Integration of LCA and BIM
Considering early Building/Construction Design Stages

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ABSTRACT

Construction industry is moving towards sustainability, but it is still inefficient, and therefore, the root problems of inefficiency have to be solved. LCA implementation in the early design phases will contribute to the achievement of a sustainable building, assessing environmental criteria. Nevertheless LCA has some drawbacks that need to be solved such as lack of data, manual data re-entry, or difficulties for non-experts to perform the assessment. The integration between LCA and BIM could solve these drawbacks and boost the implementation of LCA in the design phase. There are some new developments seeking integration such as LCADesign and BSLCA, but further improvement is needed in order to achieve an efficient interoperability.

KEYWORDS

Sustainability, Life Cycle Assessment (LCA), Building Information Modelling (BIM), Construction Industry, Integration, Design.
RESEARCH STATEMENT

Since the concept of sustainability was defined, it is clear that it is something that cannot be ignored, and an effort to include it as a behavior pattern has to be done. The construction sector and building sector in particular, have noticeable impact in the three pillars of sustainability (environmental, economic and social), consequently, there is no doubt that nowadays sustainable construction has become a must. But how can sustainable construction be assessed? To find the answer to this question, the concept of sustainable development has to be clear, and attention must be paid to the fact that the assessment of the sustainability is going to be constricted by the particular features of the building industry.

At the present, powerful tools that could bring us big advantages concerning sustainability implementation already exist, such as LCA and BIM tools; but as the appropriate use of them has not been achieved yet, these tools are being misused and are losing an important part of their potential.

On the one hand, LCA could assess decision-making in all the phases of the building life cycle, being a very useful tool when comparing different alternatives. Nevertheless, the LCA implementation in the building industry has been hindered by some drawbacks inherent to the LCA procedure.

On the other hand, BIM is a powerful tool that enables continuous communication between the stakeholders involved in the process, immediate access to the multidisciplinary updated information, time saving and increment of accuracy. Moreover, nowadays the use of BIM is becoming more common and in some countries, it has become compulsory or it will in a near future.

Therefore, if for achieving a sustainable building, the environmental assessment of the product is required, if a powerful modeling tool is needed for the development and control of all the project phases, and what is more, if these powerful tools are already available, the solution could be their integration in order to take advantage of their potential.

The sought aim is to achieve an integrated use of LCA and BIM tools during all project phases, but especially during the design and preconstruction phases, due to as it is well known, the capacity of influencing the project is higher in these phases. If these tools are used since the early phases, their retrofitting will be more efficient and a wide range of opportunities for achieving sustainability will be offered.

This is enhanced in the present report due to one of the great aims of the construction sector could be the complete interoperability of the whole industry, and in order to achieve this, a great work has to be done, so it is high time to start.
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LIST OF ACRONYMS

ACMME : Australian Cost Management Manual
AEC : Architecture, Engineering and Construction
AIA : American Institute of Architects
BCA : Building Construction Authority
BIM : Building Information Modelling
BREEAM : Building Research Establishment Environmental Assessment Method
BS : Building Service
CAD : Computer-aided Design
CiTB : Construction Industry Training Board
CML : Institute of Environmental Sciences
CO₂ : Carbon dioxide
CORENET : Construction and Real Estate Network
CPM : Center for Environmental Assessment of Product and Material Systems
CRC : Cooperative Research Centre
CSIRO : Commonwealth Scientific and Industrial Research Organization
D : Dimensional
DAIA : Decision Analysis Impact Assessment
DALY : Disability Adjusted Life Years
DGNB : Deutsche Gesellschaft für Nachhaltiges Bauen
EDM : EXPRESS Data Manager
ELCD : European Reference Life Cycle Database
ENSLIC : Energy Saving through promotion of Life Cycle assessment in buildings
EPS : Environmental Priority Strategy
EU : European Union
GDP : Gross Domestic Product
HUT-600 : Helsinki University of Technology Auditorium Hall 600
HVAC : Heating, Ventilation and Air Conditioning
iBIM : Integrated Building Information Modelling
ICT : Information and Communication Technology
IFC : Industry Foundation Classes
ILCD : International Reference Life Cycle Data
IT : Information Technology
LCA : Life Cycle Assessment
LCI : Life Cycle Inventory
LCIA : Life Cycle Impact Assessment
LCM : Life Cycle Management
LEED : Leadership in Energy and Environmental Design
MEP : Mechanical, Electrical and Plumbing
NIBS : National Institute of Building Science
NREL : National Renewable Energy Laboratory
PM4D : Product Model and Fourth Dimension
R&D : Research and Development
REPA : Resource and Environmental Profile Analysis
SETAC : Society of Environmental Toxicology and Chemistry
SME : Small or Medium Enterprises
SMOG : Space Modelling Software
U.S. = USA : United States of America
UK : United Kingdom
UNEP : United Nations Environmental Programme
XML : Extensible Markup Language
CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Since sustainability was defined for the first time, different attempts emerged seeking its achievement. Currently, there is no doubt that sustainability implementation should be a must, and construction industry as many others industries is trying to move into it.

Nevertheless, the implementation of sustainability in the construction industry will not be easy due to this industry because of some of its current particular features is inefficient, and therefore important changes are needed in order to improve its performance.

Sustainability is mainly based on three pillars, environmental, economic and social. There are already different tools such as BIM and LCA that contribute to sustainability implementation. On the one hand BIM represents a new way of working based on a multidisciplinary collaborative framework that enables the direct access to the project updated data. On the other hand, LCA tools can perform an environmental assessment during the product whole life cycle, from cradle to grave.

It has to be also highlighted that the project phases with higher capacity of influencing the project are the early phases. These phases have the strength of adding value to the project, and the costs of changes implementation are lower than in later phases.

Therefore if sustainable buildings want to be achieved, sustainable criteria have to be implemented since the early project phases in order to succeed. Tools such as BIM and LCA will have better performance if they are applied since the early project phases, due to they will have higher capacity of influencing the project.

Moreover, one of the aims of the new construction model is the achievement of effective data transfer among the multidisciplinary and collaborative framework. This is one of the fields that could contribute to the construction inefficiency improvement, and therefore, currently different developments are seeking interoperability.

1.2 AIMS AND OBJECTIVES

The main aim of this Master final dissertation is to achieve an overall view and deep understanding of the concept of sustainable construction; comprehend the adaptation of the building sector to the sustainability concept, and present how sustainability is becoming a key factor when decision-making is concerned.

Therefore, the objectives of this project are:

Understand the current status of Sustainability, Building Information Modelling and Life Cycle Assessment in the construction industry, with special attention to the building sector.
CHAPTER 1: INTRODUCTION

Understand the main features of the construction industry and in particular the building sector in order to comprehend the sector performance.

Moreover, a deep knowledge of these concepts and their relationship under the sustainability framework is sought.

Highlight the capacity of the early project phases to influence the project and the importance of including sustainable criteria during the design phase in order to achieve a sustainable building.

Show the real demand existing in the market of a LCA and BIM integrated tool in order to contribute to the achievement of a sustainable design.

Analyze the requisites for achieving LCA and BIM integration and its application during the design phase as a decision-making assessing tool. And highlight recommendations for further developments in the field.

1.3 RESEARCH METHODOLOGY

This present report is mainly included under the framework of a theoretical research. The methodology followed is explained below:

First a general overview of what sustainability means and its application in the construction industry will be done. Attention will be paid to the main features of the construction industry, and in particular of the building sector, and its current problems, in order to find solutions, at the same time that sustainability is enhanced.

Two tools, BIM and LCA, will be highlighted as possible solutions, and an overview of both of them will be developed, focusing attention to their contribution to sustainability, in order to understand the framework in which the research is included.

Next, the problem definition will be formulated, and the integration of LCA and BIM will be suggested as a solution.

Two real application cases will be analyzed, LCADesign and BSLCA. On the one hand, their strengths will be highlighted so that future researches can continue in this direction; and on the other hand, their weaknesses will be shown, in order to improve them. A multicriteria assessment of both of them will be also developed.

The criteria for the assessment of the cases studied will be based on all the reading, information gathered, users and experts’ opinion, and contact, when possible, with developers.

Finally, a general conclusion of the whole report and some recommendations for further developments will be given.
CHAPTER 1: INTRODUCTION

1.4 LIMITATIONS AND SCOPE

Sustainability is based on three main pillars, environmental, economic and social. All of them have to be taken into account when implementing sustainability. In this report the implementation of sustainability in the construction industry is studied but only from an environmental point of. Therefore, economic and social pillars of sustainability are out of the scope of this research, despite that for achieving sustainability a combination of the three of them is needed.

Moreover, the research is focused on the construction industry; nevertheless, it is mainly oriented to the building sector, not analyzing civil constructions. The building sector represents the 77% of the total construction in the European Union, being this the reason why it has been chosen as the main field of attention.

In a building life cycle different phases can be identified: pre-project phase, design phase, construction phase, operation and maintenance phase and disposal phase. In this research the attention is focused on the design phase, due to it is one of the project phases with higher capacity of influencing the project. The implementation of changes in the early project phases has lower costs than its implementation in later phases because as the project is evolving, it loses flexibility. Therefore, for achieving a sustainable building, sustainable criteria have to be included since the early project phases. This is the reason why this research is focused on the design phase, due to it is one of the project phases with major potential for enhancing the project sustainability, being the rest of the project phases out the scope of this research.

LCA has been selected as the tool for environmental assessment, due to the capacity of assessment the environmental performance of the product during its whole life cycle, from cradle to grave. Therefore, other environmental assessment tools are out of the scope of this research.

BIM has been chosen as the modeling system for enhancing sustainability, due to its capacity of updated data sharing in a multidisciplinary collaborative framework, being a source of information that enables the building modeling and monitoring during its whole life cycle.

Moreover, for achieving LCA and BIM integration, interoperability between both of them has to be achieved. Nevertheless, the deep study of tools interoperability and data transfer formats such as IFC is out of the scope of this research.

1.5 DISSERTATION REPORT OUTLINE

The initial chapters set the background and the framework of the research. They offer a general overview and current status of the research’s main fields and highlight the existing problems. Then a problem definition chapter has been developed, summarizing the main problems that have been found and highlighted during the general overview and current status included in the previous chapters. After that, a chapter with the suggested solution and cases
studied is included. And finally, as the closure of the report, a conclusion chapter is presented with the main issues of the whole report and recommendations for further developments.

After the present introduction chapter, the chapter “Sustainability state of the art” is included. This chapter covers a general sustainability definition and different directives and initiatives related with it. Then an overview of the construction industry, and in particular the building sector, presents the main features of the industry in order to understand the current situation showing the main existing problems and highlighting the need of a change in the working procedures. Finally some attempts of the construction industry to move into sustainability are also presented.

This chapter is followed by “BIM state of art” and “LCA state of the art” chapters. The first one starts with a general overview of BIM concept including definition, explanation of what is not BIM, highlighting the need of a change in the construction working procedures in order to implement BIM effectively; an overview of the BIM implementation in the construction industry and current status of BIM adoption, analyzing some countries cases, is also presented. Then the attention is focused on BIM implementation with green objectives and its contribution to sustainability.

The chapter about LCA covers a general introduction to the concept including definition, brief history and explanation of LCA databases. Then the attention is focused on its implementation in the construction industry and in particular in the building sector, and its contribution to sustainability when used as an assessing decision-making tool during the design phase. Finally, LCA main advantages and limitations when applied in the construction industry are explained.

After the overview of the three main topics (sustainability, BIM and LCA), a chapter summarizing the problem definition and a possible solution, is included. The integration of LCA and BIM is highlighted as a solution.

In the implementation chapter, the integration of BIM and LCA is analyzed, studying two real cases, LCADesign and BSLCA and their evaluation, including an assessment following different criteria based on all the previous research.

Finally, the conclusion chapter is included, with a conclusion of the whole report and recommendations for further development.
2 CHAPTER 2: SUSTAINABILITY

2.1 GENERAL INTRODUCTION TO SUSTAINABILITY

2.1.1 GENERAL FRAMEWORK

Nowadays it has been estimated that as an average, 16 tonnes of materials resources per year are consumed per person in the European Union; 6 of these tonnes are wastes. If this trend continues, by 2050 an equivalent of two planets will be needed for maintaining this rate of consumption (European Commission, 2011). Moreover, during the 20th century, the worldwide consumption of fossil fuels has been multiplied by 12, and the materials resources consumption by 34 (European Commission, 2011).

This unsustainable situation has been reached in Europe after a long period of growth and wellbeing supported on a high resources use. Therefore, this trend has to change and Europe has to find the way of achieving growth and well-being but ensuring also moderate resources consumption, in order to transform this challenge into an opportunity to achieve a sustainable development. To make this possible, a policy framework will be needed in order to promote a sustainable growth base (European Commission, 2011).

2.1.2 SUSTAINABILITY DEVELOPMENT DEFINITION

One of the questions that must be asked is: what is sustainability? Different answers have been given to this question, and many interpretations have been spread.

The Brundtland Report which is known as “Our Common Future”, published by the World Commission on Environment and Development in 1987, presented a new concept, the “sustainable development”. This concept was defined as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, n.d.); presenting also the three pillars of the sustainability, that are environmental, social and economic aspects.

![Figure 2.1. The three pillars of sustainability. (European Commission, 2011)](image)
Therefore, due to its flexibility, this concept has been used with diverse interpretations and for different purposes by a wide variety of users (United Nations, 2012).

Since this definition appeared, the concern about sustainability and sustainable development grew among the governments, different industries and citizens. A proof of this, are the different international initiatives that have taken place, such as The Rio Summit in 1992, the Kyoto Protocol in 1997 and the Johannesburg Meeting in 2002 (Chong, et al., 2009). Furthermore, the concern regarding achieving sustainability in all human activities is continuously increasing due to the fact that limited natural resources are running out (Said, et al., 2010).

### 2.2 SUSTAINABLE INITIATIVES AND DIRECTIVES

Due to the general concern about sustainability, different initiatives have taken place around the world.

In Europe, as the first attempt of achieving sustainability, each country focused on their own situation; nevertheless, fortunately different European programs and subsidies, oriented to cooperation and knowledge exchange have been developed (Novem, 2002). Among the European Union some initiatives to promote sustainability could be highlighted, such as the “2020” initiative and “The roadmap to a resource efficient Europe”.

The 2020 “a resource efficient Europe” initiative was launched by the European Union in 2010, to address the pitfalls of the present growing model and create a framework where a sustainable approach could be achieved (European Commission, 2013). This initiative sets medium and long term objectives to drive through a sustainable future (European Commission, 2011).

The initiative “Europe 2020” consists on some fixed objectives that seek to be achieved by 2020. It temps to be a change in the European direction, fixing the targets for the next 10 years. This initiative was thought as a collaborative effort between the European Union and the different European countries themselves. For this purpose 5 targets dealing with “employment, education, research and innovation, social inclusion and poverty reduction and climate/energy” have been set (European Commission, 2013). Concerning climatic and energy issues the targets to be achieved are the emission of a 20% less than in 1990 of greenhouse gases; besides, the 20% of the total consumed energy will come from renewable sources, increasing also the energy efficiency up to a 20% (European Commission, 2013). Furthermore, it has been estimated that the 20% reduction of the energy consumption could bring a save of 50 billion € for the UE (Europäisches Parlament Informationsbüro in Deutschland, 2012). Moreover, these common targets will also be translated into national targets in order to achieve the common aim (European Commission, 2013).

“The Roadmap”, was launched by the European Commission in September 2011, with the aim of highlighting how a sustainable economy could be reached in Europe by 2050. For this purpose, it shows where policies could have a big effect, which actions can be implemented in the future and which changes have to be implemented to reach the 2020 objectives, in order to
achieve a sustainable and resource efficient Europe. As nutrition, housing and mobility are the sectors with higher environmental impacts, some measurements are also suggested in these fields (European Commission, 2011). Considering one of its main milestones the reduction of a 80% of the Green House Emissions by 2050 (European Climate Foundation, n.d.)

Despite that the 2020 objectives were already set, the existing initiatives were not enough for the achievement of the 20% reduction of the energy consumption. Therefore, in October 2012 the European Union launched the Directive 2012/27/EU dealing with energy efficiency, with the purpose of improving the effectiveness of the existing regulations and cover the lack of legislation when needed (European Parliament, 2012). This Directive will bring some changes, such as the following measures: each year a 3% of the public buildings will be refurbished in order to achieve a reduction in the energy consumption, while the public bodies from now on will purchase energy efficient products; consumers will be better informed in their energy bills in order to make them more conscious about their consumption; and companies will have to undertake energy audits every 3 years (European Commission, 2011).

Other initiatives such as “Vision 2050” also emerged in a worldwide framework, due to the widespread concern of achieving a sustainable future. “Vision 2050” initiative was developed by World Business Council for Sustainable Development, trying to answer the following three questions: “what does a sustainable world look like?”, “How can we realize it?”, “What are the roles business can play in ensuring more rapid progress toward that world?” (World Business Council for Sustainable Development, n.d.).

Furthermore, some international certificates have appeared with the purpose of assessing sustainability in different industries. Concerning the construction industry, the European Committee for Standardization developed the CEN/TC 350 “Sustainability of construction works”, a voluntary method for assessing sustainability in the construction. It gives the framework for evaluating building’s sustainable performance (environmental, social and economic), during its whole lifecycle (CEN, 2009). Moreover, ISO standards for achieving sustainability in buildings construction are also being developed under the ISO framework ISO/TC 59/SC 17 “Sustainability in buildings and civil engineering works”. It can be highlighted the ISO 21931-1:2010 “Sustainability in building construction – Framework for methods of assessment of the environmental performance of construction works – Part 1: Buildings”, where the different issues that have to be taken into account when evaluating the environmental performance of a building, are mentioned (ISO, 2010)

Finally, concern about the sustainability in the construction sector has been showed up by different countries. Germany can be taken as a reference, expressing its concern about the sector growing inefficiency; Germany is exposing which are the main construction problems and implementing the necessary measures to improve construction industry. Even if changes have to be done in legislation, Germany is devoted to perform the required changes. Moreover, a manual in order to guide large-scale projects is being developed and it will be available by the middle of 2015 (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013).
As a conclusion, in order to accomplish all these objectives, some barriers such as excessive prices and taxes of the resources or international competitiveness should be disposed and efforts should be gather around promoting long-term business initiatives, and development of research (European Commission, 2011).

2.3 THE CONSTRUCTION INDUSTRY (BUILDING SECTOR)

As in many other fields, the construction industry launched different efforts in order to apply the concept of sustainability. Construction industry is aiming at taking profit of the knowledge and technology in order to achieve sustainability in all its activities (Chong, et al., 2009). Understanding sustainable construction as the one seeking sustainable development joining the effort of all the stakeholders, taking into consideration environmental, social and economic issues (Taskforce on sustainable construction, 2007).

For this purpose, sustainable assessments are currently being developed. Building sustainability assessment refers to an evaluation of the building performance in a systematic and objective complex method through a life cycle methodology, considering environmental, economic and social factors (Burdová & Vilceková, 2012). But it has to be taken into account that the definition of the building performance is not easy to determine due to the different aims and stakeholders involved in the construction industry process (Haapio & Viitaniemi, 2008).

Furthermore, the construction sector is characterized by some special features. These particular features constitute an identity sign; however, they also condition the achievement of a sustainable construction (Burdová & Vilceková, 2012) and they can be responsible of the construction inefficiency. Concern about the industry inefficiency is raising and a change is becoming more demanded.

2.3.1 CONSTRUCTION INDUSTRY FEATURES

To reach a better understanding of the building sector in order to achieve sustainability, some of its particular features have to be highlighted.

2.3.1.1 PROJECT-BASED INDUSTRY (BUILDING AS A UNIQUE PRODUCT)

The main distinctive feature of the construction industry is that it is a project-based industry, where each project is a new product with its own features. Among these distinctive project features are the different design alternatives, the specific construction site, the execution process, materials supply and the specific organization and project management (Nawari, 2012).

Each building is a unique product; therefore, it has to be designed according to its specific needs and features (Khasreen, et al., 2009). The building has a specific location and it has to be design in order to achieve a suitable orientation. Moreover, due to its location is fixed, an important part of the production process takes place in the site where the building is going to be used (Organisation for Economic Co-operation and Development, 2002).
Each building meets the specific needs of the clients, so it has to be adapted to the surrounding conditions and to the specific environment in which it is located. Therefore, different specific features have to be taken into account when designing, such as the specific climate, ground, the specific setting, infrastructures, etc. (Organisation for Economic Co-operation and Development, 2002), adapting the different design parameters, such as orientation, insulation, materials election etc. trying to take the most profit of these specific conditions.

On the other hand, due to its design flexibility, it enables performing important improvements or reduction of the building’s impact just implementing some changes in the design (Khasreen, et al., 2009). The design of each building tries to take the most profit of it. Hence, a high initial investment is needed when dealing with buildings, and one of the reasons of this fact is that they are placed in the land, and land is a limited resource in the cities nowadays. And the specific land in which the building is located also forces the design. (Organisation for Economic Co-operation and Development, 2002).

2.3.1.2 DIFFERENT STAKEHOLDERS INVOLVED

Different stakeholders with different characteristics and aims are involved in the different phases of the building process (Organisation for Economic Co-operation and Development, 2002), making more difficult the standardization of the construction process (Khasreen, et al., 2009).

Furthermore, companies of different scale are involved in the construction process. A big portion of the companies involved in the building sector are small or medium scale ones (SME’s). They do not have as much resources for adopting new technologies and developing research as the big companies. Therefore due to the limited resources, the implementation of the needed changes for achieving sustainability is more difficult (Organisation for Economic Co-operation and Development, 2002).
Figure 2.2. Sectorial analysis of the enterprises' size. (Eurostat, 2013)

Figure 2.3. Construction enterprises in the EU by number of employees in 2007. (Eurostat, 2012)
Another important characteristic of the construction sector is that long life time products are obtained. The building itself has a long lifespan. This period depends on many factors such as the location of the building, the materials used, the implemented construction techniques, the uses for which it is designed, the maintenance etc.; nevertheless buildings are usually designed for being used during long periods of time as decades or even centuries (Organisation for Economic Co-operation and Development, 2002). During the building life span they can undergo different
changes concerning the building shape and functions. This leads to a high level of uncertainty about the building’s future, making it so complicated to predict the whole life-cycle (Khasreene, et al., 2009). Moreover, buildings consume energy and a variety of resources during its lifetime, having the highest environmental impact during the usage phase (Buyle, et al., 2012). As a result, uncertainty exists when dealing with building life cycle. It cannot be predicted if the building is going to change its use in the future, or the treatment and maintenance that is going to receive. Accordingly, some assumptions regarding the future are being done, and moreover same of the taken decisions would affect the future generations.

Hence, if sustainability wants to be achieved, among the different project life-cycle phases of a building, the ones with higher ability for adding value to the project have to be highlighted.

When looking at the constructed facility as a whole, different phases during the product life-cycle can be distinguished, each of them characterized by different tasks, level of effort required and stakeholders involved (Burke, 2001). These phases are:

- **Pre-Project Phase:** There are a wide variety of reasons that can trigger a project development. And in this phase is where the project selection takes place (Burke, 2001).

- **Project Life-Cycle:** This phase can be divided into 4 main phases: conception and initiation, design and development, implementation and manufacture, and commissioning and handover. The concept phase consists on the definition of the project’s needs and the development of a feasibility study considering different alternatives, determining if the project is feasible or not and the selection of the best option. Then the design and development phase is based on the design development and project planning including schedule, budget, and resources management, etc. When the design phase is completed the construction phase takes place, with the execution of the baseline plan elaborated during the previous phases. And finally the commission phase where the final product is revised and is officially handled to the owner (Burke, 2001).

