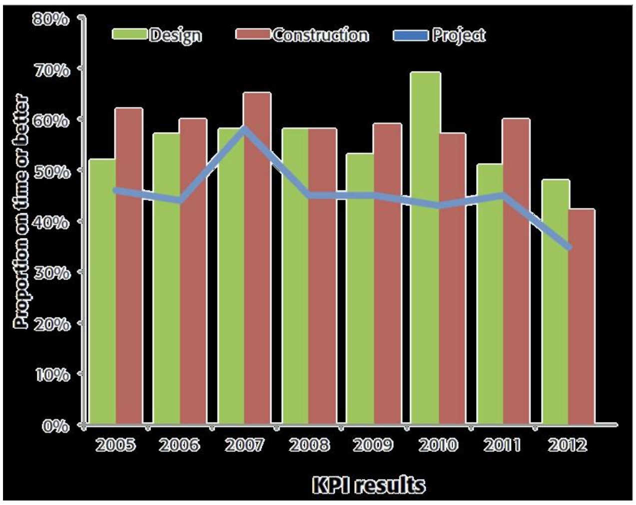

Figure 2.3 - Time predictability variations during design, construction and overall project in UK construction projects from 2005 to 2012 (Glenigan & Constructing Excellence, 2012)

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.

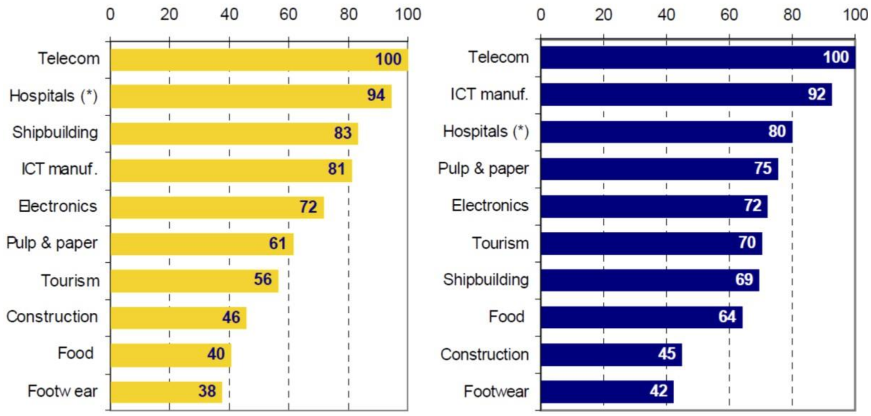

Figure 2.5 - Comparison of ICT adoption rates for 10 different industry sectors (e-Business W@tch, 2006)

'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.

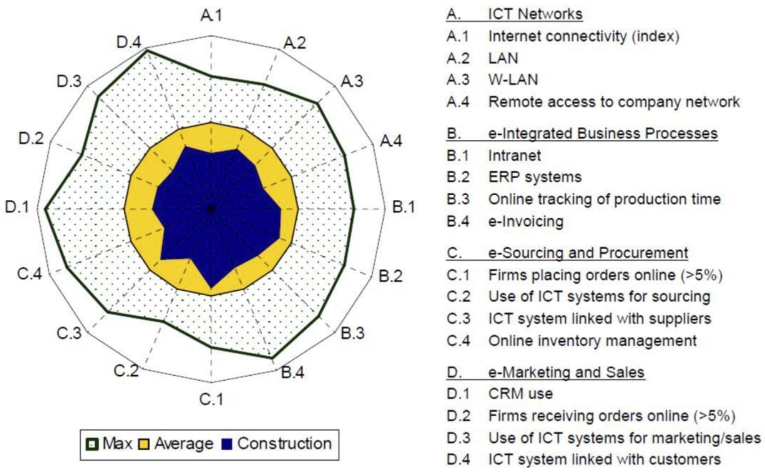

Figure 2.6 - Maximum, average and construction adoption of ICT by branches (e-Business W@tch, 2006)

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^{TM} (LPS).

Last Planner System^{TM} (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).

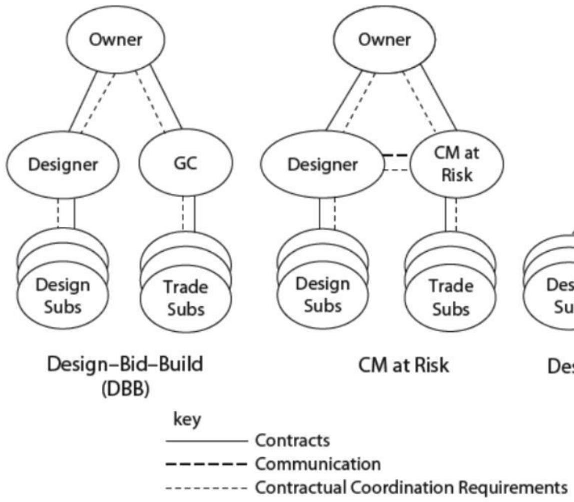

Figure 2.8 - Different contract methods utilized in the US construction industry (Eastman et al., 2011)

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).

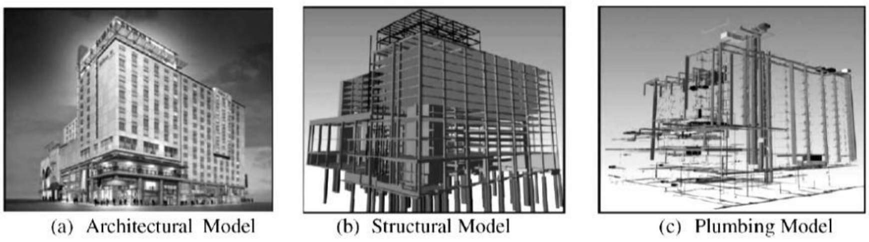

Figure 2.9 - Coordination between different disciplines models (Azhar, 2011)

- **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.

