POLITECNICO DI MILANO
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A GREEN BIM FRAMEWORK FOR SUSTAINABLE BUILDING PROJECT MANAGEMENT - A CASE STUDY AT JACOBS ITALIA S.P.A.

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Master thesis presented to the Graduate Program in Building and Architectural Engineering of Politecnico di Milano as a prerequisite to obtain the master's degree in Building and Architectural Engineering.

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“So, remember to look up at the stars and not down at your feet. Try to make sense of what you see and wonder about what makes the universe exist. Be curious. And however difficult life may seem, there is always something you can do, and succeed at. It matters that you don't just give up.” (Hawking, 2016)

ABSTRACT

Introduction: The construction industry has experienced significant transformations in the last decade, from the awareness of environmental responsibility to the use of digitalized processes. With that, conventional project management became inadequate to handle all information and details that sustainable projects entail. **Objective:** This research aims to propose a framework that helps to improve the management of LEED projects by investigating the difficulties and impacts related to the credits' achievement and by identifying BIM use cases and parameters. **Research method:** After an exhaustive literature review, a lean new project management framework to deal with LEED projects is developed. An exploratory case study with quantitative and qualitative approaches is carried out at Jacobs Italia S.p.A., considering several sources of evidence. **Results:** A Green BIM framework presents the credits' difficulty of achievement, points' contribution, and impacts, and identifies BIM model uses and parameters for each credit, therefore improving the sustainability assessment process. A dynamic ranking is proposed giving teams the possibility to classify the LEED credits according to the project priorities and constraints. **Conclusion:** Finally, the management of LEED projects can be improved if sustainability targets are set in collaboration with sustainability teams. Furthermore, to increase a project's performance, it is essential that other project's actors, besides the sustainability professionals, understand the LEED credits and what information will be used throughout the sustainability assessment processes.

Keywords: Green BIM; Project Management; Sustainable buildings; LEED assessment; Green construction.

ABSTRACT (ITALIAN)

Introduzione: L'industria delle costruzioni ha vissuto significative trasformazioni nell'ultimo decennio, dalla consapevolezza della responsabilità ambientale all'uso di processi digitalizzati. In conseguenza a ciò, le tecniche convenzionali di project management sono diventate inadeguate a gestire tutte le informazioni e i dettagli che i progetti che ambiscono a obiettivi di sostenibilità comportano. **Obiettivo**: Questa ricerca si propone di proporre un quadro di riferimento che aiuti a migliorare la gestione dei progetti LEED, indagando le difficoltà e gli impatti legati al raggiungimento dei crediti e individuando casi e parametri di utilizzo del BIM. **Metodo**: Dopo un'esaustiva analisi della letteratura scientifica viene sviluppato un framework di riferimento per gestire in modo lean progetti LEED. Presso la Jacobs Italia S.p.A. viene condotto un caso di studio esplorativo con approcci quantitativi e qualitativi, considerando diversi esempi. **Risultati**: Un framework Green BIM presenta la difficoltà di raggiungimento dei crediti, il contributo dei punti e gli impatti, e identifica gli usi e i parametri del modello BIM per ogni credito, migliorando così il processo di valutazione della sostenibilità. Viene proposta una classifica dinamica che dà ai team la possibilità di classificare i crediti LEED in base alle priorità e ai vincoli del progetto. **Conclusioni**: Infine, la gestione dei progetti LEED può essere migliorata se gli obiettivi di sostenibilità sono fissati in collaborazione con i team di sostenibilità. Inoltre, per aumentare le prestazioni di un progetto, è essenziale che gli altri attori del progetto, oltre ai professionisti della sostenibilità, comprendano i crediti LEED e quali informazioni saranno utilizzate durante i processi di valutazione della sostenibilità.

Keywords: Green BIM; Project Management; Sustainable buildings; LEED assessment; Green construction.

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1 - INTRODUCTION

The construction industry has been facing several transformations that impact its final products and the sector's management processes. These transformations can be related to many aspects, but especially to environmental awareness and technology applications.

The environmental responsibility awareness started to become more evident from the 90s when sustainable buildings were being constructed and when the first rating systems were developed to assess those buildings' performance, therefore mitigating the environment's impact. Since then, it has already been proven that buildings are responsible for a significant part of the total energy consumption and of the global greenhouse gas emissions. In Europe, for example, buildings accounted for 40% of the total energy consumption of the Union (Directive 2010/31/EU, 2010), proving that the construction industry has a significant impact on climate change. Moreover, the United Nations' release of the seventeen sustainable development goals encouraged the industry to be more engaged with sustainability. As a result, the number of green buildings increased together with the increase in the number of certifications used to assess these sustainable buildings' performance.

Another transformation that has impacted the sector is the use of technology in different areas of application. It is known that the construction industry has a long record of low productivity and digitalization (Barbosa et al., 2017), mainly when compared to other industries, such as manufacturing and even agriculture. Although this is still a reality, the sector has improved and become more digitalized. From 2010, the adoption of building information modeling and virtual design and construction, as an example, increased the digitalization index of the industry and enhanced the quality of the industry’s products. The use of these technologies has brought more quality, accuracy, agility, and more information that can enhance the project's processes and representation.

These transformations were accompanied by additional project's requirements and data that could result in low project performance and failure to achieve success if not well managed. The management of engineering and construction projects that account for sustainability and technology in its scope became more complicated than usual due to extra project's needs, such as multidisciplinary and collaborative work between all actors of a project, high performing systems, early decision-making, commitment to sustainable development, among many others. Therefore, the traditional project management method has become inadequate to handle all the project's information and requirements. There are other project management methods besides the traditional, and one of these methods is focused on the construction industry. Lean construction has been proposed by Koskela (1992) from an adaptation of the Lean philosophy. Even though lean construction has been adapted to the sector, its use in construction and engineering processes are not yet the same. The application of lean construction is much more spread in construction site processes than in engineering processes. Hence, a more particular method should be considered to enhance the project's performance and guarantee that the project’s goals will be achieved and that no resources will be wasted.

The use of an appropriate management method brings many benefits to the entire production chain, but finding a perfect match is not easy. That is why it has been decided to investigate the LEED certification and the sustainability assessment of green buildings and propose a framework that will help to improve the management of LEED projects.

1.1 - PROBLEM FORMULATION

This thesis intends to study project management and its application on sustainable construction projects, considering the following research question: How to improve the management of green construction projects, specifically, a project that seeks the LEED certification?

1.2 - OBJECTIVE

1.2.1 - GENERAL OBJECTIVE

The goal of this research is to propose a framework that helps to improve the management of LEED BD+C NC v4 projects.

1.2.2 - SPECIFIC OBJECTIVES

1. Map project management methods against sustainable construction projects;
2. Investigate the LEED BD+C NC v4 rating system, its difficulties, points' contribution and impacts on the project;
3. Identify BIM use cases and parameters to enhance methods;

1.3 - THEORY BUILDING

Considering the changes that the sector has been facing, the need for a method adaptation, and knowing that methods that focus on the construction industry are not entirely adopted by engineering processes, this thesis intends to propose a framework that will help to improve the management of sustainable projects. This proposal will be developed throughout a case study that will investigate the current management practices during the sustainability assessment processes of an engineering company, investigate the LEED rating system difficulties, points' contribution and impacts, and identify BIM use cases and parameters to enhance methods.

The proposed framework will provide a foundation for a sustainable building process. It will help the design team, and other actors understand important points related to the LEED requirements. Therefore, a better understanding of the LEED difficulties, impacts, and possible BIM application will improve the management of a green construction project, enhancing the design and sustainability assessment processes' performance, helping the actors to define the project's sustainability targets better considering LEED since the initial phases of the project.

1.4 - STRUCTURE OF THE THESIS

The research is divided into six chapters described in the following.

Chapter one (Introduction) introduces green construction project management, the research purpose, objectives, and justification. Moreover, the structure of the work is described.

In chapter two (Theoretical foundation), the thesis's essential topics are addressed in-depth, such as project management, sustainability, green construction, and Building Information Modeling.

Chapter three (Systematic literature review) reviews articles that studied project management and sustainability assessment of buildings (Green Construction Project Management). The literature review is done to understand questions already answered by existing studies related to the topic and understand where there is a knowledge gap. Previous researches are essential to underline more objective and insightful questions on the same topic.

The theoretical foundation (Chapter two) and the discussion over the latest developments (Chapter three) on green construction project management call attention to points that are going to be covered by the case study (Chapter five).

Chapter four (Methodology) describes the investigation process of the thesis. It starts with the characterization of the research method and the definition of the case study. Then, it delineates the research design and explains the data collection and analysis technique. Finally, it presents the research limitations.

The results of this thesis are presented and discussed in Chapter five. This chapter is divided into three stages: Stage one is related to specific objective number one (1. Map project management methods against sustainable construction projects). Stage two is related to specific objective numbers two and three (2. Investigate the LEED BD+C NC v4 rating system, its difficulties, and impacts on the project; 3. Identify BIM use cases to enhance methods). Stage three is about the main objective of this thesis, the proposal of a framework that helps to improve the management of LEED BD+C NC v4 projects. In addition to the framework presentation, a dynamic ranking will also be presented, and an example will be explained. This ranking will give project’s teams the possibility to set their own LEED priorities according to the project requirements and constraints.

Finally, the sixth chapter (conclusion) concludes the research and proposes possible future research topics on Green Construction Project Management and sustainability assessment of projects.

After the conclusion of the thesis, the bibliographic references are listed, followed by an appendix and two annexes.

2 - THEORETICAL FOUNDATION

This chapter sets the core concepts of green construction project management. The chapter is separated into the following conceptual sections: project management, sustainability, green construction, and building information modeling (BIM). The first includes the definition of project management, its methodologies, life cycles, and processes. The second explains what sustainability is, its history, current developments, and its application with project management. The third, green construction, highlights the relationship between construction and sustainability and explains green construction rating systems. The last conceptual section of this chapter is on BIM: it includes the definition of BIM, its relationship with green construction, and its contribution to the sustainability assessment process. Finally, a summary of the chapter is presented.

2.1 - PROJECT MANAGEMENT

Project management has been used for thousands of years before the term was even defined and used. Project management involves different areas of knowledge. It has several phases that vary according to the adopted approach, and its development is a crucial part of achieving a project's success. To better understand what project management is, it is fundamental first to define what a project is from different viewpoints:

For the International Organization for Standardization (ISO), a project is "a set of coordinated and controlled activities with a start and finish dates, undertaken to achieve an objective conforming to specific requirements including the constraints of time, cost and resources" (International Standards Organization, 2015, p. 15).

According to the Project Management Body of Knowledge (PMBOK), a project is "a temporary endeavor undertaken to create a unique product, service, or result" (Project Management Institute, 2017, p. 4). The PMBOK is a guide for project management good practices developed by the Project Management Institute (PMI), one of the most important organizations on project management worldwide.

For PRojects IN Controlled Environment (PRINCE2), a worldwide used management method, project is "a temporary organization that is created for the purpose of delivering one or more business products according to an agreed business case" (Axelos, 2017, p. 8).

With the explanation of what a project is, it is now easier to understand project management definition according to different perspectives, since it can vary depending on the source. For ISO, project management is the "application of methods, tools, techniques, and competencies to a project. Project management includes the integration of the various phases of the project life cycle" (ISO, 2012). ISO 21500 continues saying that:

> Project management is performed through processes. The processes selected for performing a project should be aligned in a systemic view. Each phase of the project life cycle should have specific deliverables. These deliverables should be regularly reviewed during the project to meet the requirements of the sponsor, customers and other stakeholders (ISO, 2012).

Another well recognized definition of project management is given on the PMBOK:

> Project management is the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements. Project management is accomplished through the appropriate application and integration of the project management processes identified for the project. Project management enables organizations to execute projects effectively and efficiently (Project Management Institute, 2017, p. 10)

For PRINCE2 , “project management is the planning, delegating, monitoring and control of all aspects of the project, and the motivation of those involved, to achieve the project objectives within the expected performance targets for time, cost, quality, scope, benefits and risk” (Axelos, 2017, p. 9).

For the Association for Project Management (APM):

> Project management is the application of processes, methods, skills, knowledge and experience to achieve specific project objectives according to the project acceptance criteria within agreed parameters. Project management has final deliverables that are constrained to a finite timescale and budget (APM, 2019).

All definitions given above follows the idea that project management is a practice used to achieve, in the best way possible, the goals of a project using the available resources.

For a company to go from its current position to a future one, it is necessary to develop a strategy and to pass through some processes. Projects are means of achieving the goals, so they should be aligned within the organization's strategic plan. The goal is what is desired to achieve, and the strategy is how the company is going to position itself to get a competitive advantage that will translate to superior performance (Porter and Roach, 1996). Which comes to the point that “effective and efficient project management should be considered a strategic competency within organizations” (Project Management Institute, 2017, p. 11).

Project management has different lines and it is essential to have a background on modern project management to understand the need for having different methodologies and philosophies. Over the years, companies noticed that to increase their productivity, an improvement in the organizational processes was necessary. As human life developed, these processes' improvements happened, and they can be divided into four waves, being the first, the industrial era.

At the beginning of the 20th century, the publication of "The scientific principle of management" from Frederick Taylor, in 1911, opened the discussion across the topic. Taylor declared that by optimizing the way the work was done, productivity would increase. Moreover, he proposed that workers and managers should cooperate: Scientific management has, from its very foundation, that employers and employees' interests are the same (Taylor, 1911). Around that same time, Fordism arose with the concept of mass production. In addition to the idea of increasing productivity and simplifying the work, the mass production concept also reduced the production’s cost (Womack et al., 1990). Taylorism and Fordism were two significant management concepts of the industrial era, followed by Toyota's Production System (TPS). Like the previous systems, the TPS also focused on higher productivity and efficiency. However, it had a different arrangement in its processes that included interaction with suppliers and customers, considered product quality, and that focused on minimizing waste (Womack et al., 1990). This last feature is why the TPS is considered to be the precursor of lean manufacturing, the second kind of processes' improvement. Around the 70s, was the first time that quality management was discussed with the idea of creating organizational awareness about standardization processes seeking continuous improvement.

The third wave of processes' changes happened in the 90s and can be called reengineering processes. The focus was on the re-think and re-design of the processes to match the organization's mission. As a result, there was an improvement in customer satisfaction, a decrease in operational costs, and reduction in defects in the products. Until the end of the century, although there were changes in the processes, a linear behavior was observed, which followed the traditional project management methodology proposed by the PMBOK. The first version of the Guide was published in 1996 with the idea of standardizing accepted project management information and practices.

With the advancements of computers and the development of information technology, new processes arose, as well as the need for a new project management methodology. In 2001, The Agile Manifesto brought the discussion of the need for a new methodology for software development. This methodology was created to explore feasibility in short cycles and quickly adapt based on evaluation and feedback (Project Management Institute, 2017, pt. Agile practice guide). Nowadays, the agile methodology is used not only for software development projects and can be adapted for any type of project. During all these years of processes' refinements, project management tools and techniques were also developed to help visualize the project's development. Some of them are Gantt bar charts, Critical Path Method, Scrum, Earned Value Method and Critical Chain Project Management, among many others.

2.1.1 - TRADITIONAL

The traditional methodology of project management is also called predictive, waterfall, or serial. This methodology follows a sequential linear process driven by a plan and has a high certainty level. The significant feature of predictive methodology is how much plan is done at the beginning of the process with a detailed identification of the requirements, and separation of the work in packages and deliverables. The team working on a traditional project aims to minimize change during the process by creating detailed requirements and plans at the beginning of the project, so the constrains can be articulated, which will later be used to manage cost and risk. Monitoring and controlling the process is needed to understand if there are changes, and if these changes can affect the project's scope, schedule, or budget (Project Management Institute, 2017).

Traditional project management follows the sequential process of initiating, planning, executing, monitoring and controlling, and closing, which are better explained later in this chapter. Moreover, it has ten knowledge areas that a project should contain. In this methodology, the delivery of the business value is only done at the end of the project. The project life cycle can be defined by analyzing the type of requirements, activities, delivery, and goal of the project. These characteristics will determine what life cycle a project is more likely to have. A traditional project life cycle has high certainty due to the planning process that drives the work with a low rate of change and fixed requirements. Moreover, it has a low frequency of delivery. The project's characteristics that define the life cycle are defined as the following.

- Requirements: Fixed;
- Activities: Performed at once;
- Delivery: Single (by the end of the project);
- Goal: Manage the knowledge areas.

Figure 2.1 - Predictive life cycle – from traditional methodology.

Source: (Project Management Institute, 2017).

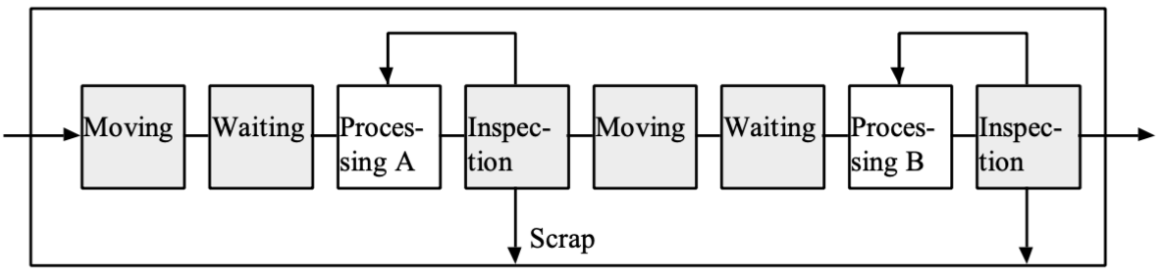
2.1.2 - LEAN

The term 'Lean' to name a production system based on the Toyota manufacturing industry was used in the report *The machine that changed the world* (Womack et al., 1990). The lean manufacturing process focuses on reducing waste and non-value-added activities in a project while maximizing productivity, cost efficiency, conformance quality, and customer value (Womack et al., 1990). As described by Ballard and Howell (2003), the features of the lean system were to produce "more and better in less time, in less space and when using fewer labor hours than the mass or craft production systems that preceded it".

According to Koskela (1992), the new production philosophy (lean) is a combination and generalization of models from other fields such as the just in time and quality movement, which resulted in the development of a model that covers all important features of production.

> "Production is a flow of material and/or information from raw material to the end product. In this flow, the material is processed (converted), it is inspected, it is waiting, or it is moving. These activities are inherently different. Processing represents the conversion aspect of production; inspecting, moving and waiting represent the flow aspect of production. Flow processes can be characterized by time, cost and value. Value refers to the fulfillment of customer requirements. In most cases, only processing activities are value-adding activities. For material flows, processing activities are alterations of shape or substance, assembly and disassembly" (Koskela, 1992).

Figure 2.2 - Production as a flow process.



Source: (Koskela, 1992)

The studies on lean philosophy have developed some principles to guide the design, control and improvement of the flow process. Koskela (1992) highlights that it is unusual to devise the best possible process only by design but designing and implementing provides a starting point to continuous improvement.

Koskela (1992) listed the eleven principles of lean as:

1. Reduce the share of non-value-adding activities.
2. Increase output value through systematic consideration of customer requirements.
3. Reduce variability.
4. Reduce the cycle time.
5. Simplify by minimizing the number of steps, parts and linkages.
6. Increase output flexibility.
7. Increase process transparency.
8. Focus control on the complete process.
9. Build continuous improvement into the process.
10. Balance flow improvement with conversion improvement.
11. Benchmark.

These principles can be used for every process, not only for improvement of production but also for the management of an enterprise. In the report published by Womack et al. (1990) there was a chapter dedicated to the management of a lean enterprise (chapter 8), in which the authors affirm that to succeed in managing a lean enterprise, "lean producers must approach the tasks of finance, personnel management, and global coordination in a very different way from mass-producers". When it comes to finance, it was observed that the lean producers are patient, extremely long-term in orientation, very well informed, and critical to inadequate performance. These characteristics reflect in considerable knowledge that reduces the risks of failure and result in heavy investment to finance corporate (Womack et al., 1990). In personnel management, the main difference is that in lean enterprises, a career path is provided to each employee and that decision making and problem solving are the most important part of any job. In other words, team members are shifted to subsequent teams, and they may be asked to learn new skills as they move through their careers, and "the capacity to solve increasingly difficult problems is the most meaningful type of achievement" (Womack et al., 1990). The global coordination approach had a long narrative in the report, from presenting five advantages of becoming a global enterprise to specifying the multiregional enterprise, in which they proposed a new corporate form that considered the following features: Integrated and global personnel system that promotes personnel from any country in the company as if nationality did not exist; A set of mechanisms for continuous, horizontal information flow among the enterprise activities, and; A mechanism for coordinating the development of new products in each regions, facilitating their sale as niche products in other regions (Womack et al., 1990).

All these features of the lean production system were learned from the manufacturing industry. Since lean started to be studied, much potential was observed to apply the lean philosophy and its principles in other industries as well.

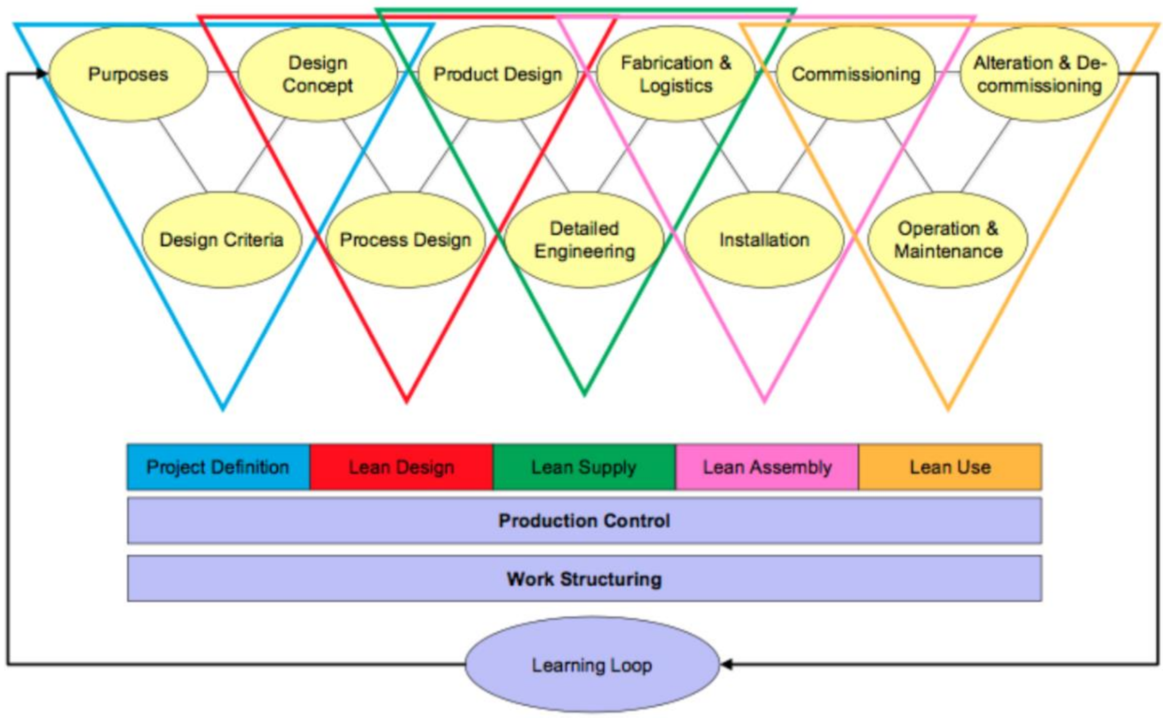
2.1.2.1 - LEAN CONSTRUCTION

Late in the 80s, studies have already recognized the lack of sufficient conceptual framework for construction project organizational design, and that project management for construction had to be further studied (Koskela, 1992) (Laufer and Tucker, 1987). In 1992, Lauri Koskela gave a new interpretation to the construction industry based on the new lean philosophy and proposed that construction adopt the new production philosophy (Koskela, 1992). The year after Koskela's publication, researchers decided to adopt the term 'Lean Construction' to apply the lean philosophy and its principles into the construction industry. For Ballard and Howell (2003), "construction is one among many types of project-based production systems" so when engineering and construction are planned to be delivered while maximizing value and minimizing waste, they are said to be lean.