- **Operational and maintenance phase:** It covers the use phase and the different required maintenance tasks in order to keep the product in the required conditions. During the design phase the required maintenance can also be considered as a decision-making criterion (Burke, 2001).

- **Disposal phase:** It is the last phase of the project life-cycle. As environmental awareness is raising, this phase has gained attention, and can be also included as an aspect to analyze during the design phase (Burke, 2001).

During the 1960’s and 1970’s it was believed that the main attention and effort should be focused on the implementation phase, considering it as the project’s life cycle phase with higher effort and expenses assigned. Nevertheless in the 1980’s this perspective changed and the
construction industry started to realize that it is the design phase the one with higher potential to add value to the project. It is in the design phase where the different stakeholder’s needs are studied and the building is designed. Despite big expenses take place during the construction phase, the project has already lost flexibility and only small changes can be performed, having high costs; being the execution of what it has been designed in the previous phases the main task of this phase. The design influence and its capacity of adding value to the project decreases while the project evolves and goes further into the different project phases (Burke, 2001).

As it is shown in the figure below, in the previous phases the project is really flexible and has a great potential to implement changes, study different alternatives, improve the performance, and cost reduction; this flexibility is reduced progressively as the project goes forward (Burke, 2001).

![Figure 2.4. Ability to Influence Construction Cost over Time. (Hendrickson, 2008)](image-url)
2.3.1.4 SECTOR WITH HIGH IMPACTS ON SUSTAINABILITY

It is a fact that infrastructures and buildings are an important feature of our actual urban environment. Buildings and construction facilities are surrounding people in the uncountable existing cities all around the world. The construction industry is one the largest economic engines at the present; nevertheless it also consumes a massive amounts of energy and resources and have great impact in the surrounding environment (Berry & McCarthy, 2011). According to the Directive 2010/31/EU (19 May 2010), the 40% of the consumed energy in the European Union is due to the buildings sector, moreover it is a sector in expansion, and so will the energy consumption. This sector also represents the 40% of the consumption of national resources and the 40% of the wastes generated in the world (ISO, 2010).

As well, it could be said that buildings emit a third of the global greenhouse gases. So, due to growth of the new construction and the inefficient use of the existing building stock, the rate of emissions will continue raising if precautionary measures are not implemented in order to chance it (United Nations Environmental Programme, 2009).

Therefore, buildings have impact on the three pillars of sustainability: Buildings have environmental impacts during their construction and during their life time, as it has already been explained. Economic impacts, due to this sector is one of the most important economic sectors in the world (Novem, 2002). It has been estimated that the tenth fraction of the whole global economy accounts for construction (Adapt4EE Consortium, 2012). Moreover, construction industry and construction products constitute the 9,5% of GDP and 10% of the workforce in Europe (European Commission, 2013). They have also a social impact, due to buildings and infrastructures can affect the well-being and life quality of the citizens, having influence on their social interaction and health (Novem, 2002).
Despite the challenge is big, if sustainability wants to be achieved a transformation is needed; being a political framework encouraging a sustainable management of resources, essential (European Commission, 2011).

These particular features of the sector, that have already been explained, can be responsible of the construction inefficiency. As concern about this inefficiency is rising a change is becoming more demanded.

### 2.3.2 CONSTRUCTION INDUSTRY INEFFICIENCY

The concern about the construction industry current situation is growing, as it has been expressed by different institutions; for example in the Germany construction, despite it is worldwide known due to its good reputation, some projects have recently undergone costs and schedules overruns. This has resulted on several questions concerning the inefficiency of the construction industry. And it is clear that a change is required to ensure the improvement of the construction industry (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013). Moreover, the Norwegian government highlights that a change is needed due to it is one of the industries with highest inadequate quality, and with the lowest development in IT and innovation in comparison with other industries such as manufacturing industry (Sjøgren, 2011).

The construction sector inefficiency is unsustainable due to it has effects on the environment and the economy. Different estimations about the inefficiency of the construction industry have been done, such as the one reported by The Economist, in the article “New Wiring” the 13th January 2000, asserts that a third of the total yearly American construction expenses were wasted; or as it is shown by the IT Construction Best Practice service, around 1 billion euro was spent in UK for correcting mistakes due to undetailed information (Autodesk, 2005). Also a study developed by the Stanford University shows that in the period from 1964 until 2004 the productivity of the construction sector has decreased a 10% (British Standards Institution, 2010).

Some of the reasons of the already mentioned construction inefficiency are explained below:

#### 2.3.2.1 HIGH RATE OF LOW-SKILLED WORKERS

One of the main causes of the construction inefficiency is that currently exists in the market a high demand of low-cost buildings, and this is prompting a high competitive behavior within the sector. Moreover, it is encouraging the “hire and fire” especially in the SMEs, leading to a really low investment in training (Danish Technological Institute, 2009). As the workers’ salaries are lower, their skills are also lower (Eastman, et al., 2011). Furthermore there is a need in the European Construction Sector of new technologies, and skilled workers specialized in sustainability, planning and management. Also several studies such as “Construction Skills Forecast. Report 2003” developed by The Construction Industry Training Board (CITB) have highlighted that concerning skilled workers (such as
carpenters, electricians, etc.), a change from a specific background to a multi-skilled profile in order to achieve higher cooperation is being demanded (Danish Technological Institute, 2009).

Figure 2.6. Manufacturing and construction workers hourly earnings ($) (1974 - 2008). (Eastman, et al., 2011)

2.3.2.2 LOW INVESTMENT IN INNOVATION AND DEVELOPMENT

Concerning the investment in research and development, the expenses of the construction sector are lower than in other sectors. Nevertheless, R&D is mainly promoted by large construction companies, while SME have a really low contribution to R&D, despite the implementation of new technologies will be basic for the construction industry development (European Foundation, 2005). Large construction firms only stand for a 0.5% of the construction sector while almost a 65% are small firms, so it is really difficult for them due to their small size to undertake high investments to implement new technologies. Moreover, the creation of temporal partners alliances, which is a very often practice in the sector hinders the chance of gain applied learning (Eastman, et al., 2011).

Furthermore, for the implementation of Information and Communications Technology (ICT), a proper management support has to be provided by the organization (Peansupap & Walker, 2005).

Construction industry has always been one of the industries with lower rate of innovation (buildingSMARTAustralasia, 2012). For the achievement of IT innovation it has to be accepted by all the stakeholders involved in the industry, and sometimes IT is seen as an auxiliary tools instead as a new construction approach that can improve construction performance (CEFRO, 2011).
2.3.2.3 LACK OF COOPERATION

Furthermore, the lack of cooperation also contributes to the construction inefficiency. A factor that influences the construction lack of cooperation is that the relationship between the project participants is not usually based on an open communication or trust. Another influencing factor is that there are still clients that assign the projects by tenders based only on prices; this could be one the main obstacles for the sector’s progress; hence a change in the clients mind is needed in order to based their selection in the greatest value, not in the lowest price and encourage project’s quality instead of competitiveness (Cheung, et al., 2003). Besides, the lack of cooperation influences the low ICT implementation (Peansupap & Walker, 2005).

2.3.2.4 WASTE OF PROJECT RESOURCES

Finally, evidences also highlighted the different waste sources in the construction sector. It has been estimated that the same information can be entered almost seven times in the same building project (Sjøgren, 2011); besides it has also been estimated that a 30% of the project’s work has already been done before, and a 60% of the time is misused (WSP and Kairos Future, 2011). This could be a consequence of the lack of interoperability; due to interoperability is the capacity of sharing information between the different stakeholders involved in the project during the whole project life cycle (Sjøgren, 2011); it has been estimated that the lack of efficient interoperability could cost around 100 billion euro per year in the UK (British Standards Institution, 2010). Moreover, the concept of isolated work has to be changed, and move into collaborative procedures (WSP and Kairos Future, 2011).

Therefore, as the root of the construction inefficiency is in some of its characteristics, if inefficiency has to be eliminated, it is important to understand the construction special features.

Furthermore, due to the building sector represents the 77% of the total construction in the European Union, being 46% residential and 31% non-residential; whereas civil works accounts for the 23% of the industry (Taskforce on sustainable construction, 2007), this work is focusing attention mainly in the building sector.

2.3.3 CONSTRUCTION INDUSTRY ATTEMPTS TO MOVE INTO SUSTAINABILITY

The construction industry is facing new challenges; the society is demanding new infrastructures, reduction of energy and resources consumption, and implementation of a sustainable construction, moreover the market leadership is also pressing the industry. There is also a need of costs reduction and quality increase, and moving the focus from products to services for the society; changing the industry from a cost-driven philosophy into a value-driven one. (Sjøgren, 2011).

Nowadays construction is moving towards sustainability. This implies that a change is needed in the construction industry. New criteria and priorities have emerged in the construction field switching from economic, utility, durability concern to a higher importance of health,
Design could be considered the first stage for achieving sustainability; as it has been accepted by the British government “Good design is synonymous with sustainable construction” (HM Government, 2008). In fact, for achieving a sustainable building an all-embracing design is essential, due to every design decision has environmental consequences (C-SanD, 2001).

Consequently, it has to be highlighted the importance of the decisions taken in the early project’s phases. They give the chance of avoiding future errors, with higher costs if changes have to be implemented. Therefore, a special effort has to be done during the early phases, devoting more resources and expertise skilled professionals (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013).

It is essential to establish all the projects needs in the planning phase, because if the needs are not clearly determined, future changes in the design will have to be performed. Everything has to be planned and analyzed in detail before the construction phase, if not, a sharp decrease in the construction efficiency is observed. Moreover, if different alternatives have been studied during the design phase, a higher performance is achieved. And despite the design costs will increase due to more resources are used, the saves in future projects stages will highly compensate them (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013).

Furthermore, for reaching a sustainable design, coordination between the different stakeholders is essential; this coordination should exists since the beginning and it can be facilitated by tools such as BIM. If the responsibilities are not clear within the project since the
beginning, this could lead to important misunderstandings. Moreover, a coordinated work is needed in order to improve the results (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013), due to all the stakeholder should move in the same direction to achieve a balance between environmental, economic and social criteria (C-SanD, 2001).

Therefore, the design phase is the key to a sustainable construction, trying to achieve at the same time a reduction of the resources and energy consumption, and a comfortable inside atmosphere, while pollution and costs are reduced. In order to achieve this scope some of the design items where attention could be focused in order to achieve a building with high environmental performance are: health interior environment, energy efficiency, ecologically favorable materials, environmental form and good design. This will imply emissions decrease, the improvement of the energy performance of the buildings, the selection of materials taking into account environmental criteria, and the adaptation of the building to the environment by means of a suitable and efficient design. Being “building envelope, air-conditioning system, security and fire control, lighting system, power and communication system and integration of building and services” influencing features for this purpose (C-SanD, 2001).

Moreover, sustainable design should be exhaustive, with higher effort in the early phases than the traditional one, due to the great influence that these decisions have on the whole project; and taking into account the building’s whole life cycle. Therefore, sustainable construction is not a more complicated or expensive trend; it is a matter of implementing an integrated design, where all the components of the project are considered under a holistic framework, instead of analyzing them individually (C-SanD, 2001).

In order to face all these new challenges, and avoid past problems, while the customers confidence is recovered, innovative technologies have to be implemented in the construction field (Taskforce on sustainable construction, 2007). Tools such as BIM and LCA can be integrated in the construction procedure in order to contribute to a sustainable design.

The use of BIM has the strength of improving the information flow on the projects, achieving a better project’s performance and quality. Some government at the glance of this tool potential are already taking profit of it for tasks such as automated code checking, check if buildings meet with the environmental and energy requirements, availability of the information, etc. (Sjøgren, 2011). Moreover, this tool enhances transparency and collaborative work between the stakeholders in order to reduce wastes (HM Government, 2012). It enables the coordination between the different stakeholders since the early phases with the purpose of reducing future errors. Due to its proven advantages the use of BIM is already becoming mandatory in some countries such as UK, USA and the Scandinavian countries (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013).

Moreover, an evaluation of the building performance during its life cycle is needed. So LCA, can be implemented as a tool for assessing the environmental performance during the whole life
span (C-SanD, 2001). Moreover, LCA can be used as an assessment tool for decision-making in order to contribute to the development of a sustainable construction (Ortiz, et al., 2009).

To conclude, BIM and LCA could be very useful tools if they are properly implemented, contributing to sustainability achievement.
CHAPTER 3: BUILDING INFORMATION MODELLING (BIM)

3.1 GENERAL INTRODUCTION TO THE BIM’S CONCEPT

3.1.1 BIM’s DEFINITION

Many different definitions have been spread about BIM, as an example, the National Institute of Building Science in the United States (NIBS), defines BIM as “a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onwards” (National Institute of Building Sciences, 2012). Owing to the wide variety of existing definitions, BIM concept could be defined differently by the different stakeholders involved and this could lead into wrong expectations about BIM; therefore, there are still some items that could be highlighted and explained in order to avoid misunderstandings (Abbasnejad & Moud, 2013). Thus, what is BIM?

BIM is based on digital models that have the capacity of laying up information that is accessible by all the stakeholders (Connaughton, 2012).

BIM could be define as a digital model which enables an easy visualization and that includes rich and structured information, covering the whole life cycle of the represented element, empowering work collaboration, saving of time and costs and improvement of quality and accuracy (buildingSMARTAustralasia, 2012).

The main characteristics of BIM are detailed below:

3.1.1.1 B=BUILDING

As BIM means Building Information Modelling, the B of Building could drive to a misunderstanding; BIM is not a tool only for buildings, it could be as useful for buildings as for civil engineering (WSP and Kairos Future, 2011). The base of BIM is to achieve a collaborative multidisciplinary design process in order to save costs and time, improve the accuracy of the required estimations, prevent from mistakes because of loss of information or avoid repeatedly entry of information. All these objectives are desirable for the whole construction industry not just for buildings. Moreover, as it can be highlighted from the BIM’s given definition, BIM represents facilities’ characteristics and it is an information sharing tool with the purpose of assessing the decision-making process during the whole life cycle of the facility; therefore, there is not a specific feature in the concept of BIM that makes it only available for buildings.

One of the reasons why BIM use is more developed in buildings than in other sectors of the construction is because it could be wrongly assumed that BIM is just a 3D drawing tool, and aesthetic design is more important for buildings than for other infrastructures (WSP and Kairos Future, 2011). With this approach two big mistakes are made, the first one is the wrong
interpretation of what BIM is, that ends in a misuse of the tool; and the second one is considering BIM just for buildings, when BIM tools are information modelling systems that can be used by all the stakeholders involved in the construction industry, therefore, due to this mistake a lot of potential and opportunities are being wasted.

3.1.1.2 I= INFORMATION

It could be considered as the key factor in the BIM’s definition. In some situations, it could be thought that BIM is just a 3D model, focusing only on the graphic aspects; nevertheless, despite the graphics aspects are important in construction and help the designer to project their ideas, the greatest advantages of using BIM result from the capacity of including information in the model (WSP and Kairos Future, 2011).

With BIM it is possible to reuse information, check it and correct it if needed, while this information is automatically updated (British Standards Institution, 2010). Therefore, models with a rich content of information are achieved with BIM, enabling the performance of complex analysis (WSP and Kairos Future, 2011).

Due to the fact that designing with BIM is not just drawing lines, but also adding information and properties to the drawn elements, a great part of the work has to be done at early project phases (WSP and Kairos Future, 2011). Therefore, a change of mind is needed, and it has to be accepted that the design works are going to expend more effort and consequently more money; but on the other hand, this will bring the opportunity to implement changes in early phases, saving time and resources.

Moreover, nowadays Building Information Models are known as 6D, where 3D is the graphic three dimensional modelling, that constitute an efficient visualization tool and enables the detection of possible mistakes during the design phase, before the building is already under construction. 4D includes time information, being really useful for construction planning. 5D deals with costs information allowing costs estimations. And finally, 6D refers to lifecycle management (Abbasnejad & Moud, 2013).

This labeling could continue as “nD” being “n” different types of information included in the model, such as energy consumption, temperature etc., or the different dimensions for planning. Nevertheless, this labeling could be ignored, and just think about the model as a rich source of information, that includes a wide variety of data; because in fact, all this dimensions could be considered as the same dimension, being the model an information model that enables the development of an important part of the work in the earliest phases of the project avoiding future errors (WSP and Kairos Future, 2011).

An example of the information management capacity of BIM is shown in the figure below, where BIM can be implemented in the different construction phases, dealing with different types of information.
CHAPTER 3: BUILDING INFORMATION MODELLING (BIM)

Figure 3.1. BIM implementation in the different project phases. (Sjøgren, 2011)

Figure 3.2. Information sharing in BIM among the different stakeholders. (Connaughton, 2012)
CHAPTER 3: BUILDING INFORMATION MODELLING (BIM)

3.1.1.3 MODELLING

3D-modelling could be the most noticeable advantage of BIM, as humans are visual beings, this capability catches their attention. Moreover, BIM cannot be seen just as a 3D-CAD, due to it is not an improvement of the existing CAD methods; it is a new way of working (WSP and Kairos Future, 2011). So if evolution wants to be achieved, BIM has to be looked as something more than just a graphic design tool.

Despite that the BIM definition seems to be clear, in some situations BIM attributions are given to tools that are not.

3.1.2 WHAT IS NOT BIM

As sometimes the concept of BIM is hard to understand, to avoid misunderstandings, some examples of what is not BIM are shown below:

- Models that only have 3D data and without objects attributes: Only graphic visualization is available because they do not contain information about the object properties, just geometrical and appearance information. Therefore, they cannot be used neither as a support for design analysis nor for data integration (Eastman, et al., 2011).

- Models with no behaviour options: This type of models only defines the objects but without using parametric information; therefore, the position or proportions of the model cannot be adjusted. Moreover, the introduction of changes is a hard task (Eastman, et al., 2011).

- Models built by a variety of combined 2D CAD reference files: In this type of models it cannot be assured that the achieved 3D model is consistent (Eastman, et al., 2011).

- Models that when changes are made in one view, do not update them automatically in the rest of the views: Precisely, one of the distinctive features of BIM is that it enables the automatic update of the changes made in one view to the rest, in order to avoid big mistakes while working with different views of the model (Eastman, et al., 2011).

These are examples of how the designing and management tools used in the construction sector changed and evolved due to the ambition of improving the sector. But for reaching the current status big changes have been implemented in the sector and this changing effort will have to be continued in the future.
3.1.3 PREVIOUS METHOD OF WORKING AND A BRIEF HISTORY

For achieving the current construction procedures, different changes and achievements in the working procedure concerning design and management were done.

The achievement of a 3D-model was sought since the 1960s. The first appearance of a building model based on 3D was in the late 1970s and early 1980s. Moreover, in 1980s the object-based parametric modelling came out; this modelling represents objects based on parameters and rules in order to define their geometry and other non-geometrical features, and enables an automatic update of the information. BIM tools that currently exist are based on these object-based parametric modelling principles (Eastman, et al., 2011).

The term BIM appeared in the late 1990s and early 2000s (British Standards Institution, 2010). Until the appearance of BIM, and even later, due to the implementation of BIM is not widely spread yet, the communication method in the construction industry has been paper-based (Eastman, et al., 2011). This way of working based on drawings and reports and characterized by a non-collaborative structure, generates a huge amount of documents, and can entail unanticipated costs and delays due to errors or missing information (British Standards Institution, 2010).

The graphic below shows the different stages of the evolution of the construction working procedure until reaching BIM.

![Figure 3.3. BIM maturity levels. (Connaughton, 2012)](image)

Significant differences can be found in the performance of conventional tools and BIM.
BIM tools allow the evaluation of different alternatives during the design phase, taking into account different features such as structural behavior, costs, energy consumption, etc. For performing this analysis with a CAD-based tool, extra time and resources will be needed, and therefore these type of analysis are undertaken when the design is ready, being the implementation of the required changes based on the analysis more difficult and expensive (Eastman, et al., 2011).

Moreover, BIM enables the visualization of the building with all its characteristics, such as materials, structure, and performance. The representation of how the building will look once it is constructed can also be performed by BIM while the building is being design. And the required information and documentation is provided in a more accurate way than with CAD-based tools. This great advantage really contributes to obtaining a sustainable product (Autodesk, 2005).

It can be seen in the graphic below, how higher effectiveness with less effort is achieved with parametric building information models than with traditional CAD. Being the horizontal line of the graphic, the minimum level of effectiveness that can be taken into account for a parametric building modeler (Autodesk, 2003).

As it is shown the CAD-based technologies have a really low effectiveness and need a big effort to achieve the minimum level of effectiveness that the parametric building modeler can reach. Then the Object-CAD, that are the ones that use 3D geometry to obtain data about the building and develop the required documentation, have better performance than the CAD-based technologies, but stills lower than the parametric one. The graphic clearly shows how BIM technology can achieve better performance with lower effort than previous working methodologies (Autodesk, 2003).
Therefore, a revolution of the construction sector will come with the complete implementation of BIM. When CAD tools were implemented in the construction sector, the change consisted only in upgrading the way of working by including noticeable improvements. But with BIM, it is not a matter of updating the existing working methods, but a matter of changing the working procedure.

### 3.1.4 REASONS WHY A CHANGE IS NEEDED IN THE CONSTRUCTION SECTOR FOR AND EFFECTIVE BIM IMPLEMENTATION

The BIM’s particular features, which can bring important progresses for the construction industry, are driving the increasing incentive for the sector’s revolution.

BIM is by definition multidisciplinary, this implies that it is not enough with isolated collaboration between the different involved stakeholders, but also a united work must be done (WSP and Kairos Future, 2011). BIM should be included under the framework of a globalized construction industry with bases on homogeneous information requirements; that is why some alliances are emerging between USA, Europe, and Far East (Department of Business, Innovation and Skills, 2011).

Moreover, BIM tools are based on information sharing structures that enable the use of information up and down in the information chain, reaching a higher degree of management. Therefore, the whole project can be analyzed, achieving a cradle to grave monitoring (British Standards Institution, 2010).

The main advantages of BIM could be summarized as: important savings in design coordination, drawing phase, and information management taking into account all the project phases; improvement of the quality and the efficiency; and increase of the design accuracy and sustainability (British Standards Institution, 2010).

What BIM tries to achieve, is the perfect match between technology and the whole working process, if one of these parts is missing, BIM will be incomplete. Nevertheless, this concept could sometimes be misunderstood and BIM could be seen just as the technology tool instead of the combination of the tool and the working process. Furthermore, the implementation of BIM sometimes is wrongly seen as a change of software, but this process is much more than just the software change, it implies a change of the way of working. Therefore, if the advantages that BIM offers for the industry wants to be achieved, all the stakeholders involved in the construction industry must get used to the new BIM’s way of working (WSP and Kairos Future, 2011).

As a conclusion, BIM is changing the working methodology from a paper-based one implemented by the current 2D and 3D CAD, to an integrated procedure characterized by the coordination and collaboration between all the stakeholders (Eastman, et al., 2011). It could be said that a big change in the industry should be performed, but this change is going to take time and a big effort. In fact, there are several factors that could pull the trigger for a massive
implementation of BIM in the construction sector such as the need of increase productivity, the reduction of wasted resources due to an inefficient information management and the need of a structured information system. Moreover, there are some requirements that encourage the BIM implementation, such as the priority of implementing sustainable construction in Europe and the existing available technologies. In fact different progresses have been done in different countries, as it will be shown below.

3.1.5 IMPLEMENTATION OF BIM IN THE CONSTRUCTION INDUSTRY (DESIGN PHASE)

As it has already been mentioned BIM implementation can be carried out during the whole project’s lifecycle, with different advantages in the different phases. Some of the tasks developed by BIM along the different project phases are going to be explained (British Standards Institution, 2010).