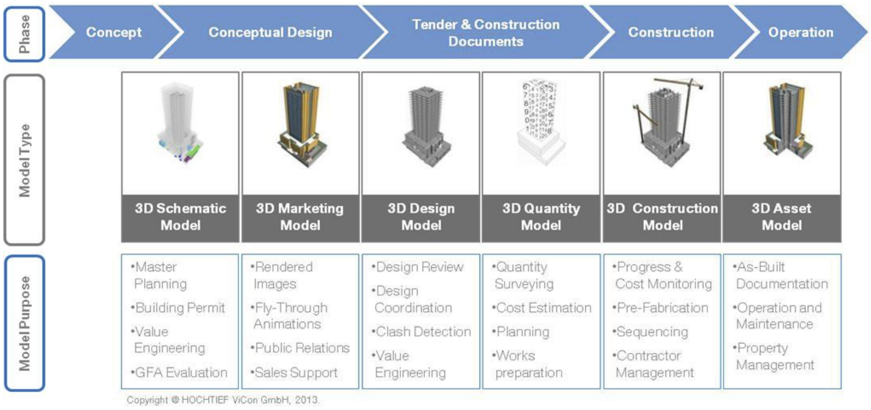

Figure 2.11 - Different purposes of the BIM model through the life cycle of a project (BIM Journal, 2013)

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.

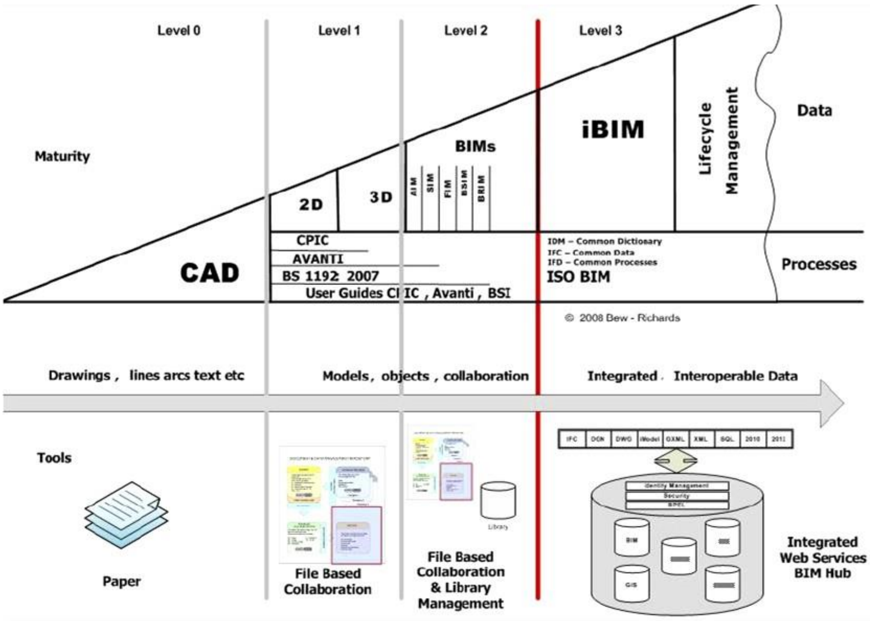

Figure 2.12 - BIM maturity levels (BIM Task Group, 2011)

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.

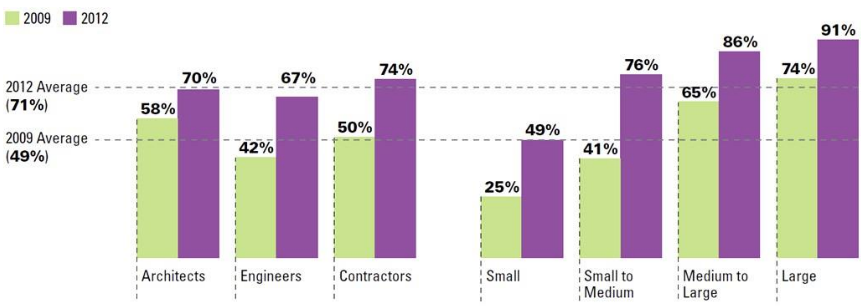

Figure 2.13 - Comparison between 2009 and 2012 BIM implementation in North America by player and firm size (McGraw-Hill Construction, 2012)

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.

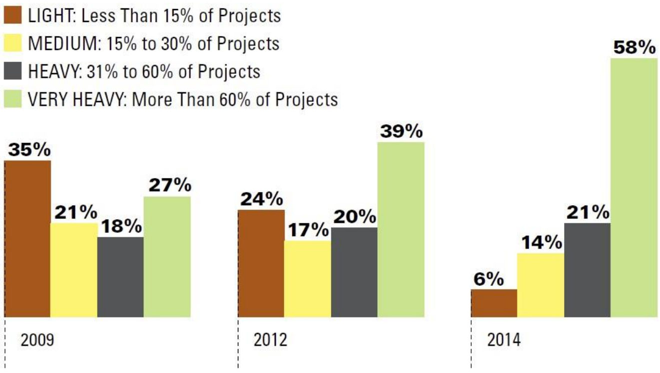

Figure 2.14 - Share of projects implementing BIM and predictions (McGraw-Hill Construction, 2012)

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	
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	
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.