In the year 2000, the Lean Project Delivery System model (LPDS) has been proposed by (Ballard and Zabelle, 2000) to contribute to lean project management to adapt the traditional project management to the construction industry. According to the Lean Construction Institute, LPDS is defined as "an organized implementation of lean principles and tools combined to allow a team to operate in unison to create flow."

The. LPDS model has been updated since its initial ideas and brought a different perspective to the phases of a project, which from the traditional point of view, were seen as: predesign, design, procurement and construction, installation and use. With the LPDS, the phases became more detailed and were defined as: Project definition, Lean design, Lean Supply, Lean Assembly, and Use (Ballard and Howell, 2003).

Figure 2.3 - Lean Project Delivery System (LPDS).



Source: (Ballard, 2008)

During the years, many systems and techniques that contribute to lean project management have been developed, such as the LPDS, the Last Planner System (LPS), and Target Value Design (TVD), to name a few.

Lean construction is always receiving new contributions since it is a philosophy that focuses on continuous improvement of all management processes, from the initial concept until the product delivery and use.

2.1.3 - AGILE

The agile methodology can be used in other projects even though it was created to define a new approach for software development projects. The agile manifesto states four values and twelve clarifying principles that guide the agile approach. Since then, these principles and values that are part of the agile mindset have spread to many other industries. (Project Management Institute, 2017, pt. Agile practice guide).

According to the Agile Manifesto, the four values are:

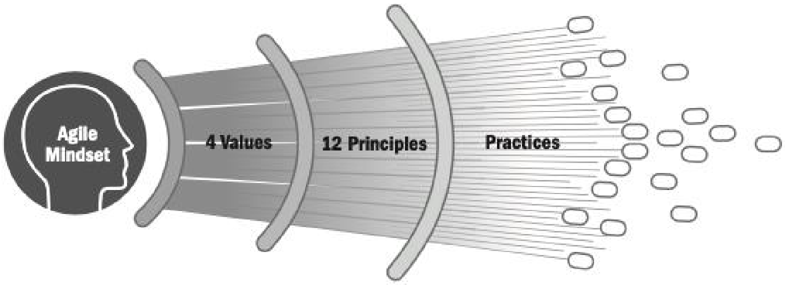
1. Individuals and interactions over processes and tools;
2. Working software over comprehensive documentation;
3. Customer collaboration over contract negotiation;
4. Responding to change over following a plan.

According to the Agile Manifesto, the twelve principles are:

1. Our highest priority is to satisfy the customer through early and continuous delivery of valuable software.
2. Welcome changing requirements, even late in development. Agile processes harness change for the customer’s competitive advantage.
3. Deliver working software frequently, from a couple of weeks to a couple of months, with a preference to the shorter timescale.
4. Business people and developers must work together daily throughout the project.
5. Build projects around motivated individuals. Give them the environment and support they need, and trust them to get the job done.
6. The most efficient and effective method of conveying information to and within a development team is face-to-face conversation.
7. Working software is the primary measure of progress.
8. Agile processes promote sustainable development. The sponsors, developers, and users should be able to maintain a constant pace indefinitely.
9. Continuous attention to technical excellence and good design enhances agility.
10. Simplicity—the art of maximizing the amount of work not done—is essential.
11. The best architectures, requirements, and designs emerge from self-organizing teams.
12. At regular intervals, the team reflects on how to become more effective, then tunes and adjusts its behavior accordingly.

“Agile is a mindset defined by values, guided by principles, and manifested through many different practices. Agile practitioners select practices based on their needs” (Project Management Institute, 2017, pt. Agile practice guide, p. 10).

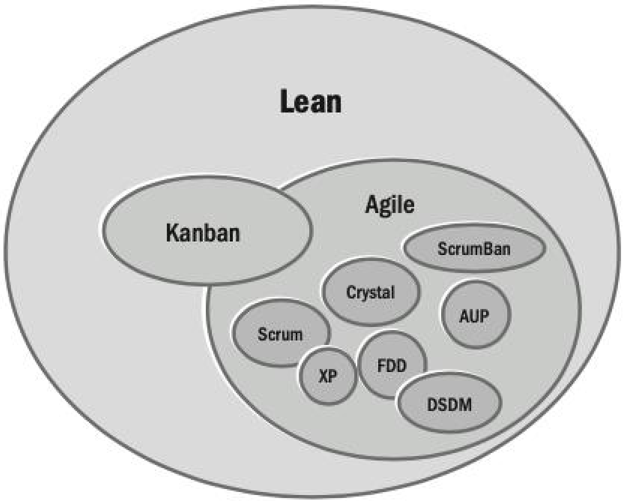
Figure 2.4 - Agile mindset.



Source: (Project Management Institute, 2017, pt. Agile practice guide).

Different features of a project can characterize the need to use this methodology, such as high rates of change, complexity, risk, customer collaboration, short cycles, several releases before the final result, etc. The agile methodology is part of a broader way of thinking within the lean philosophy, and for this reason, attributes are shared between agile and lean. These shared features are the focus on delivering value, respect for people, minimizing waste, being transparent, adapting to change, and continuously improving. A relationship between agile and lean is represented in the figure below, extracted from the PMBOK.

Figure 2.5 - Relationship between Lean and Agile.

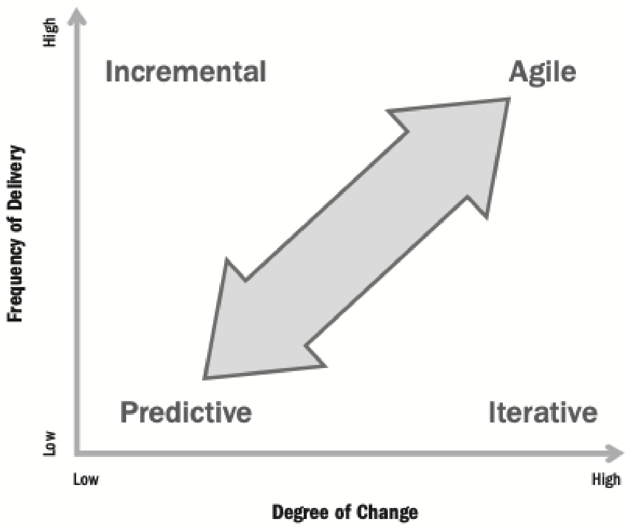


Source: (Project Management Institute, 2017, pt. Agile practice guide).

Some different techniques and frameworks fulfill the Agile Manifesto's values and principles, so they are considered to be part of the agile methodology. Therefore, it is essential to remember that some of these methods already existed before the publication of the manifesto. As an example, the Scrum technique was first mentioned in an article published by Takeuchi and Nonaka, in 1986 in the Harvard Business Review Journal.

As mentioned previously, the project life cycle can be defined by analyzing the type of requirements, activities, delivery, and goal of the project. According to the PMBOK – Agile practice guide, it is also possible to predefine the life cycle considering the frequency of delivery and the degree of change involved. These two variables are plotted on the axis of the Figure 2.3, and each life cycle is distributed according to the variables' classification.

Figure 2.6 - Project life cycle.



Source: (Project Management Institute, 2017, pt. Agile practice guide).

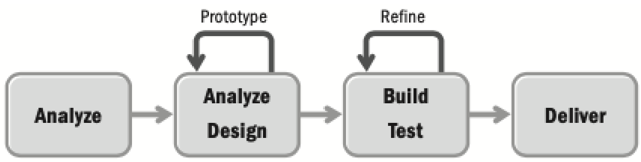
To better understand the agile life cycle, a brief description of both iterative and incremental life cycles is given.

An iterative project's life cycle has feedback as an important element. The process focuses on the constant improvement of the product considering insights from the team and stakeholder feedback, which means that it has a high rate of change.

- Requirements: Dynamic;
- Activities: Repeated until correct;
- Delivery: Single (by the end of the project);
- Goal: Correctness of solution.

The iterative life cycle starts with a plan that is later on improved with the development of the project and feedbacks resulting in a refined product's output.

Figure 2.7 - Iterative life cycle.



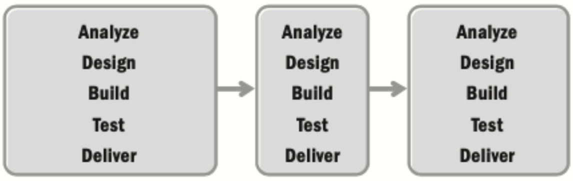
Source: (Project Management Institute, 2017, pt. Agile practice Guide).

An incremental life cycle focus on having fast and small deliveries. In this type of project, the requirements change constantly, and the deliveries are a subset of the overall solution.

- Requirements: Dynamic;
- Activities: Performed once for a given increment;
- Delivery: Frequent smaller deliveries;
- Goal: Speed.

The incremental life cycle is a repetition of practices, from planning to delivery of a product that the customer is able to use immediately.

Figure 2.8 - Incremental life cycle



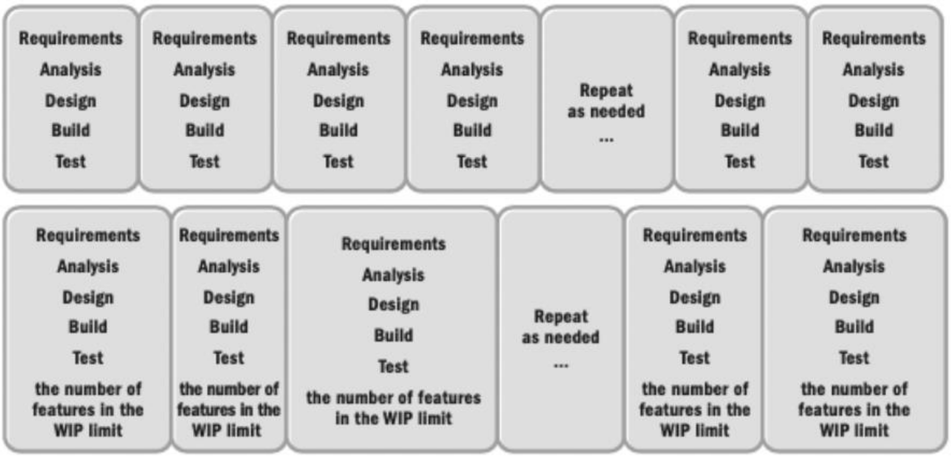
Source: (Project Management Institute, 2017, pt. Agile practice guide).

The agile life cycle is a combination of both iterative and incremental life cycle with a focus on customer satisfaction. It has a high degree of change and several deliveries. The requirements change with the development of the project and the feedback, thus aligning goals with customer needs even more.

- Requirements: Dynamic;
- Activities: Repeated until correct;
- Delivery: Frequent smaller deliveries;
- Goal: Customer value via frequent deliveries and feedback.

There are two agile life cycles, iterative-based or flow-based. The former one prioritizes some features and works from the highest priority to the lowest. These iterations always have the same timeframe. The latter has an approach that chooses which features to work on depending on the team's available capacity, so there is no fixed timeframe.

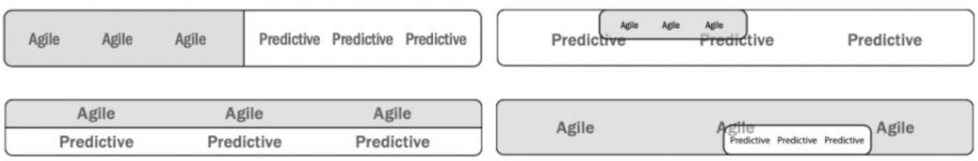
Figure 2.9 - Agile life cycles (top: iterative-based / bottom: flow-based).



Source: (Project Management Institute, 2017, pt. Agile practice guide).

Finally, there is the hybrid life cycle that combines characteristics of different life cycles. It can happen in series, in parallel, inside each other as a component, a part of the project. As an example, a project can start in the initiating and planning phase with features of an agile method but continue with a more traditional approach.

Figure 2.10 - Hybrid life cycles.



Source: (Project Management Institute, 2017, pt. Agile practice guide).

2.1.4 - PROJECT MANAGEMENT PROCESSES

A project is a combination of processes that can be categorized into groups (project's life cycle) and knowledge areas (different domains of a project).

2.1.4.1 - PROCESS GROUPS

Project management processes groups are divided in a logical and temporal form that helps to achieve the project's objectives. The logic is structured so that the output of a previous group is the input of the next one. Each group is defined below following the PMBOK (Project Management Institute, 2017) definition:

- **Initiating:** Processes performed to set a new project by acquiring permission to start.
- **Planning:** Processes required to set the scope of the project, sharpen the objectives, and define the next steps.
- **Executing:** Processes performed to complete the work defined in the planning.
- **Monitoring and controlling:** Processes required to monitor and review the progress and performance of the project considering the impact on other activities; identify necessary changes.
- **Closing:** Processes performed to close the project.

It is possible to relate the traditional project management processes groups to the building process and lean construction (LPDS). On the table below, four different approaches are presented on the right side of the table and are compared to the PMBOK processes groups on the left side of the table.

Table 2.1 - Project management processes groups and Building processes.

PMBOK	Building process	RIBA 2020 (UK)	PSU (USA)	LPDS
Initiating	Pre-design	Strategic definition	Plan	Project definition
		Preparation and Briefing		Lean Design
Planning	Design	Concept design	Design	
		Spatial coordination		
		Technical design		Lean Supply
Executing	Construction	Manufacturing and construction	Construct	Lean Assembly
Monitoring and controlling	Handover / Use (O&M)	Handover	Operate	Use
Closing	End of life	Use		

Source: (Project Management Institute, 2017; RIBA, 2020; Messner et al., 2020; Ballard, 2008;).

The building process stages are a more general and traditional approach, divided into pre-design, design, construction, handover, and use. The two next, RIBA and PSU, are adaptations done by institutions that want to define their work plan in a specific way that better fits their needs. The Royal Institute of British Architects (RIBA) has a very detailed plan of work updated in 2020, divided into eight stages. The five phases defined on version 3 of the BIM Project Executing Planning Guide (under development) developed by Pennsylvania State University

(PSU) are Plan, Design, Construct, and Operate. The Lean Project Delivery System (LPDS) is a model defined by Ballard and Howell (2003), divided into five phases that are interconnected, as presented in Figure 2.3.

Even though there are different definitions for the stages, their goals are the same, "to provide the project team with a road map for promoting consistency from one stage/phase to the next, and to provide vital guidance to clients undertaking perhaps their first and only building project" (RIBA, 2020).

These process groups are used to identify areas of study on the literature review presented on Chapter 3.

2.1.4.2 - KNOWLEDGE AREAS

Project management processes are also divided into knowledge areas that are usually interrelated to each other. These areas are defined and described in terms of practices, inputs, outputs, tools, and techniques. The PMBOK (Project Management Institute, 2017) considers the following ten knowledge areas:

- **Integration Management:** Processes and activities to identify, define, combine, unify, and coordinate the various processes and activities within the Process Groups.
- **Scope Management:** Processes to guarantee the inclusion of all the work to complete the project successfully.
- **Schedule Management:** Processes to successfully manage the completion time of the project.
- **Cost Management:** Processes involved in planning, estimating, budgeting, financing, funding, managing, and controlling costs to complete the project within the approved budget.
- **Quality Management:** Processes to assure the incorporation of the organization’s quality policy. Project and product quality requirements to meet stakeholders’ expectations.
- **Resource Management:** Processes to identify, acquire, and manage the resources needed (human and mater) for the successful completion of the project.
- **Communications Management:** Processes to ensure timely and appropriate management of the project's information.
- **Risk Management:** Processes for planning, identifying, analyzing, implementing, and monitoring risk on a project.
- **Procurement Management:** Processes for purchasing or acquiring products or services needed from outside the project.
- **Stakeholder Management:** Processes required to identify who could impact or be impacted by the project. Analyze their expectations and their impact on the project and develop strategies for effectively involving them in project decisions and execution.

These knowledge areas can be applied in every type of project, including construction projects. Another area of knowledge can be applied in the case of sustainable projects: sustainable management. Sustainable management is an area of expertise that grew a lot since 2009, which is when the Green Project Management Consortium (GPM) was established, becoming essential for projects that aim for sustainable outputs. Item 2.2.2 of this thesis covers the topic of Sustainable Project Management, before that, an introduction to sustainability is done.

2.1.5 - SUMMARY

Project management is a fundamental part for the achievement of success of a project, and as it was seen, there are different approaches that can be used depending on many variables and on the goals of the project. A brief summary between the three project management approaches presented in this section of the thesis is presented on Table 2.2.

Table 2.2 - Project management methods summary.

TRADITIONAL	LEAN	AGILE
Linear processes Fixed requirements High certainty Single delivery Improved periodically Long cycles No stakeholder collaboration	Flow processes Minimize waste Maximize value 11 principles Continuous improvement Long cycles Stakeholder collaboration	Flow processes Variable requirements High change rate Deliver value Several deliveries 12 principles Continuous improvement Short cycles Stakeholder collaboration

Source: Developed by the author (based on the literature of the thesis section).

In the construction industry, traditional project management is still the most used across the industry, from the conceptual design and engineering process until the construction site. Although traditional project management is the most used, it has already been proven that it is not the best approach to the construction industry. The best would be to adopt the lean construction philosophy for the continuous improvement of construction site production and engineering and design processes. In construction, activities have mostly been seen as "conversions" and not as "flows", which expands the non-value adding activities. Conventional managerial methods have ignored the principles of flow process design and improvement, therefore, there is considerable waste in construction (Koskela, 1992). The lean construction philosophy can be implemented by initially adopting a few of the lean principles and techniques. It is a multidimensional change and learning process that, if successfully institutionalized, adoption of other principles will be later easily accepted and implemented (Koskela, 1992).

2.2 - SUSTAINABILITY

It is known that the earth has limited resources, and humans have been consuming it excessively (EC COM 22, 2019). Sustainability is about stewarding these resources without damaging and destroying its source, maintaining a harmonious interaction between humans and natural systems. For that to be possible, there are three considered dimensions, which are known as the pillars of sustainability: economic, environmental, and social. During the years, many researchers started studying the interaction between humans and natural systems in order to understand the best way to guarantee a better future for everyone, both for humans and the planet. With these studies, emerged the idea of sustainable development. Thus, with sustainable development, there was a need to have a different project management approach that included sustainability during the process, which cared about developing a project considering sustainable development goals and targets.

2.2.1 - SUSTAINABLE DEVELOPMENT

Sustainable development has been defined in the Brundtland Report published in 1987: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987). Since then, the United Nations (UN) has spread sustainable development's common concerns with the world in numerous meetings to discuss the related topics and actions. The latest plan of action of the UN is the 2030 Agenda, in which several goals and targets are defined. More precisely, the 17 goals and 169 targets are "integrated and indivisible and balance the three dimensions of sustainable development: the economic, social, and environmental, and will stimulate action over the next 15 years in areas of critical importance for humanity and the planet" (UN, 2015). Agenda 2030 was published in 2015, and since then, the progress of the sustainable development goals (SDG) has been tracked and informed on annual reports. The 17 SDG are listed on the Table 2.2 and illustrated in Figure 2.9 presented by the United Nations.

Table 2.3 - Sustainable development goals.

1	No poverty	**10**	Reduced inequalities
2	Zero hunger	**11**	Sustainable cities and communities
3	Good health and well-being	**12**	Responsible consumption and production
4	Quality education	**13**	Climate action
5	Gender equality	**14**	Life below water
6	Clean water and sanitation	**15**	Life and land
7	Affordable and clean energy	**16**	Peace, justice and strong institutions
8	Decent work and economic growth	**17**	Partnerships for the goals
9	Industry, innovation and infrastructure		

Source: (UN, 2015).

Figure 2.11 - Sustainable development goals.

Source: United Nations (https://sdgs.un.org/goals).

2.2.2 - CONSTRUCTION INDUSTRY'S SHARE

In the year that the SDGs were announced, the Paris agreement happened and recognized goal 13 as one of the most urgent ones. The agreement recognized climate change as a possibly irreversible threat to society and the planet, thus requiring collaboration between countries to reduce the emission of global GHG and to limit the temperature increase to 1.5°C above pre-industrial levels (UNFCCC, 2015).

Years before, in 2010, the European Commission had released the Europe 2020, a European strategy for smart, sustainable and inclusive growth (European Comission, 2010). The targets proposed by Europe 2020 were, in some way, also covered by Agenda 2030, by the United Nations (UN, 2015). One of the EU 2020 targets is directly related to the construction industry becoming more sustainable:

- Reduce GHG emissions by at least 20% compared to 1990 levels or by 30% if conditions are right, increase the share of renewable energy sources in the final energy consumption to 20%, and a 20% increase energy efficiency (European Comission, 2010).

Particular attention is given to the EU 2020 sustainable growth strategy that aimed to promote a more resource-efficient, greener, and more competitive economy, with specific actions on combating climate change and improving energy efficiency. It should be considered that by the time Europe 2020 was published, buildings accounted for 40% of the European Union's total energy consumption, according to the Directive 2010/31/EU on the energy performance of buildings. This directive promoted the improvement of the energy performance of buildings in the EU, considering outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness (Directive 2010/31/EU, 2010). Moreover, due to the impact that buildings have on improving energy efficiency, the directive listed many of the new requirements for new buildings, existing buildings, and nearly zero-energy buildings across the Union.

With the year of 2020 coming close, a review on the EU 2020 and the Directive 2010/21/EU was done. New milestones and actions to achieve short-term (2030), mid-term (2040), and long-term (2050) were established. Thus, with the changes in the new Directive 2018/844/EU, the importance of the strategies to transform the building stock in the European Union became even more clear, since the increase in energy performance would contribute to the independence of the Union as well as reaching the targets and SDGs (Directive 2018/844/EU, 2018).

Europe has developed some of the highest environmental standards to put in place the ambitious climate policies (EC COM 22, 2019). The commitment of the EU to sustainable development includes six headlines ambitions for the years between 2019-2024, in which one is the European green deal. The European green deal is even more ambitious than the Directive of 2018 and brings new short and long-term targets. It considers the use of clean energy and a new circular economy action plan that are some of the features that will help Europe reduce its environmental impact. For 2050, it is wanted to be a climate-neutral - no net emissions of GHG and a decoupled from resource use economic growth. For 2030, the focus is to "put sustainability and well-being of citizens at the center of the economic policy, and the SDGs at the heart of EU's policymaking and actions" and "to increase the EU's GHG emission reductions target to at least 50% and towards 55% compared to 1990" (EC COM 640, 2019).

2.2.3 - SUSTAINABLE PROJECT MANAGEMENT

Projects affect sustainability in both direct and indirect way, the first, by polluting and misusing resources, and the later, by delivering products and services (GPM, 2019). Since projects drive change, it is essential to align them with the SDGs to achieve a sustainable practice in project management. Nowadays, most projects have to be managed with shorter schedules, tighter budgets, fewer resources, and higher quality specifications. For that, companies are taking advantage of project management techniques to achieve their goals, to remain competitive in the market, and deliver business value. Although projects are temporary, their deliverables go beyond until the end of their service life; and due to that, projects should produce deliverables of a social, economic, environmental, and material nature. (Project Management Institute, 2017).

Social, economic, and environmental dimensions are the pillars of sustainability. Thus, if projects are being developed, taking into consideration those three dimensions in a way to produce sustainable deliverables, it could be said that sustainable project management is being practiced. However, it is essential that the organization integrates sustainability in its culture and strategic plan, a practice that is growing in the last years. Peter Drucker once said, "Culture eats strategy for breakfast". Sustainability has to be inserted in both the company's culture and strategy. If it is only a matter of strategy, it may not be put in practice as it should be, regardless of how powerful the strategy is. People should commit and be passionate about the cause (Project Management Institute, 2017).