3.1.5.1 BIM IMPLEMENTATION IN THE CONSTRUCTION PHASES

PRE-PLANNING PHASE

This phase is characterized by needs definition and verification of the project compliance of these needs, evaluation of the different alternatives and viability of the project. For achieving a successful BIM’s implementation, BIM has to be implemented since this very early phase by all the stakeholders (buildingSMART Norge, 2012). BIM can be implemented during the previous planning for assisting the different verifications such as if the project meets the regulations (British Standards Institution, 2010). This phase should be developed carefully due to an incomplete definition of the project’s needs could lead to design changes with higher costs in later phases (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013).

DESIGN PHASE

BIM can be implemented during the design phase allowing updated information sharing between the different stakeholders involved; moreover, it also contributes to problems and nonconformities detection in this early phase when the changes costs are lower. Moreover, BIM provides several simulations tools so that different parameters can be checked, such as heating, light and comfort, giving the chance of improving the design (British Standards Institution, 2010). By means of BIM the consequences of the decisions taken can be checked before putting them into practices (buildingSMART Norge, 2012).

One the greatest BIM’s contribution to sustainability is its possibility for developing an integrated design, and by means of the variety of analysis and simulation tools, enables an early analysis improving the building’s performance (McGraw Hill Construction, 2010). As it was stated by Tony Moretti (AIA, CSI and principal at CO Architects), “when we talk about BIM, we are also talking about integrated design” (McGraw Hill Construction, 2010).
Furthermore it is also used for 3D visualization, which could be very useful in the design phase; besides, it can be shown to the client how the final product will look like, raising like this the client’s trust (British Standards Institution, 2010).

The implementation of BIM during the design causes a change in the effort distribution during the project phases, as it is shown in the figure below.

![Figure 3.5. Effort/Effect comparison between BIM and traditional workflow. (Singapore Buildign and Construction Authority, 2011)](image)

Whereas traditional construction focuses the higher rate of effort during the construction phase, BIM implements the higher level of effort during the design phase.

**CONSTRUCTION PHASE**

BIM can also be implemented for construction management purposes due to its capacity of including time and costs data (British Standards Institution, 2010). This could avoid errors caused by paper-based information management, and it will improve coordination and communication (Davies & Harty, 2013).

**OPERATION AND MAINTENANCE PHASE**

BIM can also be implemented during the operation and maintenance phases, having great opportunities in the facilities management field due to its capacity of updating and managing information. Moreover, it has a great potential for assessing the building’s performance during these phases. The performance of the building can be monitored and compared with the predicted performance during the design phase, enabling the designers to learn from the experience (British Standards Institution, 2010).

The use phase of the building is the one with higher costs due to energy consumption, operations and maintenance. Then it is followed by the construction phase and finally the design phase, which is the one with the lowest costs. Being the relations between the design,
construction and use phase in a range of 1:10:100. Therefore, BIM can be used in order to perform simulations of the design and the construction phases, and moreover, it can also be implemented during the use phase in order to do a complete assessment of the whole building’s life (British Standards Institution, 2010).

BIM implementation will also imply new roles and tasks of the involved stakeholders, as it is going to be shown below.

### 3.1.5.2 BIM STAKEHOLDERS AND ACTIVITIES

The new role of the stakeholders involved in a project developed implementing BIM, is going to be explained as it is proposed by buildingSMART Norway. Due to for achieving an effective implementation of BIM, it is very important to understand the new needs and the new way of working in the project.

In the figure below it is shown the different uses of BIM by the different stakeholders along the different project phases. BIM can be used actively (green cells in the table), or just as an auxiliary tool (blue cells in the table).

<table>
<thead>
<tr>
<th>Project Phases</th>
<th>Stakeholders</th>
<th>Preplanning Phase</th>
<th>Design Phase</th>
<th>Construction Phase</th>
<th>Operation and Maintenance</th>
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<td></td>
<td>Early Design</td>
<td>Detail Design</td>
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<td></td>
<td>Client / Project Manager</td>
<td>Active use of BIM</td>
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<td>Project Leader</td>
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<td>Designers and Engineers</td>
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<td></td>
<td>Contractor and Subcontractor</td>
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<td>Manager</td>
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<td></td>
<td>Client</td>
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</tbody>
</table>

Table 3.1. BIM use by the different stakeholders in the different project phases. (buildingSMART Norge, 2012)

**CLIENT OR PROJECT MANAGER**

They have a strong influence for the implementation of BIM in the whole project, encouraging the multidisciplinary collaboration since the project’s early beginning. It is very important that the client or Project Manager really understand the great potential of BIM and its benefits (buildingSMART Norge, 2012).
The decision of implementing BIM in the project is the key for a wide variety of processes that could improve the project performance. Therefore, in order to plan and organize all this processes within the whole project, the decision of implementing BIM should be taken since the beginning; so that the selection of the different workforces involved and the planning of the activities is done taking into account that the project will be developed using BIM as the baseline (buildingSMART Norge, 2012).

- **Preplanning phase: (spatial program)**

Define the procedures that will be more effectively developed with BIM.

Set some spatial bases: It will include a list of the building’s rooms, the size and the use of these spaces. This will be a base for the design, and planning of the project, therefore, it should be developed before or at the same time of the first sketches of the location and esthetic of the building (buildingSMART Norge, 2012).

This spatial program will contain a data sheet for each room, including the use of each space. All the building requisites should be determined (buildingSMART Norge, 2012).

- **Early design phase: (spatial program, calculation, model)**

Check using the spatial program that the design is fulfilling all the set requisites related to rooms and use, architecture, logistic, budget and users’ needs (buildingSMART Norge, 2012).

The model enables budget estimation, and also it can be checked if some requisites about fire, light, acoustic, energy and design are satisfied (buildingSMART Norge, 2012).

- **Detailed design phase: (spatial program, calculation, model)**

The client or project manager has to have a general overview of the project including: budget and schedule (calculated taking the model as a base); check if the rooms fulfill the requirements of the spatial program, and update it if needed. Check also the quality of the model (buildingSMART Norge, 2012).

The main tools used are the budget estimator and the multidisciplinary model with the 3D view (buildingSMART Norge, 2012).

- **Construction phase: (spatial program, and model)**

He has to solve the disagreements with the contractor. Organize the start-up meeting with the contractor. The model will be used as a communication tool. The 4D model application is used for managing time information (buildingSMART Norge, 2012).
CHAPTER 3: BUILDING INFORMATION MODELLING (BIM)

PROJECT LEADER

The project leader has an essential role in a BIM project, due to he is the one who has to coordinate all the activities in order to take the best decisions, achieve the best results and satisfy the client’s needs and expectations (buildingSMART Norge, 2012).

- **Preplanning phase: (Spatial Program)**
  
  He has to prepare a realistic schedule and organize the first meeting with the designers and engineers. Moreover, he has to develop also a BIM manual, suitable for the specific features of the project. Taking as a base the spatial data bases and the BIM manual, they have to organize the information and the project. Furthermore, he has also to plan the multidisciplinary collaboration (buildingSMART Norge, 2012).

- **Early design phase: (spatial program, calculation, model and collision checking)**
  
  The calculations have to be planned. Moreover, he has to check the model’s quality and ensure the collaboration between the different designers and engineers involved. He will also organize the meetings. Thanks to BIM the access to the required information is easier (buildingSMART Norge, 2012).

- **Detailed design phase: (spatial program, calculation, model and collision checking)**
  
  Trace the technical calculations and the elaborated project budget. The project cost estimation will be developed based on the BIM details. Check the quality of the model, and the data exchange and collaboration between the different designers and engineers involved (buildingSMART Norge, 2012).

- **Construction phase: (model)**
  
  Check that the model is continuously updated, and the information is available for all the stakeholders, ensuring the periodical revision and distribution of the model (buildingSMART Norge, 2012).

DESIGNERS AND ENGINEERS

BIM implementation improves the efficiency of the project and enables the collaborative work in order to generate synergies among the different designers and engineers involved. Furthermore it eases the information flow and allows a continuous access to the updated information (buildingSMART Norge, 2012).

Moreover the design team can work simultaneously in the same issue, increasing the project efficiency (buildingSMART Norge, 2012).
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- **Preplanning phase: (spatial program)**

  They start to be familiar with the BIM manual, the project features requested and the schedule. Moreover, there is an initial meeting and the multidisciplinary BIM team should be tested in order to avoid future misunderstandings. Furthermore, they will have to prove that they have the required BIM skills (buildingSMART Norge, 2012).

- **Early design phase: (spatial program, calculation, model, acoustic and collision checking)**

  Assess this early phase, checking the model and planning the needed tasks in order to fulfill the program and database requirements. Furthermore they will make some simulations using the model as a base and do some checking (buildingSMART Norge, 2012).

- **Detailed design phase: (spatial program, calculation, model and collision checking)**

  Make accurate simulations and exchange the updated model between the different agents involved. Moreover, a description of the quantities will be developed. And all the disciplines will work in parallel with the model, assuring the quality, checking the model in order to fulfill all the requirements (buildingSMART Norge, 2012).

- **Construction phase: (model)**

  They will revise and check the model and update it if any modification is needed (buildingSMART Norge, 2012).

**CONTRACTOR / SUBCONTRACTOR**

He is the one responsible of ensuring that the project is developed following the clients requirements. He will receive from the designers and engineers all the documentation showing how the project will be developed. Moreover, it is their responsibility to ensure that everything has been projected as agreed achieving the project’s aims and objectives (buildingSMART Norge, 2012).

BIM enables a better understanding and planning of the project, reducing the project risks. The contractor can access easily the project information, such as the visualization of the model or the quantities data. Moreover, it is easier to obtain the needed data for the operation and maintenance documentation (buildingSMART Norge, 2012).

- **Preplanning phase: (calculation)**

  Identify what is more suitable concerning the soil conditions and construction process. Moreover, he will show what is the most affordable choice so that the engineers take it into account when starting the project. Identify future needs. (buildingSMART Norge, 2012).
Early design phase: (calculation, and model)

Give advice concerning which is the most suitable choice related to construction, the ground conditions and the project site. Moreover, they can perform some early estimations. Thanks to these advices concerning the construction phase, the efficiency of the project will be increased (buildingSMART Norge, 2012).

Detailed design phase: (model)

The contractor can do some costs calculations based on the quantities taken form the model. Moreover, he can use the 4D and 3D model, becoming familiar with the project (buildingSMART Norge, 2012).

Construction phase: (model and e-commerce)

It enables price calculations based on the model and purchase products by means of the E-commerce. Moreover, he can contribute to the model enrichment, adding products’ information; he can also generate an accurate schedule based on the 4D model (buildingSMART Norge, 2012).

Furthermore he can keep track of the work and the progress of the project by using the 4D model (buildingSMART Norge, 2012).

Finally the contractor should also ensure the quality of the project and check if the subcontractors are fulfilling the requirements (buildingSMART Norge, 2012).

MANAGER (DURING OPERATION AND MAINTENANCE)

He is the one in charge of the final construction during the Operation and Maintenance phase. Moreover, during the early phases he has to denote which information will be needed for the operation and maintenance phase, in order to include these needs in the project definition since the beginning (buildingSMART Norge, 2012).

Preplanning phase: (Spatial Program)

He will define the operation and maintenance requirements (buildingSMART Norge, 2012).

Operation and Maintenance phase: (Simple XML and IFC)

Develop the operation, administration and maintenance by means of the BIM application for operation and maintenance (buildingSMART Norge, 2012).

CLIENT

The client has to show its needs and requirements in order to have them into account during the project’s solutions development. Moreover, the BIM tools let the user visualize the project easily (buildingSMART Norge, 2012).
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- **Preplanning phase: (spatial Program)**
  
  He has to show his needs and requirements in order to include them in the project database. The client has to be aware and know how the project is being developed (buildingSMART Norge, 2012).

- **Early design phase: (spatial Program)**
  
  He will identify his needs, and he will be aware of the project development. He will use the model as a visualization tool in order to achieve a better understanding of the project (buildingSMART Norge, 2012).

- **Detailed design phase: (spatial Program)**
  
  He will contribute by enriching the database and he will assist to the different meetings and check the quality of the project (buildingSMART Norge, 2012).

- **Operation and Maintenance phase: (simple XML and IFC)**
  
  Sometimes the obtained building is not identically to the one planned due to some changes have been made during the whole process. If in the future some changes have to be done, the client will identify the needs and take profit of the existing information instead of starting the process since the beginning (buildingSMART Norge, 2012).

  After analyzing why a change is needed in the construction industry, what should be changed and the new roles required, an overview of the current BIM adoption is going to be shown.

### 3.1.6 ADOPTION OF BIM

#### 3.1.6.1 SOME DATA ABOUT BIM’S ADOPTION

The BIM’s implementation in the construction sector has experienced a significant growth in the last years (McGraw-Hill Construction, 2012).

As it has been highlighted in the report called “The Business Value of BIM in North America” developed by McGraw Hill and published in 2012, BIM’s adoption in the construction industry has raised in North America from a 17% in 2007 up to a 70% in 2012 (McGraw-Hill Construction, 2012).

Another study also developed by McGraw-Hill in 2010 (“Green BIM. How Building Information Modeling is Contributing to Green Design and Construction”) showed that only a 36% of the European construction industry used BIM until then. Being this value lower than the one in North America, where a 49% of the construction industry used BIM until 2009. Furthermore less than the half of these European BIM users (a 45%) considered themselves BIM expert users; having only a 34% of the BIM users more than 5 years of experience. Besides, architects are the
ones with higher rate of BIM adoption, followed by engineers, being the contractors the ones with lower rate of BIM implementation. (McGraw-Hill Construction, 2010).

![Figure 3.6. Comparison of the BIM implementation in Europe and North America. (McGraw Hill Construction, 2010)](image)

In order to achieve a deep understanding about the current status of BIM in the construction industry, after this general data, some countries are going to be analyzed in detail.

### 3.1.6.2 CURRENT STATUS OF BIM IN SOME COUNTRIES

#### NORWAY

Norway is one of the countries with more success concerning BIM implementation, being the persistent government’s initiatives the key for this success (WSP and Kairos Future, 2011).
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Furthermore, since 2010 the IFC based BIM implementation is compulsory in all projects (Wong, et al., 2009).

The Government facilities management institution Statsbygg carried out several pilot projects for the implementation of BIM; among these projects it was the Akershus University Hospital project in which BIM was aimed to track all the objects during their whole life cycle (Khemlani, 2005).

Moreover, Statsbygg, that is the Norway’s institution in charge of building commissioners and project management for the civil sector, has created a BIM Manual, known as “Statsbygg Building Information Modelling Manual” (its last version released in 2011); in this manual, the requirements for BIM implementation are detailed and it can be also a guidance for software providers (Statsbygg, 2011). Moreover, it is also in charge of giving formative courses and research funds in the country (WSP and Kairos Future, 2011).

It can also be highlighted that the government is trying to include the BIM culture in the education, so as the Byggenæringens Landsforening (Norwegian Construction Industry Association) has achieved a deal with ArchiCAD for free licenses in the secondary schools (WSP and Kairos Future, 2011).

FINLAND

The BIM implementation in Finland is not completed yet, but it is very advanced, and Finland could be taken as a reference when talking about successful implementation of BIM (WSP and Kairos Future, 2011).

The Finish government by means of the Senate Properties, which is a government owned enterprise that manages the government properties, has launched several measures in order to achieve the implementation of BIM in the country.

Senate Properties has required to meet the IFC standards in its projects since 1st October 2007 (Senate Properties, n.d.). Modelling is required for new constructions but also for renovations projects exceeding 2 million of euro, being excluded only the projects where modeling will not bring any advance; the modeling will include also monitoring from the alternatives presentation until the end of the tender documents of the contracting stage (Senate Properties, n.d.), including the visualization of the early stage and the control of the scope and the costs (Kiviniemi, et al., 2007).

What is sought by the Finish government is the improvement of the information management, the reduction of design errors and increase of efficiency and quality in order to be sure that the obtained results meet the initial objectives; moreover the support with decision-making is tempted to be achieved and if possible, the analysis of costs and life cycle (Kiviniemi, et al., 2007).
The keys of the success of the implementation of BIM in Finland are the features of the country, which is a not very big country, with an active construction sector based on cooperation and trust, and technologically advanced; but undoubtedly, the initiatives of the government have a lot of power to propel the industry through a change, due to the large public sector of Finland. Moreover, there are powerful enterprises related with BIM tools development such as Tekla Corporation and Solibri, with a long history in the BIM field (WSP and Kairos Future, 2011).

SWEDEN

OpenBIM appeared in 2009 as a programme for the construction sector development and since 2011 it has become a non-profit organization in Sweden. OpenBIM has fixed some long term objectives for BIM in the construction sector, organizes conferences and seminars, and publics 11 newsletters per year; it also offers a contract template in order to avoid frictions related with liability and intellectual property (openBIM, n.d.).

Moreover, in 2013 an agreement between OpenBIM, buildingSMART and fi2 Förvaltningsinformation (in charge of standards for the information management) was reached creating a BIM alliance in Sweden (Föreningen för FÖRVALTNINGSINFORMATION, 2013). This is an opportunity to achieve a BIM global overview and to gain the efforts of the three main country unions related with BIM implementation, into one direction (openBIM, 2013).

The BIM’s furtherance in the country has coincided with some important new construction projects; due to the dimensions and complexity of these projects, the implementation of BIM is fundamental for their success. This fact has places Sweden at the vanguard of BIM. Some of these important projects are the Förbifart Stockholm and the Citybanan (WSP and Kairos Future, 2011). The Förbifart Stockholm (The Stockholm bypass Project), is a link between southern and northern Stockholm, consisting mainly in underground connections and it will be one of the worldwide longest road tunnels; it will start in 2014 and its construction is planned to least 10 years (Trafikverket, 2013). Due to its characteristics the Stockholm bypass is a challenge for the Swedish construction industry. Besides it will be one of the first projects to use ProjectWise (Trafikverket, n.d.). ProjectWise is a software used for information management for the construction sector based on collaboration and information sharing during the design and construction process (Bentley, 2013).

GERMANY

BIM implementation in the construction sector in Germany is slightly a step behind, and if Germany seeks to be competitive internationally and achieve costs reduction, a change is needed in the sector. Despite it is a big challenge, the tools are already available, but a change in the way of working is needed. A change in the working procedures and a higher rate of collaboration has to be achieved (Wernik, 2012).

Some of the reasons for this lower implementation could be the following:
In Germany the most popular BIM software is Allplan, developed by a national firm “Nemetschek”. The use of the word BIM is not as common in Germany as in the rest of the country and this could be related to the fact that the BIM designation has been highly used by Autodesk and in Germany the hegemony belongs to Nemetschek (WSP and Kairos Future, 2011).

Furthermore, the language can also influence the BIM implementation, due to it can be an obstacle for those countries were the use of English is less common (WSP and Kairos Future, 2011).

Another reason for the lower BIM acceptance could be that the software Allplan was able to work with 3D since a long time. As it has already been mentioned, sometimes BIM is misunderstood with just a 3D design tool. This misunderstanding could be in the root of the lower interest on BIM implementation (WSP and Kairos Future, 2011).

Moreover, the fragmented nature of the German construction industry is also an obstacle for BIM implementation (WSP and Kairos Future, 2011).

Nevertheless, some changes are emerging in the German construction sector. Currently the problems of the construction sector are being highlighted and the country is highly decided to implement the necessary measures in order to improve the construction industry. BIM implementation has been shown up as a possible solution, showing how in other countries such as UK, USA and Scandinavian countries, the BIM implementation is already compulsory. And a report is going to be release in 2015, with the purpose of being a guide for large-scale projects in order to improve the current situation (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013).

Moreover, since 2008 the BIM concept has already been accepted by Nemetschek (WSP and Kairos Future, 2011).

Furthermore, some projects such as the Maximilianeum Expansion in Munich have already tried to implement BIM with the purpose of achieving project data available during the whole life cycle of the project, and avoid reentering information. The Berlin’s architecture firm Léon Wohlhage Wernik developed this extension of the Bavarian state parliament finished in 2012, implementing successfully the BIM philosophy (McGraw-Hill Construction, 2010).

Also some programs such as MEFISTO have been launched by the German Federal Ministry of Education and Research under the “IKT 2020“ framework program, seeking the achievement of a collaborative working platform enhancing transparency and trust (RUHR-Universität BOCHUM, 2013).

UK

The UK government has the aim of achieving by 2015, a reduction of the 15% or 20% of the project’s costs. For this purpose the government run in 2011 a BIM programme; and the Department of Business, Innovation and Skills developed the BIS BIM Strategy, with the purpose of reducing the assessment costs and increment its efficiency and contribute to the expansion of the
new way of thinking needed in the construction sector (HM Government, 2012). Moreover, by 2016 it will be mandate the use of BIM in all public construction projects (HM Government, 2012).

A “Building Information Modelling Task Group” was also created with the aim of helping to achieve the goals of the Government Construction Strategy and reinforce the implementation of BIM in the public sector. This group consisting of expert form the industry, the government, public sector and the academic environment, really believes that the implementation of an appropriate information managing system will reduce costs, increase value and improve the carbon performance in the construction sector; moreover, they also seek to implement life-cycle assessment in order to gain efficiency (Building Information Modelling Task Group, n.d.).

In order to understand the processes and the tools that BIM implementation requires, a scheme of BIM Maturity Levels has been created. It has been divided in levels from 0 to 3, where:

- **Level 0**: This level represents an unmanaged use of CAD, using paper as the most common information exchange way (Department of Business, Innovation and Skills, 2011).

- **Level 1**: This level manages 2D or 3D CAD, where some finance data is handle but without integration of this information (Department of Business, Innovation and Skills, 2011).

- **Level 2**: This level is based on a 3D framework but with the use of BIM tools including commercial data and the proprietary’s needs. It can also include cost and time data (Department of Business, Innovation and Skills, 2011).

- **Level 3**: This level reaches the full integration of BIM by means of complete data integration thanks to “web services” and the use of IFC standards. It can also be known as integrated BIM (iBIM) (Department of Business, Innovation and Skills, 2011).

The greatest part of the UK market belongs to level 1, while the ones that have passed to level 2 are enjoying the benefits (Department for Business, Innovation & Skills, 2012).

It has been estimated that the losses in the construction industry in the UK due to the lack of interoperability, could reach £100 million per year. And it has been discussed that the savings could rise up to a 30% with the implementation of BIM (British Standards Institution, 2010). In fact, the UK is aware of the need of converge to a globalized construction, and understands the need of coordinated BIM strategies. At the present UK is developing a combined strategy with USA for Holistic Facility Sustainability, with the aim of coordinate the development, research and implementation of information management strategies in the facilities industry by means of using BIM tools (Department of Business, Innovation and Skills, 2011).

Due to all the initiatives that are being developed by the UK’s government, the reaction of the industry to the implementation of BIM has been very positive. Moreover, the fast BIM
integrated in other countries such as China, has also prompted the initiatives in order not to lose market. What is more, UK aims to achieve a leading position concerning BIM exploitation in order to take profit of it; having the ambition of becoming global leader in BIM technology (HM Government, 2012).

**USA**

USA due to its influence, it is also an important point of reference. Nowadays, BIM use is compulsory in all government projects, and therefore a big proportion of the private sector is also starting to use it (RICS, 2012). General Services Administration, Army Corps of Engineers, Coast Guard and Air Force demand BIM use in their projects (Quarry Group, n.d.).

A big effort if being done by the government of the USA, associations and the BIM firms such as Autodesk home-based in USA, in order to achieve the BIM implementation in the construction industry. This implementation is continuously growing, but perhaps not as fast as in the Nordic countries such as Norway or Finland; this is due to the huge size of the construction industry of the USA, that makes more difficult the coordination, collaboration and trust among the stakeholders involved (WSP and Kairos Future, 2011). Therefore, an important effort has to be done to redirect the society into the BIM’s path; this effort has already started with different initiatives, as the ones shown below.

The U.S. General Services Administration set in 2003 the National 3D-4D-BIM Program, being one of the first government initiatives for the implementation of BIM; this programme was based on encouraging the 3D, 4D and BIM implementation in all projects, offering assessment for this integration, collaborating in alliances with BIM vendors, standard organizations and professionals, and guides development (U.S. General Services Administration, 2013).

Furthermore the CAD/BIM Technology Center for Facilities, Infrastructure and Environment was also created with the same objectives, and developed some initiatives such as the USACE BIM Roadmap for the BIM implementation in the U.S. Army Corps of Engineers (CAD.BIM Technology Center, n.d.).

The National BIM Standard-United States (NBIMS-US) is a project carried out by buildingSMART alliance; by means of this project the National Institute of Building Sciences of the USA wants to achieve an standard for the information management procedures of the building industry, with the aim of enabling an efficient access to the information (National Institute of Building Sciences, 2013). What is more the NBIMS-US V2 is being taken as a base by other countries for the development of their own standards.

Moreover, an alliance between the National Institute of Building Sciences building SMART and the correspondent entity of buildingSMART in UK and Ireland are collaborating since 2012 in a common project for the development of BIM standards. The purpose of this alliance is to achieve a mutual retrofit in the development of their own BIM standards. Furthermore they will also
collaborate in the promotion of other issues such as life cycle information exchange (National Institute of Building Sciences, 2012).

**SINGAPORE**

Singapore was one of the first countries in admitting the benefits and opportunities of a model-based design. One example of this early commitment was The Construction and Real Estate Network (CORENET) project launched by the Ministry of National Development in 1995 with the purpose of speed and coordinate work in the construction industry (Evelyn & Fatt, n.d.).

Different initiatives have been developed under the CORENET programme, CORENET e-submission, CORENET e-PlanCheck and CORENET e-Info (buildingSMART, n.d.).

CORENET e-Submission makes possible the submission of projects applications on the Internet, where all the stakeholders have access to the progress of the online application. The first BIM electronic submission was enable in 2008 by the Building and Construction Authority (BCA) and since then, this system's implementation has been growing until now that it is applied by almost the whole construction industry in Singapore (Building and Construction Authority, 2011). CORENET e-Info storages information of building and construction Singapore’s industry on the internet. This application is as wide spread as the previous one. CORENET e-PlanCheck seeks for enabling the control of new buildings design automatically according the building codes. This application that avoids printing and paper based communication, is being gradually implemented in the country (buildingSMART, n.d.).

Furthermore, other initiatives have been carried out by the government as an effort of improving the construction sector. The BCA run in 2010, the BIM Roadmap, having as a goal BIM implementation in almost an 80% of the industry for 2015 (Building and Construction Authority, 2011).

Moreover, in May 2012, the BCA realised The Singapore BIM Guide; it includes an overview of the responsibilities of the different stakeholders when BIM is used in the project. Moreover, it also highlights the need of include a BIM Execution Plan in all the projects due to it is a document resulting of the agreement between the employer and the project members at the very beginning of the project in order to clarify the details concerning BIM implementation within the project (Building and Construction Authority, 2012). Finally BCA is also providing different academic courses related with BIM (Building and Construction Authority, 2011).

### 3.2 BIM IMPLEMENTATION FOR ACHIEVING GREEN OBJECTIVES

#### 3.2.1 CURRENT STATUS OF GREEN BIM

Currently, two relatively new concepts are emerging in the construction sector (Bynum, et al., 2013). On the one hand, the Green buildings trend is becoming very common and accepted among the construction industry. On the other hand, the BIM concept is also being widespread
within the industry. Therefore, a new trend that could be called Green BIM is emerging due to the use of BIM tools for green purposes while the construction industry is accepting the BIM’s potential within sustainability field (McGraw Hill Construction, 2010).

It is suggested by the results of the already mentioned study “Green BIM. How Building Information Modeling is Contributing to Green Design and Construction”, carried out by McGraw Hill, that as the practitioners of Green buildings are just starting to realize the great benefits of Green BIM, the implementation of green construction practices with BIM’s support will be soon highly widespread among the construction industry (McGraw Hill Construction, 2010).

The BIM’s potential for green purposes is just starting to be discovered, and an enthusiasm is shown by the practitioners that are starting to use it, due to they ensure that higher success could be reached with BIM. This fact shows that the construction industry has a real interest on becoming sustainable, with the help of tools such as BIM (McGraw Hill Construction, 2010).

Figure 3.9. Realization of BIM’s potential to achieve Green Objectives, according to Green BIM practitioners. (McGraw Hill Construction, 2010)

Moreover, Green BIM is not just applied to design phase, but also to construction, operation and maintenance; in fact, there is an optimistic trend concerning BIM’s application in green retrofitting projects and in building performance monitoring (McGraw Hill Construction, 2010).

Despite the recognition by the construction industry of the BIM’s potential, its market diffusion has been lower. Nevertheless, as it is shown in the next graph, a great rise is predicted.

Figure 3.10. Timing Expected to Green BIM Market penetration, according to non-Green BIM Companies. (McGraw Hill Construction, 2010)
This expected rise on the Green BIM implementation could be highly influence and prompt, firstly by the owner demand, followed by the costs and time savings and the availability of BIM tools. Despite architects could influence BIM implementation, clearly the owner demand and market differentiation are the most influencing factors. Therefore, owner demand could be boosted by more education about the BIM advantages, and widespread the effectiveness of BIM not only during the design and construction phases, but also during the operation and maintenance phases, being also a good opportunity not only for new buildings but also for existing ones projects (McGraw Hill Construction, 2010).

Furthermore, despite the construction industry has recognized the potential of BIM for sustainability purposes, right now sustainability is not the main field in which BIM is being exploit, as it is shown in the study developed by Bynum, et al. “Building Information Modelling in Support of Sustainable Design and Construction”; nowadays the most widespread BIM’s applications are in the field of graphic representation and project coordination (Bynum, et al., 2013).

Then, as a conclusion it could be said that as soon as construction stakeholders really understand the opportunities that BIM could enable in the sustainability field, it will become an essential tool for sustainable projects (Bynum, et al., 2013).

As the demand of sustainability and BIM is continuously growing, these tools have to be continuously improved. Sustainability request are getting more exigent and if BIM tools want to take part on this sustainable construction, has to improve its environmental assessment tools and the interoperability. But of course, then it is highly important that the stakeholders involved in the AEC industry, have an open position related with these tools and create a collaborative working environment (Bynum, et al., 2013).

### 3.2.2 HOW BIM CONTRIBUTES TO SUSTAINABILITY

A profitable synergy is growing between BIM tools and sustainable construction, having BIM tools a great potential to promote sustainability. Green design feeds from an integrated design with an overall view of the whole project, whereas BIM due to its particular characteristics enables this integrated design (McGraw Hill Construction, 2010).

Then, Green design seeks for building performance improvements, whereas BIM-based tools enable performance simulations and analysis of different parameters, in order to study different alternative and determine the needed design changes so as to improve the building performance (McGraw Hill Construction, 2010).

Moreover, BIM models as a source of structured-data have a great application on prefabrication, which contributes to the reduction of wasted resources, time and costs, achieving a more sustainable construction (McGraw Hill Construction, 2010).
3.2.2.1 BIM SIMULATIONS

The BIM’s capability of developing virtual models of the building, instead of waiting for the building’s construction, clears up some uncertainties in the early phases, contributing to a smoother transition from design to construction phase, enabling a more efficient design, and a reduction of wastes (Bynum, et al., 2013). Moreover, one of the key aspects of building design are the assumptions that have to be made, so though simulations by using virtual models of the building these assumptions can be assessed (Adapt4EE Consortium, 2012). The building geometry developed in the BIM model can be used by other applications to make different features analysis that have to be taken into account in order to develop a sustainable project. Some of these features are: energy analysis, daylighting analysis, rainwater harvesting, solar access, recycled content, etc. (Krygiel & Nies, 2008).

BIM can be implemented as a tool to check the building performance. There are different definitions of building performance, based on the parameters that are analysed in each one; the most frequently performed analysis by the construction professionals due to the respondents of the already mentioned study developed by Bynum, et al. were, energy analysis (59%), mechanical, electrical and plumbing (MEP) analysis (50%), structural analysis (44%) and lighting analysis (47%); one of the reasons why these types of analysis are the most performed is due to these are the ones that are able to be integrate into the BIM software (Bynum, et al., 2013). BIM could also contribute to the analysis of the building orientation, and the selection of different materials (Azhar, 2011). Furthermore, some authors such as Stadel et al. highlight the great potential of BIM tools for performing LCA analysis (Stadel, et al., 2011).

It is well known that some sustainable factors such as energy efficiency are gaining concern among the construction sector; as it is showed in the already mentioned study “Green BIM. How Building Information Modeling is Contributing to Green Design and Construction” by McGraw Hill, it is expected that a 95% of the companies that already use BIM for green construction purposes and a 79% of the companies that do not use BIM yet, will carry out energy performance simulations, looking forward for a huge increment of new BIM users. Furthermore, some legislation and some green certification systems such as LEED ask for building performance reports; besides, the concerning about CO₂ emissions measurement is also increasing, so this facts could boost the BIM’s implementation for building simulations (McGraw Hill Construction, 2010).

The advantages of BIM-based simulations tools such as energy modelling, compared with the traditional energy models, are quite noticeable. Traditional energy models use information from the available independent sources, such as drawings and project data, as a base for a model development in the simulation software. This procedure can lead to errors due to a wrong representation of the building’s geometry obtained from CAD. Moreover, due to the simulation program requirements, some simplifications have to be done to the design parameters; therefore, the inaccuracy of the model increases. Another disadvantage is that if some changes are performed in the original design, the model for the energy evaluation has to be revised and
modified manually. Hence, this process takes a lot of time (United States General Service Administration, 2012).

On the other hand, the BIM-based simulations, simplify the process by reusing the existing BIM model, avoiding assumptions or misinterpretation errors and saving time and improving accuracy (United States General Service Administration, 2012).

Thanks to the energy performance simulations some key factors for the building design can be calculated such as thermal loads, interior lighting and acoustics analysis, and air-flow models (Adapt4EE Consortium, 2012).

Nevertheless, due to the doubtless advantages of BIM simulations, they are relatively new tools with some gaps that have to be improved in order to achieve a great evolution in the field of BIM for sustainable design. The most noticeable currently gap is the interoperability between the different simulations software and the BIM (Bynum, et al., 2013).

3.2.2.2 PREFABRICATION

Sustainable practices can also be supported by prefabrication. It contributes to a reduction of wastes, a lower resources consumption, and time reduction, achieving a more efficient construction and an improvement of the project’s carbon footprint (McGraw Hill Construction, 2010). As BIM can achieve more detail in the building design, it enables the prefabrication of more complicated items.

In the prefabrication process a wide variety of stakeholders are involved, and therefore the information sharing has to be effective. Due to this requirement, BIM is a really suitable tool thanks to its visualization capacity and its performance in storing and sharing the updated project data, enabling a transparent data access of the different stakeholders (Nawari, 2012). That is the reason why, BIM enhances prefabrication of different buildings typologies with repetitive parameters and modularity.

The main aims of prefabrication is producing what the clients expect in the shorter time and fulfilling all the requirements (Nawari, 2012). The goal is reaching a building with efficient performance but also efficiency during its construction (McGraw Hill Construction, 2010). Being possible, great achievements with prefabrication, such as time and costs reduction and efficiency raise (Nawari, 2012).

Some of the main reasons highlighted by the users for using BIM in prefabrication are shown below:
3.2.3 BENEFITS OF BIM FOR THE THREE PILLAR OF SUSTAINABILITY

Nowadays the building industry is facing environmental concern, and the awareness about the energy consumption and the living comfort, leading to sustainable construction (Autodesk, 2005). Among the new technologies that are being implemented in the construction industry in order to encourage sustainability, BIM is one of the most successful.

But in which phase of the project life cycle BIM’s implementation could be more efficient? This question tries to find an answer in the study developed by Bynum, et al. “Building Information Modeling in Support of Sustainable Design and Construction” in 2013. According to this report, the phase where BIM’s implementation is more effective is the schematic design phase (40), followed by the predesign (31%) and the design development phase (20 %). That means that for the majority the implementation of BIM as a tool for sustainable purposes achieves its highest performance during the early design phases (Bynum, et al., 2013). This is a logical conclusion due to the highest flexibility of the project takes place during these early design phases. It is in these phases when changes in the design can be done with a lower impact in the cost of the project, whereas changes in later phases are more difficult or even impossible to perform.

BIM has the ability of achieving an integrated design, nevertheless facility management should be taken into account during the design, because when designing it can not only be taken into account the construction process but also the operation and maintenance phase, in order to ensure sustainability during the whole project’s life cycle. (McGraw Hill Construction, 2010).

Therefore, the already explained tasks that BIM can perform can be used to enhance sustainability with positive impacts in the three pillars of sustainability.


3.2.3.1 ENVIRONMENTAL

The energy analysis can be used to achieve a more energy efficient design, reaching a reduction of the energy consumption. Moreover, it can also influence in the materials selection, due to an analysis of their environmental impact can be done, and use it as a decision criterion. It also can be used to check if the building is fulfilling the objectives of the green design (Autodesk, 2005).

Moreover, it also reduces wastes and increases the project efficiency.

3.2.3.2 ECONOMIC

As more information is analysed in the design phases, the cost of the design phase is higher than the traditional one, but this extra cost of this phase really compensates the costs saves in the later phases. BIM has the capacity of reducing the cost of the sustainable design due to it provides the required information, and analyses it (Autodesk, 2005).

All these complex analysis are faster and easier with the BIM-based tools implementation (Autodesk, 2005). Moreover, BIM implementation also improves efficiency in the Project and enhances coordination so as the wastes of energy and materials are reduced (Autodesk, 2005).

3.2.3.3 SOCIAL

The analysis and simulations of different parameters, would be really complicated if BIM-based tools were not used due to the hard task of data introduction. But thanks to BIM implementation complex analysis such as daylight can be done, in order to create better working or living conditions so as people achieve comfort and well-being (Autodesk, 2005).
CHAPTER 4: LIFE CYCLE ASSESSMENT (LCA)

4.1 GENERAL INTRODUCTION TO THE LCA’s CONCEPT

The increasing concern about environment and the different impacts of the consumed products and services is prompting the development of methodologies that help to understand and avoid these impacts. Life Cycle Assessment (LCA) is one of the tools developed with this purpose (AENOR, 2006).

LCA helps to find the best chances for environmental performance improvement during the project’s lifecycle, supplying information to help decision-making (AENOR, 2006).

4.1.1 LCA GENERAL DEFINITION

LCA performs an analysis of the environmental aspects from cradle to grave (International Energy Agency, 2005). The LCA methodology is environmental oriented, whereas if the economic and social aspects want to be analyzed, it should be combined with other tools (AENOR, 2006).

LCA includes the whole product’s life cycle from the procurement of the raw materials until the final disposal; due to the holistic view and integrated procedure in which LCA is based, a possible environmental load displacement along the different lifecycle phases can be detected or even avoided (AENOR, 2006). In the figure below an example of the flows in the life cycle stages is shown.

![Figure 4.1. Life cycle stages. (Scientific Applications International Corporation, 2006)](image)

During the lifecycle of the products different phases can be stood out, if it is an industrial product the phases are material acquisition, manufacturing, use and maintenance and end-of-life; whereas if it is a building the phases are materials manufacturing, construction, use and maintenance and end of life (Georgia Institute of Technology, 2010).
LCA is defined in the ISO 14040 as a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle". It is divided in four main steps (AENOR, 2006):

1. Goal and Scope Definition
2. Inventory Analysis
3. Impact Assessment
4. Interpretation

These four phases are going to be explained below.

4.1.1.1 GOAL AND SCOPE DEFINITION

The Goal definition consists on establishing the purpose for doing the analysis, the expected applications, and the people that are expected to use the results (AENOR, 2006).

The Scope must be well defined in order to ensure that the Goal can be achieved; the scope includes the following items: the product system, the functional unit, the system boundaries, the selected impact categories, the methodology for evaluating the impacts and for the interpretation, the data requisites, the limitations, and the data initial quality; as LCA is an iterative...
procedure, as the analysis evolves, and more data is obtained, some changes might have to be done in the scope in order to reach the goal (AENOR, 2006).

The functional unit is an important item due to it is a reference unit that describes the functions of the product; it is fixed in order to be used as a reference for inputs and outputs and to ensure that the results of different systems can be compared (AENOR, 2006).

Finally, the system boundaries establish the procedures that are included in the system, being its definition conditioned by the goal and scope, the assumptions, and the data restrictions; these boundaries as are defined in the beginning could be adapted later (AENOR, 2006).

4.1.1.2 INVENTORY ANALYSIS

The inventory analysis is an iterative procedure that is based on the data acquisition and the calculation procedures in order to obtain the system’s inputs and outputs. Among the data that can be collected are, energy and raw materials inputs, emissions and wastes. The data collection is followed by the calculation processes that consist on the data validation, connection of the data with each unit process, and link the calculated data with the functional unit. The quality of the data is a really conditioning factor, due to the accuracy of the results depend on the accuracy of the data (AENOR, 2006). A simplified scheme of the inventory procedure is shown in the figure below.

Figure 4.4. Simplified procedures for inventory analysis. (Khasreen, et al., 2009)
CHAPTER 4: LIFE CYCLE ASSESSMENT (LCA)

4.1.1.3 IMPACT ASSESSMENT

The Impact Assessment consists on assessing the importance of the environmental impacts through the results obtained in the previous phase. This is achieved by defining the impacts categories, relating the data from the inventory phase with the different impacts categories and with the indicators of each category. It can also include an iterative process where the goal and scope of the LCA can be modified if the results show that they cannot be reached (AENOR, 2006).

In this phase transparency is essential in order to ensure that the assumptions are clearly defined and supported. It has to be highlighted that this is not a complete environmental evaluation, it only covers the environmental aspects included in the objective and scope. Nevertheless, there is not a fixed methodology for the relationship between the inventory data with the impacts categories (AENOR, 2006).

4.1.1.4 INTERPRETATION

Finally, the interpretation of the life cycle gives a coherent and understandable explanation of the results of the LCA taking into account the goal and scope. It also provides some recommendations based on the results of the LCA (AENOR, 2006).

4.1.2 LCA BRIEF HISTORY

The LCA methodology has its origins in the early 1960’s, as a consequence of the growing concern about the depletion of limited natural resources and the energy consumption. In the 1970’s the first life cycle analysis were performed by different companies; these processes were called “Resource and Environmental Profile Analysis (REPA)” in the United States, and “Ecobalance” in Europe. In the last 1970’s and early 1980’s the interest in these tools increased due to the environmental concern induced by the oil crisis (Scientific Applications International Corporation, 2006), being the life cycle studies focused on analyzing the energy and materials consumption and the generated wastes (Sharma, et al., 2011). In the early 1990’s the public awareness about the use of LCA with marketing purposes by different manufacturers, boosted the development of the ISO standards for LCA under the framework of the series 14000, which highly contributed to the LCA acceptance by the stakeholders (Scientific Applications International Corporation, 2006).

cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis” provides some examples of life cycle inventory analysis following ISO 14044 (ISO, 2012). It has to be highlighted that these standards just give a general framework for LCA performance, but they do not give a unique methodology (ISO, 2006).

Moreover, the concern about LCA increased in the 21st century, and other international initiatives emerged, such as the “Life Cycle Initiative” developed in 2002 by the United Nations Environmental Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC). This initiative involves three programs, Life Cycle Management (LCM), Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) with the purpose of spreading the culture of the life cycle thinking (Scientific Applications International Corporation, 2006).

Furthermore, a key element for LCA development and issue of current care are the databases; they have been evolving and improving trying to give the data as accurate and complete as possible for achieving an accurate assessment. Some of the current LCA databases are explained below.

### 4.1.3 LCA DATABASES

One of the main difficulties when developing an LCA is the data availability. Sometimes there is not enough data or the available data has a limited value. The main reasons of the limited value of a database are: on the one hand, the information is not updated, due to in some cases the data was collected in the 80s; and on the other hand, some data does not fit with the requirements set in the standards (Jensen, et al., 1997).

The selection of the database will depend on the quality of the data needed for the assessment. The software currently used for performing life cycle assessments already provide databases. It has to be highlighted that for the development of a LCA different databases can be used depending on the data quality required (ENSLIC, 2007).

Furthermore, due to the importance of the data for achieving an accurate LCA performance, there are some public standards concerning databases, such as SPINE developed in Sweden by the Center for Environmental Assessment of Product and Material Systems CPM, and ECOINVENT from the Swiss Center for Life Cycle Inventories (Pieragostini, et al., 2012).

Some of the currently most used databases are analyzed below:

#### 4.1.3.1 ÖKOBAU.DAT

It is a German database for construction materials environmental impacts assessment; it is included in the research program ZukunftBAU developed by the PE International GmbH in collaboration with the German construction industry. It is composed by almost 950 data sheets concerning construction materials, transport and construction processes; including also
information about the source and quality of the data. The data categories included in this data base are the following (Bundesministerium für Verkehr, Bau und Stadtentwicklung, n.d.):

- **Mineral building materials**
- **Insulation**
- **Wood Products**
- **Metals**
- **Coatings and sealants**
- **Construction of plastics**
- **Components of windows, doors and curtain walling**
- **Building**
- **Other**

The last updated version is Ökobau.dat 2011, available since 12th January of 2011; the datasheets are available in a XML format (Bundesministerium für Verkehr, Bau und Stadtentwicklung, n.d.).

This database includes the life cycle assessment data of around 600 products and it is used as a base for the German Sustainable Building Certificate (PE International, 2010).

### 4.1.3.2 EU’S EUROPEAN REFERENCE LIFE CYCLE DATABASE (ELCD)

It includes information concerning European materials, energy, transportation processes and waste management, including also data from European business associations. The last updated version is ELCD 3.0, released in February 2013 and it is available at [http://elcd.jrc.ec.europa.eu/ELCD3/unitgroupList.xhtml](http://elcd.jrc.ec.europa.eu/ELCD3/unitgroupList.xhtml); the database can be downloaded at [http://elcd.jrc.ec.europa.eu/ELCD3/](http://elcd.jrc.ec.europa.eu/ELCD3/), being the access to the database free (European Commission and Joint Research Centre, 2013).

It includes the revision following the “ILCD Data Network entry-level data quality requirements”. Despite that it already offers compatibility with several LCA tools, the import and export procedures with LCA tools are under development. The data sheets follow ISO 14040 and ISO 14044 and the access to the database is free (European Commission and Joint Research Centre, 2013).

The data sets are divided into: Processes, LCIA Methods, flows, flow properties, unit groups, sources and contacts (European Commission and Joint Research Centre, 2013).
4.1.3.3 ECOINVENT Version 3.0

This database has a wide variety of datasheets in the fields of “agriculture, energy supply, transport, biofuels, biomaterials, bulk and specialty chemicals, construction materials, packaging materials, basic and precious metals, metals processing, ICT and electronics, and waste treatment” (Swiss Centre for Life Cycle Inventories, n.d.).

This database is not free, having an educational version that can be accessed freely (Swiss Centre for Life Cycle Inventories, s.f.). Its latest version is ecoinvent 3.0 realized the 6 May 2013 (Swiss Centre for Life Cycle Inventories, 2013).