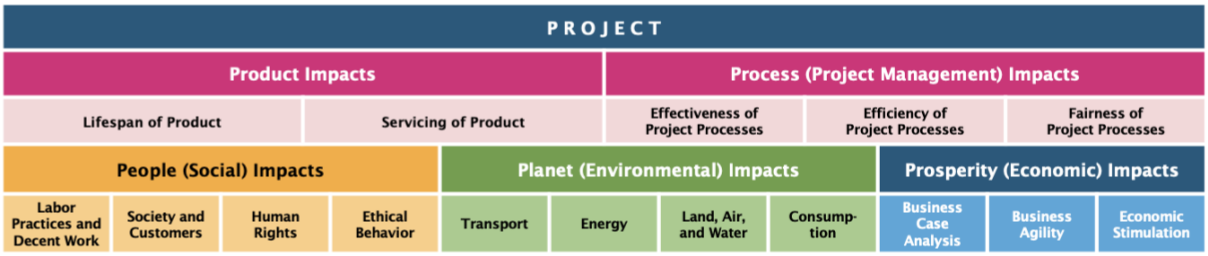
In an organizational perspective, a way to incorporate sustainability into companies is through the creation of shared value, a management strategy, that can be defined as "policies and operating practices that enhance the competitiveness of a company while simultaneously advancing the economic and social conditions in the communities in which it operates" (Porter and Kramer, 2011). With the incorporation of sustainability into the organization's culture and strategy, positive impacts are observed in customers, employees, stakeholders, and the environment (Tharp, 2012).

The PMBOK approach considers ten different knowledge areas, and none is specifically related to sustainability. Therefore, to manage sustainable projects, an additional knowledge area, or a different approach for sustainable management would be welcome to promote the integration of sustainability and project management. The Green Project Management (GPM) organization has been created to advocate for sustainability. During the years, the GPM supported the development of sustainable business and the realization of the SDGs throughout the integration with project management. Some of the materials written by GPM are the P5 Standard, the Principles of sustainability, the PRojects integrating Sustainable Methods (PriSM), and the Sustainable Project Management reference guide.

The evolution of project management' focus is described on the "The GPM P5 Standard for Sustainability in Project Management v2.0". Initially, the focus was on the "Iron triangle", maintaining the project on schedule within budget and according to the specifications. Later on, the focus was on the "Triple Bottom Line" concept of profit, people and planet. More recently, project management was focusing on risk management and the delivery of value and benefits, with approaches such as PRINCE2, Managing Successful Programmes (MSP), and PRiSM (GPM, 2019). The P5 Standard, which stands for Product, Process, People, Planet, and Prosperity, combines the previous mentioned perspectives and creates a new view of project management. This new perspective is aligned with the UN SDGs providing greater focus on shared value when addressing global challenges, by focusing on "the potential impacts of the project's activities, results, and outcomes" (GPM, 2019).

The P5 Standard ontology is presented in the image below, showing the main categories for each of the subject areas (5Ps).

Figure 2.12 - P5 Standard ontology.



Source: (GPM, 2019).

2.2.4 - SUMMARY

This section brought the concepts of sustainability and sustainable development. Through literature, it has been shown that the construction industry has a crucial share in the achievement of a more sustainable world. Besides that, it has been explained that companies' culture and strategies should be aligned in order for companies' actions to be correctly sustainable. Moreover, projects, independently of its scope, affect sustainability both directly and indirectly, which means that projects should be aligned with the SDG, and that the best way of doing that is by adopting sustainable project management.

2.3 - GREEN CONSTRUCTION

Green construction, or sustainable construction, exists for a long time, but the term “green” that is now adopted was not always used. Typical examples of green construction in history are the vernacular architecture and buildings of ancient population that considered natural climate conditions by understanding, solar exposure, daylight availability, wind direction and other conditions. Examples of these ancient buildings are igloos, pueblos, ancient Roman, Babylonian, Egyptian buildings, etc.

Studies point out that green design studies started around a century ago, but only more recently, at the beginning of the 70s, there was a push to energy-efficient and green buildings due to the energy crises (Kubba, 2016). The green wave did not become strong by then because of the low oil prices and the economic growth of the 80s, which came with the extensive use of natural resources. The attention to energy-related issues and raising problems associated with climate change and the sustainability of the built environment were ignored for many years (Kubba, 2016; Yellamraju, 2011). During the 90s, several international conferences took place to discuss green issues related to the built environment and climate change, which resulted in the creation of green building standards, and rating systems for green buildings. Later on, after the definition of the sustainable development targets and goals by the UN, the adoption of more sustainable approach and strategies inside governments and companies became more visible and better defined, and actions to transform the world into a more sustainable and greener environment have grown.

Nowadays, governments are committing and are incentivizing green initiatives and creating policies to ensure that SDGs are achieved within a timeline. Companies are developing new plans to take into account the SDGs of the United Nations and government’s new regulations to improve their services and products. With that, the construction sector understood how important it is to integrate sustainability into companies' culture, strategies, and products (buildings, infrastructure, etc.) in order to have a positive impact and contribute to sustainable development. Moreover, green building rating systems have grown in number and quality of assessment, basically becoming a framework to the design, construction and operation of sustainable buildings.

2.3.1 - GREEN BUILDINGS’ CONTRIBUTION TO SDGS

The World Green Building Council (WGBC) believes that the process of a green building creation and its use after built have an important contribution in achieving a more sustainable world. Green building is “an opportunity to not only save energy, water and carbon emissions but to educate, create jobs, strengthen communities, improve health and wellbeing, and much, much more (Czerwinska, 2017). The WBGC has demonstrated that green construction contributes in a significant way to some of the SDGs set by the UN, more precisely, building green can contribute to nine among the seventeen goals.

Figure 2.13 - Green building's contribution to SDGs.

Source: Adapted from (Czerwinska, 2017).

The contribution that green buildings has on each of the nine SDGs is summarized in a sentence written on the WGBC's study and further commented by the author of this thesis.

- **Goal 3 – Good health and well-being:** "Green buildings can improve people's health and well-being" (Czerwinska, 2017). When designing a green building, comfort conditions of the indoor environment are considered in order to enhance the experience of the user, therefore, influencing the user's health, well-being, and productivity. Daylight, acoustic, and indoor temperature are some of the studied parameters that influence the comfort conditions. Other aspects that impact the well-being and user's health are also considered in green building, such as: access to quality transit, availability of public transportation in the area, bicycle facilities (parking and changing areas), etc.
- **Goal 7 – Affordable and clean energy:** "Green buildings can use renewable energy, becoming cheaper to run" (Czerwinska, 2017). There are several ways of reducing the energy demand of buildings, therefore, reducing the cost of its operation. From the use of passive design strategies (proper envelope design, natural ventilation, solar exposure, etc.) in order to minimize the need for active strategies (use of HVAC system); To the use of clean energy production on-site (photovoltaics, geothermal, wind turbines, biomass, etc.). Green buildings aim at having a minimum energy demand through passive strategies and renewable energy use, thus reducing its operational costs, GHG emissions and the use of fossil fuels.
- **Goal 8 – Decent work and economic growth:** "Building green infrastructure creates jobs and boosts the economy" (Czerwinska, 2017). The green wave encourages the creation of enterprises specialized in sustainable buildings' design and construction and improves the services offered by companies already available on the market. Building green also boosts the creation of new jobs, mainly jobs related to the production and application of innovative technologies for the construction industry, which transforms the sector and the built environment in a smarter environment.
- **Goal 9 – Industry, innovation and infrastructure:** "Green building design can spur innovation and contribute to climate-resilient infrastructure" (Czerwinska, 2017).

Green buildings stimulate the economy and accelerate innovation in the construction industry and the built environment. With the construction sector's innovation, different methods emerge to assist the planning, design, construction, controlling, and maintenance phases, which makes the use of technology, disruptive or not, an essential ally to the design of climate-resilient infrastructure.

- **Goal 11 – Sustainable cities and communities:** “Green buildings are the fabric of sustainable cities and communities” (Czerwinska, 2017). The design and construction of green buildings consider not only the building itself but also the area around it. In order to make cities and communities more sustainable, some aspects are considered during the design and construction, such as sustainable transportation (bicycles, public transport, green vehicles), inclusive and sustainable urban areas, waste management plans, the use of local materials during construction, etc.
- **Goal 12 – Responsible consumption and production:** “Green buildings use circular principles, where resources are not wasted” (Czerwinska, 2017). Building sustainable buildings is a combination of small details, mainly when it comes to materials and resources (M&R). It is essential to use M&R in a circular and lean way, with maximum reduction, recycling and reuse, and minimum waste. The procurement of materials is an important phase to guarantee that M&R follow sustainable policies and priorities. For the construction phase, green buildings should have a construction and demolition management plan in order to destinate the waste of the site correctly.
- **Goal 13 – Climate action:** “Green buildings produce fewer emissions, helping to combat climate change” (Czerwinska, 2017). The use of renewable energy has an impact not only on the affordability of the operational cost but mainly on the climate. Green buildings' energy demand is partially or entirely covered by the production of clean energy, which is installed in the building or on the campus, such as photovoltaic panels, wind turbines, geothermal energy, etc. Since buildings have a significant share in energy consumption, the use of renewable energy is an important ally to combat climate change and lower the emissions of the building's stock.
- **Goal 15 – Life and land:** “Green buildings can improve biodiversity, save water resources and help to protect forests” (Czerwinska, 2017). The construction of green buildings takes into account site development through the preservation and restoration of green areas. Different measures can be adopted, but preferably, green buildings that are built in areas already disturbed try to restore green areas, and buildings that are built in not previously disturbed areas maintain, according to national policies, a percentage of the natural habitat.
- **Goal 17 – Partnerships for the goals:** "Through building green, stronger global partnerships are created" (Czerwinska, 2017). Green buildings are the result of people's commitment to a better and more sustainable world. It also serves as an inspiration for people and companies to create even more partnerships that seek to improve the world, transforming it into a better environment for the current and future generations.

2.3.2 - GREEN BUILDINGS RATING SYSTEMS

Green buildings became more popular around the 90s, which is when specialists in the field started to discuss the creation of rating systems for buildings that were considering sustainability issues. A green building rating system provides a framework for designing, building, and operating green buildings and indicates performance metrics to measure the building performance. (Yellamraju, 2011). More than the framework, there is a certification given to the building depending on the level of achievement of sustainability, that changes according to each rating system type.

The creation of green building rating systems has helped to establish a common language regarding green buildings' definition and its features. Moreover, the certification given to the buildings has impacted the market, influencing other developments to seek for that achievement as well. Green buildings are not necessarily less green because they are not certified; however, the certification is a way to guarantee that all the requirements were met. So, for the market, that building has a guaranteed value.

Several rating systems were developed since the first one emerged. The aims and objectives of these rating systems are usually similar: minimize life cycle impact on the environment, stimulate the construction of green buildings, provide market recognition for sustainable buildings, etc. A brief description of BREEAM, LEED, Green Globes and EDGE rating systems’ features is given. In the world there are additional rating systems developed by other organizations in different countries, such as DGNB (Germany), Green Star (Australia, New Zealand, South Africa), BCS Green Mark (Singapore), BEAM Plus (Hong Kong), CASBEE (Japan). These systems have the same roots as the other systems and can have a bit more specific requirements for a particular region, with certain particularities.

As an alternative to the variety of rating systems that exists nowadays and to the lack of conformity between them, a European initiative created CESBA, the abbreviation of Common European Sustainable Building Assessment. CESBA will also be briefly described in the following topics due to its novelty and importance in the European market.

2.3.2.1 - BREEAM

BREEAM is the acronym for Building Research Establishment’s Environmental Assessment Method, which is the first rating system created in the world, published in 1990 by the Building Research Establishment (BRE) of the United Kingdom. As a rating system, BREEAM assesses the sustainability performance of projects, rates, and certifies it with the support of accredited professionals around the world.

BREEAM has specific frameworks for different types of projects: infrastructures, communities and buildings. For building projects, the framework manual differs if the project is a new construction, in-use, or a refurbishment & fit-out. The framework can also differ for projects located in the UK and for international projects. In summary, there are six possible BREEAM schemes, as defined by BRE:

- **Infrastructure:** for new infrastructure projects;
- **Communities:** for developments at the neighborhood scale or larger;
- **New Construction:** for domestic new buildings (international) and non-domestic new buildings;
- **Home quality mark:** for new domestic buildings (UK only);
- **In-use:** for existing non-domestic buildings in-use;

- **Refurbishment:** for domestic buildings (UK only) and non-domestic buildings fit outs and refurbishments.

With BREEAM is possible to rate and certify buildings of different functions. The nondomestic buildings can be office, retail, hospitality, schools, healthcare, mixed use, data centers, etc. If the right technical manual is not available for the project, BRE offers the option to apply for a BREEAM Bespoke process, which will involve a tailoring criteria process of the existing standards to maximize the sustainability opportunities for that specific project and its location (BRE, 2020). The categories analyzed during the BREEAM assessment process are the following:

- Energy;
- Health and wellbeing;
- Innovation;
- Land use;
- Materials;
- Management;
- Pollution;
- Transport;
- Waste; and
- Water.

Different categories might be analyzed for Communities and In-use scheme projects, such as governance, resources, and resilience. The number of credits given to each category may vary depending on the selected scheme. Each category is divided into sub-categories that have targets and performances to be achieved for that specific area. A category score is calculated according to the number of credits achieved, and its category weighting. The final BREEAM performance rating (score) is determined by the sum of the weighted category scores. Finally, the acquired BREEAM certification will depend on the score percentage achieved by the project. For In-use schemes, there is an addition rating before "Pass", which is "Acceptable".

Table 2.4 - BREEAM certification.

BREEAM certification	% Score
Unclassified	< 30%
Pass	≥ 30%
Good	≥ 45%
Very good	≥ 55%
Excellent	≥ 70%
Outstanding	≥ 85%

Source: BREEAM.

Nowadays, BREEAM is used in more than 85 countries and has certified more than 591 thousand buildings around the world.

2.3.2.2 - LEED

The Leadership in Energy and Environmental Design (LEED) is a rating system created by the United States Green Building Council (USGBC) and released in 1998 in its first version for pilot testing. Throughout the years, LEED has updated its versions following the development of green buildings around the world. The most recent released versions are LEED v4, released in 2015, and LEED v.4.1, released in 2019.

As a rating system, LEED assesses the sustainability performance of projects, rates, and certifies it with the support of accredited professionals around the world. LEED has been developed to cover the sustainability assessment of every building type. There are four main rating systems categories with subdivisions that facilitates the selection of the rating system to be followed.

- **LEED BD+C (Building Design and Construction):** New Constructions and Major Renovation; Core and Shell Development; Schools; Retails; Data Centers; Warehouses and Distribution Centers; Hospitality; Healthcare; Homes and Multifamily Low rise; Multifamily Midrise.
- **LEED ID+C (Interior Design and Construction):** Commercial Interiors; Retail; Hospitality.
- **LEED O+M (Building Operations and Maintenance):** Existing Buildings; Retail; Schools; Hospitality; Data Centers; Warehouse and Distribution Centers; Multifamily.
- **LEED ND (Neighborhood Development):** Plan; Build Project.

The LEED assessment process analyzes different categories that vary depending on the selected rating system and the LEED version. The categories of each rating system for LEED v4 are shown in the table below.

Table 2.5 - LEED v4 categories.

LEED categories	LEED BD+C	LEED ID+C	LEED O+M	LEED ND
Integrative process	x	x		
Location and transportation	x	x	x	
Sustainable sites	x		x	
Water efficiency	x	x	x	
Energy and atmosphere	x	x	x	
Materials and resources	x	x	x	
Indoor environmental quality	x	x	x	
Innovation	x	x	x	x
Regional priority	x	x	x	x
Smart location and linkage				x
Neighborhood pattern and design				x
Green infrastructure and buildings				x

Source: USGBC.

Each category is divided into several requirements (credits) that change according to the building type. For example, the credits of Indoor Environmental Quality (EQ) for "New construction and Major renovation" may differ from the EQ credits for "Schools", even both being part of LEED BD+C. These credits are evaluated with points, and the final score of the building will depend on the number of points that the project achieved in total.

There are four certification types in the LEED rating system, and the number of points achieved by the project will define the type of certification that the project receives.

Table 2.6 - LEED v4 certification.

LEED certification	Number of points
Certified	40 - 49
Silver	50 - 59
Gold	60 - 79
Platinum	+ 80

Source: USGBC.

The LEED rating system is briefly described here. A better description is given in a new topic since the focus of the thesis is on LEED, more specifically on the LEED v4 BD+C New Construction and Major Renovation rating system.

2.3.2.2.1 LEED CERTIFICATION PROCESS

Projects that want to be LEED certified should follow an integrative process; this means having a multidisciplinary team working together and having stakeholders participating since the beginning of the design process, all with the common goal of delivering a sustainable high performing building. In this way, overlaps, risks, redundancies among systems, and more can be identified in early stages resulting in a better performing project (USGBC, 2020). By using an integrative process, the LEED credits become aspects of a whole rather than separated components and increase the chances of the project of succeeding and achieving a higher score for the certification (USGBC, 2020).

According to the USGBC, achieving higher performance requires that the team brainstorm, research, analyze, and discuss at a very early stage before anything is designed. This process is done using an iterative cycle (explained in section AGILE of this thesis) that polishes the design solutions (USGBC, 2020).

The USGBC has separated the certification process into four main sections: Register, Apply, Review, and Certify. Moreover, the USGBC has prepared a LEED work plan, which is a recommended list that contains eleven steps that clarifies the steps of the LEED application:

1. Initiate discovery phase;
2. Select LEED rating system;
3. Check minimum program requirements;
4. Establish project goals;
5. Define LEED project scope;
6. Develop LEED scorecard;
7. Continue Discovery phase;
8. Continue iterative process;
9. Assign roles and responsibilities;
10. Develop consistent documentation;
11. Perform quality assurance review and submit for certification.

Part of the LEED certification process is related to the submission of the credits. The credits are classified as "design" or as "construction" credits, making it possible to divide the submission process into design and construction. The submission divided into two phases is a decision made by the project team, since it is also possible to submit all credits by the end of the process, all at once.

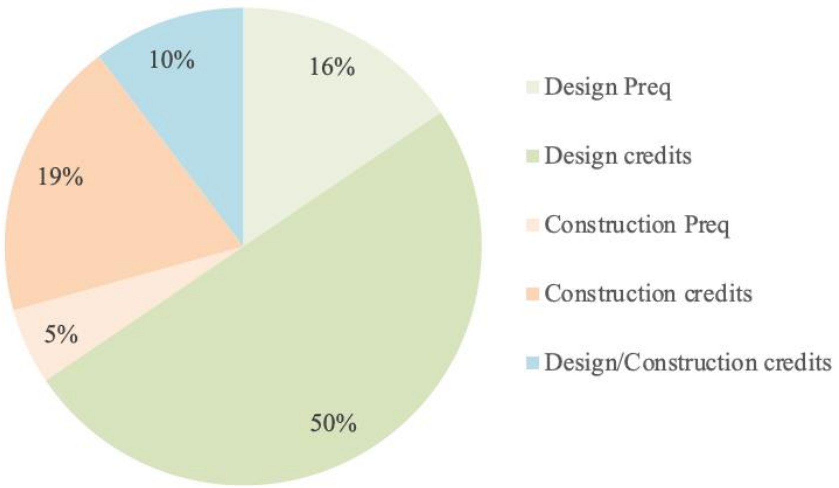
To better understand the option of submitting in two phases, a brief explanation is given, based on what the USGBC says. First, the project should be registered, and the LEED scorecard should be defined. Then, the team has the option to submit, via LEED Online (an online tool developed to facilitate the submission process) the "design" credits. This step of first submitting the design credits can already guarantee some credits' acceptance if the credits are considered "Anticipated" by the GBC. In case some credits are "Denied", the team has the option to appeal the decision, a process that requires an extra payment.

In summary, the submission process can be separated into:

- Design application phase (optional)
- Design appeal phase
- Construction application phase
- Construction appeal phase
- Certification / Denial phase

The percentage of the prerequisites and credits of the LEED BD+C NC v4 per submission phase is shown in Figure 2.14.

Figure 2.14 - LEED BD+C NC v4 prerequisites and credits % per submission phase.



Source: (USGBC, 2019a)

The information given on the chart shows that 50% of the credits can already be submitted before the final submission of the project to the GBC, during the design application phase (USGBC, 2019a), which can be a strategy adopted by the project team to anticipate some credits.

2.3.2.3 - GREEN GLOBES

Green Globes is an online assessment protocol, rating system and guide for green buildings (GBI, 2020). The system was created in 2000 by ECD Energy and Environmental in Canada, and in 2004, the rating system expanded to the United States. In the current days, this system can only be used in projects across Canada and the US. A differential of the Green Globes system when comparing to other rating systems is that it is a self-assessment that can be done by a project manager and the design team.

Initially, there was only a version for existing buildings, but later a version for new building was also released. Both versions are available for different buildings' types: commercial, retail, data centers, healthcare, multifamily, etc. There are different requirements for multifamily buildings, which made Green Globes develop specific protocols for this building type. The following certification types are available:

- Existing Buildings;
- New Construction;
- Core and shell;
- Existing buildings Multifamily;
- New construction Multifamily;
- Performance plus Multifamily;
- Sustainable interiors.

The categories analyzed during the Green Globes assessment process differ if the protocol is for a "New Construction" or for an "Existing Building". For both, the total number of credits that can be achieved in 1000, varying per category.

Table 2.7 - Green Globes categories.

New Construction	Existing Buildings
Project management	Energy
Site	Water
Energy	Resources
Water	Emissions and other impacts
Materials and resources	Indoor Environment
Emissions	Environmental management
Indoor environment	

Source: (GBI, 2020).

The final Green Globes performance rating (score) is determined by the sum of the category scores. Finally, the acquired certification will depend on the score percentage achieved by the project during the sustainability assessment.

Table 2.8 - Green Globes certification.

Green Globes certification	% Score
One Green Globes	35-54%
Two Green Globes	55-69%
Three Green Globes	70-84%
Four Green Globes	85-100%

Source: (GBI, 2020).

2.3.2.4 - EDGE

The Excellence in Design for Greater Efficiencies (EDGE) is a green building certification created by the International Finance Corporation (IFC) and administered by the Green Business Certification Inc. (GBCI). The initial drivers behind EDGE are financial, but the results are environmental, and consequently help to mitigate climate change by encouraging resource-efficient developments. The idea of the certification is to empower builders and developers to identify the most cost-effective ways to reduce energy use, water use, and embodied energy in materials (GBCI and IFC, 2020).

In order to qualify for EDGE certification, the building must achieve a 20% reduction compared to a base case building in the three analyzed categories: energy, water, and embodied energy in materials. EDGE has a free software application that shows the savings in energy, water and the embodied energy of materials compared to a local base case and from that, estimates utility savings, capital costs and the payback period. All these features help the design team to take better decisions related to what design strategies to adopt "while immediately viewing the financial and environmental impact" (GBCI and IFC, 2020).

According to the creator of this certification, EDGE is a fast and easy mass market transformation tool for emerging markets. It can be useful for all stages of a project's life cycle and it can be applied to:

- New construction;
- Existing buildings and Major renovations of homes;
- Offices;
- Hotels;
- Retail;
- Hospitals.

Since it is a certification that focus on emerging markets, the use of EDGE has a significant appearance in emerging countries. Its use is expressive in South America, Africa, Asia, and Eastern Europe.

Figure 2.15 - EDGE certification process.

Source: (GBCI and IFC, 2020).

The certification process (Figure 2.15) is divided into two stages: design and construction. During the certification process, the documentation is submitted by the client and reviewed by EDGE-trained auditors at both stages, with a site audit performed. After the auditor review, the EDGE partner (certifier) checks the documentation to confirm the certification. This process happens in both stages; the difference is that at the end of the design stage, a preliminary certification is given, while at the end of the construction stage, the final EDGE certification is given.

2.3.2.5 - CESBA

The Common European Sustainable Building Assessment (CESBA) is a joint result of two European projects (CEC5 and CABEE) that shared the aim of promoting sustainable building solutions (Berchtold et al., 2013). CESBA initiative, which started in 2011, wanted to create a harmonization process for sustainable buildings assessment at the European level due the lack of conformity between the current rating systems (Berchtold et al., 2013).

CESBA has two well defined goals. The first is to develop a common framework for building assessment that will improve the quality and usability of current certifications at a European level, and the second is to "establish a mass-movement toward near-zero emission buildings in Europe". With that, there will be an improvement on European buildings and neighborhoods standards (Berchtold et al., 2013).

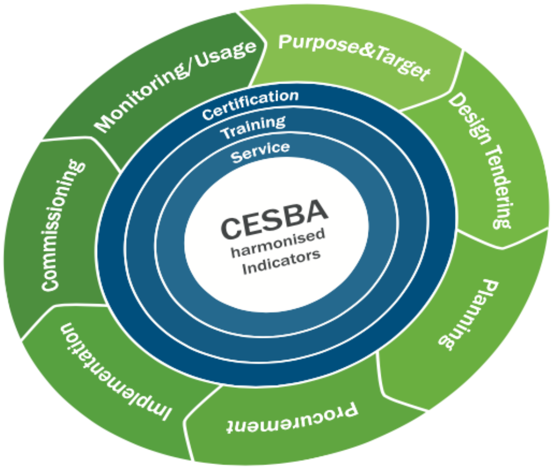
The guidelines for the harmonization of the assessment is done through principles, methods, performance issues and indicators. The approach includes nine principles, the sprint method, the CESBA cycle and tools, and stakeholder arrangements. Since this is a shallow explanation, it is important to at least understand what the principles and indicators are and how the CESBA life cycle is.

All CESBA indicators, tools, outputs, and services follow the nine principles: The user first; Sustainability; Regional contextualization; Comparability; Mass-oriented; Simples to use; Open source; Transparency; and Co-creation. CESBA has key performance indicators (KPI) and reference indicators that somehow help to synchronize the systems in the CESBA building passport. This passport informs the KPI in absolute values, so in this way, it is possible to compare the performance of buildings assessed by different certification systems and in different regions. There are eleven KPI for building scale at European level, and some additional depending on the macro region. The KPI for building scale at European level are:

- Non-renewable primary energy
- Primary renewable energy use
- Co_2 emissions
- Indoor air quality
- Thermal comfort
- Building life Cycle cost
- Reused/recycled materials
- Water consumption
- Solid waste
- User involvement
- Monitoring/optimization of operation

The life cycle "conveys the concept of CESBA that is defined by harmonized indicators, tools and services usable during the whole building life cycle and an ongoing dialogue with society" (Berchtold et al., 2013). Figure 2.16 refers to the CESBA life cycle, which is the junction of the performance indicators (white circle), the tools (blue circles), and the building lifecycle (green circle).

Figure 2.16 - CESBA lifecycle.



Source: (Berchtold et al., 2013).

Finally, this initiative had outputs that improve the buildings and neighborhood standards in European regions, such as the Alpine and the Mediterranean with the projects CESBA Alps, CESBA MED, and Greencycle. The first, CESBA Alps, is an assessment tool at territorial scale, contextualized to regional priorities. The second, CESBA MED, is an assessment tool to improve energy efficiency at the neighborhood level and has been proving that assessment at building scale is not best in reaching cost-effective improvements. The third, Greencycle, introduces a circular economy at Alpine spaces to achieve low carbon emission levels (CESBA wiki, 2020).

2.3.3 - SUMMARY

Green construction is an essential ally to sustainability and the achievement of sustainable development goals. According to the study developed by Czerwinska (2017), the development of green buildings is related to nine out of the seventeen goals of sustainable development and generates a positive impact in the world.

Throughout the building’s certification, it is possible to standardize sustainable buildings' performance, even with the variation in requirements' limits depending on the region. The certifications are a way to assure that a building is sustainable, and they can also be seen as a guideline with requirements for sustainable buildings, as "good practices".

The different certifications are developed for several building uses and applications in any area of the world. Some of these rating systems can indeed have specific and challenging requirements, and the certification process can be expensive, making it more difficult to be applied in less developed areas. However, nowadays, there is a certification focusing on emerging markets (EDGE certification), which helps these markets to have better-performing buildings and more sustainable actions. In general, green buildings' certification is a worldwide growing practice that brings positive social, environmental, and economic impacts.

2.4 - BUILDING INFORMATION MODELING

Building Information Modeling (BIM) history started back in the 1970s; however, it became deeply studied only around 2010. The term Building Modeling was first documented in English in 1986 in an article by Robert Aish. In 1992, the term Building Information Model appeared in the article by G.A. van Nederveen and F. Tolman (Eastman et al., 2008). The concept, however, was Chuck Eastman, the pioneer of BIM, who first defined it in 1975:

> "[designing by]" ... interactively defining elements... deriv[ing] sections, plans, isometrics or perspectives from the same description of elements... Any change of arrangement would have to be made only once for all future drawings to be updated. All drawings derived from the same arrangement of elements would automatically be consistent... any type of quantitative analysis could be coupled directly to the description... cost estimating or material quantities could be easily generated... providing a single integrated database for visual and quantitative analyses... automated building code checking in city hall or the architect's office. Contractors of large projects may find this representation advantageous for scheduling and materials ordering" (Eastman, 1975).

Years later, Chuck Eastman's new design concept from 1975 became known as the current known BIM. In addition to Eastman, several other authors have defined BIM during the years, which means that there is no single concept and each new definition helps to understand what BIM is. Although each new definition can help with the understanding of what BIM is and what it can do, nowadays there are standards that defined BIM as follows:

According to ISO 19650-1-2018, the term BIM is defined as "use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions" (BS EN ISO 19650-1, 2018).

For the National BIM Standard - United States®, BIM "is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward" (National Institute of Building Science and Building SMART alliance, 2015).

Another valued definition of BIM is given on the BIM Project Execution Planning Guide, developed by researchers from Pennsylvania State University: "Building Information Modeling (BIM) is a process focused on the development, use, and transfer of a digital information model of a building project to improve the design, construction, and operations of a project or portfolio of facilities" (Messner et al., 2020).

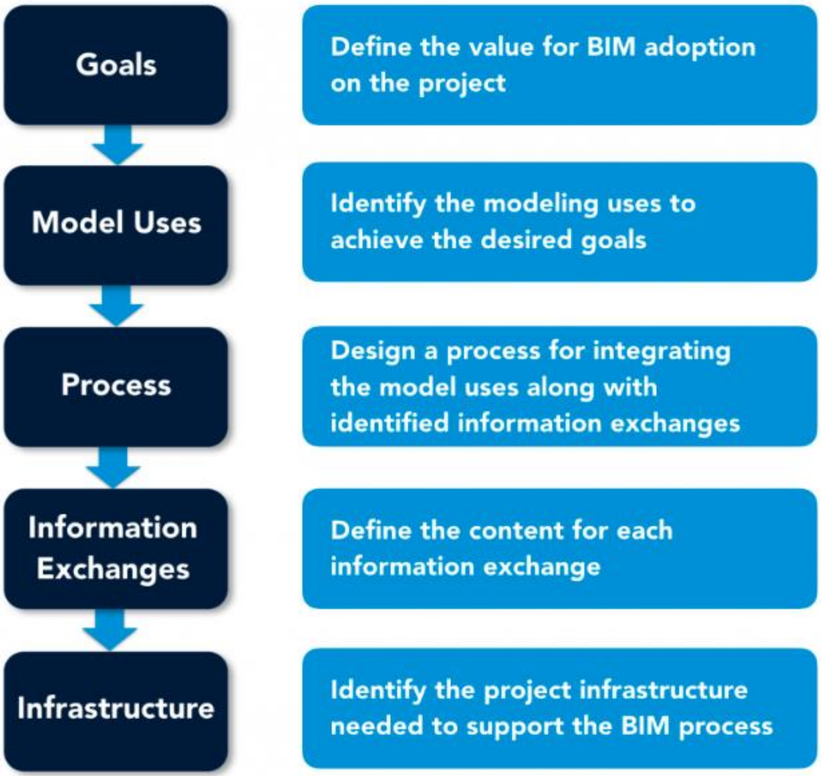
2.4.1 - BIM PROJECT EXECUTION PLANNING GUIDE

The BIM Project Execution Planning Guide's first version was published in 2009, and since then, it has passed through four revisions: version 2.0 in 2011, version 2.1 in 2012, version 2.2 (2019), and the latest in 2020, version 3.0, which is still under development. This document is a guide that provides a structured procedure for creating and implementing a BIM Project Execution Plan (BEP or BIM Plan).

The BIM Plan procedure is divided into five steps, briefly explained in Figure 2.17:

1. Define the goals for the implementation of BIM;
2. Identify high-value Model Uses during project planning, design, construction, and operational phases;
3. Design the BIM execution process by creating process maps;
4. Define the information deliverables; and
5. Develop the infrastructure in the form of contracts, communication procedures, technology, and quality control to support the implementation.

Figure 2.17 - The BIM Project Execution Planning Procedure.



Source: (Messner et al., 2020)

One of the specific objectives of this thesis is to identify Model Uses (step 2 of BEP) for a LEED project's goals, and for this reason, the Model Uses will be more in-depth explained in this section.

The NBIMS defines BIM Use as a method of applying building information modeling during a facility's lifecycle to achieve one or more specific objectives (National BIM Standard, 2015). More simply, the BIM Uses are the tasks that the team would like to perform using BIM (Messner et al., 2020).

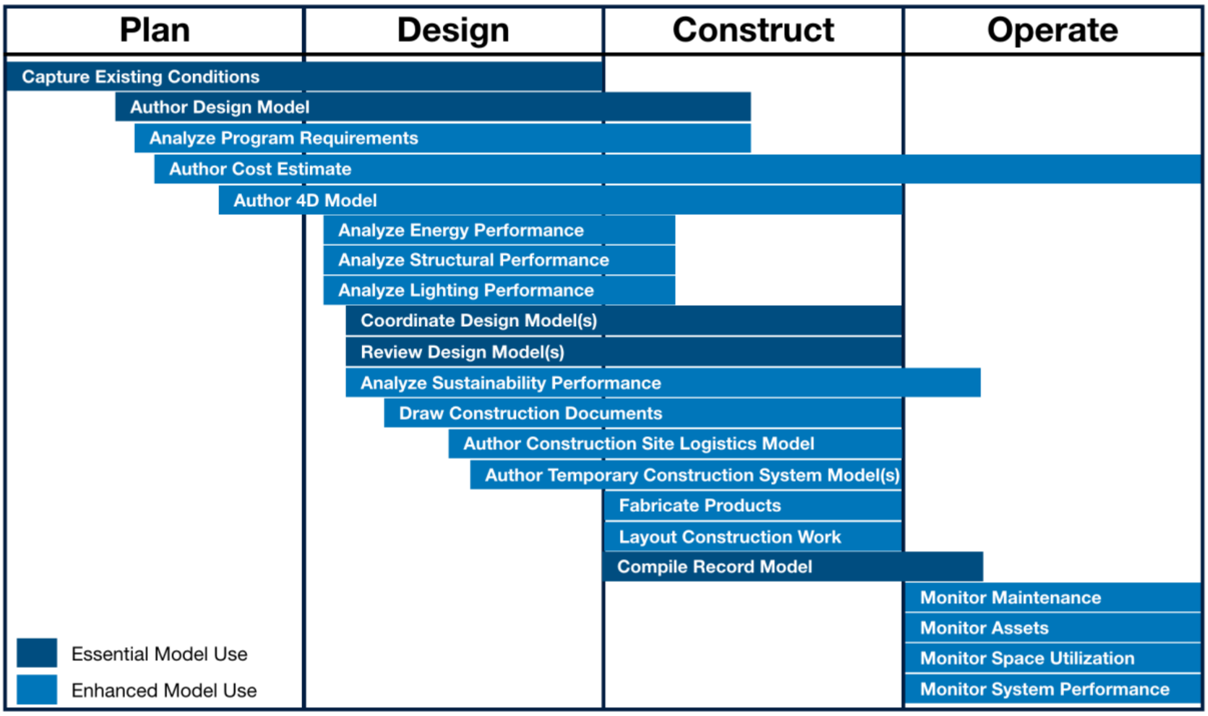
According to the BIM Plan, once a project team has defined the project's goals (step 1), the BIM Uses can be identified (step 2). The identification of these uses "should focus on the desired outcomes for the overall process", or in other words, "should begin with the end in mind". Team members must understand the future use(s) of the information developed for BIM to be successfully implemented (Messner et al., 2020). It is essential that the designers know if that information will be used in the future and how it will be used. Knowing the information that will be used in the future can impact the methods used to develop the model, and defining these uses in initial stages with the BEP facilitates and improves the whole building process.

The BIM Uses selection procedure comprises of five steps, listed below. However, for the specific objective of this thesis, only the first step will be examined.

1. Identify the potential Model Uses
2. Identify the responsible parties for each potential Model Use
3. Rate the capabilities of each party for each Model Use identified in categories A. Resources B. Competency C. Experience
4. Identify additional values and risk associated with each Model Use
5. Determine whether or not to implement each Model Use

The Planning Guide brings twenty-one common Model Uses (Figure 2.18) and four additional potential uses. In the guide, the authors affirm there are many more potential uses and that the identification of the uses should not be limited to the ones listed by them.

Figure 2.18 - Common Model Uses by Project Phase.



Source: (Messner et al., 2020)

The four addition potential uses defined at the BIM Plan are:

- Site Analysis
- Engineering Analysis
- Code Validation
- Disaster Planning

This background on the BIM Plan and the Model Uses is important because the third specific objective (Identify BIM use cases to enhance methods) of this thesis will relate the Model Uses with the LEED project goals, based on the LEED BD+C NC v4 credits.

2.4.2 - GREEN BIM

The integration of BIM and sustainable design has not always been directly linked. In the last decade, with the further developments of BIM, the integration between these two contemporaneous topics became one concept: Green BIM.

According to Gandhi and Jupp (2013), Green BIM is based on three pillars:

- Integrated design processes;
- Environmentally sustainable design principles; and
- Optimization of Green building certification credits.

The BIM methodology requires an integrative, multidisciplinary process for the development of a project, and this same type of process is required for the development of a sustainable building design. Thus, the integration of BIM and Green Buildings design has the integrative process as a common feature that results in building performance enhancement. However, the adoption of BIM is not only because its integrative process matches with the sustainable design process, but also because BIM serves as a tool to improve the sustainable design and assess sustainability performance in buildings, improving the green building certification process.

There are several study areas for when it comes to using Green BIM in projects seeking a green building certification. Researchers have explored different possibilities to try to improve the sustainability assessment process considering the different types of green certification: LEED, BREEAM, CESBA, and others. Some examples of studies focusing on Green BIM for projects seeking the LEED certification, but with a completely different research area:

- Design assistance and certification management (Wu, 2010);
- Automatically calculating the compiled number of LEED points (Jalaei and Jrade, 2015);
- Integrating Lean with Green BIM (Hyatt, 2011);

There are many other studies on this specific topic (Green BIM + LEED). However, these examples show that even by narrowing the study (Green BIM + LEED), the different study areas are still vast.

2.4.3 - SUMMARY

The information of a project, or even of an object, can vary during the design phase, and for the accuracy of the future developments that depend on that information, it is crucial that the info inserted in the model is reliable. For the achievement of the objectives of a Green Building being certified with LEED, the LEED Professional needs to gather data from the model to prepare the required LEED documentation for the submission. Therefore, it is important that the Model Uses identification and the properties inserted in a BIM object are thought with a LEED mindset when preparing a BIM Execution Planning.

After having a grasp of Green BIM and understanding the relationship between BIM, sustainable design, and in this case, LEED certification, it is possible to say that the framework proposed by this thesis has a Green BIM approach.

2.5 - SUMMARY

In the construction industry, significant changes were seen over the last twenty years (2000-2020), mainly over the last ten years, such as the awareness of environmental responsibility and the use of technology to improve the industry's products, to name a few. These changes add new requirements to the management process and impact the way projects are managed. Thus, traditional project management techniques, the most used in construction projects, became inadequate to manage sustainable construction projects.

Project management is a fundamental part of a construction project, and different approaches can be followed depending on many variables, including the goals of the project team. Three main project management methods have been covered in the first section of this chapter: traditional, lean, and agile. The lean philosophy has been highlighted as being the method that best fits the design and construction industry. Its adoption can be initially done by embracing a few of the lean principles and techniques, not necessarily all at the same time. It is a change and learning process that focuses on the continuous improvement and the minimization of waste of resources, features that, in a broad perspective, have something in common with sustainability.

In the second section of this chapter, sustainability has been further discussed both in a general perspective and from the construction industry point of view. The discussion demonstrated that the construction industry is responsible for a great share in achieving a sustainable world. A reliable way for construction companies to add sustainability into its actions is by incorporating sustainability into the company’s culture and strategies and adopting sustainable project management practices.

Sustainability practices in the construction industry have many areas of application, and one is the construction of green buildings, followed by its certification. In this section, several rating systems were discussed, and it has been seen that they all have similar objectives, even though there are differences between each system. During the discussion about the LEED rating system, an explanation of the assessment process is given, showing the recommended steps and practices that the project’s team should adopt to achieve higher performance.

Building Information Modeling has been deeply studied for several years now, and it is proven that its use brings several benefits to the construction industry. The definition of a BIM Plan is crucial for a successful adoption of BIM. The identification of BIM Uses for the goals of a LEED project can improve the management of a Green Building project, bringing benefits to the whole building process. Moreover, the adoption of Green BIM requires the professionals to use an integrative process involving all stakeholders since the beginning of the project, therefore improving the sustainable design and the achievement of a green building certification.

To further develop this thesis and accomplish the research goals, the LEED certification will be deeper analyzed through a case study in a sustainability consultancy team. A framework will be proposed, which will help projects teams better define the LEED project’s goals and integrate BIM within the sustainability assessment process.

3 - SYSTEMATIC LITERATURE REVIEW

This chapter brings a literature review of the studies in green construction project management. Initially, a broader spectrum of papers was analyzed, and then these papers were filtered, considering studies that were also including information management. The systematic literature review is separated into three stages, starting with a quantitative analysis, followed by a meta-analysis, and a qualitative analysis. Finally, a conclusion of the review is presented.

The collection of the data done by the author has been guided by the research question: What are international studies talking about green construction project management (project management + green construction)?

3.1 - QUANTITATIVE ANALYSIS

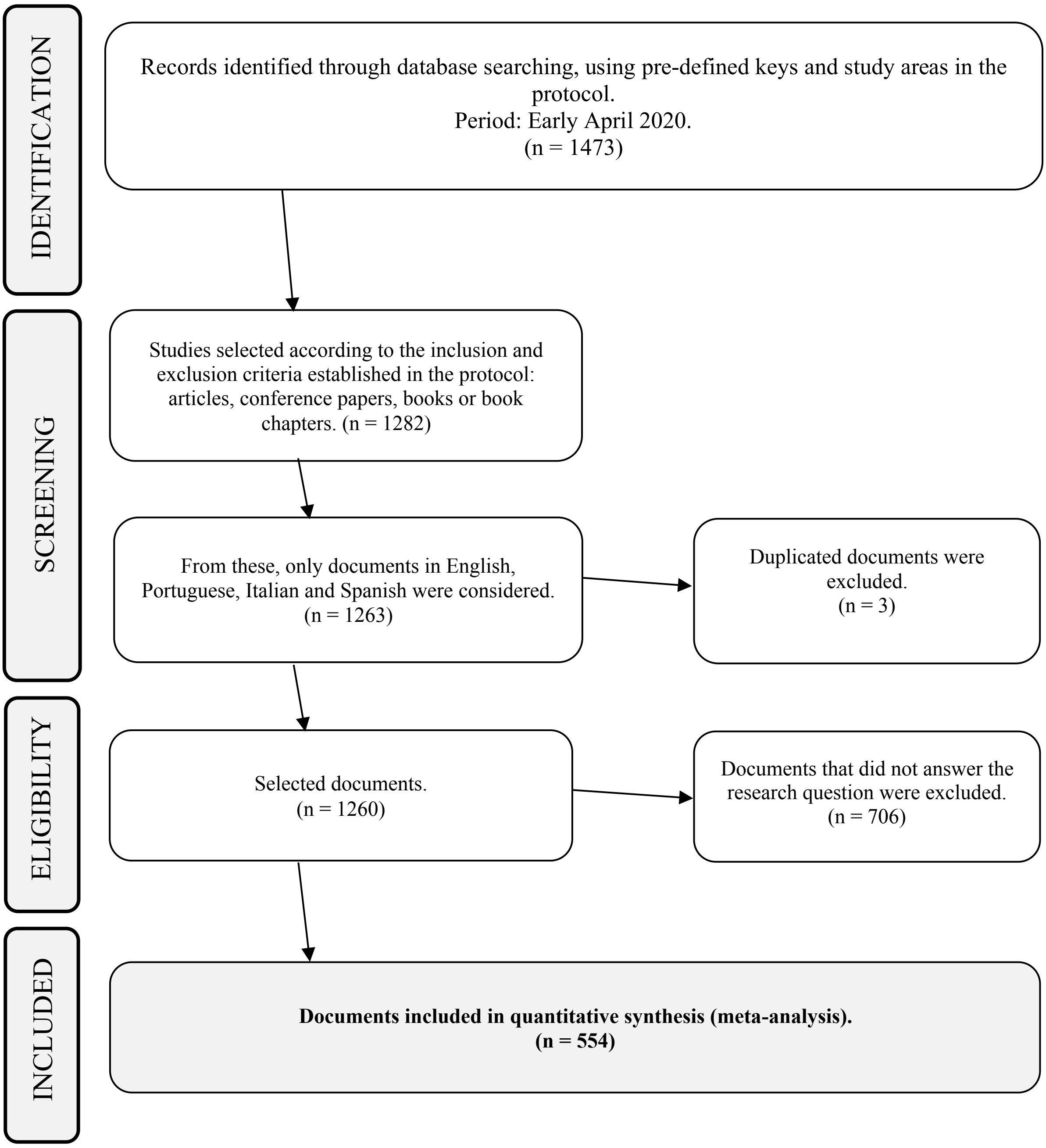
An initial search to identify studies was carried out in early April of 2020 in the Scopus database. It has been decided to use only this database due to its broad collection and universe. An advanced search was done considering Boolean operators such as "*and*" and "*or*", and keywords. The keywords selected for this first search were: project management / LEED / BREEAM / CESBA / sustainability / green / built environment / construction / building / AECO. The results were refined according to the following selected subject areas: engineering; business, management and accounting; environmental science; social sciences; energy; material science; earth and planetary science; computer science; decision science; and economics, econometrics and finance.

This first search resulted in a total of 1473 documents; however, only complete articles, conference papers, books, and book chapters were considered for the literature review, resulting in 1282 documents. Moreover, the search was limited to documents written in English, Portuguese, Italian, and Spanish, which resulted in 1263 documents. Between all the documents, 3 of them were duplicated, which decreased the number of documents to 1260. No filter of date of publication was used in order to show the development of the topic through the decades.

On the following stage, the titles and abstracts were read in order to understand if the documents would answer the research question. After that, 706 documents were excluded resulting in a total number of 554 documents.

Figure 3.1 represents the first stage, quantitative analysis, and summarizes the process described above in a diagram as proposed in the PRISMA methodology (Moher, 2009). According to PRISMA methodology, the quantitative process is divided into four steps: identification, selection, eligibility, and inclusion.

Figure 3.1 - Methodological process for data survey.



Source: Created by the author. Diagram based on Prisma model (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), Moher (2009).

3.2 - META-ANALYSIS

In the second stage, all the 554 documents are deeper analyzed with the use of Bibliometrix, a R-tool for comprehensive science mapping analysis. An initial analysis is done on the type of document to understand the contribution of each type. This initial analysis is summarized in Table 3.1.

Table 3.1 - Document type contribution.