Originally the database was based on Swiss data and it was mainly applied in European countries. Nevertheless, with the new version, ecoinvent 3.0, this has changed, and new data has been included in order to be used globally. Moreover, some reports that used to be only in German are already available also in English. (Swiss Centre for Life Cycle Inventories, s.f.).

4.1.3.4 US LIFE CYCLE INVENTORY DATABASE

This database has been developed by the Athena Sustainable Materials Institute and the National Renewable Energy Laboratory (NREL). It is a free database in English available for Canada and United States. It was first released in February 2004 and the last time that it was updated was in March 2005. It includes data about frequently used materials, products and processes, following international standards seeking transparency achievement. (European Commission. Institute for Environment and Sustainability, 2013).

The energy and materials flow information is given for all the life cycle stages (National Renewable Energy Laboratory, 2012). The included categories are: “energy and fuels; transportation; water; transformation processes; infrastructures; metals; paper and paper products; glass; plastics; chemicals and minerals; wood and wood products; agricultural and biobased products; packaging; building products and assemblies; textiles; and end of life” (National Renewable Energy Laboratory, 2009).

The database can be accessed at: https://www.lcacommons.gov/nrel/search and it contains 2041 items divided in flows (1402), and process (639), providing information for the whole life cycle (National Renewable Energy Laboratory, 2012).

It seeks to achieve transparency, providing data about the United States materials, products and processes (National Renewable Energy Laboratory, 2012).

4.1.3.5 BOUSTEAD MODEL

This database is provided by Boustead Consulting Limited, and can be applied globally. It is an extensive database divided into two main parts; on the one hand there is the core part with 33300 unit operations for a wide variety of countries, and 6000 materials processing operations. On the other hand, there is the Top part with a capacity for 6000 unit operations. It enables the

The students’ version of this database is available free but the commercial one has to be paid (European Commission. Joint Research Centre, 2013).

4.1.3.6 ATHENA DATABASE

This database developed by the Athena Sustainable Materials Institute includes data about building materials during their whole life cycle (from cradle to grave), energy use, transportation, construction and demolition processes, in order to enable the environmental impacts assessment. The Athena database also takes into account the region where the project takes place (Athena Sustainable Materials Institute, 2013). It follows the ISO 14040 and ISO 14044 standards (Athena Sustainable Materials Institute, 2013).

The database latest version of the impact estimator 4.2.0208 has been updated in 2013 (Athena Sustainable Materials Institute, 2013). It has been mainly developed for being implemented in North America (Canada and United States) (Seo, 2002). It includes data about concrete products, steel products, wood products, claddings, insulation and barrier products, paint products, gypsum board products, roofing products, and windows (Athena Sustainable Materials Institute, 2013).

In order to synthetize the information about the different databases analyzed, a table has been created with their main features:
### CHAPTER 4: LIFE CYCLE ASSESSMENT (LCA)

#### Data bases

<table>
<thead>
<tr>
<th>Features</th>
<th>ATHENA</th>
<th>US Life Cycle Inventory Database</th>
<th>EU’s European reference Life Cycle Database (ELCD)</th>
<th>Ecoinvent 3.0</th>
<th>Boustead</th>
<th>Ökobau.dat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of application</td>
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<td>Canada and United States</td>
<td>Europe</td>
<td>Globally</td>
<td>Globally</td>
<td>Germany</td>
</tr>
<tr>
<td>Specific only for construction industry</td>
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<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
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<td>English and German</td>
<td>English</td>
<td>German</td>
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<tr>
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<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Provider</td>
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<td>Athena Sustainable Materials Institute and National Renewable Energy Laboratory</td>
<td>European Commission and Joint Research Center</td>
<td>EcoCentre for Life Cycle Inventories</td>
<td>Boustead Consulting Limited</td>
<td>German Federal Ministry of Traffic, Building and Urban Development</td>
</tr>
</tbody>
</table>

Table 4.1. LCA databases features
4.2 LCA IN THE CONSTRUCTION INDUSTRY (BUILDING INDUSTRY)

The materials used in construction in its origins were stone, ceramics and wood, which have lower environmental impact. But as construction industry has evolved, different new materials have been developed, such as cement, concrete, PVC etc.; these material contribute to the rise of embodied energy and carbon footprint of the building (ENSILC, 2007).

Buildings are an important feature of the current society; nevertheless they produce important environmental impacts, consuming resources and energy, and generating emissions during their life-cycle. As concern about sustainability is growing, in order to perform a sustainability evaluation, the environmental assessment of the building is needed, and it can be developed based on the LCA methodology (Buyle, et al., 2012). LCA tools can be selected as the tool for evaluating the interaction of the buildings with their environmental framework, being these tools based on computer models and databases (International Energy Agency, 2005).

Due to there is an evident linkage and interplay between the different life-cycle phases of a building, a global methodology has to be implemented in order to achieve an effective building assessment. This can be achieved through LCA methodology, contributing to a better assessment for decision-making (ENSILC, 2007).

The development of LCA in the construction industry is lower than in other industries, despite the fact that LCA has been implemented in the construction sector since 1990 and it is an important tool for implementing sustainability in the building process (Khasreen, et al., 2009). The instructions given in the different LCA standards fit well with industrialized processes, nonetheless, when dealing with buildings, due to some particular features of the sector, the standards do not fit so well. The main building features that influence the LCA methodology are the long lifecycle of the buildings, and the fact that each product is unique (Arena & Rosa, 2003). The building’s long life span is really influencing in the LCA analysis, due to it reduces the impacts, redeeming them during a longer period; on the other hand it brings a lot of uncertainty, because the building’s future use or conditions cannot be predicted (International Energy Agency, 2005). Hence, some special considerations have to be taken into account when applying LCA guidelines to buildings, due to little standardization exists when dealing with LCA for buildings (Arena & Rosa, 2003); these standards do not give an specific methodology to perform the assessment, but some guidelines and requirements (The World Bank Group, 2012).

Moreover, it is important to have a deep understanding of what LCA is because if not, due to the implementation of LCA in the construction sector is relatively recent confusion can emerge around this concept and lead to a misuse of the tool (Georgia Institute of Technology, 2010).

The LCA tools can be applied in the different project phases and different impacts can be analyzed; therefore, due to buildings have such a long live span the LCA methodology is really suitable, since an accurate environmental impact analysis can be obtained taking into account the different phases of the building’s life cycle (International Energy Agency, 2005).
The characteristic phases of a building life-cycle where LCA can be applied are:

- **Materials manufacturing**: it analyzes raw materials since they are obtained from the earth until they are delivered as building products, covering all the intermediate stages including also transportation (Georgia Institute of Technology, 2010).

- **Construction**: it refers to all the activities related with the building construction (Georgia Institute of Technology, 2010).

- **Use and Maintenance**: It includes all the building operations, covering the energy and resources consumption, the wastes generation and all the operations needed to maintain the building in the required conditions (Georgia Institute of Technology, 2010).

- **End of Life**: It analyzes all the activities related with the building disposal and wastes transportation and treatment (Georgia Institute of Technology, 2010).

The traditional construction phases follow another classification, but as the decisions and design phases do not have environmental impacts they are not analyzed in the LCA procedure. But despite not causing direct environmental impacts, the design phase has a huge influence in the performance of the other phases; the decisions taken during the design phase will determine the environmental impacts of the other phases, due to all the phases of the life-cycle have to be taken into account when designing (Tritthart, et al., 2010).

A scheme of the different procedures analyzed in an LCA of the whole life cycle of a building is shown below:
It could be said that the use phase of the building is the one with highest contribution to environmental impacts due to the energy consumption and the emission produced by the heating and cooling systems. But, as new buildings are becoming more efficient, other phases are becoming more important concerning impacts (Buyle, et al., 2012). As buildings are nowadays tending to energy efficiency, the energy necessary for the materials production and transportation gains more importance. One of the great advantages of LCA is that it is able to assess the resources consumption during all the project phases, from cradle to grave (Tritthart, et al., 2010).

Nevertheless, the environmental impact can be reduced with special effort during the design phase, developing an effective design and a careful selection of the materials (Khasreen, et al., 2009).

4.3 LCA AS A DECISION MAKING TOOL: CONTRIBUTION OF LCA TO SUSTAINABILITY

Due to the current concern about sustainability and environmental impacts of the construction industry, different methods are being developed in order to assess environmental performance and reduce the impacts; being LCA one the most suitable tools (Georgia Institute of Technology, 2010). The implementation of LCA as a decision-making tool, could really contribute to the achievement of a sustainable construction (Ortiz, et al., 2009).
LCA has been highlighted by the European Commission in the Integrated Product Policy, as the most suitable methodology for assessing environmental impacts (European Commission, 2012). And nowadays, LCA is being fostered as a tool for environmental impacts assessment and decision-making support in order to reduce the building’s impacts and achieve a sustainable design (Georgia Institute of Technology, 2010).

LCA helps the stakeholders involved in the project to comprehend the different environmental impacts of the project during its different lifecycle phases (Georgia Institute of Technology, 2010). Moreover, it can support the decisions taken during the design phase, by providing a scientific base for them (Georgia Institute of Technology, 2010).

LCA is a really suitable tool for assessing decision making, due to coordinated with other tools, allows the designer to achieve a balanced between cost, functional requirements and environment, and therefore a sustainable design (Khasreen, et al., 2009). In fact, the decisions that are taken in the early stages of a project have a big influence in the whole lifecycle of the building (International Energy Agency, 2005), and LCA brings the possibility to analyze different alternatives taking into account different impacts in order to select the most suitable one (Khasreen, et al., 2009).

Architects and Engineers are the ones that are going to use the LCA information in order to assess the decision-making process for achieving a building with the lowest impacts. Therefore, the given information has to be easy to understand by the architects or the engineers that are going to use it as a design criterion in order to behave as an efficient assessment tool (Tritthart, et al., 2010).

Due to one of the phases in which LCA can be applied, with higher capacity to influence the project is the design phase, LCA contribution during this phase is going to be analyzed.

4.3.1 LCA AS AN ASSESSING TOOL DURING THE DESIGN PHASE

As it has already been mentioned in this report, it has to be highlighted the high potential of the design phase for adding value to the project. LCA can also be implemented during the different stages of the design phase in order to assess decision-making (Georgia Institute of Technology, 2010).

4.3.1.1 PRE-DESIGN PHASE

The implementation of LCA during this phase could contribute to the definition of the project’s environmental goals. LCA can also assess the choice between different alternatives, by providing environmental criteria to the decision process (Georgia Institute of Technology, 2010).
4.3.1.2 SCHEMATIC DESIGN STAGE

During this phase, LCA contribution is mainly focused on the selection of the different building elements, and decisions concerning for example energy conservation measures, using the information provided by LCA as a base (Georgia Institute of Technology, 2010).

4.3.1.3 DESIGN DEVELOPMENT STAGE

During this phase a detailed design is developed, being LCA useful for the detection of the elements with worst environmental performance in order to implement the needed changes so as to improve the building performance. Moreover, different materials can be compared in order to select the most suitable one, and the environmental impacts of the lighting, heating, ventilation and air conditioning (HVAC) projected systems can also be analyzed in order to check their environmental performance (Georgia Institute of Technology, 2010).

Therefore, as it has already been explained LCA can actively contribute to the decision making process during the whole design phase, comparing different alternatives, assessing the selection of the different building’s products and systems, and reducing the environmental impacts highlighting the stages or elements with higher impacts (Georgia Institute of Technology, 2010).

The following table summarizes the possible LCA uses during design phases and the stakeholders that took part on it.

<table>
<thead>
<tr>
<th>Stakeholders</th>
<th>LCA use</th>
<th>Project Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultants advising municipalities and urban designers</td>
<td>Establish objectives at municipal level and for development areas. Highlight zones where building is fomented or banned.</td>
<td>Pre-design Phase</td>
</tr>
<tr>
<td>Property developers and clients</td>
<td>Select the building’s location. Determine the size of the project.</td>
<td>Pre-design Phase</td>
</tr>
<tr>
<td>Architects</td>
<td>Comparison between the different design alternatives.</td>
<td>Early and detailed design phases</td>
</tr>
<tr>
<td>Engineers / consultants</td>
<td>Comparison between the different design alternatives.</td>
<td>Early and detailed design phases</td>
</tr>
</tbody>
</table>

Table 4.2. Applications of LCA in a building project. (Zabalza et al., 2009)

4.4 THE NEED OF LCA IN THE CONSTRUCTION INDUSTRY

4.4.1 LCA ADVANTAGES

Currently the construction sector is becoming more competitive, seeking to achieve costs reduction. LCA enables a reduction of the costs due to it reduces the environmental costs, and it contributes to the reduction of energy and resources consumption. Furthermore, LCA could be considered as one of the most suitable tools for environmental assessment, contributing to the
environmental consideration, which is gaining importance currently (ENSLIC, 2007). Moreover, one of the key strengths of LCA is its capacity to analyze broadly the whole project, taking into account different environmental impacts (The World Bank Group, 2012). Therefore, LCA implementation in the construction sector should not be optional, but necessary (ENSLIC, 2007).

Furthermore, the life-cycle philosophy fits well in the framework of the European policy making. A life cycle assessment is required when reporting about Green House Gases. Moreover, Environmental Product Declaration, which is based on the results of an LCA, is being currently promoted (The World Bank Group, 2012).

The main advantages of the LCA implementation in the building sector are:

Assessment of decision-making of new buildings design or refurbishment of existing ones. LCA will guide the selection of the materials, the planning of the procedure for residues management, development of the construction plan, etc. (ENSLIC, 2007). Moreover, LCA can also avoid sub-optimization, which could cause the effectively development of one part of the system to the detriment of others (The World Bank Group, 2012).

A comparison between different design alternatives can be done with LCA in order to choose the one with better environmental performance. And it also highlights the main opportunities for improving environmental performance of the construction all over the whole life cycle (ENSLIC, 2007).

Moreover, it encourages the development of Zero emission Buildings, by means of an eco-design to obtain the most efficient building performance (ENSLIC, 2007). Besides, it helps the avoidance of pollutants generation, instead of only their treatment when they have already appeared (The World Bank Group, 2012).

It contributes to the achievement of a building environmental labeling. This could bring different benefits for the owner such as marketing or reduction of taxes due to the good environmental performance of the building (ENSLIC, 2007).

Furthermore, the LCA methodology enables the comparison of the environmental performance of different buildings, in order to learn from the experience (ENSLIC, 2007). Different environmental aspects can be analyzed, due to it is not only a matter of energy consumption, but there are also other impacts with high repercussions (Buyle, et al., 2012).

It shows the influence that the early design decisions have in the rest of the building life phases (ENSLIC, 2007), with a high potential to improve the building’s performance (Buyle, et al., 2012).

Moreover, LCA assessment can be combined with other tools such as life cycle cost assessment, so that the economic performance of the building can also be improved (ENSLIC, 2007).
It contributes to increase social awareness about environmental impacts. Currently the costs of the environmental impacts are not included in the final budgets; therefore, the chance of showing the environmental costs of a construction and its environmental effects is a great opportunity to contribute to sustainability achievement. Actually, society must be conscious of the real costs that the environmental impacts have (Buyle, et al., 2012).

The relevance of LCA as an environmental evaluation tool within the construction sector is increasing but there is still a need of development and improvement. Despite the advantages of LCA in construction industry are clear, currently LCA have some inherent limitations and therefore, special care should be taken when analyzing its results (Buyle, et al., 2012).

4.4.2 LCA LIMITATIONS

LCA has different limitations and it is currently under development. One of these limitations is the lack of investment in LCA development despite this situation is expected to change due to the use of LCA during the design phase is being promoted (Georgia Institute of Technology, 2010).

For the performance of a LCA some especial requisites have to be fulfilled. A LCA expertise is needed for its execution, specific software for LCA performance is required and a complete database has to be available, due to the quality of the analysis depends on the quality of the data. Furthermore, time is going to be invested due to LCA could be a very time consuming task (The World Bank Group, 2012).

There is also a lack of completed databases needed to perform the LCA analysis, therefore different assumptions have to be done, increasing inaccuracy. These limitations could be improved by more governments’ emphasis and will be solved as the LCA procedure becomes more utilized (Georgia Institute of Technology, 2010).

One of the main drawbacks of LCA is that it depends on the quality and the availability of the data which has a big influence on the quality of the analysis results (Scientific Applications International Corporation, 2006). A huge amount of data has to be collected for the inventory analysis. The data unavailability hinders LCA performance, being the data collection a laborious task (Georgia Institute of Technology, 2010). Moreover, the data bases and the used tools vary depending different factors such as the user, the location, and the scope (Ortiz, et al., 2009).

Furthermore, the documentation concerning the different LCA analyzed aspects such as energy consumption, transportation, maintenance, etc. is delivered in different formats due to lack of regulation. Each document is created by the different building experts for their own purpose, being each of them responsible for their LCA data. These disagreements complicate the transfer and gather of the building’s LCA information (Tritthart, et al., 2010).

The results of the LCA have to be easily understood by the different stakeholders involved in project, such as architects, engineers and users (ENSLIC, 2007). Moreover, LCA is an expensive analysis and gives limited answers to which is the optimum combination of different options, or
which will be the best location for the project, or choosing the size and time of the whole project (The World Bank Group, 2012).

LCA application in the construction industry is only focused on an environmental point of view, without considering the economic and social aspects that are also necessary to achieve sustainability (Buyle, et al., 2012).

Then, as LCA is underdevelopment and it evolves progressively, there is not a fixed methodology for the LCA performance. For example the calculation of the impacts varies depending on the impact category. Then the weight of the different impact categories is not fixed and depends on assumptions (Georgia Institute of Technology, 2010).

The multi-indicator nature of LCA is one of the key factors for the LCA success, but it also hinders the results communication to the project stakeholders that are not LCA practitioners. Furthermore, as LCA keeps evolving, the list of indicators increases. And due to the wide variety of indicators that can be analyzed in LCA, it is a challenge for the experts developing the assessment, to present the results in an understandable way for all the project’s decision makers (Hoof, et al., 2013).

Moreover, as each building is a unique product it is difficult to compare the results. And different assumptions have to be made concerning the different stages of the life-cycle, increasing uncertainty (Buyle, et al., 2012).

Another problem is the misused of the tool due to its use in the late phases of the project. In Europe a high percentage of the performed LCAs are developed for constructed buildings with certification purposes, instead of using LCA in the early design phases as a decision-making tool. It has been highlighted that one of the most effective phases for the LCA performance is the design phase, due to the high potential for adding value to the project that this phase has, the chances of achieving ecological optimization are higher (Trithart, et al., 2010). One of the problems that appear when implementing LCA as a decision support tools is that in the early design phases the choice between different alternatives has to be done, and a lot of information and data is required. Nevertheless, in later phases, a lot of decisions have already been taken, and therefore, the LCA performance is easier, it has higher quality and a lot of information is available; but on the other hand the flexibility of the project has been reduced and the influence of the LCA results in the design has noticeably decreased. The key factor for avoiding this problem is the improvement of data and information availability in order to perform better LCA assessments of the different early alternatives. Hence, if data availability wants to be improved, the implementation of Building Information Modelling can be considered (ENSLIC, 2007).

In the following figure it can be seen how as design evolves the LCA precision increases, whereas the change options decrease.
There are also some barriers for the general acceptance of LCA. A great effort is needed for LCA performance, due to the huge volume of energy and materials flows all along the building’s life span. Therefore, different efforts have to be done. An effort from the public administrations is required in order to develop policies dealing with LCA. Moreover, there is a lack of national information databases. The LCA practices are only well-known by a small proportion of the sector so this hinders the acceptance of the LCA practices by the construction stakeholders. And also the low demand of green-products limits the expansion of LCA techniques among the construction sector (Tritthart, et al., 2010).

Moreover, the LCA assessment of the whole building has not been developed yet, and little research has been done concerning this assessment due to several reasons. First, the building itself is made of a wide variety of products with its own characteristics and life-span; this means that the different products will have different requirements and will be replaced when required by each product. In addition, each of these products will have a different relevance concerning environmental impacts. Then, there is uncertainty concerning the building’s future use, maintenance or refurbishment operations; these changes that the building could suffer in the future can not be predicted. And finally, there is a lack of standardization due to buildings are unique products. All these reasons make it really difficult to achieve the assessment of the whole building as a single product (Tritthart, et al., 2010).

Finally, the access to the LCA data is not easy for a non-expert. The way of presenting the data varies from one database to another. Therefore, the operation of the databases could be complicated to understand for a person who has not a LCA background. Moreover, this fact of the different ways of presenting the data could also make more difficult the comparison between the different databases in order to select the most suitable for each study. This may result in the rejection of the designers (architects and engineers) to use LCA as an assessing tool due to the complexity of its performance and the difficulties to understand the data and the results. The
following figures show different print screams of some of the analyzed databases, where it can be seen how each of them present the data in a different way.

Figure 4.8. Ökobau.dat database (original version). (Bundesministerium für Verkehr, Bau und Stadtentwicklung, n.d.)

Figure 4.9. Ökobau.dat database (translated). (Bundesministerium für Verkehr, Bau und Stadtentwicklung, n.d.)
Due to all the mentioned limitations mainly related with the complexity and costs of the procedure, the lack of accuracy and the difficulty of the data access and interpretation (ENSLIC, 2007), further development is needed in the LCA field in order to achieve its effective implementation as an assessing decision-making tool.
CHAPTER 5: PROBLEM DEFINITION AND POSSIBLE SOLUTIONS

5.1 SUMMARY OF THE EXISTING PROBLEMS

For achieving sustainability in the construction industry, the lowest environmental impact has to be achieved, at the same time that the social and economic development is encouraged (Hakkinen, 2008). Currently, there are already different assessment tools for construction, but they do not provide a global evaluation (Hakkinen, 2008).

A sustainable design tool has to be able to evaluate the building performance according to different criteria, at the same time that the information is integrated in the design framework in order to enable the comparison between different alternatives (Hakkinen, 2008).

Furthermore, a building sustainable assessment method should enable the comparison between different alternatives in order to select the most suitable one according to sustainable criteria. For this purpose a huge amount of information has to be handled; and this is one of the main reasons why these sustainable tools are implemented in the late projects phases, when the final solution is already developed instead of implemented them in the early design phases. Therefore, if they are applied in late phases, the great potential and the capacity of influencing the project of these tools is highly reduced (Hakkinen, 2008).

Integrated design could be considered as a key factor for achieving sustainable projects (McGraw Hill Construction, 2010). As it has already been mentioned, the higher capacity for influencing the project and adding value is in the early phases, where integrated design focused the effort.

Moreover, currently construction industry is inefficient. Being the root of this inefficiency in different features such as the lack of cooperation and the wasted of resources. Therefore a change is needed and construction industry performance has to be improved (Bundesministerium für Verkehr, Bau und Stadtentwicklung, 2013).

5.2 POSSIBLE SOLUTIONS

Powerful tools are being developed nowadays in the field of construction. This report is going to focus attention in two tools: BIM and LCA.

5.2.1 BIM

On the one hand, BIM could be considered as a key tool for achieving sustainability due to it is a great support for integrated design implementation. BIM enables collaboration of the different stakeholders involved in the project since the early design phases, achieving an overall vision of the project, and improving the results (McGraw Hill Construction, 2010).
On the other hand, BIM contributes to the improvement of the construction industry performance. The lack of cooperation in the construction industry could be enhanced with BIM implementation, due to one of its main advantages is the coordination and collaboration between all the stakeholders (Eastman, et al., 2011).

Moreover, concerning wasted resources, BIM use could avoid waste of time and resources due to inefficient data management; preventing form reentering the same data. It has been estimated that due to the current way of working in the construction industry, the same data could be entered almost seven times (Sjøgren, 2011). This situation is frequent when LCA performance is concerned, due to the data has to be entered in the LCA software, being this a time consuming task (Eastman, et al., 2011).