Document type	Number of documents
Book	11
Book Chapter	12
Article	244
Conference Paper	287

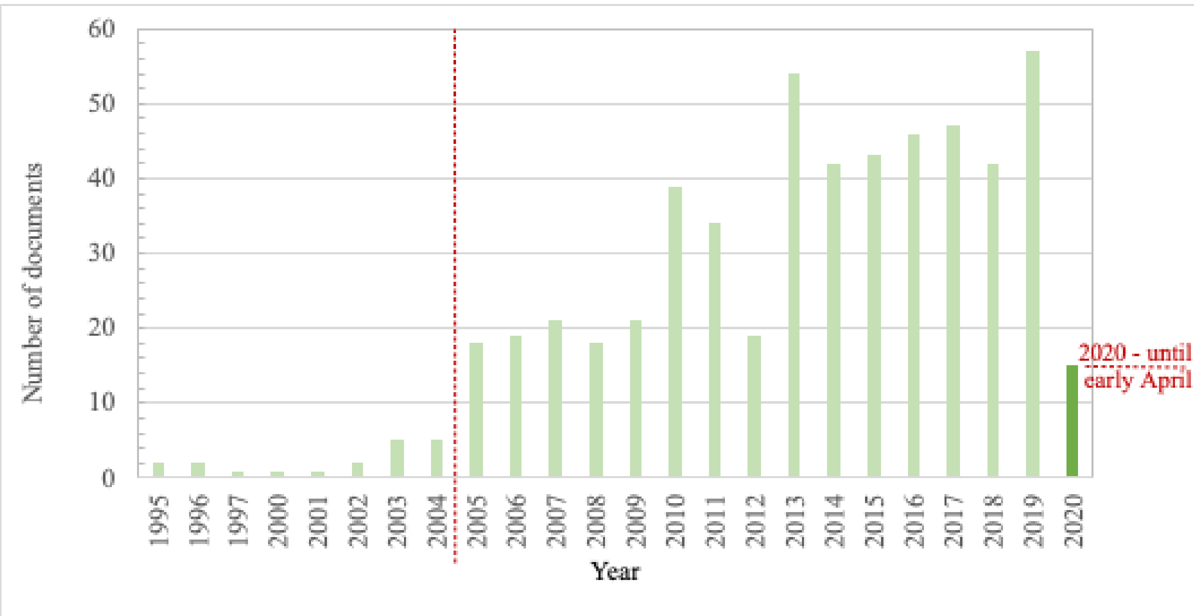
Source: Created by the author.

Regarding the period of publication (Figure 3.2), it started in 1995 with two publications in the year. Until 2004, the production was following an average of two publications per year, with a gap in 1998 and 1999. The studies related to project management and sustainability became widespread in the new millennium, and this growth can be explained by understanding the situation of both topics in the first years of the century.

The publication of ISO standards such as ISO 15288:2001 (Project management) and ISO 10006:2003 (Quality management), and the release of new editions of the PMBOK (2nd edition in 2000 – 3rd edition in 2004) could influence the increase of the number of studies in the area of Project Management. In parallel to the previous topic, studies on sustainability and global warming were getting more attention in those years. Moreover, the LEED rating system was releasing its second version in 2001, and reaching a significant milestone in 2004, when achieving the number of 100 certified projects.

The majority of the documents were published within the last decade (2010-2020), more precisely, 79% of the documents. It should be emphasized that only documents published until early April of 2020 are included in the literature review, totalizing 15 documents. It is possible that the circumstances that the world has been facing since the beginning of 2020 due to the COVID-19 virus can influence the scientific production of the year of 2020.

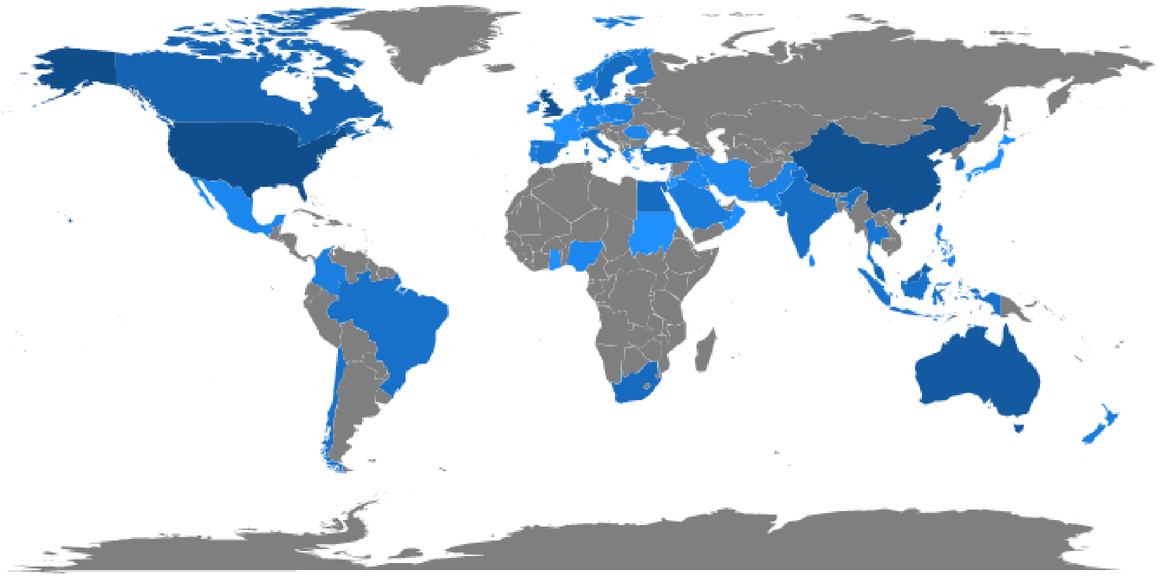
Figure 3.2 - Scientific production per year.



Source: Created by the author.

According to Figure 3.3, United States of America is the country that has the highest number of documents published in Sustainability Assessment and Project Management, followed by China, United Kingdom and Australia. The 15 countries that publish the most in order from the one that publishes the most to the least on this topic are the following: USA, China, UK, Australia, Malaysia, Singapore, Canada, Taiwan, South Africa, Sweden, Egypt, India, South Korea, Brazil, and Chile.

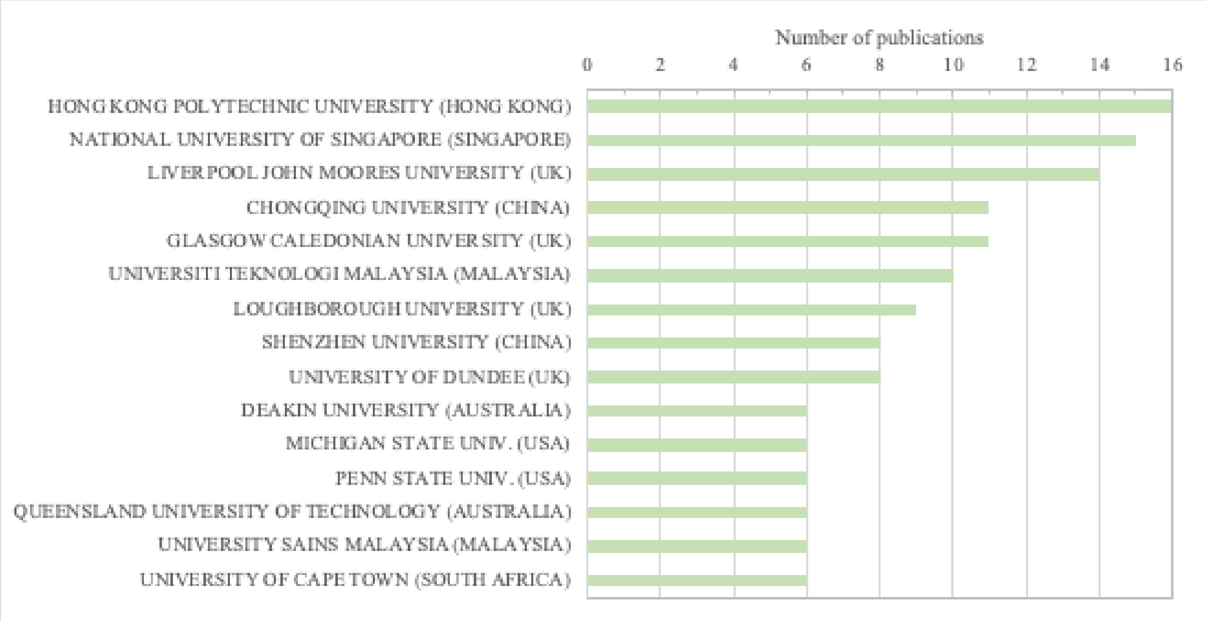
Figure 3.3 - Country scientific production.



Source: Created by the author.

The scientific production of documents related to sustainability assessment and project management can also be explored from the point of view of relevant affiliations. First, it has been analyzed the number of publications per country and now, per universities. The universities that publish the highest number of documents are not located in the countries that does the same. As it is seen in Figure 3.4, the Hong Kong Polytechnic University is the one with the highest cumulative number of publications, while Hong Kong is not even listed of countries. When analyzing when universities from the USA appear in the ranking, it is observed that Michigan and Penn State universities are the 11th and 12th in the ranking of most relevant affiliations while the USA is the country with most publications.

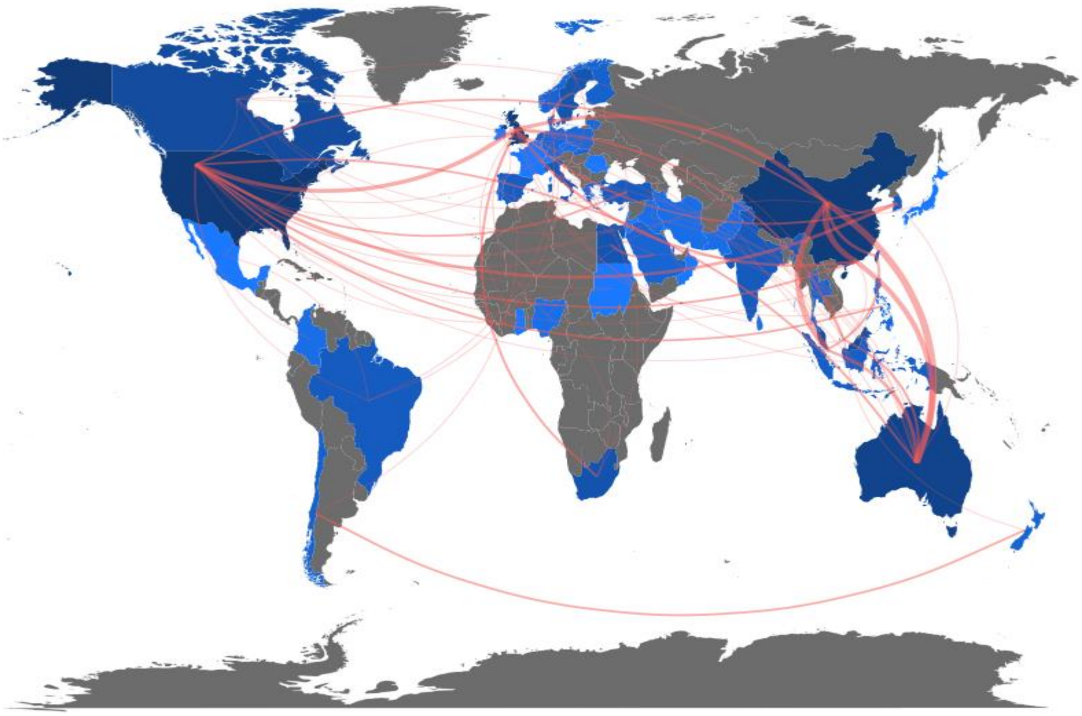
Figure 3.4 - Most relevant affiliations.



Source: Created by the author.

It is known that many studies are carried out with collaboration between universities. Thus, it is important to understand the collaboration map of the world. In Figure 3.5, it is seen that the four countries that publish the highest number of documents are also the ones that collaborate the most: USA, China, UK and Australia. These countries are highlighted in dark blue in the world map and they present several red arrows that represents the collaboration between countries.

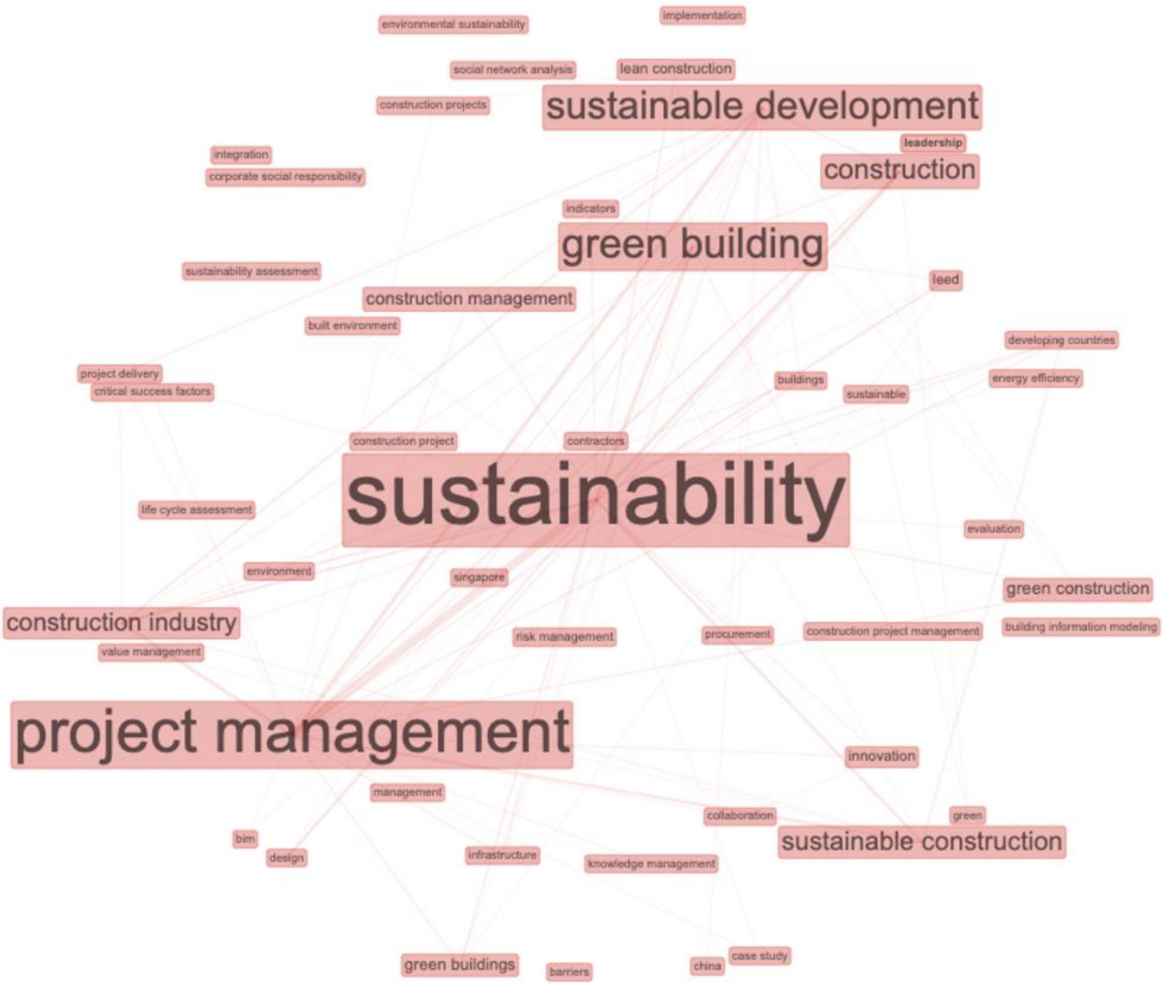
Figure 3.5 - Country collaboration map.



Source: Created by the author.

An analysis of the author's keywords occurrence of the 554 documents has been done considering the association between them. Figure 3.6 analyzes the network of the 50 most used keywords in all documents.

Figure 3.6 - Author's keyword network analysis (554 documents).



Source: Created by the author.

3.3 - QUALITATIVE ANALYSIS

In the Scopus database, new keywords were added to the search: information management, information and communication technology (ICT), digitalization, digitalisation, digitization, and digitisation. The idea is to now filter the 554 documents even more in order to find documents that are talking about sustainability assessment and project management, and that are also related to information management and digitalization. When the previous filters are matched with the new ones, a total of 61 documents were found. Nine of those documents were not accessible.

The third stage of the systematic literature review, qualitative analysis, is done with the articles listed in Table 3.2. The listed documents are following the descending order of year of publication. Documents number 7, 8 13, 15, 32, 33, 41, 52 and 59 were not accessible.

Table 3.2 - Selected documents list.

Number	Author	Title	Year of publication
1	LIU L;RAN W	RESEARCH ON SUPPLY CHAIN PARTNER SELECTION METHOD BASED ON BP NEURAL NETWORK	2020
2	SAFIULLIN R;MARUSIN A;SAFIULLIN R;ABLYAZOV T	METHODICAL APPROACHES FOR CREATION OF INTELLIGENT MANAGEMENT INFORMATION SYSTEMS BY MEANS OF ENERGY RESOURCES OF TECHNICAL FACILITIES	2019
3	ISMAIL ZA	DEVELOPING A MAINTENANCE INDEX FRAMEWORK FOR HERITAGE CONCRETE BUILDINGS	2019
4	ABRAMOV IL	SYSTEMIC INTEGRATED METHOD AS THE BASIS FOR HIGH-QUALITY PLANNING OF CONSTRUCTION PRODUCTION	2019
5	KAEWUNRUEN S;LIAN Q	DIGITAL TWIN AIDED SUSTAINABILITY-BASED LIFECYCLE MANAGEMENT FOR RAILWAY TURNOUT SYSTEMS	2019
6	STEGNAR G;CEROVEK T	INFORMATION NEEDS FOR PROGRESSIVE BIM METHODOLOGY SUPPORTING THE HOLISTIC ENERGY RENOVATION OF OFFICE BUILDINGS	2019
~~7~~	JOZWIAK E;CUENCA M	UTILIZING PERFORMANCE METRICS TO MEASURE THE IMPACT OF SUSTAINABILITY ON NYC WATER & WASTEWATER INFRASTRUCTURE	2019
~~8~~	TOPCHIY D;TOKARSKIY A	FORMATION OF HIERARCHIES IN THE SYSTEM OF ORGANIZATION OF STATE CONSTRUCTION SUPERVISION IN CASE OF REORIENTATION OF URBAN AREAS	2019
9	ARAGAO RR;EL-DIRABY TE	SEMANTIC NETWORK ANALYSIS AS A KNOWLEDGE REPRESENTATION AND RETRIEVAL APPROACH APPLIED TO UNSTRUCTURED DOCUMENTS OF CONSTRUCTION PROJECTS	2019
10	JAYASINGHE RS;RAMEEZDEEN R;CHILESHE N	WASTE MANAGEMENT PRACTICES IN AUSTRALIA: COMPARISON OF STRATEGIES	2019
11	MASUIN R;ROFI'UDIN M;LATIEF Y	IMPORTANT CLAUSES CONSTRUCT THE INTEGRATION PROCESS OF QUALITY, SAFETY, OCCUPATIONAL HEALTH, AND ENVIRONMENT MANAGEMENT SYSTEMS	2018
12	MOCERINO C	DIGITAL REVOLUTION IN EFFICIENT SELF-ORGANIZATION OF BUILDINGS: TOWARDS INTELLIGENT ROBOTICS	2018
~~13~~	MESRO P;MANDIK T;SPIKOV M	SUSTAINABILITY TROUGH BIM TECHNOLOGY IN CONSTRUCTION INDUSTRY	2018

Number	Author	Title	Year of publication
14	SIMPEH E;SMALLWOOD J	FIELD DIAGNOSIS OF CHALLENGES AND FACILITATORS TO THE ADOPTION OF GREEN BUILDING PRINCIPLES IN MULTI-PURPOSE OFFICE FACILITIES	2018
15	HAMAD JA;ZGHEIB Y;FARES M	PROJECT MANAGEMENT: RISK MITIGATION IN A VOLATILE ENVIRONMENT	2018
16	MOROZENKO A;KRASOVSKIY D	DEVELOPMENT OF REFLEX-ADAPTIVE ORGANIZATIONAL STRUCTURE OF HIGH ROBUSTNESS	2018
17	HOSSEINI MR;BANIHASHEMI S;RAMEEZDEEN R;GOLIZADEH H;ARASHPOUR M;MA L	SUSTAINABILITY BY INFORMATION AND COMMUNICATION TECHNOLOGY: A PARADIGM SHIFT FOR CONSTRUCTION PROJECTS IN IRAN	2017
18	SOON ERN PA;KASIM N;ABD HAMID Z;KAI CHEN G	CRITICAL ICT-INHIBITING FACTORS ON IBS PRODUCTION MANAGEMENT PROCESSES IN THE MALAYSIA CONSTRUCTION INDUSTRY	2017
19	DE PAULA N;ARDITI D;MELHADO S	MANAGING SUSTAINABILITY EFFORTS IN BUILDING DESIGN, CONSTRUCTION, CONSULTING, AND FACILITY MANAGEMENT FIRMS	2017
20	KOPPELHUBER J;BAUER B;WALL J;HECK D	INDUSTRIALIZED TIMBER BUILDING SYSTEMS FOR AN INCREASED MARKET SHARE - A HOLISTIC APPROACH TARGETING CONSTRUCTION MANAGEMENT AND BUILDING ECONOMICS	2017
21	KLAND A;JOHANSEN A;TUFTO E;KYLLING IE	LEARNING BY DOING: PUBLIC AND PRIVATE SEARCH FOR QUICK DELIVERY AND SUSTAINABILITY IN BUILDING PROJECTS	2017
22	KLAND A;JOHANSEN A;BESTE T;GJESTEBY E	STANDARDIZATION AND MODULARIZATION OF PRISONS	2017
23	TARIMO M;WONDIMU P;ODECK J;LOHNE J;LDRE O	SUSTAINABLE ROADS IN SERENGETI NATIONAL PARK: - GRAVEL ROADS CONSTRUCTION AND MAINTENANCE	2017
24	NGUYEN TH;TOROGHI SH;JACOBS F	AUTOMATED GREEN BUILDING RATING SYSTEM FOR BUILDING DESIGNS	2016
25	ALADAG H;DEMIRDGEN G;ISIK Z	BUILDING INFORMATION MODELING (BIM) USE IN TURKISH CONSTRUCTION INDUSTRY	2016
26	BANSAL VK	POTENTIAL APPLICATION AREAS OF GIS IN PRECONSTRUCTION PLANNING	2016
27	CHOI JO;BHATLA A;STOPPEL CM;SHANE JS	LEED CREDIT REVIEW SYSTEM AND OPTIMIZATION MODEL FOR PURSUING LEED CERTIFICATION	2015
28	KAPOGIANNIS G;GATERELL M;OULASOGLOU E	IDENTIFYING UNCERTAINTIES TOWARD SUSTAINABLE PROJECTS	2015

Number	Author	Title	Year of publication
29	HOPKIN T;LU SL;ROGERS P;SEXTON M	DETECTING DEFECTS IN THE UK NEW-BUILD HOUSING SECTOR: A LEARNING PERSPECTIVE	2015
30	UPSTILL-GODDARD J;GLASS J;DAINTY A;NICHOLSON I	DEVELOPING A SUSTAINABILITY ASSESSMENT TOOL TO AID ORGANISATIONAL LEARNING IN CONSTRUCTION SMES	2015
31	LEHMANS A	AN ECOLOGICAL APPROACH TO COLLABORATIVE KNOWLEDGE MANAGEMENT IN SMALL PROFESSIONAL COMMUNITIES: SUSTAINABLE INFORMATION PRACTICES FOR SUSTAINABLE WORK	2015
~~32~~	TRANI M;BOSSI B;CASSANO M;TODARO D	BIM ORIENTED EQUIPMENT CHOICE ON CONSTRUCTION SITE	2015
~~33~~	GAUNTT P;GOSH S;HARTNEY MJ	GOING FROM BLACK TO GREEN - THE DC WATER SUBMITTAL PROCESS	2015
34	IMEL MR;GASTESI R;STONE R	MONROE COUNTY, FLORIDA A CASE STUDY IN SUSTAINABLE ENERGY MANAGEMENT	2015
35	ZIDANE YJT;JOHANSEN A;EKAMBARAM A	PROJECT EVALUATION HOLISTIC FRAMEWORK - APPLICATION ON MEGAPROJECT CASE	2015
36	LI T;WANG Y;WU H	A GREEN CONSTRUCTION INFORMATION MANAGEMENT PLATFORM BASED ON EMERGING INFORMATION TECHNOLOGY	2014
37	WU W;ZHOU H	BIM FOR SUSTAINABLE CONSTRUCTION: A STRATEGIC FRAMEWORK FOR HANDLING CHALLENGES OF THE INTERNATIONAL GREEN CONSTRUCTION CODE	2014
38	HOPKIN T;LU SL;ROGERS P;SEXTON MG	PLACING DEFECTS AT THE HEART OF HIGH QUALITY NEW HOMES: THE LEARNING PERSPECTIVE	2014
39	YANG M;BALDWIN A	INFORMATION MANAGEMENT FOR SUSTAINABLE BUILDING PROJECTS	2013
40	LI W;LI Y	IMPROVEMENT OF THE COURSE OF CONSTRUCTION MANAGEMENT	2013
~~41~~	NGUYEN TH;TOROGHI SH	KNOWLEDGE REPRESENTATION IN BIM FOR EVALUATING SUSTAINABILITY OF A BUILDING DESIGN	2013
42	SEZER AA	INDICATORS OF ENVIRONMENTAL AND PRODUCTIVITY PERFORMANCE FOR BUILDING REFURBISHMENT PROJECTS	2013
43	TAYLOR P;WIELKI J;SHEA T	INCORPORATING ENVIRONMENTAL CONSIDERATIONS INTO PIPELINE INTEGRITY MANAGEMENT PROGRAMS	2012

Number	Author	Title	Year of publication
44	LIKHITRUANGSILP V;PUTTHIVIDHYA W;IOANNOU PG	CONCEPTUAL FRAMEWORK OF THE GREEN BUILDING INFORMATION MANAGEMENT SYSTEM	2012
45	FATHI MS;RAWAI N;ABEDI M	MOBILE INFORMATION SYSTEM FOR SUSTAINABLE PROJECT MANAGEMENT	2012
46	WEI G;RUI L	RESEARCH OF RURAL RESIDENTIAL DEMONSTRATION PROJECT POPULARIZATION MECHANISM BASED ON NETWORK INFORMATION PLATFORM IN CHINA	2011
47	REZGUI Y;MARKS A	SUSTAINABLE CONSTRUCTION ONTOLOGY DEVELOPMENT USING INFORMATION RETRIEVAL TECHNIQUES	2011
48	LIANG DH;LIANG DS;LII P	THE INNOVATION MANAGEMENT OF ENGINEERING PLANNING AND DESIGN - SPECIFICALLY IN ENGINEERING CONSULTING INDUSTRY	2011
49	KIM C;KIM B;LIM H;KIM H	INTERACTIVE COMMUNICATION PLATFORM FOR CONSTRUCTION MANAGEMENT USING MOBILE COMPUTING AND AUGMENTED REALITY	2010
50	SETTERFIELD C;DUNN E;MARCKS R	SIMULATING THE COLLABORATIVE DESIGN PROCESS THROUGH A MULTIDISCIPLINARY CAPSTONE PROJECT	2010
51	NEWTON PW;HAMPSON KD;DROGEMULLER RM	TECHNOLOGY, DESIGN AND PROCESS INNOVATION IN THE BUILT ENVIRONMENT	2009
~~52~~	CHENG MY;LIEN LC;TSAI MH	AN INTRODUCTION FOR MEGA HOUSE	2008
53	PADE C;MALLINSON B;SEWRY D	PROJECT MANAGEMENT PRACTICE FOR RURAL ICT PROJECT SUSTAINABILITY IN DEVELOPING COUNTRIES	2008
54	FORGUES D;KOSKELA L;LEJEUNE A	TOWARD A CLIENT-DRIVEN REQUIREMENT MANAGEMENT FRAMEWORK FOR ACHIEVING BEST VALUE FOR MONEY	2007
55	MLLER J;SANCHO GIL JM;HERNNDEZ F;GIR X;BOSCO A	THE SOCIO-ECONOMIC DIMENSIONS OF ICT-DRIVEN EDUCATIONAL CHANGE	2007
56	PADE CI;MALLINSON B;SEWRY D	AN EXPLORATION OF THE CATEGORIES ASSOCIATED WITH ICT PROJECT SUSTAINABILITY IN RURAL AREAS OF DEVELOPING COUNTRIES: A CASE STUDY OF THE DWESA PROJECT	2006
57	SELL J;KOELLNER T;WEBER O;PEDRONI L;SCHOLZ RW	DECISION CRITERIA OF EUROPEAN AND LATIN AMERICAN MARKET ACTORS FOR TROPICAL FORESTRY PROJECTS PROVIDING ENVIRONMENTAL SERVICES	2006

Number	Author	Title	Year of publication
58	GIACARDI A	SELF-HELP MADE VIABLE: THE IMPORTANCE OF MANAGEMENT OF RESOURCES AND DATA	2005
59	ANDREWS A;RANKIN J;WAUGH L;BRYDEN P;BARTEAUX P;WATSON R	OPPORTUNITIES FOR ICT SUPPORT: A CASE STUDY OF A LEED CONSTRUCTION PROJECT	2005
60	ANGELIDES D;XENIDIS Y	A METHODOLOGY FOR THE DEVELOPMENT OF A EUROPEAN APPROACH CONCERNING PERFORMANCE AND RISKS OF BUILT SYSTEMS	2005
61	GRAHAM S	SUSTAINABLE BUILDING DESIGN - A SYSTEMATIC APPROACH	2005

Source: Created by the author.

All available articles were separated into categories related to sustainability competencies in projects according to LEED v4 BD+C credits, and to project management competencies according to the Project Management Body of Knowledge (PMBOK 6th edition) process.

Sustainability competencies (LEED v4 BD+C) are separated in:

- Integrative process;
- Location and transportation;
- Sustainable sites;
- Water efficiency;
- Energy and atmosphere;
- Materials and resources;
- Indoor environmental quality;
- Innovation; and
- Regional priority.

Project management competencies are divided according to the process groups of the PMBOK:

- Initiating;
- Planning;
- Executing;
- Monitoring and controlling; and
- Closing.

The competencies mentioned above are distributed into a matrix. On the horizontal axis, there are the LEED v4 BD+C competencies, and on the vertical, the project management ones. The decision for choosing LEED credit categories as one of the axes of the matrix is explained by the significant position the certification has in the market, which is later confirmed by articles included in the review. The PMBOK decision has been done due to its international scope and significance. The matrix (Table 3.3) categorizes the 52 documents according to the area of interest, and considering this analysis, it is evident that some areas of interest lack investigation.

Table 3.3 - Classification of articles according to thematic category.

Green Construction Project Management competencies		LEED v4 - BD+C - credit categories								
		Integrative process (IP)	Location and transportation (LT)	Sustainable sites (SS)	Water efficiency (WE)	Energy and atmosphere (EA)	Materials and resources (MR)	Indoor Environ. quality (EQ)	Innovation (IN)	Regional Priority (RP)
PMBOK - Project Management process	5. Closing									
	4. Monitoring and controlling	3, 35, 44				2, 34	10		19	
	3. Executing	21				9	20		18, 19, 49	
	2. Planning	4, 5, 24, 25, 31 36, 37, 39, 44, 45, 48, 50, 61	24, 26	24	24	6, 24, 34	24	24	12, 17, 19, 24, 60	24, 53
	1. Initiating	27, 28, 30, 47, 54								56

Source: Created by the author.

The following articles did not fit in any of the matrix categories, so they are not considered in the discussion of the review: 1, 11,16, 22, 23, 29, 38, 40, 42, 43, 46, 51, 55, 57, 58.

A synthesis of the studies has been done for the realization of the last methodological phase of the literature review, the qualitative analysis.

Regarding the publications related to project management and sustainability assessment in buildings, it has been observed that several studies are being carried out on the theme. In a general perspective, research in the area exists since the 90s, which can be related to discussions that emerged after Agenda 21, a result of Eco-92 conference in 1992 in Rio de Janeiro, Brazil. After the conference, there was the publication of Agenda 21 CIB report 237, in 1999, concerning sustainable construction, which was one of the first documents that explained the influence that the products of the construction sector have on the environment.

When combining green project management with information management and digitalization, a reduction in the number of publications is observed. These studies started to get attention in the first decade of the years 2000. By this time, some aspects were already being discussed, such as IFC2x schema to improve interoperability and collaborative design, and integrated ICT approach to allow designers to promote early decision making in projects (Graham, 2005). The relevance of the theme is even higher nowadays with industry 4.0, and the improvements that the digitalized process is bringing to the construction sector.

The analysis of the literature listed above confirms that Building Information Modeling (BIM) is the most common approach for allowing an integrated project method and digitalized process in the construction sector. Furthermore, researchers affirm that BIM could accelerate and facilitate green building rating processes and that for this to be possible, the information should be represented in a way that the rating system criteria could be extracted from the model to support the assessment (Nguyen et al., 2016). One of the biggest challenges in the adoption of BIM is the need to ensure it helps deliver built assets that perform effectively with minimum impact over their whole life. When it comes to adopting BIM within the sustainability dimension, it is known that it could reduce performance vulnerabilities during the project management life cycle (Kapogiannis et al., 2015).

The articles included in this review show that the most used rating system worldwide is the Leadership in Energy and Environmental Design (LEED). Although LEED has this featured position in the international market, the evaluation process can be optimized in order to arrive at the best LEED category for a specific project and to decide which credits to pursue, thus becoming more digitalized (Choi et al., 2015; Nguyen et al., 2016)

The competencies related to project management are divided into processes group of a project, which start with the initiation (1), passing through planning (2), execution (3), monitoring and controlling (4), until closing (5). When translating these management terms to building process stages, the following can be used: pre-design (1), design (2), construction (3), operations and maintenance (4), and end of life (5). The articles were categorized on the matrix according to the management process or project stage.

For the sustainability competencies analysis, the articles were categorized depending on the sustainable aspect (LEED category/credit) being covered in the content of the document. The LEED v4 BD+C credit categories have been used without any terms translation to the construction sector since they are already part of it.

The matrix analysis is done by lines, starting at the first project management competence (1. initiating), until the last (5. closing). Content examples are given, followed by the author's identification. When necessary, the category of the matrix will be named as the *number of project management competence + abbreviation of sustainable competence* (e.g., *1.IP*: initiating + integrative process).

From the first project management competence, a small number of documents in that area of investigation is observed. Between all the documents of the initiating process competence, 83% are combined with integrative process sustainable competence. The initiating category contains documents discussing different ideas: a tool to assess which credits to seek for the LEED certification (Choi et al., 2015); organizational learning as a limiting factor in successful sustainability implementation (Upstill-Goddard et al., 2015); client requirement to improve the efficiency of the project's ability to generate the best value for money (Bresnen, 2008).

At the following project management competence, planning, it is seen that it was the only management process group that filled all the sustainability columns, meaning that much research is done related to the planning phase. 25% of all the studies focus on category *2.IP* (planning process + integrative process). These articles mention that the integrative process during the design stage brings quality, precision, effectiveness, and even more benefits for the following process of a project. Many of the articles included in this category are analyzing successful implementations of different managerial tools in projects and confirming the importance of using an integrated process in sustainable projects. It is important to remind that the analysis of the sustainability competence related to IP category of LEED considers the intent and the 'behind the intent' of the Integrative Process as described in the (USGBC, 2013).

When going forward with analysis, the matrix becomes empty again, showing that the executing process, different than the planning, has fewer research articles discussing it. Besides that, only four out of the nine sustainability competencies are covered by the documents included in the executing process. Discussion includes investigation on energy use in the construction phase (Aragao and El-Diraby, 2019); evaluation of the degree of success in quick delivery projects (Økland et al., 2017); use of modern timber construction method to shorten the construction period and site cost reduction (Koppelhuber et al., 2017).

The operation stage, represented by the monitoring and controlling competence, presents researches on the same sustainable competencies as the construction stage. Discussions cover different topics, such as maintenance in heritage buildings (Ismail, 2019); analysis of the delivered result of a project in terms of relevance, effectiveness, impact, and sustainability (Zidane et al., 2015); management of energy resources to reduce consumption during the operational phase (Safiullin et al., 2019).

The last project management process, closing, has not been covered by any of the articles included in the review.

3.4 - CONCLUSION

The review has shown that green construction project management is studied in several aspects. The studies in this area have grown in the last two decades, proving its relevance.

A filter has been applied to put together studies related to green construction project management, information management, and digitalization. In the last methodological phase of the literature review, many case studies validating methods developed by partnerships of researchers and enterprises have been found, with results proving that academia and companies are working together on behalf of green construction. This partnership between the academia and enterprises will be a feature of this thesis, that develops an exploratory case study at Jacobs Italia S.p.A., in order to investigate management practices related to green construction, to achieve the research objectives.

Moreover, a matrix has been created relating project management and sustainability competencies. The matrix identified where there is a knowledge gap and what areas received the most attention. The analysis of the matrix has shown that the planning process is the main studied area when it comes to project management competencies, and that initiating comes in second place, while the others receive much less attention, mainly the closing phase. This knowledge gap related to the executing, operating and closing phases should be more explored by the academia. For example, studies on Asset management of green buildings could be an interesting area of research to fill this knowledge gap. Concerning the sustainability competencies, the most studied is the integrative process, followed by innovation, and energy and atmosphere. The review also concluded that BIM is the most used method to allow the integrative process of projects and that LEED is the most used building rating system.

The matrix results analysis showed that there are not studies investigating the difficulties of the achievement and the points' contribution of the LEED credits, neither the relation of the credits to the impacts on the project's cost and schedule. Moreover, the literature review showed that BIM is the most common approach to provide an integrative process between all project actors. However, it has not been found any study identifying possible BIM Model Uses and parameters associated with the LEED credits.

The review reached its objective of defining what has been studied about green construction project management worldwide, identifying topics already consolidated, and highlighting some that lack investigation, and therefore, will be investigated in this thesis.

4 - METHODOLOGY

This chapter explains the adopted methodological procedures for the development of this thesis. First, the research is characterized, then, there is a description of the research design, followed by the description of the data collection and analyses, and the research limitations.

4.1 - RESEARCH CHARACTERIZATION

Different research methods can be followed in order to motivate and defend a thesis. This is a research that follows a case study methodological approach. According to Robert K. Yin, in the fifth edition of the book "Case study research: design and methods", a case study is preferred when questions such as "how" and "why" are asked. The author affirms that a case study should be applied when the investigator has little control over the events, and when it is about a contemporary phenomenon with some real-life context (Yin, 2014). In summary, a research can consider following a case study methodology if the following questions are answered with a "Yes": Can "Why" and "How" answer the research question? Does the investigator have little control over the event? Is the research focused on a contemporary event in a real-life context?

For Yin, 2014, a case study research contributes to the understanding of individual, organizational, social, and political phenomena. It is a type of study that can be used as a strategy in different fields of study, such as political science, sociology, psychology, economy, business, and planning. It permits to investigate real-life events preserving significant characteristics such as organizational and administrative process, international relations and maturation of sectors, as well as individual life cycles. Moreover, in this type of study, it is possible to use several sources of evidence such as observation of the event, interviews with people involved in the event, analysis of documents, etc. (Yin, 2014).

According to Yin's theory, case studies can be single or multiple. The first is appropriate depending on some circumstances, called single-case rationales: 1. a critical test of an existing theory; 2. an unusual circumstance; 3. A common case; 4. a revelatory case; or 5. a longitudinal case. Thus, the chosen single case study will be used to understand and explain the propositions made on the theory. In a multiple case, not all rationales can be applied, since critical, unusual, and revelatory are features of one case only. Both types have drawbacks, the single-case can result in less reliable results, while the multiple can require extensive resources and time, in addition to a new set of questions (Yin, 2014, pp. 106–108).

This thesis is a single case study of exploratory type, has a mixed qualitative and quantitative approach, and a non-probabilistic sampling. The research is exploratory because it aims to investigate and understand the management of LEED projects and propose an improvement. The mixed approach is characterized by the application of a questionnaire (with qualitative and quantitative questions) and the conduction of interviews with professionals who can provide essential information to add to the exploration. Bibliographical research is carried out to support and guide the data analyses and interpretation. Moreover, a literature review is done to underline more objective and insightful questions on the same topic (Yin, 2014, p. 51).

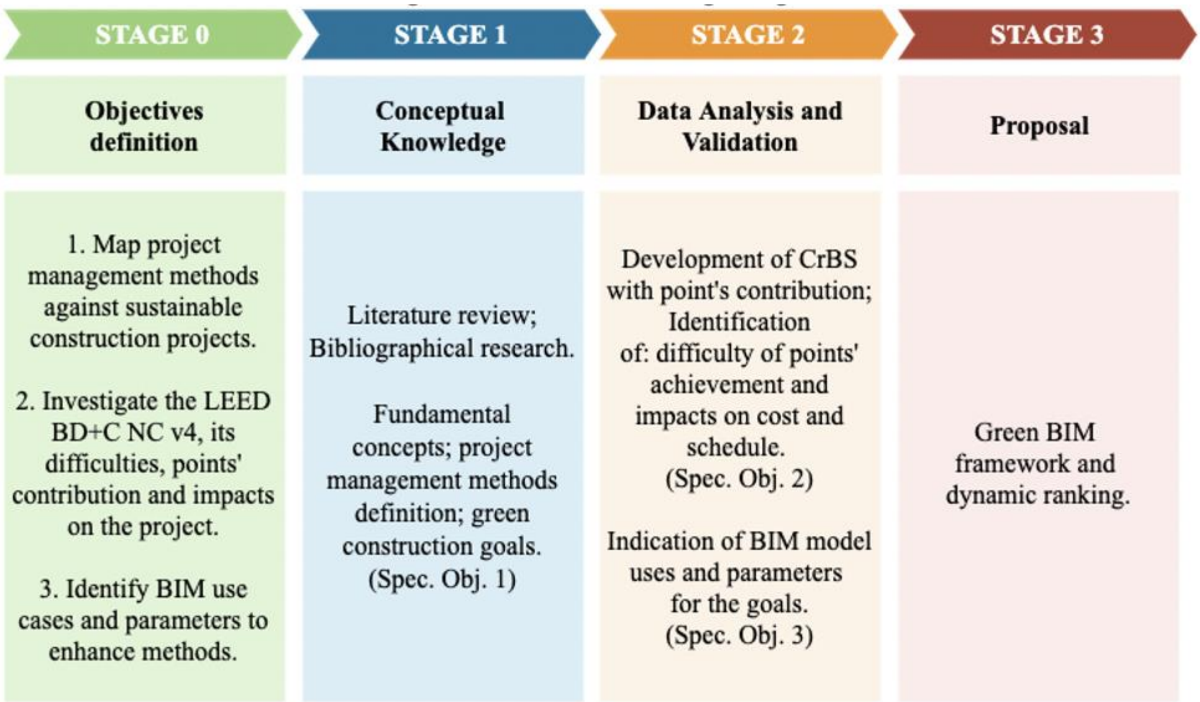
The study was developed in one of the world's largest engineering and construction companies, Jacobs Engineering Group Inc. The headquarters is located in Dallas, USA, but the company has several offices around the world. The study carried out in this thesis took place at Jacobs Italia S.p.A., located in Milan, Italy. More precisely, the study has been done during an internship at the sustainability consultancy team of Jacobs Italia S.p.A., where the author had the opportunity to participate in the pre-assessment and assessment of LEED projects. Although the author had tasks on specific projects during the internship, the work at Jacobs was not directly related to the research, but indirectly. That is because being part of the team allowed the author to observe and to capture insightful information for the research purpose. Therefore, the case study is the sustainability assessment process and not a specific project.

4.2 - RESEARCH DESIGN

The research's methodological process is designed to address the research objectives, and in order to structure this process, some stages have been designed. A life cycle model is designed considering "a necessary sequence of stages or phases" because a logical program regulates these stages' content (Van de Ven, 2007). The considered sequence starts with the definition of the research objectives (Stage 0), passing through conceptual knowledge (Stage 1), data analysis and validation (Stage 2), and finally, it arrives at the proposal (Stage 3).

In Stage 0, the definition of the thesis' objective and the three specific ones are presented (Chapter 1). The following stages focus on developing the work to achieve the research goals and answer the research question. Stage 1 brings a background foundation including all necessary data that will be used in the process. This stage is presented throughout the thesis's body (Chapter 2), and its main parts will be analyzed in section 5.1 (Chapter 5). Then, in Stage 2, after mapping the data from the literature, applying the questionnaire, and doing interviews, the data is analyzed, and the results are shown and validated. Finally, the framework and a dynamic ranking are proposed in Stage 3. The research design is shown in Figure 4.1.

Figure 4.1 - Research design stages.



Source: Created by the author.

Another way to visualize the research design is by observing the development of each specific objective of the thesis. Starting from specific objective 1, passing through all its steps, then arriving at specific objectives 2, 3, and finally, at the proposed framework, the thesis' central objective.

Thus, to map project management methods against the sustainability construction project's task (specific objective 1), it was necessary to understand the process behind the sustainability assessment of buildings that seek LEED certification. This knowledge has been fulfilled through the application of some research techniques. At first, a literature review was conducted to understand what the international studies were discussing about green construction project management and the use of digitalization. Then, bibliographical research has been carried out, and interviews with sustainability engineers and the consultancy manager have been conducted to better understand green construction project management at Jacobs.

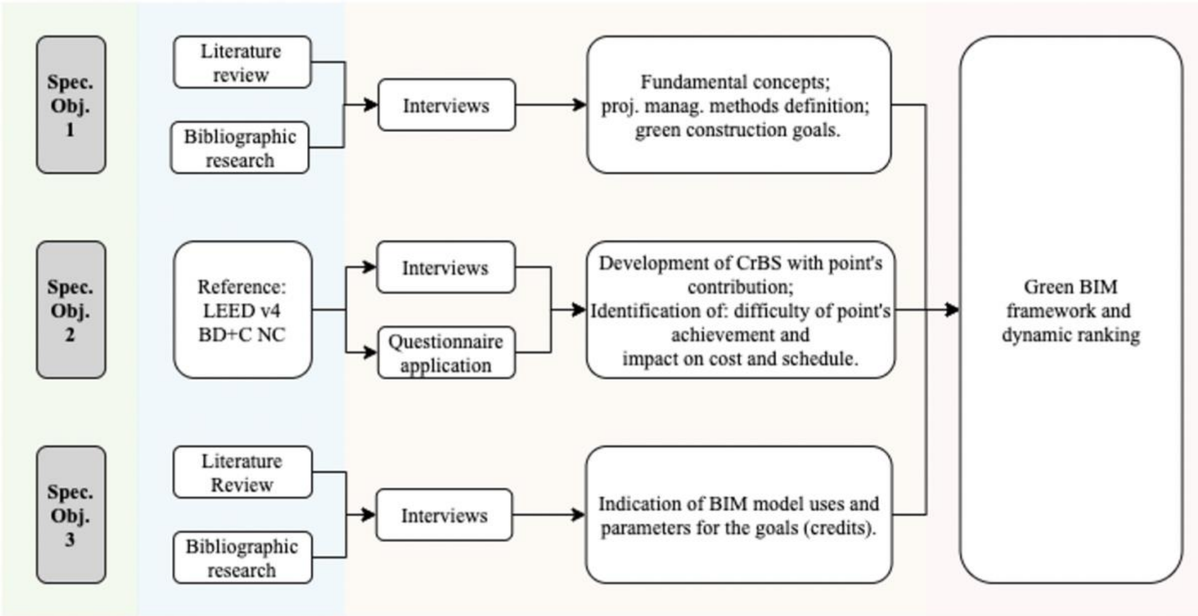
After mapping the data from the literature, the following stage helps to select and validate the difficulty of the credits and what type of impacts it can give on the project (specific objective 2). This investigation was based on the LEED reference guide and incremented with questionnaire application and interviews with Jacobs' sustainability consultancy team. The contact with the team was fundamental and helped the author understand the process and Jacobs's role during the sustainability assessment of projects. Four are the outputs of this part:

I. Development of the Credit Breakdown Structure (CrBS);
II. Indication of the points' contribution of each category and credit over the rating system (included in the CrBS);
III. Investigation of the difficulty related to the achievement of points in each category and credit;
IV. Investigation of the impact that credits' achievement has on the overall cost and schedule of the project;

The identification of BIM use cases to enhance methods (specific objective 3) has considered literature review and bibliographic research as initial research techniques to understand the current use of BIM in projects that aim at LEED certification. The identification of the BIM use cases for the LEED credits has, as a reference, the BIM Execution Planning Guide (BEP), developed by Pennsylvania State University. An adaptation of the goals and model uses part is done to deliver the identification of BIM model uses. Moreover, possible parameters to add to a BIM model have been identified for each credit. These parameters can be specific, and their utilization will vary depending on the level of detail adopted by the design team.