BIM is a tool with great potential for achieving sustainable design, but currently this potential is still underused; one of the main reasons is the lack of interoperability (British Standards Institution, 2010).

Despite BIM tools are quiet evolved, currently there is a need of development and innovation in the BIM field in order to achieve a higher performance and enable a sustainable design. The already mentioned report developed by Mc-Graw Hill in 2010 “Green BIM, How Building Information Modeling is Contributing to Green Design and Construction”, gathers some statements of the BIM industry professionals, highlighting the need for new improvements in order to achieve a sustainable design.

Currently the BIM software’s firms are focused on improving interoperability in order to achieve green design. One of the biggest future goals of the BIM industry is achieving interoperability, as it is claimed by Huw Roberts (Bentley System’s global marketing director); but not only interoperability between BIM and the analytical software but also between the different processes in which BIM is involved (McGraw Hill Construction, 2010).

Don McLean (president and founder of Integrated Environmental Solutions), asserts that there is a real need among the construction sector, of achieving an effective management of a large amount of information, and reaching an effective transfer of this information from the BIM model to an analytical tool (McGraw Hill Construction, 2010).

Furthermore, Miklos Sved (product development manager at Graphisoft) has stated that the next future use of BIM will be related with assessing the energy performance of a building during its life cycle. Moreover, despite already exist tools that can perform different analysis, there is a lack of a tool able to perform an accurate life cycle analysis with a continuous flow of information from the model. And Graphisoft is working hard to achieve this aim (McGraw Hill Construction, 2010).

As the demand of sustainable buildings is increasing, software tools have to meet this need (McGraw Hill Construction, 2010). Therefore, there are evidences in the market that there is a real demand of a BIM tool able to perform LCA.
In this same report it was also highlighted the demand by the BIM users of a higher software integration, standing out specially the case of energy performance modeling software; these energy performance software are among the most used ones nowadays but the whole amount of data contained in BIM model can not be yet used by these software (McGraw Hill Construction, 2010).

If the integration is achieved, construction professionals will be able to compare the initial estimations with the final behavior of the building. And the impacts of the design could be shown, assessing the design process (McGraw Hill Construction, 2010).

5.2.2 LCA

LCA offers a great potential for environmental performance improvement during the project life cycle (AENOR, 2006). The environmental assessment of the building can be performed by implementing LCA methodology. Contributing like this to the achievement of one of the aims of sustainability (International Energy Agency, 2005).

Moreover, it is a useful tool assessing decision making. Therefore, environmental criteria can be included in the early design phases (Georgia Institute of Technology, 2010).

Nevertheless, the LCA methodology has several drawbacks that could be solved by integrating it with BIM.

When environmental assessment is concerned, LCA has a great potential for analyzing different alternatives in order to compare them (Eastman, et al., 2011). However, one of the main problems when using LCA in the early design phases as a decision-making assessing tool, is that the needed information about the different alternatives is not easy to achieved in this early phase (ENSLIC, 2007). Currently for collecting the needed data, the available 2D drawings are used and the data has to be entered manually in the software for the LCA performance. This process is laborious, time consuming and expensive due to a large amount of the data that previously has been entered, needs to be entered again for the LCA development. Therefore, time is wasted and costs increased, and hence it is frequent to undertake the LCA assessment during the late project phases or when the building is already finished. This situation could be improved, if the LCA tool were integrated with BIM; due to data required for the LCA performance during the design phase could be provided by BIM (Eastman, et al., 2011).

Moreover, LCA is only focused on the environmental field, but for achieving sustainability it is also important to enhance social and economic development (Buyle, et al., 2012). If the LCA tool will be integrated within the BIM framework, it could be complemented with the other assessment tools in order to cover all the sustainability fields.
5.2.3 SUGGESTED SOLUTION: LCA AND BIM INTEGRATION

It has already been explained the great potential that the design phase has to create value and to influence the rest of the building life-cycle phases. So if powerful tools such as BIM and LCA want to be used, they will achieve higher efficiency if they are implemented in the design phase.

If the project is being developed using a BIM model, all the information concerning to the project is already included in the model. So if the LCA assessment if going to be performed, it will be more efficient, if the information is directly taken from the model instead of reentering it again. Moreover, the waste of time and the possible errors due to the data reentering will be reduced.

Therefore, if the environmental impacts could be assessed automatically from the model, design professional could easily evaluate different alternatives taking into account environmental criteria in order to take informed decisions during the early project phases (Tucker, et al., 2003).
6 CHAPTER 6: IMPLEMENTATION

6.1 INTEGRATION OF LCA AND BIM

Construction industry is turning into sustainability, and for achieving sustainability a balance between environmental, economic and social aspects has to be reached. Therefore these criteria have to be taken into account during the building design phase.

Concerning environmental aspects, LCA is a very good tool for assessing buildings environmental performance. Nevertheless it has some drawbacks that need to be solved for its integration in the design process and use as an assessing design tool.

Currently, the manual re-entry of the project data into the LCA tool is one of the main drawbacks that LCA tools have to overcome, due to it is a redundant and time consuming task. Furthermore the data is already in the building model so there is no need of re-entering again the same data, due to profit can be taken of the work already done. If the building data has to be re-entered again, there is a risk of mistakes and misunderstandings due to different stakeholders might be working with different data, instead of working all of them with the same model. Therefore, this drawback could be solved if interoperability between BIM and LCA is achieved, and the LCA tool could directly access the BIM model data.

Furthermore, the lack of information is an obstacle for LCA performance during the early phases and it is one of the reasons why the majority of buildings’ LCA are performed after the design phase. Nevertheless, the phases with higher potential for influencing the project are the early phases, therefore if the environmental performance of the building needs to be improved, the LCA tools have to be implemented in these early design phases. By integrating LCA and BIM, the access to the project information will be easier, and the assessment will be faster.

The average LCA assessment takes a long time, due to the mentioned drawbacks, and non-expert users can find difficulties performing them and understanding their results; this could be improved integrating LCA with BIM tools achieving a synergy between both tools.

Moreover, for achieving sustainability not only environmental aspects have to assessed, but also economic and social. Currently, BIM tools have already developed the economic assessment and they also contribute to the social aspects with different tools for assessing human comfort, daylight, etc.

Therefore, if BIM and LCA tools are combined, an assessment of the three pillars of sustainability can be achieved, and higher profit from both tools can be gained.

In this chapter two development cases of LCA and BIM integration are going to be studied, LCADesign and BSLCA. The aim of this assessment is to understand their characteristics and how they work, and highlight their strong features in order to strengthen them, and their weakness for improving them.
First their main features and working procedure is going to be explained, and an evaluation of tools will be performed.

The evaluation of the tools will consist on an explanation of the advantages and disadvantages of the tools followed by a multicriteria evaluation, ending by a comparison between both tools. The criteria selected for the multicriteria evaluation are explained below.

6.2 CRITERIA FOR THE MULTICRITERIA EVALUATION

According to the readings, information gathered, users experiences, experts opinion and contact with some enterprises, five criteria have been set for the assessment of the analyzed tools.

The different criteria divided in sub-criteria, have been evaluated in order to assess the tool performance and how it could be improved to be more popular among the users or have a more widespread use in the construction industry.

The criteria used for the assessment are the following:

6.2.1 SCOPE OF THE ASSESSMENT

The objective of this criterion is to evaluate the type of assessment that the tool can perform.

6.2.1.1 COMPONENTS ASSESSMENT AND LIFE CYCLE

The main goal is the achievement of a complete assessment for the whole building during its whole life cycle. Whereas the assessment of the different building materials is currently more developed compared to the assessment of the whole building.

A wide variety of materials and products with their own characteristics and life cycles are included in the building, moreover during the whole life cycle of the building different aspects such as the use, maintenance activities and refurbishment that are difficult to predict, and influence the building future performance. Therefore, achieving a tool able to consider all the aspects of the building life cycle and perform the assessment taking them into account is the challenge that LCA tools are facing currently. Due to this reason, this achievement will score the higher punctuation in this scale of values.

6.2.2 TOOL USE

Under this criterion, the type of user, the time spent in the assessment, if it enables the implementation of changes or not and if it includes 3D view of the model, have been analyzed.
6.2.2.1 TYPE OF USER

One of the disadvantages of current LCA tools is the need of an expert for the assessment performance.

In order to achieve the tool integration in the design process it has to be easy for designers and engineers to use. If the tool is going to be frequently used by designers and engineers as an auxiliary tool for decision making during the design phase, it has to be easy and intuitive to use without requiring an extra effort, in order to encourage them to use it as one of their regular tools.

Therefore, in this evaluation the achievement of a tool that can be easily used by non-experts accounts for the highest score.

6.2.2.2 TIME FOR ITS PERFORMANCE

A big drawback of current LCA is that it is a time consuming task, especially if the data has to be entered manually. If LCA has to be included as an assessing tool during design, the assessment procedure can not last long, due to it has to provide a real time assessment and enable the evaluation of different alternative.

Therefore, the capacity of performing a real time assessment represents the highest value in this sub-criterion assessment.

6.2.2.3 CHANGES IMPLEMENTATION

A key factor for achieving a real integration of LCA in the design will be that the changes according to the LCA results could be made directly from the assessment tool, in order not to lose time and effort going back to the BIM software and editing the changes there.

The highest score of this sub-criterion is represented by the possibility of performing the required changes according to the assessment results, directly from the assessment tool.

6.2.2.4 3D VIEW

A 3D view of the building while dealing with the LCA tool can be useful for the user. This makes the tool use easier for the user, who can have a clear image of the project during the whole assessment, helping him with the selection options.

Therefore, the highest score is given for the possibility of having a 3D view of the model.

6.2.3 RESULTS

This criterion evaluates the results obtained from the assessment, if they are understandable and enable comparison between different alternatives.
6.2.3.1 ALTERNATIVES COMPARISON

In order to take the most profit of a decision making assessing tool, it has to include a benchmark option, in order to compare the different design alternatives, so that the user can select the most efficient option.

In this sub-criterion, the capacity of performing alternatives comparison accounts for the highest rate.

6.2.3.2 UNDERSTANDABILITY

The results have to be clear to read and easy to understand. If the results are difficult to understand and the designers have to consume time and effort for understanding them, the tool will not be efficient as an assessing tool and it will not be popular among the users. The tool has to show the users what they need to know in an efficient way.

Therefore, the easy to understand, the higher rate will achieve in this sub-criterion.

6.2.4 DATA

The data quality and availability is the base of an efficient life cycle assessment. Moreover, one of the main goals of the integration of BIM and LCA is to avoid data re-entry, taking profit of the information already contained in the BIM model.

Under this criteria, it will be assessed how the building data is entered, the LCI and the materials data available.

6.2.4.1 BUILDING DATA ENTRY

One of the main objectives of achieving BIM and LCA integration is the avoidance of manual data re-entry. The BIM model contains important building’s data that has to be re-entered manually again in the conventional LCA tools. By data re-entering, inaccuracy and inefficiency increase. Therefore, a direct data transfer to the LCA tool is sought, taking profit of the project work already done.

The achievement of a complete interoperability has been considered as the highest score that can be reached in this sub-criterion.

6.2.4.2 LCI

As it has already been mentioned, the base of an accurate life cycle assessment is the availability of accurate data. The higher the accuracy and availability of life cycle inventory data, the more accurate the assessment; and therefore the higher score will be achieved in this sub-criterion.
6.2.4.3 MATERIALS DATABASE

A wide materials database contributes to the accuracy of the assessment due to the reasons already explained. Therefore, this sub-criterion will be measured following the same pattern as in the previous one.

6.2.5 TOOL FLEXIBILITY

Flexibility is an important characteristic of a decision-making tool. The more flexible the tool is, the higher its versatility is.

6.2.5.1 GEOGRAPHICAL APPLICATION

If the tool can be worldwide applied, it will become more popular and widespread used. Moreover, it will improve its performance as a decision making tool due to the construction professionals will be able to apply the tool in the different projects in which they are involved.

The higher the application area is, the higher mark achieved.

6.2.5.2 SELECTION POSSIBILITIES

A decision assessment tool has to offer the user the option of selecting different parameters for the assessment. Since it has to provide the user the required information, and therefore, the user should be able to select the characteristics of the analysis according to the project needs.

Moreover, if the tool is flexible while selecting the assessment options, its use will become also more widespread.

Therefore, the chance of selecting the analysis criteria scores for the highest grades in this sub-criterion.

6.3 CASE STUDIED: LCADesign

6.3.1 PROJECT DEFINITION

LCADesign was developed with the purpose of achieving an automatic environmental assessment of commercial buildings in Australia, including a comprehensive database. It has achieved a uniform supply of information and procurement of environmental and costs evaluation of different designs and alternatives (Tucker, et al., 2003). Moreover, it has evolved and currently it also enables the assessment of residential buildings (Jones & Jones, 2009).

LCADesign is an automatic take-off tool that extracts the building data directly from the BIM model; this data is used for the performance of the building LCA, enabling the comparison between different alternatives and therefore, becoming a decision-making support tool during the design phase (Tucker, et al., 2003).
6.3.2 DEVELOPMENT FRAMEWORK

This project was developed by the Cooperative Research Centre for Construction Innovation (CRC Construction Innovation) under the framework of its project “Sustainable Built Assess” (Larsson & Trusty, 2004).

The development of LCADesign software and database started in 2001, then after several industry tests from 2003 until 2005, it was upgraded an improved, and finally it was released in 2008. This software was developed with the collaboration of different partners such as the Queensland University of Technology, the Royal Melbourne Institute of Technology, CSIRO and ARUP among others; and it was presented by the Australian Prime Minister at the World Sustainable Building Conference in Melbourne in September 2008 (CRC Construction Innovation, n.d.). Currently, Ecquate Pty Ltd is the Australian company in charge of its management (Singerman, 2008).

This tool was developed with the main objective of enabling building professional the performance of environmental assessments in order to implement eco-design. Therefore LCADesign has the capacity of performing LCA assessment of the building materials or of the whole building following the ISO Standards (ISO 14040), covering the whole life cycle from cradle to grave or reuse (CRC Construction Innovation, n.d.).

Concern about the building’s resources consumption and environmental impacts was growing among the Australian society and construction industry; therefore the Council of Australian Government developed several initiatives in order to address this concern, such as the “National Strategy for Ecologically Sustainable Development” in 1992 (Tucker, et al., 2003).

Furthermore, there was also concern about the need of an integration of the environmental assessment tools in the design process. This is a challenge where the existing tools have several limitations. If environmental criteria are going to be included during the design phase, a uniform data supply is required (Tucker, et al., 2003).

LCADesign emerged as a tool developed with the purpose of answering the already expressed buildings’ environmental concern and for achieving the integration of the environmental criteria in the design process (Tucker, et al., 2003).

Moreover, the LCADesign developers are thinking about a bigger project in order to achieve a tool that can be used in all the phases of the project life cycle. It is called LCADevelop and it has the following structure (Watson, et al., 2005):
Where LCADefine will be applied for project definition, LCADesign in the design phase, LCADetails for procurement and supply, LCADeliver will be applied in the project delivery phase and LCADeconstruct for analyzing reuse and end of life (Watson, et al., 2005).

### 6.3.3 HOW DOES IT WORK?

The main goal of this tool is to achieve an automated environmental assessment in order to enable decision making based on updated data. For this purpose an integrated approach was needed in order to have automated access to the building data (Tucker, et al., 2003).

1- The first step is the data extraction from the BIM model, obtaining data about the different building elements. These data are extracted by IFCs files that identify all the building elements with classes, providing building product quantities. This IFCs files are imported into LCADesign database (Tucker, et al., 2003).

2- The data contained in the IFCs files by means of the default reasoning rules encrypted in the software, are automatically transformed into metrics such as kilograms, required for the LCA calculation (Huysmans, et al., 2007). Furthermore, the building elements specified in the IFCs extracted from the 3D CAD, are classified following the Australian Cost Management Manual (ACMME) (Tucker, et al., 2003). Then, by combining this information with the LCI database, the resources depletions and the emissions to air, land and water of the building components are calculated from cradle to grave (Tucker, et al., 2003).

3- The resources consumption and emissions generated are factored for each damage and impact category calculating the different environmental indicators (Tucker, et al., 2003).
4- Finally, viewing facilities for results display are offered, enabling the detection of hot spots at different building levels (Tucker, et al., 2003). LCADesign shows the results of the LCA, in different tables, graphics and reports. Enabling the comparison between different design alternatives (Watson, et al., 2004).

In the following figure the main phases of the process are shown.

![LCADesign process](image)

**Figure 6.2. LCADesign process. (Seo, et. a, 2005)**

Firstly the inputs, that consists on the creation of a 3D CAD model, and the extraction of the dimensional data in order to determine the building materials quantities (Seo, et al., 2007).

Then the analysis, which is based on the calculation of all materials and building components environmental performance, by relating the materials quantities with their resources consumption and emissions generation from a database. As a result of the life cycle analysis different environmental indicators are obtained (Seo, et al., 2007).

Finally the improvement, that enables the comparison of different alternatives and benchmark assessment in order to select the option with lower environmental impact during its life cycle (Seo, et al., 2007).

As it is shown in the figure LCADesign can perform environmental assessment and economic performance evaluations combining the data taken from the 3D CAD model, with materials and life cycle inventory data.

A scheme of LCADesign is shown below in order to achieve a better understanding of how it works:
As it can be seen in the scheme, LCADesign offers a 3D viewer that enables the user to have access to a 3D view of the model.

Moreover, some examples of the software interfaces are going to be shown below, in order to achieve a better understanding of the tool.
Figure 6.4. LCADesign tagging with object, product and LCI reasoning rules. (Jones & Jones, 2009)

Figure 6.5. LCADesign elements tagged. (Jones & Jones, 2009)
Finally a scheme with the information flow in LCADesign during the whole process is shown below; it can be seen how the building data is directly taken from the model, and combining it with the materials database the products specifications are obtained. Then the resources consumption and emissions generations are determined and the different environmental indicators calculated. Obtaining finally the environmental assessment results represented in different formats (Tucker, et al., 2003).
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IFCs Dimensions, location, building products etc.

Calculate system inputs & outputs

Database and Default reasoning rules

Eco-Indicator 99 CML

Tools for information viewing

Drill-down facilities

Performance analysis, costs and benchmark

Figure 6.8. LCADesign Information flow. (Tucker, et al., 2003)
6.3.4 DATA EXCHANGE

One of the main drawbacks of the environmental assessment of a building is the amount of data required, that has to be entered in the assessment tool, being this a time consuming task. Furthermore, the data update is also a laborious procedure and the introduction of changes could lead to errors or misunderstandings (Tucker, et al., 2003).

The project’s data transfer can be easier with BIM tools that provide this option, due to these BIM models include the needed data and bring the opportunity of extracting it, so that the calculation software can develop different assessments such as an environmental one (Tucker, et al., 2003).

The data sharing format used in LCADesign is IFC. Therefore if all the objects of the model are identified by a class, the building data can be accessed easily by the environmental assessment tool (Tucker, et al., 2003).

Then this IFC files taken from the CAD model are stored in an EXPRESS Data Manager (EDM). This database contains all the building information including the data taken from the CAD model and the environmental model (Tucker, et al., 2003).

IFC DEFINITION

A brief explanation of what IFC consists on is going to be given.

IFC is an international information exchange standard developed by the International Alliance of Interoperability (Fischer & Kam, 2002), that uses the EXPRESS data definition language (buildingSMART, 2013).

In a building the different things included in it are specified through data. Each of these specifications is called class; being a class a set of things with common characteristics. These classes are called Industrial Foundations Classes (IFC’s). An example of a class in a building model can be “door” or “window”. When a class is used more than once, each of these uses is an object (International Alliance of Interoperability, 1999).

By means of the IFC-based objects, a project model can be shared by the different stakeholders involved, continuously sharing the project data electronically (International Alliance of Interoperability, 1999).

Furthermore, if each object in a drawing is identified as a class, then analytical software could calculate different parameters directly from the drawing (Tucker, et al., 2003).

6.3.5 PROJECT DATABASE

The project database is based on EXPRESS Data Manager (EDM), due to it allows the import of IFCs files (Tucker, et al., 2003).
The project database includes the building quantity data that is extracted directly from the BIM model and imported in the database by IFCs files. A materials database and the Default Reasoning Rules, that relate the building elements with their properties, are also part of the project database. Moreover, a Life Cycle Inventory database with resources consumption and emissions generation is also included (Tucker, et al., 2003).

### 6.3.6 LIFE CYCLE INVENTORY

The Life Cycle Inventory includes data about resource consumption and emissions generation of building construction products. The emissions and resources consumption are calculated using the Bousted Model 4.4 covering from cradle to grave; this inventory is delivered in the product database and linked by using the Default Reasoning Rules (Tucker, et al., 2003).

The building life cycle inventory covers: “resources procurement, transport, manufacture, delivery, construction, maintenance, final demolition, recycling and water and energy use during the occupancy for a given life period” (CRC Construction Innovation, n.d.).

The LCI databases were developed for Australia, Germany, The Netherlands and California; besides one was created for the 2000 Green Olympic Games (Sydney Olympic Games) (Huysmans, et al., 2007).

### 6.3.7 ENVIRONMENTAL INDICATORS

Different indicators can be used for different purposes and goals, but all of them need a wide amount of information about the inputs (resources consumptions) and the outputs (emissions) of the different processes involved in the product’s production (Tucker, et al., 2003).

The environmental indicators are obtained by combining the quantity building data obtained from the 3D CAD model, with the life cycle inventory data. Furthermore the calculated indicators and its weigh in the assessment can be chosen by the user in order to fulfill the clients’ needs (CRC Construction Innovation, n.d.), due to they can be used for environmental assessment or for monitoring performance improvements (Tucker, et al., 2003).

The impact assessment methodologies usually show the results by midpoint or endpoints indicators. The midpoint impact category or problem-oriented approach shows the impacts on different environmental issues such as human toxicity, ozone layer depletion, global warming, etc. Whereas the endpoint indicators or damage-oriented approach, shows the impact on global subjects such as human health or climate change (PE International, n.d.).

LCADesign enables the representation of the environmental results using 70 different indicators (CRC Construction Innovation, n.d.). A list of some of the indicators used by LCADesign is shown below:
The environmental indicators available in LCADesign are based on the international recognized indicators CML and Eco-Indicator 99 (Seo, et al., 2005), and the user can select different indicators in order to develop the assessment according to his needs (Tucker, et al., 2003), as it can be observed in the figure below.
CML

The CML methodology was developed by the Center of Environmental Science of Leiden University. It uses mainly European data and it is one of the most used currently. It is based on a midpoint methodology (Solidworks, 2013).

ECO-INDICATOR 99

The eco-indicator 99 assesses the environmental impacts focusing on three damage categories: human health, ecosystem quality and resources (Ministry of Housing, Spatial Planning and the Environment Communication Directorate, 2000).

The standard eco-indicators are used for numerically representing the environmental load of products or processes. Moreover, as they offer a numerical result, different alternatives can be compared, and they can be considered as dimensionless due to their main purpose is the comparison of different alternatives. They have been developed with the purpose of being used as a design assessing tool (Ministry of Housing, Spatial Planning and the Environment Communication Directorate, 2000).

Below a scheme of the Eco-Indicator 99 methodology is shown, in order to see how the finals score of the indicator is obtained. The white boxes represent procedures and the rest are intermediate results.
Some examples of the eco-indicators results obtained with LCADesign are shown below:

![Diagram](image1)

**Figure 6.11.** Eco-Indicator 99 methodology. (Goedkoop & Spriensma, 2000)

![Diagram](image2)

**Figure 6.12.** LCADesign EcoIndicator 99 example assessing three damage categories. (Jones & Jones, 2009)
6.3.8 EXAMPLES OF LCADESIGN IMPLEMENTATION

LCAvesign has already been applied in several real projects. Some of them are mentioned below.