The main objective comes along after the development of all research specific objectives. After understanding the goals, difficulties, impacts, and possible improvements on specific parts of the green building assessment process, a framework is presented to help improve the management of LEED projects and fulfill the thesis's general objective. Figure 4.2 presents the path of the research objectives following the research design stages.

Figure 4.2 - Research objectives path.



Source: Created by the author.

4.3 - DATA COLLECTION AND ANALYSIS

The data collection has been done during the realization of an internship in the sustainability consultancy office of Jacobs Italia that lasted for around five months. In addition to the daily work involved in LEED consultancy, the author had the opportunity to observe and interact with the team for research purpose doing interviews and applying questionnaires.

The literature research and the document analyses supported the evidence collected from other sources. Documents related to the building project, standards, and literature associated with the topic were analyzed. The collection of data through interviews was an essential source of evidence to collect qualitative information about the management of the LEED process. The manager of the consultancy team and the sustainability engineers were the participants of the interviews, and the latest were the respondents of the questionnaire.

The questionnaire has been developed to interrogate the team members about their LEED experience. In this questionnaire, there were ranking and rating questions. The first type has been used for the difficulty of points' achievement and the later for impact that LEED can cause on the cost and schedule of a project.

The ranking questions were developed based on a study from Dr. Valentina Ferretti, an expert in decision analysis. In Dr. Ferretti's study, the authors proposed a technique called Simple Ranking with Multiple Points (S-RMP). An adaptation of this S-RMP technique was used, in a simpler way. The questions were asking the decision-makers (team members) to establish a preference order (ranking) on a set of alternatives (categories and credits) on the bases of difficulty criteria. According to the study, it is suitable to use the technique when:

> "(i) the availability of a relatively large data set, thus calling for the need to indirectly elicit part of the parameters from the Decision Makers; (ii) the type of results needed by the Decision Makers (i.e. a ranking from the most suitable to the least); (iii) the complexity of the decision-making problem, reflected in

> the need to take into account the expertise and preferences of multiple Decision Makers, whose views would need to be compared. (Ferretti et al., 2018)

Based on this, a set of ranking questions were developed to have as an output a ranking in terms of difficulty of achievement of the LEED categories and credits.

The rating questions were used both for the impact on schedule and cost. Five alternatives have been given to understand the influence that those credits have on the schedule and cost of the project: significant decrease, slight decrease, none, slight increase, big increase. Each alternative had a weight, and after all resulted in a final score.

After collecting the necessary data, through documentation analyses, interviews, and questionnaire application, a way to start the data analyses, according to Yin, is to "play" with the data in order to find patterns, insights, or concepts that seem promising. Another way to manipulate the data is by creating data displays, flowcharts, or graphics, use some temporal scheme to organize the data, to name a few (Yin, 2014).

According to (Yin, 2014), there are four general analytic strategies: 1-Relying on theoretical propositions; 2-Working the data from the "ground up"; 3-Developing a case description; 4-Examining plausible rival explanations. This case study followed two of the just mentioned strategies, the first, and the third. The theoretical propositions are used to shape the original objectives and design of the case study, helping the researcher to maintain the focus on what is necessary. The development of a case description helps to organize the work according to some descriptive framework (Yin, 2014). The data analysis is done through data manipulation, generating data displays, tables and charts. The establishment of these outputs facilitates the understanding of the LEED process, shaping the original objectives, and organizes the work describing the case (sustainability assessment process).

4.4 - RESEARCH LIMITATIONS

The thesis discusses the adaptation of a project management method for the sustainability assessment of buildings and includes delimitation on its scope. From the sustainability point of view, the delimitation in on the sustainability certification type, which is the Leadership in Energy and Environmental Design (LEED) for Building Design and Construction (BD+C) with the rating system New Construction (NC) in its version four (v4). Through the text, the rating system certification type is identified as LEED BD+C NC v4. There are many other LEED rating systems and other certification types; however, the work will focus only on LEED BD+C NC v4.

Another limitation of this thesis is that the questionnaire and the interviews were done only with the sustainability consultancy team of Jacobs Italia S.p.A., which can be considered a limited number compared to the population of LEED Accredited Professionals in the world. Nonetheless, it is essential to mention that Jacobs is a leading engineering company worldwide and that the sustainability consultancy team of Jacobs Italia is qualified, experienced, and has a prominent role in the European scenario.

5 - RESULTS AND DISCUSSION

This chapter presents the results of this thesis work. The information is presented and discussed in order, considering the research outlines.

5.1 - CONCEPTUAL KNOWLEDGE (STAGE 1)

Most engineering and construction companies use project management practices that can be associated with the traditional project management method. Studies have already shown that lean philosophy can be extremely beneficial to the engineering and construction industry, and an adaptation of it has been made to facilitate the adoption of this philosophy in the industry. Lean principles can be associated with engineering and construction practices, meaning that lean can be used for more than just construction site improvement, where lean has been more widespread in the industry.

It has been said that a company can start implementing lean thinking through the adoption of some of the eleven principles. Moreover, Koskela (1992) has also listed and explained four key factors that should be balanced when implementing the lean philosophy: 1) Management commitment; 2) Focus on measurable and actionable improvement; 3) Involvement of all parts; and 4) Learning. Thus, the ideal way to adopt lean thinking into an engineering and construction company is by balancing the four key factors and assuring that a top-bottom approach is used to implement lean thinking.

Balancing the four key factors means that: 1) Leadership is fundamental; The change will happen through people and the understanding of the new philosophy; An environment that allows feedback for continuous improvement must be provided. 2) Flow processes should be defined and measured to allow a comparison for continuous improvement; Cycle time and variability reduction should be target. 3) Employees' involvement is essential for self-directed and problem-solving teams; however, not sufficient; management has a crucial role during implementation. 4) Learning is fundamental for all hierarchical scales; All employees, managers, and directors must understand the philosophy to contribute to the change; Training and studying within the team should happen. Koskela (1992) further explains in his publication.

Adopting a top-bottom approach means that the effort to change organization management practices must come both from the highest and lowest positions. There should be a collaboration between top and bottom in order to make the change happen. If not, the processes change will likely be dismissed on the way by someone that is not being able to pass up or down the new practices and thinking. This approach puts into practice all the four key factors in order to make it happen.

Although some studies show the possibility of adopting a lean approach to engineering and construction processes, it is not easy to find companies that have been fully adopting lean thinking into engineering processes. Nowadays, the adoption is mostly done to improve construction production practices and results. This situation is also valid for the company in which the case study has been developed.

In addition to the project management method types TRADITIONAL, LEAN, and AGILE, this thesis' theoretical foundation also discussed SUSTAINABLE PROJECT MANAGEMENT, a practice that can be integrated into all the three project management methods. It has been seen that sustainable practices are better integrated into a company if considered in the culture of the enterprise and its strategic plan. Considering the time frame available for this thesis's development, a brief analysis of Jacobs' sustainable project management practices has helped to understand their ambitions and current practices. Before discussing that, a short introduction to the company is given.

Jacobs is a giant of the engineering, construction, and consultancy market, founded in 1947. Jacobs had, in 2019, approximately 52k employees and an annual revenue of around 13 billion dollars (Jacobs Engineering Group Inc., 2020a). The Built Environment business of Jacobs is a connected global network that includes strategists, planners, architects, interiors, designers, engineers, managers, consultants, and constructors that provide strategic leadership, design innovation, project execution and more (Jacobs Engineering Group Inc., 2020b). The Milan office, where the study has been carried out, has several of these fronts, including sustainability consultancy that focuses on delivering green buildings with LEED, BREEAM, WELL, and WIRED SCORE certifications across Europe.

The company has a very consistent sustainable strategy developed considering aspects discussed in section 2.2.3 of this thesis (SUSTAINABLE PROJECT MANAGEMENT). Jacobs' approach to sustainability is called 'PlanBeyond' – "Plan beyond today for a sustainable future for everyone" (Jacobs Engineering Group Inc., 2018). The document sets out how the company will continue to fully integrate sustainability into its culture and global business and deliver solutions for a more connected and sustainable world (Jacobs Engineering Group Inc., 2018). The 'Plan Beyond' strategic framework (Figure 5.1) considers the United Nations' seventeen sustainable development goals distributed in six focus areas organized around three core pillars: People, Partnerships, and Places.

Figure 5.1 - PlanBeyond strategic framework.

Source: (Jacobs Engineering Group Inc., 2018)

The sustainable priorities and focus areas have been identified through a sustainable management tool, a sustainability priorities matrix (Figure 5.2), that comprised stakeholder engagement, an industry benchmark, and other research. Aspects related to the three core pillars were analyzed, and the result showed that in general, the importance for both internal and external stakeholder is high, as well as the ability to influence change.

Figure 5.2 - Sustainability priorities matrix.

Source: (Jacobs Engineering Group Inc., 2020c)

Jacobs is committed to global sustainability and has been integrating sustainability into the business by making it part of Jacobs' culture, which is proved to be the best way to integrate sustainable practices into a company. Their commitments, written on the PlanBeyond document, are the following (Jacobs Engineering Group Inc., 2018):

- Positively contribute to our global PlanBeyond goals that were developed in consultation with the UN Sustainable Development Goals.
- Foster a culture of sustainability that promotes economic prosperity, environmental benefit and social value.
- Continue a dialogue with all our stakeholders to raise awareness of sustainability and provide feedback on how we can do better.
- Research and develop innovative methods and applications for enhanced sustainability performance.
- Enable knowledge sharing and capacity-building around sustainability across our enterprise and all our projects.
- Be accountable for delivering our strategy through the sustainability governance structure that reports up to our Board.

All the information given above shows that Jacobs is committed to sustainability both in its strategic plan and culture. Jacobs took advantage of sustainable management tools and techniques to transform their business and their products into more sustainable, putting the company in the spotlight regarding companies that care about the environment, people, and economy.

With the knowledge of project management methods and sustainable management practices, and the company's position, the author has interviewed Jacobs' consultancy and sustainability manager to understand current management practices related to the sustainability assessment of projects. Moreover, the author has participated in several projects' meetings during the internship, therefore, acquiring more knowledge to perform and analyze the research. The interview and the meetings covered different topics, from the management practices to more specific discussions related to the pre-assessment and assessment process of LEED projects. These discussions related to projects that the team was working on were confidential, and for this reason, further details will not be given. Nonetheless, the discussions had significant content that added to the research purpose.

In general, engineering processes at Jacobs are managed traditionally. The traditional method is adopted to manage LEED projects for around 95% of the projects unless the client requests a leaner approach (5% of the projects). Still, when a leaner approach is requested, its adoption is not 100% lean due to constraints encountered during the development of a project.

Usually, a project arrives at the sustainability consultancy team after the conceptual design phase. However, the ideal approach is that the sustainability team participates in the conceptual design phase to support some design decisions that will meet the green certification requirements. As a result, when the project arrives at the sustainability team, most of the sustainability targets were already defined, which can negatively influence the process. With the conceptual project 'on the table', the sustainability team can discuss how to achieve the targets, based on the green certification requirements and on what has been developed for the project. This discussion is tailored by the project objectives and by the project's budget.

The LEED consultancy work can be divided into two phases:

- **Pre-Assessment:** During the pre-assessment phase, the team prepares a document called "LEED Pre-Assessment" that identifies the most suitable rating system protocol, reports the analysis of the prerequisites, the obtainable credits, the credits that can be obtained in case of modifications in the project are done, and the not obtainable credits, highlighting the possible critical issues related to achieving each credit. The Pre-Assessment is an intermediate step that passes through updates and additional phases.

- **Assessment:** The assessment phase starts after the client's approval and with the project's registration to the GBC. The assessment phase goes together with the design phase, in which the LEED AP keeps up with the design process (usually weekly meetings), follow any additional design choices, and to identify decisions that would positively or negatively impact the achievement of the credits. It is also during the assessment phase that all documentation is prepared for the submission phases. The sustainability team's most common submission approach is dividing the submission into two phases, as recommended by the USGBC, therefore anticipating some credits. When the project has a short schedule, it is more likely to have all credits submitted all at once during the construction submission phase.

The company usually deals with the construction phase differently than with the design phase. Commonly, there is a LEED AP at the contractor side, working as an external consultant, that keeps up with the construction credits and make sure that everything is correct and being followed. The construction credits of LEED v4 are focused on cost, so it is crucial to have someone focused only on the construction phase credits. The sustainability consultancy LEED AP usually has monthly meetings with the contractors' LEED AP to keep up with the work and ensure everything is happening as planned. The frequency of the meetings can change depending on the project's schedule.

Most of the projects that pass through the sustainability consultancy team target the gold certification (around 90% of the projects), which requires achieve 60 to 79 points for LEED BD+C NC version 4. The team adopts an approach that allows them to have flexibility. For example, when the target is the gold certification, they focus on achieving a minimum of 65 points, so there is a margin of points, and in case not all 65 points are achieved, they still reach the gold certification because there is never that many points difference. The team has always achieved the defined target (certified, silver, gold, or platinum), even if there was a small difference in the final number of points. These results can be achieved because the team has experienced LEED accredited professionals working on the projects. The LEED AP is sometimes consulting for more than one certification. Which happened with one of the projects that the author participated in during the internship. This specific project was pursuing LEED and WELL certification.

The definition of the achievement of some credits in the pre-assessment phase can be based on the difficulty related to its achievement, in terms of how challenging it is to fulfill the requirements considering all the aspects that involve a project, location, objectives, budget, schedule, and more. Some credits are straightforward to understand if they are achievable or not, considering the project's features. Moreover, the team pointed out that the clients usually cut the budget from the sustainability part of the project, which can influence the achievement of certain credits that impact the project's cost. The difficulty related to the credits' achievement and the impact on cost and schedule are analyzed in the following section of this thesis - UNDERSTANDING LEED.

Another topic that has also been discussed with the team is the use of BIM during the assessment processes. This discussion has been based on the theoretical background and literature review that showed that BIM could improve the sustainability assessment process in many ways; however, its adoption to assist the process is not always possible, neither easy.

Regarding the use of BIM in the sustainability assessment process, it has been noted that the team does not use BIM to assess the sustainability targets yet, except to perform the energy modeling that will facilitate the understanding of credits related to the Integrative Process and Energy and Atmosphere categories. The team's current adopted methodology is solid and delivers only positive results. However, the team knows that adopting a Green BIM approach can bring more benefits and higher performance to work. Hence, BIM is being explored, but the exploration is being done at an experimental pace to ensure that when these new methodologies are adopted, the results will positively impact the process without compromising the current work's performance. An example of current BIM exploration is to assess credits related to Life Cycle Assessment, which is a requirement of the LEED v4.

Moreover, the use of BIM to facilitate the assessment process depends not only on the sustainability consultancy team but also on the design teams. The use of BIM to assess a LEED project depends on the defined BIM Uses that should have been thought when preparing a BIM Execution Planning because this will impact the information inserted in the model (i.e. what parameters to add). For this reason, section 5.3.2 (GREEN BIM - BEP FOR LEED) of this thesis will present possible BIM Model Uses and parameters that can be adopted by the design teams. The adoption of these uses will facilitate the assessment process and unify the information of the project.

5.1.1 - CONCLUSION

This stage puts together concepts studied in the theoretical background to map project management methods against sustainability practices at the company in which the case study has been developed. Moreover, the section discusses Jacobs' current practices related to sustainability assessment of projects pursuing LEED and to the use of BIM.

It has been seen that the company has sustainability principles in its culture, and its strategic plan has well-defined priorities to keep improving on this topic. Moreover, it has been concluded that Jacobs's sustainability assessment process follows a traditional project management methodology. However, lean principles are observed in the team's daily routine, but due to the whole engineering processes involving several other teams, full incorporation of the lean practices is not yet possible. Some of the key factors listed by Koskela (1992) are perceived in the daily routine of the team, such as leadership involvement and commitment; a hunger to continuously improve the processes; employees are involved, self-directed and problem-solving driven; all hierarchical scales are always searching for new methods, certifications, and licenses, to keep up with new developments. These features show that the Sustainability team of Jacobs Italia has a solid methodology that brings positive outcomes. Nonetheless, there is space for improvements. The team does not work in isolation, and enhanced collaboration with all other actors is fundamental for the overall improvement of a sustainability assessment project.

5.2 - DATA ANALYSIS AND VALIDATION (STAGE 2)

This stage presents topics related to specific objectives 2 and 3, respectively. First, UNDERSTANDING LEED investigates the difficulties, points' contribution and impacts of LEDE. Then, GREEN BIM - BEP FOR LEEDidentifies BIM use cases and parameters for a LEED project.

5.2.1 - UNDERSTANDING LEED

This part is divided into four sections:

I. Development of the Credit Breakdown Structure (CrBS);
II. Indication of the points' contribution of each category and credit over the rating system (included in the CrBS);
III. Investigation of the difficulty related to the achievement of points in each category and credit;
IV. Investigation of the impact that credits' achievement has on the overall cost and schedule of the project;

The CrBS is an adaptation of frameworks proposed by the PMBOK for schedule (Work Breakdown Structure – WBS) and cost (Cost Breakdown Structure – CBS). The CrBS is a hierarchical decomposition of the requirements and credits of the rating system LEED BD+C v4 New Construction and Major Renovation that helps project's teams to visualize the objectives better and trace deliverables for the project. Just major information is included in the table, for more specific info, it is important to check the LEED reference guide.

The CrBS table comprises seven columns, being the first five an adaptation of information given by the USGBC in the New Construction and Major Renovation LEED BD+C v4 guideline. The other two are a simple calculation done by the author to understand each category's and credit's contribution over the rating system and each credit over the categories.

- Categories ID and name;
- Credits ID and name;
- Sub credits;
- Description (when necessary);
- Number of maximum points (given for each category, credit, and sub-credit);
- Weight of the category and credit over the whole project;
- Weight of the credit over the category of which the credit is part.

The content analysis is done both for the categories and for the credits of each category. The analysis will always be accompanied by its correspondent CrBS to facilitate the understanding. Therefore, during the content analysis, the CrBS will not be presented as one table only. But a complete version of the CrBS without interruptions is available in APPENDIX A - CREDIT BREAKDOWN STRUCTURE.

First, sections I, II, and III are discussed for the categories of LEED v4, which means presenting a shorter CrBS (only with the categories), discussing the contribution of points, and the difficulty of achieving the points. Then, with the breakdown, sections I, II, III, and IV are discussed for each category's credits. This means presenting the CrBS, discussing the points' contribution to the overall rating system and the related category, the difficulty of achieving each credit's points, and its impact on the project's cost and schedule.

A preview of the CrBS first lines is given to understand the organization of the table, according to what it has just been described.

Table 5.1 - CrBS preview.

Credits Breakdown Structure (CrBS)						
Category ID and name	Credit ID and name	Sub credit	Description	Max points	Weight over the whole project	Weight over the category
IP Integrative Process				1	0.9%	
	1 Integrative Process			1	0.9%	100.0%

Source: Adapted by the author from LEED v4 reference guide.

5.2.1.1 - LEED CATEGORIES

Starting with the categories' analyses, attention is paid at the first, fifth, and sixth column of the CrBS, which is where the data about the categories are. The rating system reference guide give the information of maximum points, and a simple percentage calculation is done to see each category's contribution. It is observed (Table 5.2) that the points are not equally distributed, and that each category has a different weight over the rating system.

The category that contributes the most in terms of points is Energy and Atmosphere (with 30%), followed by Indoor Environmental Quality and Location and Transportation (14.5% each), Materials and Resources (11.8%), Water Efficiency (10%), Sustainable Sites (9.1%), Innovation (5.5%), Regional Priority (3.6%), and finally, Integrative Process (0.9%).

Table 5.2 - CrBS (categories).

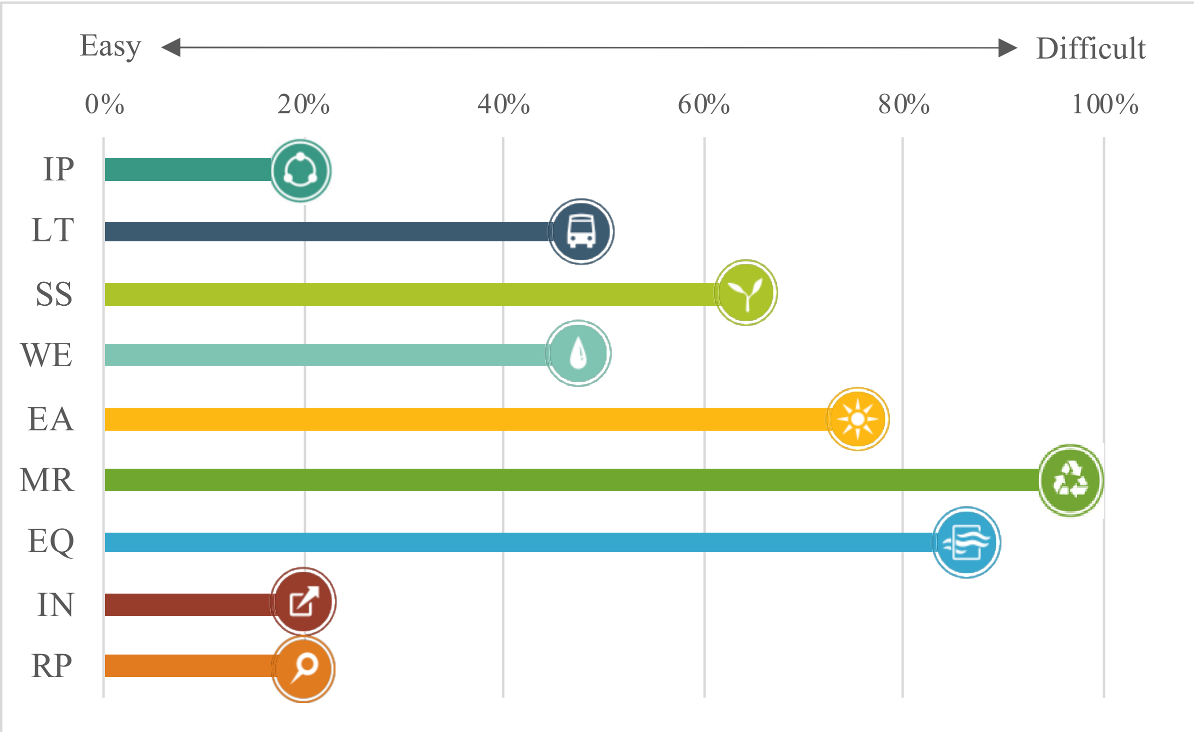
Credits Breakdown Structure (CrBS)						
Category ID and name	Credit ID and name	Sub credit	Description	Max points	Weight over the whole project	Weight over the category
IP Integrative Process				1	0.9%	
LT Location and Transportation				16	14.5%	
SS Sustainable Sites				10	9.1%	
WE Water Efficiency				11	10.0%	
EA Energy and Atmosphere				33	30.0%	
MR Materials and Resources				13	11.8%	
EQ Indoor Environmental Quality				16	14.5%	
IN Innovation				6	5.5%	
RP Regional Priority				4	3.6%	
			Total Possible Points:	110		

Source: Created by the author.

By looking at the numbers above, it is seen that the points are not equally distributed and that some categories are worth more points than others. Though, a question emerges: Does the difficulty of points' achievement of a category follow the order from the lowest contribution of points as the easiest to achieve to the highest one being the most difficult? Or the difficulty to achieve is not related to the number of points the category can achieve?

In order to understand that, the members of the sustainability consultancy team have been asked to rank the difficulty of achievement of points of the LEED v4 categories. Figure 5.3 shows which categories are more challenging to achieve. The chart in the figure shows on the Y-axis, the categories, and the X-axis, a percentage score that varies from 0 to 100%. The higher the percentage, the most difficult it is to achieve that category's credits. As a result, it is seen that the category that received the highest score is Materials and Resources, meaning that, according to the team, that is the most challenging category to achieve the points. After Material and Resources (100%), the most challenging category is Indoor Environmental Quality (89%), followed by Energy and Atmosphere (78%), Sustainable Sites (67%), Location and Transportation and Water Efficiency (50%), and Integrative Process, Innovation, and Regional Priority (22%).

Figure 5.3 - Difficulty of achievement (categories).