6.3.8.1 MELBOURNE CITY COUNCIL OFFICES (VICTORIA, AUSTRALIA)

LCAvesign was implemented in the refurbishment project of the Melbourne City Council Building. It is a 35 years old building with a total area of 7668 m², divided in a four floors car parking area, and seven floors of offices (Seo, et al., 2007).

LCAvesign was used for the estimation of the materials environmental impacts, using Eco-indicator 99 as the environmental indicator for the assessment. The eco-indicators values obtained for the whole building and for each of the components are expressed in ecopoints/m²; as all the values scored are expressed in the same units, they can easily be compared (Seo, et al., 2007).

The eco-indicators values obtained for the whole building are shown below:

![Figure 6.13. LCAvesign Ecoindicator 99 score example. (Jones & Jones, 2009)](image)
First, the building was divided into different layers such as shell, scenery, services etc., in order to assess the whole building, obtaining a total score of 127 ecopoints/m² (Seo, et al., 2007).

As it can be seen in the graphic more than half of the total environmental impacts of the building, were caused by the shell. Therefore, an assessment of the shell was done, dividing it into two main parts, superstructure and substructure, obtaining the following ecopoints/m² (Seo, et al., 2007).
As it can be seen, the 83.1 ecopoints/m² obtained by the shell are mainly cause of the superstructure that accounts for 76.6 ecopoints/m², whereas the substructure only accounts for 3.5 ecopoints/m². Furthermore a detailed view of the superstructure assessment was obtained as it is shown in the figure below (Seo, et al., 2007).

![Figure 6.17. LCADesign Melbourne City Council building superstructure ecopoints/m2. (Seo, et al., 2007)](image)

As it can be seen the higher environmental impact was caused by the upper floors followed by the internal walls and the external walls (Seo, et al., 2007).

Therefore, after this analysis, the materials and components with higher environmental impacts could be identified in order to focus the design efforts on them for improving the environmental performance of the building (Seo, et al., 2007).

In this project, after evaluating the results of the assessment, an alternative design was developed. In this case, some parts of the superstructure were replaced by recycled materials, reducing the environmental impacts by a 19%. A comparison of the ecopoints/m² of the existing building and the alternative is shown below (Seo, et al., 2007).

![Figure 6.18. LCADesign Melbourne City Council comparison of Eco-indicator 99 for the example building and the alternative. (Seo, et al., 2007)](image)
Furthermore, other indicators could also be selected in order to adjust the assessment according to the user needs. In this case other indicators such as embodied energy, embodied water, greenhouse gas emissions and recycled mass were also analyzed, as it is shown in the figure (Seo, et al., 2007).

Figure 6.19. LCADesign Melbourne City Council comparison of alternatives based on different indicators. (Seo, et al., 2007)

It has to be highlighted that in this case of analysis the alternative has better performance in all the indicators despite the embodied energy. This was because the wool carpet included in the
alternative for the floor finishing, despite that it reduces the environmental impact of the alternative, it increases the embodied energy (Seo, et al., 2007). This is a clear example of the importance of developing an assessment including different indicators, not just one point of view.

6.3.8.2 STANFORD UNIVERSITY GREEN DORM (CALIFORNIA, USA)

LCA Design was implemented during an early conceptual sketches of the Stanford University Green Dom trying to achieve an optimal composition combining timber and steel, for mitigating earthquake damages. An example of the obtained results is shown below:

![Figure 6.20. Stanford University Green Dorm schematic design and LCA Design results. (Huysmans, et al., 2007)](image)

6.3.8.3 KPMG BUILDING (ROTTERDAM, THE NETHERLANDS)

The KPMG building was the first Dutch LCA Design pilot. This is a new building of 25000 m² for offices and 13000 m² for car park (Huysmans, et al., 2007). A view of its BIM model and an example of some of the results obtained with LCA Design are shown below:

![Figure 6.21. KPMG BIM model. (Huysmans, et al., 2007)](image)
6.3.9 USERS CRITICS

LCADesign has good performance and it was applied successfully as it has been shown in the mentioned examples. Nevertheless, the main drawbacks highlighted by the users are going to be explained below.

In 2004, the report “A review of LCADesign” with the results of the assessment of LCADesign tool performance was published by the CRC Construction Innovation. This report shows the results of Wayne Trusty and Nils Larsson after analyzing a model provided by CSIRO with different computer systems, being a very useful feedback for the improvement of the tool. The main aims of this study were to analyze the functionality of the software in order to highlight its “hot spots” and gaps and improve them if possible; furthermore, its suitability for commercial use which was also analyzed in order to check if it was ready for being released in the market (Larsson & Trusty, 2004).

Despite that LCADesign is a real advance for the achievement of LCA and BIM integration, it has some defaults that have to be improved. In this report the tool was analyzed from the point of view of a user in order to highlight the main difficulties that the user could find when using this tool (Larsson & Trusty, 2004).

First, the time for calculating was long if it was compared with other simulations, due to the lowest calculation time achieved was 6 minutes, whereas the average time for an energy simulation calculation does not exceeds 30 seconds (Larsson & Trusty, 2004). However, it should be highlighted that the opportunity of developing an environmental assessment automatically despite it could last more than other assessments, is a real progress; it brings the opportunity to develop the assessment in a really short time if it is compared with the time consuming task of developing an LCA without taking the data directly from the model.

The nomenclature used may be not suitable for its implementation in different countries (Larsson & Trusty, 2004).
Furthermore, the materials quantities information was not available, despite it is supposed to be in the system due to they have to be used for the emissions and resources consumption calculation. It would be really convenient to have access to the bill of quantities due to it can be used to check that all the materials have been included in the calculations. More development concerning this has to be done working on IFC and ArchiCAD. (Larsson & Trusty, 2004).

It was also highlighted in this study that the period while the software is processing a command sometimes is not shown, leading the user to misunderstandings (Larsson & Trusty, 2004).

Moreover, the interpretation of the results sometimes was not clear due to the charts did not include the units (Larsson & Trusty, 2004). Furthermore, if the complete data set of a product wanted to be seen, the user had to select manually the measures, so sometimes this can lead into errors due to some emissions are include in several environmental indicators. And it was also highlighted that some difficulties appeared for non-expert users operation (Larsson & Trusty, 2004).

Concerning the environmental indicators, the human health category did not include factors such as noise or illumination that are important for the design assessment. Furthermore, the unit used for measuring the human health category (DALY), can be hard to understand by designers or engineers who are not LCA experts (Larsson & Trusty, 2004).

A drawback of the LCADesign system was that if any change wanted to be performed in the design in order to compare different alternative, the changes have to be performed in the 3D CAD model and generate again IFCs. Changes could not be performed directly from LCADesign, due to it is not an structural design package. When a change was implemented, the system showed a bar indicating the percentage of changes that have been included, but it was difficult to determine which are the items that have been changed (Larsson & Trusty, 2004).

Finally, it has to be mentioned that further workings are being developed for improving LCADesign. CRC Construction Innovation is working on the implementation of a Life Prediction System in future LCADesign versions. It will be mainly used for estimating the service life of the building elements (CRC for Constructions Innovation, 2007).

**6.3.10 LCADesign evaluation**

**6.3.10.1 Challenges**

The challenge that LCADesign tool has to face is big. The existing LCA tools require a manual and time consuming project data entry, leading to waste of time, work repetition, and possible errors and inaccuracy. Moreover, LCA tools and results are sometimes difficult to understand and handle.

The data about the model (location, dimensions, building quantities..etc) is already in the BIM model, and there is no need of reentering this again due to it could result in errors,
misunderstandings and waste of time. Moreover, there is a need of including environmental criteria during the design phase in order to combine this with other criteria so that a sustainable design can be reached.

The real challenge for LCADesign was to achieve an efficient extraction of the BIM model data and import it into LCADesign in order to be used for the performance of the LCA assessment, achieving a real time evaluation and a continuous flow of information. The integration of LCADesign in the design process was sought.

6.3.10.2 ADVANTAGES

- It is a flexible tool:
  - It can be used in different geographical areas just by including the most suitable impact assessment indicators and databases for the area.
  - Another characteristic that positively contributes to the tool’s flexibility is that the user has the option of choosing the indicators that have to be included in the assessment in order to adapt the analysis to the project’s needs. This makes the tool more suitable for working as an assessing decision-making tool, since it can provide the information that the user needs, being easier to manage and understand the results. In addition, as different indicators can be analyzed the decisions taken will be informed decisions, because decisions can not be taken just based on the value of one indicator; if the best building performance wants to be achieved, the optimal equilibrium between different criteria has to be reached.
  - Moreover, this tool enables LCA calculation for the whole building or just for a specific material, enhancing its use for different purposes and applications. LCADesign is a versatile tool with different applications, due to it can be used for building design assessment or for materials assessment with eco-labeling or materials selection purposes; therefore, it can be used by different stakeholders with different purposes.

- It provides useful and understandable results, with benchmarking capacity:
  - The results provided are presented in different graphics, tables and reports. This contributes to a clear understanding of the building environmental performance by the different project stakeholder. As the results are presented in a graphical way, it is easier for designers and engineers with no training or specific knowledge in LCA field, to understand the output of the assessment; and therefore the effectiveness as a design assessing tool is improved. It is very important that the designers and engineers can access fast and easily the specific information needed for decision making.
  - One of the key aspects for decision making is the benchmarking assessment capacity due to the different design alternatives can be compared in order to select the most suitable one and with better performance. Furthermore, the results are given in the same units in all the alternatives in order to achieve an objective comparison between the different alternatives.
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✓ Moreover, the results show the hot spots where attention has to be focused to improve the building environmental performance.

✓ It performs a LCA of the whole building during its whole life cycle and also provides costs analysis. The fact that it also provides costs analysis is an added value due to average LCA tools do not include costs.

✓ Furthermore, the results are not just tables, graphics and reports but a project database with the LCA information is also included. Therefore, the BIM model is enriched with the environmental data. This is one of the most significant features of LCADesign, because it is a step towards achieving a completely integrated project development and building design.

It has a good materials database:

✓ LCADesign includes one of the richest and most complete materials databases.

Capacity for assessing design:

✓ Construction professionals can assess the environmental performance of a building easily and faster compared to traditional processes. They have access to the environmental information in order to take informed decisions during the design phase, including environmental criteria when designing. Furthermore, they can also compare different alternatives in order to be sure that the chosen alternative is the one with better performance.

✓ It performs an assessment of the resources consumption and emissions generated during resources acquisition, manufacture, transport, maintenance and replacement considering some use and occupancy behavior. Moreover, it also includes water and energy consumption during the use phase, based on a fixed design life.

✓ It brings the opportunity to building’s designers and engineers of having access to LCA and environmental assessment; otherwise the process will be very complicated and time consuming for them to integrate it during the design phase.

✓ It provides a real time environmental assessment avoiding data manual re-entering due to it is taken directly from the BIM model. Moreover, it provides a uniform information flow.

✓ It is an objective tool. The assessments do not depend on a personal judgment due to it is based on ratings comparisons of the different alternatives.

✓ Furthermore, due to it is easier to use than other common LCA tools, it contributes to a better understanding by project stakeholders of the environmental impacts of a building. It has the capacity of showing the environmental impacts of the building in a way that the stakeholders become conscious about them.

6.3.10.3 DISADVANTAGES

It has a lack of data for its worldwide application:
The availability of data for different geographical areas has to be improved. This is one of the main problems that all LCA tools have to face. The data quality and availability is essential for the assessment success, and the data has to fit with the project that is being assessed. LCADesign does not provide yet wide worldwide LCI data. Despite that LCADesign includes one of the richest and most complete materials database, the life cycle inventory and materials data is not so complete in an international framework, due to the data is mainly focused in Australia.

Changes in the design can not be performed directly:

If after analyzing the results some changes have to be performed, the changes implementation can not be done directly from LCADesign, they have to be implemented in the BIM software and then export the model again using IFCs. It will be better to perform the changes directly in the LCADesing, avoiding the process of implementing the changes in the BIM software and then importing the data into the project database.

Moreover, the building bill of quantities can not be directly accessed. This information is in the project database due to it is used for the environmental assessment calculations, but it is not shown. It will be convenient to show this information due to it will be very useful for the user in order to check if everything is included or if some changes are needed.

6.3.10.4 TOOL ANALYSIS (MULTICRITERIA EVALUATION)

Based on all the information gathered and reports read about LCADesign, users experiences, and the advantages and disadvantages already mentioned, a multicriteria evaluation following the already explained criteria has been developed in order to assess its performance as an integrated assessing tool for decision making during the design process.

**LCADesign SCOPE OF THE ASSESSMENT**

- **Components assessment:** LCADesign includes the assessment of the whole building considering environmental impacts from raw materials obtaining until maintenance and replacement; moreover it also includes the water and energy use during the usage phase for a defined design life. Despite, it includes an assessment of the usage phase, in order to achieve a more accurate assessment more development is needed; a sample of this need is the research of the CRC Construction Innovation for integrating in future LCADesing versions a Life Prediction System.

- **Life cycle:** The LCADesign capacity of assessing the whole building and also building materials during their whole life cycle enhances the utility and popularity of the tool. It gives designers and engineers the possibility of making an informed decision having an evaluation of the whole life cycle of the building performance. Moreover it is useful for materials selection due to it can also assess them. This flexibility can encourage its use as a design tool integrating it in the design process. Nevertheless, some further developments can be performed concerning the evaluation of all the phases of the life cycle.
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**LCADesign TOOL USE**

- **Type of user**: LCADesign, as it has been highlighted by some users, needs to improve some aspects in order to make its use more affordable for non-experts users.

- **Time**: LCADesign is able to perform real time assessment covering the whole building, building materials and comparing different alternatives in a lower time than the current LCA tools. This is one of the main strengthens of the tool that makes it more attractive for the users. Nevertheless further developments tend to reduce more the assessment time.

- **Changes implementation**: Changes in the model can not be performed directly from LCADesign, and it is necessary to perform them in the BIM software. This is something that could be improved in order to achieve a better integration between BIM and LCA.

- **3D Viewer**: LCADesign offers a 3D view of the model; this is a positive value of this tool that makes its use more intuitive for the users due to the fact that they can have a general view of the project. This feature can be attractive for the users.

**LCADesign RESULTS**

- **Alternatives comparison**: LCADesign enables an objective comparison of different alternative, in order to help the users with the selection of the best design option.

- **Results understandability**: LCADesign offers different results layouts, despite that they can be improved in order to make them more understandable.

**LCADesign DATA**

- **Data entry**: LCADesign is able to import the model data from the BIM model into the LCA tool. This is an important step forward to the effective integration of BIM and LCA, despite that further development is needed in this field.

- **LCI data**: LCADesign includes a rich LCI database, despite that it has to be improved, including more data for applying it worldwide.

- **Materials data**: LCADesign has a complete materials database, despite that it has to be improved including more data for applying it worldwide.

**LCADesign TOOL FLEXIBILITY**

- **Geographical application**: LCADesign does not offer yet worldwide databases, and this is something that has to be improved, in order to increase the tool flexibility and therefore its performance as a design assessing tool.
- **Selection possibility**: With LCADesign the users are the ones who select what they want to assess. This increases the quality of the design, due to decisions have to be taken considering different parameters not just a unique point of view, because the final design has to find a balance between different aspects.

The scores given to the different criteria according to the explained analysis are shown below in a figure where the scale of each sub-criterion is represented, and in tables showing the final scores obtained as the sum of all the sub-criterion scores multiplied by their weight inside each criterion. Finally a radial graph will be presented with the final evaluation.

**SCOPE OF THE ASSESSMENT**

![Figure 6.23. LCADesign Scope of the assessment criteria.](image)

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<th>Total Score</th>
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<td>4.8</td>
</tr>
<tr>
<td>Life Cycle</td>
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<td>8</td>
<td>3.2</td>
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</table>

**Table 6.1. LCADesign Scope of the assessment score.**
Figure 6.24. LCADesign Tool use criteria I.
Figure 6.25. LCADesign Tool use criteria II.

<table>
<thead>
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</thead>
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<td>7</td>
<td>2,45</td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td>30%</td>
<td>9</td>
<td>2,7</td>
</tr>
<tr>
<td></td>
<td>Changes implementation</td>
<td>20%</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>3D View</td>
<td>15%</td>
<td>10</td>
<td>1,5</td>
</tr>
</tbody>
</table>

Table 6.2. LCADesign Tool use score.
RESULTS

Figure 6.26. LCADesign Results criteria.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Partial Score</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternatives Comparison</td>
<td>50%</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Understandability</td>
<td>50%</td>
<td>8</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 6.3. LCADesign Results score.
Figure 6.27. LCADesign Data criteria I.


**Figure 6.28. LCADesign Data criteria II.**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Partial Score</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data entry</td>
<td>50%</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>LCI</td>
<td>25%</td>
<td>6</td>
<td>1.5</td>
</tr>
<tr>
<td>Materials database</td>
<td>25%</td>
<td>9</td>
<td>2.25</td>
</tr>
</tbody>
</table>

**Table 6.4. LCADesign Data score.**
TOOL FLEXIBILITY

Table 6.5. LCADesign Tool flexibility score.

<table>
<thead>
<tr>
<th>TOOL FLEXIBILITY</th>
<th>Weight</th>
<th>Partial Score</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographical application</td>
<td>50%</td>
<td>7</td>
<td>3.5</td>
</tr>
<tr>
<td>Selection possibility</td>
<td>50%</td>
<td>9</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
</tr>
</tbody>
</table>

Figure 6.29. LCADesign Tool flexibility criteria.
As it can be shown in the previous analysis, LCADesign is a quiet complete tool that tries to fulfill the requirements of a decision-making tool. It has a homogenous perform in all the fields evaluated.

LCADesign can be considered as a steep towards to the integration of LCA and BIM in order to achieve a completely integrated design procedure. Furthermore, it enables the integration of environmental criteria in the design, and makes LCA more accessible and understandable for non-experts.

Despite there are some aspects that have to be improved, LCADesign is a major achievement in the LCA field. With LCADesign the LCA of the whole building can be achieved in real time, taking the building data directly from the BIM model; this can encourage the designers and engineers to use the tool during the design phase, as they use other assessing tools for example for structures or systems calculations.

One of the main inconvenient of including the environmental assessment during the design phases is the data availability, the time and resources that have to be expended for this task and the need of an expert for its performance. These drawbacks, try to be solved with LCADesign.
Nevertheless, it has to be mentioned that during the information gathering about the tool it could be observed how, especially in the early stages of the project, it was referred as an “automated eco-efficiency assessment of commercial buildings direct form 3D CAD”. BIM was called 3D CAD, and this is something that should be avoided due to it could lead to misunderstandings. The building model is performed in a BIM tool such as ArchiCAD or REVIT, and naming it 3D CAD could make people think in just CAD instead of BIM. This is something that it has been started to change in the latest reports and presentations about the tool, and that should be very clear in order to help to understand the tool.

6.4 CASE STUDIED: BSLCA

6.4.1 PROJECT DEFINITION

This tool was developed by Olof Granlund Oy enterprise with the main scope of achieving an ecological design, being able to assess the building envelope and analyze the building services (Laine, et al., 2001).

The main purpose was achieving an integrated building design, liking the LCA tool with other tools such as architectural, structural, systems design etc., so that it is possible to take profit of the work that has already been done, and the available information instead of re-entering the same data again in BSLCA (Laine, et al., 2001).

Currently the tool is not available among the software offered by Granlund, and it is only applied for internal use of the company due to it is not ready for its application in wider markets, as it has been confirmed by Toumas Laine, director of Innovation and Development of Granlund Oy.

6.4.2 DEVELOPMENT FRAMEWORK

BSLCA was developed by the Finish Company Granlund in order to include environmental aspects during the design phase, trying also to address the problem of the lack of data for the LCA performance during the early design phases. This tool development was under the framework of a project funded by Finnish Technology Agency TEKES (Laine, et al., 2001).

Furthermore, as integrated design is sought, one of the objectives is to achieve the availability of the information that has been obtained during the design phase, during the later phases such as construction, operation and management (Laine, et al., 2001).

The importance of applying environmental aspects during the early phases was widely recognized by the developers. It was highlighted how different assessments can be performed in the different phases. In the conceptual phase, an evaluation of the environmental impacts and energy use of different alternatives considering orientation, different building shapes or structures, can be performed. In the next phase comparison of different technical solutions based
on more detailed information can be done. And finally, during the detailed design, the environmental impacts of the different alternatives can be compared (Laine, et al., 2001).

The scope of this tool was to achieve an efficient combination between the different Granlund’s tools for thermal simulations, building services and 3D modeling and visualization, in order to obtain a detailed project database that can be used and updated during the next project phases (construction, commissioning, operation and reuse). Therefore, the purpose of Granlund was to develop an efficient facility management system with a complete project database (Laine, et al., 2001).

The integrated Granlund’s life cycle information system is shown in the figure.

![Figure 6.31. Granlund's whole building life cycle information system. (Laine, et al., 2001)](image)

Moreover, the tool can be applied during the whole project life cycle as it is shown in the following figure.
6.4.3 HOW DOES IT WORK?

This tool is able to assess the environmental impact of the building envelope and the building services systems; different building systems can be assessed such as electrical systems, HVAC, etc. (Laine, et al., 2001).

BSLCA is based on a database where the information, which is stored hierarchically, is presented using a Windows interface for the user, as it can be seen below (Laine, et al., 2001).

![Figure 6.32. BSLCA applications during the project life cycle. (Laine, et al., 2001)](image1)

![Figure 6.33. BSLCA database interface. (Laine, et al., 2001)](image2)
Due to the database hierarchical organization, assessments with different scopes can be performed, analyzing different levels such as the building, or just a specific system (Laine, et al., 2001).

BSLCA is integrated with other Granlund software in order to create a global tool for the design of building services. All the needed information for the performance of the ecological assessment of the building envelope and the analysis of its systems is taken from the other interoperable software tools; therefore, BSLCA can take profit of the exiting information, so that less work has to be performed by the LCA tool (Laine, et al., 2001).

As it can be seen in the figure the BSLCA software receives data about the structures and geometry from “Architect CAD” by using IFC files, or if IFC compliant CAD software is not used for the building model, a Space Modeling Software “SMOG” can be used. The data about building services (“HVAC, electrical, building automation, kitchen and hospital equipment”) is taken from a systems’ design tool where the data is stored in a Building Service database compatible with BSLCA. The HVAC and Electrical networks are obtained from calculation software, and energy simulations are taken from the software “RIUSKA”, which is a comfort and energy simulation tool (Laine, et al., 2001).

In the figure below it can be seen a scheme of the data transfer of the building geometry and space through IFC files, and how the systems calculations are stored in the Building Services database (BS database).
BSLCA is able to perform an environmental assessment of the structure and technical systems of different design alternatives of the building (Laine, et al., 2001). The procedure is the following:

1- First the data about the building geometry, building envelope and calculated systems is taken from external software and included into the BSLCA database (C-SanD, 2001).

2- Then these data is related with the data from the BSLCA database about materials, products and environmental profiles (Laine, et al., 2001).

3- The life cycle inventory information is divided into different impact categories in order to calculate the value for the different indicators (Laine, et al., 2001).

4- Finally the results are shown using different displays, enabling the comparison between different alternatives (Laine, et al., 2001).

The results delivered by BSLCA include understandable comparisons between different alternatives. Moreover, the user has the possibility of selecting which level of the building hierarchy he wants to analyze. Different levels of assessment can be performed, from building level to more detailed components; obtaining as a result the environmental emissions calculated according to the selected assessment method (Laine, et al., 2001).

Furthermore, it is possible to make changes in some features of the analyzed solution and check the impact of these changes; for example, if a change is performed in a heating system, then the changes in the environmental performance of the heating system, of the whole HVAC system or of the building itself can be analyzed (Laine, et al., 2001).

Moreover, the characteristics of the assessment, including the weights of the environmental impacts and the results contents can be chosen by the user in order to adapt the assessment to the project’s needs (Laine, et al., 2001).

Some examples of the results obtained with BSLCA are shown below.
Figure 6.36. BSLCA example of characterization and emissions comparison of two alternatives. (Laine, et al., 2001)
Figure 6.37. BSLCA example of materials consumption comparison of two alternatives. (Laine, et al., 2001)
The next figures show a comparison between two materials and the other one a comparison between two possible operation and maintenance behaviors:

![BSLCA comparison of the emissions results of two piping materials. (Reinikainen & Laine, 2002)](image1)

![BSLCA comparison of two different operation and maintenance behavior. (Reinikainen & Laine, 2002)](image2)

As it can be seen, the tool enables comparison between different alternatives providing results in a format easy to understand and manage (Laine, et al., 2001).
6.4.3.1 DATA EXCHANGE

The data exchange format used by BSLCA is IFC. Nevertheless, for achieving the interoperability by means of IFC files more development is needed (Laine, et al., 2001). In order to make this task easier, Granlund developed BSPro, a middleware software for making easier the BIM models transfer from one software to another by using IFC (Granlund, n.d.).

Nevertheless, more development is needed due to not all the data can be transferred by IFC. It was only achieved the transfer of building geometry and structures by using IFC files. The data about system and equipment are automatically transferred by means of an unstandardized format database (the Building Services design database). Whereas the transference of energy consumption, ducting and piping data has to be done manually, whereas the HVAC and electrical systems need further development before achieving the IFC transfer (Laine, et al., 2001). These data flows for importing the building data into the BSLCA database, are shown in a scheme represented in the figure below.
6.4.4 PROJECT DATABASE

The BSLCA database contains:

- **Product library**: In this library data about actual products used for HVAC and electrical systems can be found. Moreover, if this data has been provided by manufacturers it will be classified by type, model and manufacturer labels (Laine, et al., 2001).

- **Structure library**: This library covers the project information and some typical building constructions. It is also linked with materials database (Laine, et al., 2001).

- **Default library**: It contains materials environmental profiles for Finland, including manufacturing and transportation, as published by VTT Building Technology. Some materials environmental profiles published by the Helsinki University of Technology are also included. Moreover, environmental profiles for energy forms are also available, including profiles of district heating and electricity published by VTT Building Technology (Laine, et al., 2001).

A scheme of BSLCA database is represented in next figure.
Furthermore, Granlund developed also an external general database for the whole project, the Building Service database (BS database). It includes the information about the building systems obtained from the different systems design tools, being used as the facility management database for the operation phase. Therefore, the information in the BS database will be available during the whole life cycle phases of the building (Laine, et al., 2001).

6.4.5 LIFE CYCLE INVENTORY

The life cycle inventory is included in the BSLCA database. It covers different environmental profiles published by VTT Building Technology and the Helsinki University of Technology. Therefore, LCI is only available for Finland (Laine, et al., 2001).

6.4.6 ENVIRONMENTAL INDICATORS

The environmental assessment can be performed following Ecoindicator 95, Decision Analysis Impact Assessment (DAIA) and Environmental Priority Strategy (EPS). It also offers to include new methods based on the estimation of resources consumption and emissions; scoring methods such as BREEAM can not be included (Laine, et al., 2001).

The EPS sets the methodology to follow for the LCA performance. This procedure follows the ISO 14040, 4042 and 14043 (currently ISO 14042 and 14043 have been substituted by ISO 14040:2006 and ISO 14044:2006). Nevertheless it gives a more detailed LCA methodology (Steen, 1999).

After all the calculation process, using established weights a total value of an indicator is obtained (Laine, et al., 2001).
6.4.7 EXAMPLES OF BSLCA IMPLEMENTATION

6.4.7.1 PRODUCT MODEL AND FOURTH DIMENSION (PM4D) (HELSINKI, FINLAND)

The Product Model and Fourth Dimension (PM4D) is a research project developed during the design and construction of the extension of the Helsinki University of Technology Auditorium Hall 600 (HUT-600) in Finland. The HUT-600 project lasted 17 months with a budget of 5 million $ (approximately 3.760.500 €). The original building was built in 1969 and the construction of the Auditorium extension with capacity for 600 people was started in April 2001 and finished in February 2002 (Fischer & Kam, 2002).

The project’s approach represents a contrast with the conventional construction projects. The main changes in the way of working were the emphasis on a collaborative and multidisciplinary environment; the avoidance of data re-entry; higher effort was dedicated to the design phases; consideration of life cycle criteria during the alternatives analysis; and all the stakeholders were working with the same model in a collaborative framework (Fischer & Kam, 2002). It could be said that this project was an implementation attempt of the new way of working that the construction industry is seeking.

The main purpose of the PM4D research project was to check the effectiveness of IFCs and some design and simulation tools. Moreover, data re-entry, which is a very frequent practice in the average construction processes, wanted to be avoided (Fischer & Kam, 2002).

This project focused its efforts on the achievement of (Fischer & Kam, 2002):

- Cost estimations
- Construction schedules
- Comfort design
- Energy analyses
- Environmental reports
- Life cycle cost studies

For this purpose the software shown in the following figure were implemented in the project.
The baseline of the project was the use of IFCs to achieve quick access to the needed information during the design phase. Moreover, the Senate Properties hired an online extranet for using it as the project database, in order to improve the project performance by means of an efficient access to the project data. This database could be accessed by all the stakeholders involved in the project, such as the designers and the contractors and subcontractors, having real-time access to the updated information. The project team highlighted the advantages of this database, due to they were able to observe less interruptions during their work (Fischer & Kam, 2002).

The main barriers that the project had to face were the lack of two-way exchanges, difficult data import and export, and software tools with non-mature IFC integration. Furthermore, if the project database consisting on an online project extranet, would have been developed properly, the different stakeholders could have gained more profit from its use during the later project phases such as construction (Fischer & Kam, 2002).

The software used in the project and the data exchange available when the project was developed are shown in the figure below. It has to be highlighted that some links already existed when the project was developed, such as the link between ArchiCAD and MagiCAD, but they were not used by the project team (Fischer & Kam, 2002).
As it can be seen in the figure the main problem was the lack of bidirectional models data transfer and efficient data exchange between the different design software.

One of the main purposes of PM4D project was the implementation of environmental criteria during the design phase. For this purpose the BSLCA software was included in project working framework. Therefore, the building quantitative values and materials descriptive information was directly imported into the BSLCA by using IFCs files (Fischer & Kam, 2002).
It was highlighted by the construction manager the benefits of including the life cycle assessment during the design phase, due to it contributed to the selection of the most suitable design option. The project team took profit of the results obtained from the BSLCA environmental assessment, and combined them with other criteria such as costs and aesthetics, in order to select the alternative with better performance (Fischer & Kam, 2002).

6.4.8 BSLCA EVALUATION

6.4.8.1 CHALLENGES

The challenges that this tool had to face concern efficient data transfer between different design, calculation and simulation software. One of the main purposes was to avoid manual data re-entry due to the already mentioned inefficiency and inaccuracy of this process. Furthermore, it also tries to avoid time and work waste trying to improve the project efficiency by taking profit of the already done work and data available.

Moreover, BSLCA was a part of a more ambitious project where the scope was to achieve a Building Services database that could be used as a facility management database during the whole life cycle of the building.

6.4.8.2 ADVANTAGES

It is a flexible tool:

- New methods for assessing resources consumption and emissions generation can be included in the tool, making the tool more flexible.

- Moreover, the user can select the assessment criteria in order to adapt the assessment to the project needs.

It provides useful and understandable results, with benchmarking capacity:

- BSLCA enables the comparison between different alternatives, trying to present the result in an understandable way using different graphs.

It has a materials and systems database:

- It has products and structure library and a default library including environmental profiles of different products and systems. This improves its performance, due to all these data is already available in the tool’s database.

Capacity for assessing design:

- It enables the comparison between design alternatives.

- It is integrated in a global project formed by different design software for achieving a Building Services database in order to be used during the whole life cycle phases of the project.
✓ It can be implemented in all the project life cycle phases.
✓ It shows the hot-spots highlighting where attention should be focused in order to improve the building environmental performance.
✓ It takes profit of the calculations of other software in order to improve the project efficiency and reduce the work to be done by the LCA tool.
✓ It enables the performance of calculations at different building levels, making the tool more flexible as an assessing tool.

6.4.8.3 DISADVANTAGES

Lack of an effective interoperability:

✗ The aim of reaching interoperability between different tools by using IFCs was not achieved. It was only achieved with building geometry and structure data transfer whereas the transfer of the rest of project data using IFCs files did not succeed. Moreover, some data such as HVAC and electrical systems had to be entered manually. Therefore, the aim was not fulfilled due to one of the main goals of the BIM and LCA integration is the avoidance of the data manual re-entry.

✗ The interoperability and data transfer was sought inside a framework based of Granlund software facilities. This can be the first step for achieving interoperability, however an efficient interoperability will be the one achieved among software independently of the enterprise that developed them. One of the features of the construction industry is the variety of stakeholders involved in the project, therefore each of them will use their own tools and an efficient data exchange will be achieved if data could be transferred among different software without forcing the use of a specific one.

✗ As development of the tool is needed, currently BSLCA is not available in the market, and it is just dedicated to internal used of Granlund Oy.

There is a lack of data for its worldwide application:

✗ The data included in the BSLCA database is only available for Finland due to it is based on data published by Finish institutions. This hinders the flexibility when using the tool, due to its application is just limited to Finland. Therefore, an important improvement has to be done concerning the geographical use of the tool and data availability if it wants to be used as an effective decision-making assessing tool.

Reduced scope of assessment:

✗ The assessment of the whole building life cycle can not be performed, due to it only enables the assessment of the building envelope, systems and technical equipment. For implementing the
tool during the design phase as an effective assessing tool, it should be able to make an assessment of the whole building.

- Its assessment methodology is very local and therefore it can not be applied in wider markets.

6.4.8.4 TOOL ANALYSIS (MULTICRITERIA EVALUATION)

Based on all the information gathered and reports read about BSLCA, users experiences, and the advantages and disadvantages already mentioned, a multicriteria evaluation following the already explained criteria has been developed in order to assess its performance as an integrated assessing tool for decision making during the design process.

BSLCA SCOPE OF THE ASSESSMENT BSLCA

- **Components assessment:** BSLCA enables the assessment of the building envelope and services systems from cradle to grave. Nevertheless the tool has to be improved in order to achieve the assessment of the whole building.

- **Life cycle:** BSLCA performs an assessment during the building whole life cycle. Nevertheless, further development is needed in this field due to the complexity of assessing all the building life phases.

TOOL USE BSLCA

- **Type of user:** The tool consists of a database with a Windows interface that presents the data in a hierarchically way, so that it is easier for the user to manage it. On the other hand, the data transfer was not achieved successfully and in some cases data has to be entered manually. Therefore, improvement is needed in order to make easier the user’s tasks.

- **Time:** As part of the required work has already been done by other software, BSLCA takes profit of it so that the work that has to be performed by the LCA tool is lower, achieving a faster assessment than a conventional tool. Nevertheless, further development is required in this field.

- **Changes implementation:** BSLCA enables the detection of the parts with worst environmental performance in order to implement the needed changes. Nevertheless, the changes can not be performed directly from BSLCA. This is something that should be developed in order to improve the performance of the tool as an integrated part of the design process.

- **3D Viewer:** BSLCA does not offer a 3D View of the model. This could be improved due to it will be helpful for the user.

-
CHAPTER 6: IMPLEMENTATION

BSLCA RESULTS

- Alternatives comparison: BSLCA enables the comparison between alternatives, in order to assess the decision-making process.

- Results understandability: BSLCA was developed seeking the assessment tool efficiency, trying to offer understandable results in an easy way for the user to understand them.

DATA BSLCA

- Data entry: One of the main objectives was the achievement of an efficient data transfer, and it was not fulfilled. Important development is needed in this field due to the aim was the achievement of interoperability between BSLCA and other design tools. It was only achieved for building geometry and structure data by using IFCs files; and in the case of HVAC and electrical systems data have to be entered manually, and this was what the tool tried to avoid.

- LCI data: The LCI data available in the BSLCA database is only applicable to Finland. Therefore, further development is needed in this field in order to achieve a more completed database for implementing the tool worldwide.

- Materials data: The same problem appears with the materials database, which also needs improvements.

TOOL FLEXIBILITY BSLCA

- Geographical application: The tool can only be applied locally, this is one of the reasons why the tool is not currently available in the market and it is only used for Granlund’s internal purposes. Improvement is needed in this field, being necessary more data availability.

- Selection possibility: The user can select the characteristics of the assessment being able of assessing different building levels. Moreover, the relevance of the environmental effects of different aspects in the whole performance can be determined. Nevertheless, further development is needed concerning the analysis options offered.

The scores given to the different criteria according to the already explained analysis are shown below, in a figure where the scale of each sub-criterion is represented, and in tables showing the final scores obtained as the sum of all the sub-criteria scores multiplied by their weight inside each criterion. Finally a radial graph will be presented with the final evaluation.
CHAPTER 6: IMPLEMENTATION

SCOPE OF THE ASSESSMENT

Figure 6.45. BSLCA Scope of the assessment criteria.

<table>
<thead>
<tr>
<th>SCOPE OF THE ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria</td>
</tr>
<tr>
<td>Components Assessment</td>
</tr>
<tr>
<td>Life Cycle</td>
</tr>
</tbody>
</table>

Table 6.6. BSLCA Scope of the assessment score.
Figure 6.46. BSLCA Tool use criteria I.
### TOOL USE

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Partial Score</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of User</td>
<td>35%</td>
<td>6</td>
<td>2.1</td>
</tr>
<tr>
<td>Time</td>
<td>30%</td>
<td>6</td>
<td>1.8</td>
</tr>
<tr>
<td>Changes implementation</td>
<td>20%</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>3D View</td>
<td>15%</td>
<td>2</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>5.2</strong></td>
</tr>
</tbody>
</table>

Table 6.7. BSLCA Tool use score.
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RESULTS

Figure 6.48. BSLCA Results criteria.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
<th>Partial Score</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternatives Comparison</td>
<td>50%</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Understandability</td>
<td>50%</td>
<td>7</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 6.8. BSLCA Results score.
Figure 6.49. BSLCA Data criteria I.
Table 6.9. BSLCA Data score.
Figure 6.51. BSLCA Tool flexibility criteria.

<table>
<thead>
<tr>
<th>TOOL FLEXIBILITY</th>
<th>Criteria</th>
<th>Weight</th>
<th>partial Score</th>
<th>Total Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geographical application</td>
<td>50%</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Selection possibility</td>
<td>50%</td>
<td>7</td>
<td>3,5</td>
</tr>
</tbody>
</table>

Table 6.10. BSLCA Tool flexibility score.
As it can be seen in the graph, BSLCA needs further development in order to mainly improve its data availability, the tool use and flexibility and the scope of the assessment.

Improvement is needed concerning interoperability due to it was not reached. Despite the framework in which the tool is included is a step towards tools’ interoperability, the data transfer was not completely achieved.

More data has to be included in the BSLCA database in order to have materials and LCI data applicable to more areas and not just Finland.

Lower development is required concerning results due to they include understandable comparisons between different alternatives. Moreover, the user has the chance of selecting which level of the building hierarchy he wants to analyze; besides, it is possible to check the impact of the performed changes at different building levels, and this is a key characteristic that shows the effect that different aspects have in the environmental performance of the whole building and during its life cycles. Furthermore, the tool can be used during all the phases of the project life cycle.
6.4.9 COMPARISON BETWEEN THE ANALYZED TOOLS

After analyzing the proposed tools their strengths are going to be highlighted in order to foster and maximize them, and be taken as a reference for future developments; whereas their weaknesses are going to be shown in order to encourage future improvements.

Both tools are LCA oriented software that try to achieve interoperability between BIM and LCA in order to achieve automated data transfer avoiding manual data re-entry.

LCADesign has a wider scope of the assessment due to enables the environmental assessment of the whole building, whereas BSLCA only assess the building envelop and technical systems. Therefore, LCADesign performs a more completed assessment of the whole building than BSLCA, despite both can be improved in this field.

Moreover, both enable materials assessment. This is a useful feature for assessing designers and engineers with materials selection.
LCADesign achieved a better interoperability by using IFCs files, being able of importing the building quantity data from the BIM model into the LCA software. Whereas, BSLCA achieved worse results concerning integration, nevertheless, it has to be highlighted that the aim was more ambitious than the LCADesign one. Despite that BSLCA only assess the building envelope and technical systems, it sought the achievement of interoperability between different design and simulation software. Finally, BSLCA is able to transfer by IFCs files the building geometry and structures, whereas the systems calculations data is transferred by a nonstandard database format, and the energy consumption and ducting and piping data has to be done manually.

BSLCA global concept is a very positive one, due to it tries to create a complete building database where the data obtained from the different design software is included, so that tools such as the LCA one can take profit of the already done work, creating synergies between the different simulation and design tools. Moreover, simulation tools such as RIUSKA are included in this framework, and therefore, the possibilities of a deeper analysis of the later project phases such as operation and maintenance, increase because more data is available. Furthermore, the common project database will serve the user in the next project phases. This idea is very related with the new way of working that BIM requires, based on data sharing and multidisciplinary collaborative framework.

Nevertheless, BSLCA focus the interoperability of the design tool within tools developed by the same enterprise, in this case Granlund. The ideal situation will be the achievement of this integration between all kinds of software not taken into account the corporation that have developed them. Different stakeholders are involved in each project and these stakeholders can change from one project to another; they use their own tools and they can not be obliged to use one tool from a specific vendor because they are taking part in a project where this tool from this specific vendor is used. If an effective collaborative framework wants to be achieved interoperability has to be reached.

The data availability is one of the weakness aspects of both tools. Nevertheless LCADesign includes more data and it is starting to include data not just for Australia, whereas BSLCA only offers available data for Finland. Special attention has to be focused on the data availability and quality due to it is a very restrictive aspect of LCA.

A positive aspect of both tools is that they enable comparison between alternatives, being useful as an assessing tool during design phase. Hot-spots can be detected and different alternatives can be proposed by the design team in order to improve the environmental performance; after a comparison taking into account different criteria, they can select the most suitable one.

Finally, both tools try to present results in an understandable way because for being used by the design team as decision-making assessing tools, its use has to be easy and the results understandable for real time decision-making.
Construction industry is turning into sustainability. Nevertheless currently construction industry is inefficient enough, and this has to be avoided in order to achieve sustainability. The construction industry inefficiency has its origin in different features such as lack of innovation and technological development implementation, lack of cooperation among the different stakeholders involved, and waste of project resources due to the repetition of tasks that have already been done.

Therefore, in order to achieve sustainability, a change is highly needed in the construction industry. The way of working has to be changed, and BIM can be taken as an exponent of this change and new construction industry philosophy.

Currently, BIM is starting to be accepted and widely implemented, as a step towards construction industry change. Nevertheless, it is not a matter of changing software, it is a matter of changing the way of working. For achieving successful BIM implementation, collaboration between the multidisciplinary stakeholders involved in the project is needed, having direct access to the updated project data.

The early project phases are the ones with higher capacity of influencing the project and adding value. Therefore, sustainability has to be implemented since the early project phases, including sustainable criteria as design criteria.

Sustainability is based on equilibrium between environmental, economic and social aspects. Therefore, how can these three criteria have to be assessed during the design phase in order to achieve a sustainable building.

On the one hand, BIM tools can perform costs and building comfort assessment in a collaborative and multidisciplinary working framework, trying to cover economic and social criteria. And on the other hand, LCA tools perform an environmental assessment, and have the capacity to show the stakeholders the environmental performance of the building in order to make them aware of the environmental impacts.

The combination of these two tools will cover as far as possible the sustainable criteria during the design phase, improving the tools performance due to the synergy created between both of them. BIM can answer some of the main drawbacks of LCA tools such as the lack of building data during the early design phases, or the manual data re-entry that make LCA tools less used by designers and engineers. Therefore, if these drawbacks were solved, LCA will become more popular among designers and engineers, and it will be applied during design phase.

The advantages of LCA and BIM integration are clear, therefore, the way of integrating them has to be sought.

The use of IFCs files for data transfer is one of the most popular solutions that try to solve this question. Moreover, IFC has been developed by a nonprofit entity as an international standard, and has nothing to do with software enterprises.
The analyzed tools used this solution, but the perfect integration between LCA and BIM able to perform a complete LCA of the whole building during its whole life cycle has not been reached yet; nevertheless, important progresses have been done in this field.

The desirable situation will be the achievement of efficient interoperability between BIM tools and different design, simulation and LCA tools. In order to achieve a common project database with all the project data, so that all the stakeholders could have access to the updated information, and take profit of the already developed work. Moreover, this interoperability should be achieved between software of different vendors (not just between software of the same vendor) in order to increase the project flexibility.

The most common way of storing information within the BIM framework is by exporting a file from one application and importing it in another application, in a way that several copies of the same data have been created during the process of exporting and importing. Nevertheless, it will be more effective if the user instead of downloading a file he just asks a question and receives an answer.

This idyllic situation has not been reached yet but the construction industry is working on it. Perhaps one of the most complicated aspects to fulfill will be the interoperability between different vendors due to business interests are involved, but its achievement will be very beneficial for the performance of the construction industry

Nevertheless, more affordable aims can be set now, as LCA implementation during the early project phases so that the construction industry integrates it as a design assessing tool. For achieving this some of the main drawbacks of LCA have to be improved; BIM and LCA integration could solve some of these drawbacks such as lack of building data and time consuming data re-entry.

Moreover, the integration of LCA and BIM will contribute to the achievement of a more complete assessment of the building taking into account the three main sustainability criteria (environmental, economic and social).

7.1 THE MAIN FIELDS WHERE FURTHER DEVELOPMENT IS NEEDED FOR ACHIEVING BIM AND LCA INTEGRATION

For achieving the integration of the LCA and BIM as an efficient assessment tool, further development is needed in the following fields:

- Encourage construction industry stakeholders to use LCA during early project phases. LCA use during design phases can be boosted by its integration with BIM, due to BIM is becoming widely used in the construction industry; moreover, LCA is starting to be included as a criteria in building certificates such as LEED, DGNB and BREEAM, and this could also boost LCA implementation.
- Data availability for different geographical areas is required, in order to achieve worldwide applicable tools.

- Improvement of the data transfer between BIM and LCA in order to take profit of the work that has already been done (using not only the building geometry data but also different simulations and calculations required by LCA, which can be performed with other tools).

- Work on the achievement of a complete project database, where all the project data is included and can be used in later phases such as operation and maintenance. A common database where all the stakeholders can have access to the updated project data, and where the data of the whole project during its whole life cycle is included; enabling a real time access the to the updated data and also the comparison with the “as built data” in order to learn from the experience. Nowadays some projects use for this purpose an online database, but further development is needed due to there are some disadvantages such as security or intellectual property of the work that have to be solved.

- Further work is required for achieving a LCA tool that can be easily used by non-experts users, in order to encourage its use by designers and engineers during the design process. Moreover, the results obtained from the LCA tool have to be easily understood by non-expert users.
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