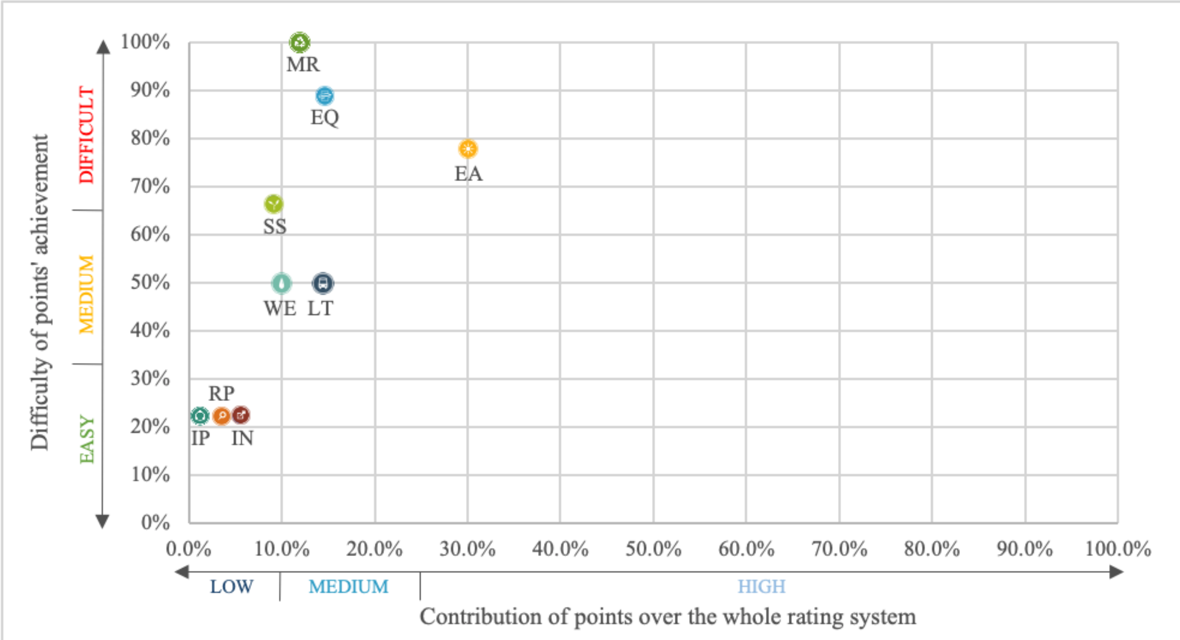


Source: Created by the author.

These results show no direct relationship between the difficulty of achieving the category's points and the weight that the category has over the rating system. For this reason, a Pareto chart has been created to comprehend the relationship between the two variables (Contribution of points and Difficulty of points' achievement). Figure 5.4 shows the different categories arranged in the Pareto chart, in which the more to the right and up the item goes, the more difficult it is, and the highest is its contribution.

The graph has on the Y-axis the scale of difficulty of points' achievement, and on the X-axis, the points' contribution over the whole rating system. The difficulty ranges were equally divided; however, the points' contribution range had a different approach. It has been considered that when the contribution of points is 10% or less over the whole rating system, it is a low contribution. When it is between 10% and 25%, it is medium. And when it is 25% or higher, it has a high contribution over the whole rating system.

Figure 5.4 - Difficulty of achievement x Contribution of points (categories).



Source: Created by the author.

5.2.1.2 - LEED CREDITS BY CATEGORIES

Different than it was for the categories, now all columns of the CrBS are essential. Indeed, some sub credits do not require description, so in that case, the description column will be empty. Now that the credits are in the spotlight, it is important to be attentive to the last column, called "weight over the category".

The analyses' presentation follow the order in which the categories and credits are presented on the CrBS. The discussion covers CrBS, points' contribution, the difficulty of achievement, the relationship between points' contribution and difficulty of achievement, and credit's impact on the project's cost and schedule.

5.2.1.2.1 INTEGRATIVE PROCESS (IP)

The integrative Process category has only one credit in its scope, also called Integrative Process (IP1). This category is considered as easy difficulty of achievement and low points' contribution to the overall rating system. The IP1 credit is from the LEED Design stage submission, and it is not eligible for exemplary performance.

IP1 is divided into two sub credits (Energy-related systems and Water-related systems), and in order to achieve the point related to IP1, both sub credits have to be completed. The following table shows the maximum points, the weight over the whole project, and weight over the category. Since IP1 is the only credit in this category, the credit and the category have the same contribution over the whole rating system, which is 0.9%. Moreover, because IP1 is the only credit of this category, its contribution is 100%.

Table 5.3 - CrBS (IP).

Category ID and name	Credit ID and name	Sub credit	Description	Max points	Weight over the whole project	Weight over the category
IP Integrative Process				**1**	**0.9%**	
	1 Integrative Process			1	0.9%	100.0%
		AND	Energy related systems Discovery - simple box energy modeling analysis that explores how to reduce energy loads. Assess at least two of the listed potential strategies Implementation - Document how the above analysis informed design and building form decisions in the project's OPR and BOD and the eventual design of the project Water related systems Discovery - Perform a preliminary water budget analysis that explores how to reduce potable water loads. Assess and estimate the project's potential nonpotable water supply sources and water demand volumes Implementation - Document how the above analysis informed design and building form decisions in the project's OPR and BOD and the eventual design of the project. Dem- onstrate how at least one on-site nonpotable water supply source was used to reduce the burden on municipal supply or wastewater treatment systems by contributing to at least two of the water demand components listed. Demonstrate how the analysis informed the design of the project	1		

Source: Adapted by the author from LEED v4 reference guide.

The difficulty of achievement of this credit has been investigated differently than credits from categories with multiple requirements. From the categories' analysis, it is known that it is not difficult to achieve the points related to the IP category. This information is used to understand that the difficulty of achievement of IP1 is low. For this credit, preliminary energy modeling and water budget analyses have to be done for the project, a practice that is already done in many projects, even if not pursuing the LEED certification. The additional work to achieve IP1 would be related to the adaptation of these analyses to what LEED is asking and to gather the necessary information and submit the required documentation.

The relationship between credits contribution and difficulty of achievement is considered as easy achievement and low contribution of points to the rating system. Regarding the impacts of section IV, it has been perceived that the integrative process credit achievement does not influence the project's cost and schedule.

5.2.1.2.2 LOCATION AND TRANSPORTATION (LT)

The LT category is divided into eight credits. This category is considered to be of medium difficulty of achievement and medium points' contribution to the overall rating system. All LT credits are from the design submission stage, and the following credits are eligible for exemplary performance: LT3, LT4, LT5, and LT7.

In this category, there are two options that the team can choose in order to proceed with the LEED certification. One option is to choose the first credit, which is called LEED for neighborhood development location, and this only credit can reach the whole punctuation, depending on the selected sub credits. The second option is to choose the other seven credits to try to reach the maximum points. In USGBC words, projects attempting to LEED neighborhood development credit are not eligible to earn points under other LT credits (USGBC, 2019b).

Table 5.4 - CrBS (LT).

Credits Breakdown Structure (CrBS)						
Category ID and name	**Credit ID and name**	**Sub credit**	**Description**	**Max points**	**Weight over the whole project**	**Weight over the category**
LT Location and Transportation				**16**	**14.5%**	
	OR LEED for neighborhood development location credit OR all the other					
	1	LEED for Neighborhood Development Location		16	14.5%	100.0%
		Boundary of a development certified under LEED ND v4 rating system				
		OR	Certified	8		
			Silver	10		
			Gold	12		
			Platinum	16		
	2	Sensitive Land Protection		1	0.9%	6.3%
		OR	Option 1- Locate the development footprint on land that has been previously developed	1		
			Option 2 - Locate the development footprint on land that has been previously developed or that does not meet some criteria for sensitive land	1		
	3	High Priority Site		2	1.8%	12.5%
		OR	Option 1- Historic district	1		
			Option 2 - Priority designation	1		
			Option 3 - Brownfield remediation	2		
	4	Surrounding Density and Diverse Uses		5	4.5%	31.3%
		AND/OR	Option 1 - Surrounding density			
			Combined Density (5050 sqm/hectare of buildable land)	2		
			Combined Density (8035 sqm/hectare of buildable land)	3		
			Separate residential and non residential (17.5DU/hectare or 0.5 FAR)	2		
			Separate residential and non residential (30DU/hectare or 0.8 FAR)	3		
			Option 2 - Diverse use			
			800m distance to 4 to 7 other publicly diverse use	1		
			800m distance to 8+ other publicly diverse use	2		
	5	Access to Quality Transit		5	4.5%	31.3%
		OR	Minimum daily transit service for projects with multiple transit types			
			72 weekday trips / 40 weekend day trips	1		
			144 weekday trips / 108 weekend day trips	3		
			360 weekday trips / 216 weekend day trips	5		
			Minimum daily transit service for projects with commuter rail or ferry			
			24 weekday trips / 6 weekend day trips	1		
			40 weekday trips / 8 weekend day trips	2		
			60 weekday trips / 12 weekend day trips	3		
		Projects served with 2+ routes such that no one route provides more than 60% of the documented levels, may earn an extra point (up to the max)		1		
	6	Bicycle Facilities		1	0.9%	6.3%
		AND	Bicycle network Bicycle storage and shower rooms (varies if commercial, residential, mixed use)	1		
	7	Reduced Parking Footprint		1	0.9%	6.3%
		Do not exceed the minimum local code requirements for parking capacity. Provide parking capacity that is a percentage reduction below the case retios recommended by the Parking Consultants Council as shown in the Institute of Transportation Engineers' Transportation Planning Handbook, 3rd edition, Tables 18-2 through 18-4.				
		OR	Case 1 - Baseline location - Achieve 20% reduction of parking capacity (for projects that didn't earn point in LT4 and LT5)	1		
			Case 2 - Dense and/or transit served location - Achieve 40% reduction of parking capacity (for projects that earned one or more points in LT4 and LT5)			
		Credit calculations should include all existing and new off-street parking spaces that are leased or owned by the project, even when outside the project boundary. Pooled parking share should be accounted. Prefered carpool parking 5% of the total parking after reductions (not required if no off-street parking is provided.				
	8	Green Vehicles		1	0.9%	6.3%
		AND one opt	Preferred parking - 5% of all parking spaces for Green vehicles or discounted parking rate of 20% for green vehicles	1		
			Option 1 - Electric vehicle charging - install in 2% of all parking spaces			
			Option 2 - Liquid, gas, or battery facilities			

Source: Adapted by the author from LEED v4 reference guide.

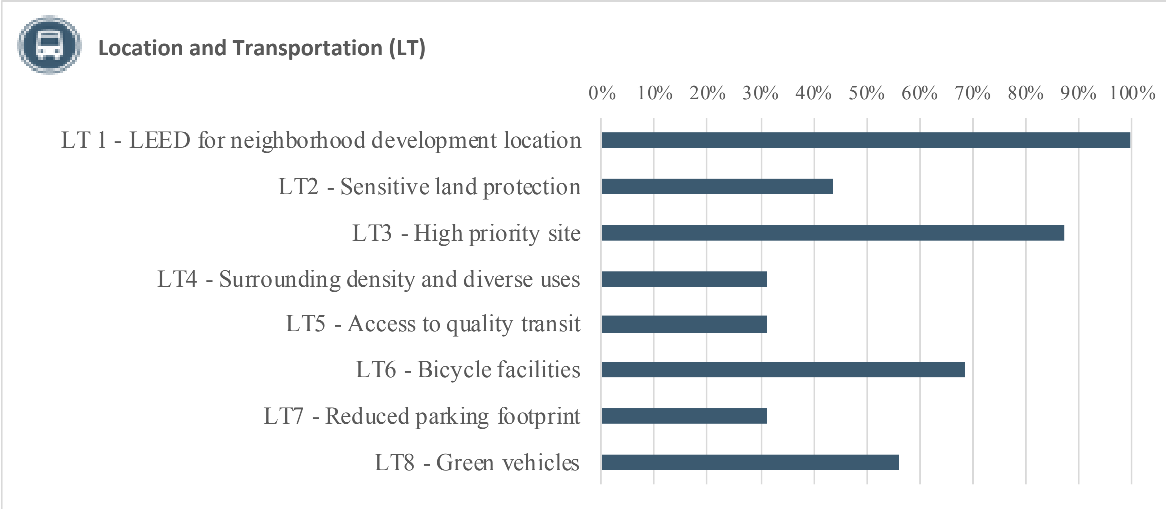
By analyzing the eight credits of this category (Table 5.4), it is seen that there are different types of contributions. As already known, if LT1 is chosen, it could contribute up to 15 % of the whole system, depending on the selected boundary, and a 100% to the category, because if LT1 is chosen, no other credit can be taken. On the other hand, if the other seven credits are chosen, there are three types of contribution over the category, 6%, 13%, and 31%. Organizing all the credits in a classification of the points that contribute the most to the category, the order is LEED for Neighborhood Development (100%), Access to Quality Transit (31%), Surrounding Density and Diverse Uses (13%), and the others with 6%.

In some cases (valid for all the categories of LEED v4), the contribution can be even lower depending on the adopted sub credit. For example, in Access to Quality Transit credit, the maximum number of points is five, but not always a project can achieve all those points, and in that case, the contribution would be even lower. Another example of a credit that can achieve less than the maximum is the Surrounding Density and Diverse Use. In that case, both sub credits can be achieved, but there is also the possibility to achieve only one or the other, which will not allow the project to achieve all the five points attributed to that category. To better understand the last process, it is essential to keep an eye on the part of the CrBS that shows if the sub credits have to be achieved together (AND) or if the achievement is optional (OR).

The difficulty of the achievement of those credits is shown in Figure 5.5. According to the team, the credit that received the highest score is LEED for Neighborhood Development (100%), which is the most challenging credit of the LT category. After LT1, the most challenging credit is High Priority Site (88%), Bicycle Facilities (69%), Green Vehicles (56%), Sensitive Land Protection (44%), and Surrounding Density and Diverse use, Access to Quality Transit, and Reduced Parking Footprint (all with 31%).

An interesting detail pointed out by the LEED APs is that the difficulty of achieving a credit is different if for New Construction or Major Renovation. Usually, buildings registered under LEED New Construction are located in suburban areas, while Major Renovation buildings are usually located in the city center. An example of a credit that is easier to achieve for Major Renovation but more difficult for New Construction is Access to Quality Transit (LT5). That is just one example of many. This happens with credits of other categories as well, such as Open Space (SS3), Rainwater Management (SS4), Renewable Energy Production (EA5), and more.

Figure 5.5 - Difficulty of achievement (LT).

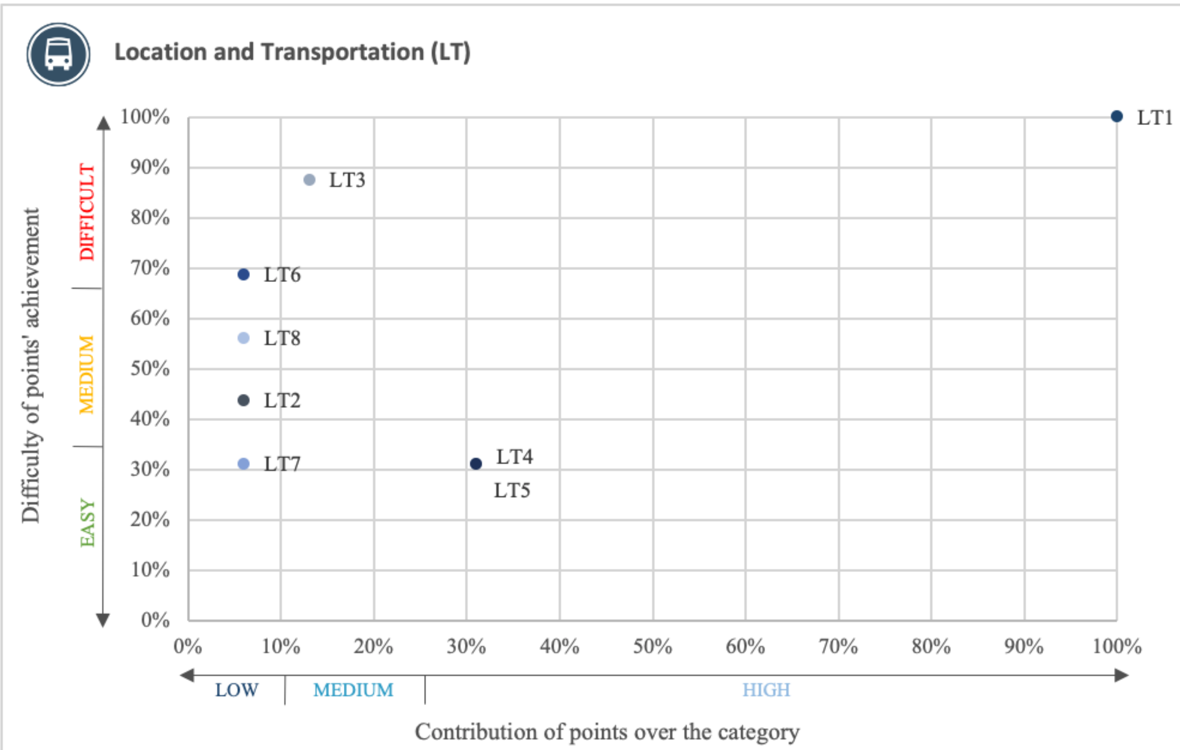


Source: Created by the author.

The difficulty's analysis pointed out that LT1 is the most challenging credit to achieve and that it is the one that contributes the most to the category's points. This result is due to the long list of requirements that LEED for Neighborhood Development rating system has. In order to gain points related to LT1, the building has to be located on a site that is part of a certified green neighborhood.

The relationship between difficulty and points' contribution (Figure 5.6) is only direct for the first credit. For all the others, there is no direct relationship between these two variables.

Figure 5.6 - Difficulty of achievement x Contribution of points (LT).



Source: Created by the author.

This means that the credit that contributes the least in terms of points to that category is not necessarily the easiest. A chart that relates the variables is presented in Figure 5.6 and helps to better understand the Location and Transportation credits. Like it was for the categories, the graph has on Y-axis the scale of difficulty to achieve the points. However, on the X-axis, the points' contribution is over the category instead of the whole rating system. The considered ranges are the same as it was presented before.

Regarding the influence that each credit has on the cost, it has been perceived that two out of the eight credits have an impact on the cost of the project. The credits Bicycle facilities (LT6) and Green vehicles (LT8) have a slight increase impact on the project's cost, while the other six credits have no impact at all. Focusing on the influence of the credits on the project's schedule, it has been noticed that only bicycle facilities (LT6) can have a slight increase impact on the project's schedule. The increase in cost can be related to extra consultancy for planning bicycle network and electric vehicle supply equipment (charging), and installation of equipment. The delay in the schedule can be connected to the development of the bicycle network, which "may be counted if they are fully funded by the date of the certificate of occupancy and are scheduled for completion within one year of that date" (USGBC, 2019b).

5.2.1.2.3 SUSTAINABLE SITES

The sustainable sites category is composed of one prerequisite and six credits. In general, this category is considered to be of medium difficulty of achievement and low points' contribution to the overall rating system. The prerequisite is from the LEED construction stage submission, and all credits are from the LEED design stage submission. The following credits are eligible for exemplary performance: SS2, SS4, and SS5.

The points' distribution is given in detail in the CrBS of Sustainable Sites.

Table 5.5 - CrBS (SS).

Credits Breakdown Structure (CrBS)						
Category ID and name	**Credit ID and name**	**Sub credit**	**Description**	**Max points**	**Weight over the whole project**	**Weight over the category**
SS Sustainable Sites				**10**	**9.1%**	
	Prereq	Construction Activity Pollution Prevention		Required		
			Create and implement an erosion and sedimentation control plan for all construction activities with description of implemented measures. Apply for construction general permit			
	1	Site Assessment		1	0.9%	10.0%
		AND	Complete and document a site survey or assessment including: topography, hydrology, climate, vegetation, soils, human use, human health effects. Demonstrate the relationship between site features and project design	1		
	2	Site Development - Protect or Restore Habitat		2	1.8%	20.0%
		AND 1opt	Preserve and protect from development and construction 40% of the natural greenfield, if existed	2		
			Option 1 - On-site restoration of 30% of all site identified as previously disturbed			
			Option 2 - Provide financial support to a local conservation organization or recognized land trust (equivalent to U$4/sqm of total site area)	1		
	3	Open Space		1	0.9%	10.0%
		AND	Provide outdoor space > 30% of total site area (including building footprint). A minimum of 25% of that outdoor space must be vegetaded. The outdoor space must follow some criteria	1		

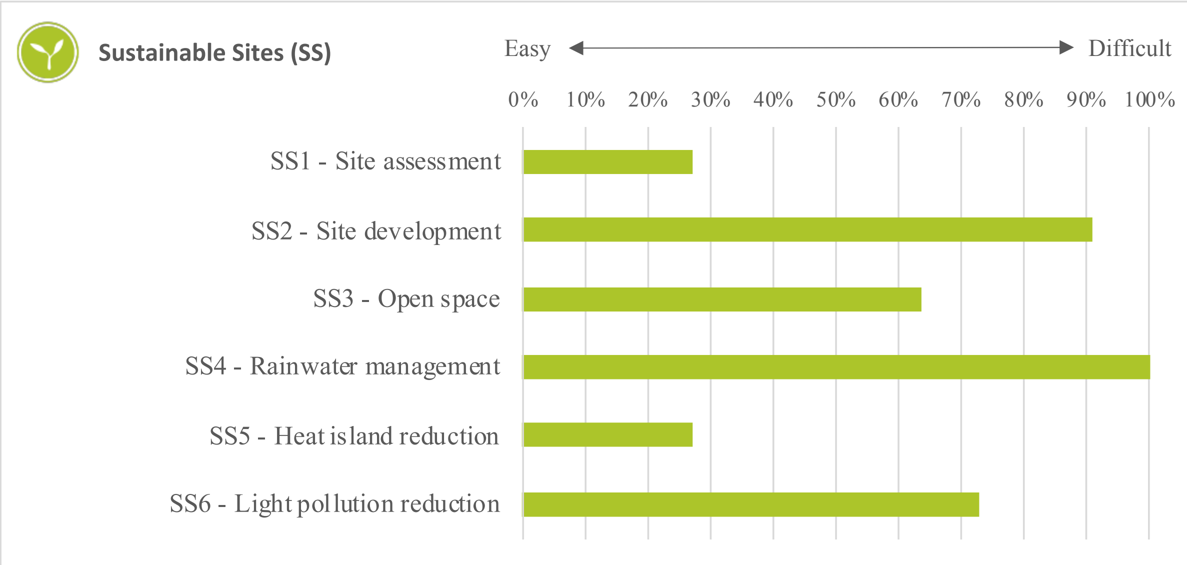
4	Rainwater Management		3	2.7%	30.0%
	OR	Option 1 - Percentile of rainfall events			
		Path 1 - 95% percentile of regional or local rainfall events using low-impact development (LID) and green infrastructure	2		
		Path 2 - 98% percentile of regional or local rainfall events using low-impact development (LID) and green infrastructure	3		
		Path 3 - Zero lot line projects in urban areas with a minimum density of 1.5 FAR - 85% percentile of regional or local rainfall events using low-impact development (LID) and green infrastructure	3		
		Option 2 - Natural land cover conditions	3		
5	Heat Island Reduction		2	1.8%	20.0%
	OR	Option 1- Nonroof and roof - Use a combination of nonroof measures, high-reflectance roof, vegetaded roof that respects the formula below $\frac{\text{Area of Nonroof Measures}}{0.5} + \frac{\text{Area of High-Reflectance Roof}}{0.75} + \frac{\text{Area of Vegetated Roof}}{0.75} \geq \text{Total Site Paving Area} + \text{Total Roof Area}$	2		
		Option 2 - Parking under cover - A minimum of 75% of parking spaces under cover with the following criteria: three year aged SRI of at least 32; be a vegetaded rood; or be covered by energy generation systems	1		
6	Light Pollution Reduction		1	0.9%	10.0%
	AND	Uplight - do not exceed the ratings OR: Option 1 - BUG rating method Option 2 - Calculation method Trespass - do not exceed the ratings OR: Option 1 - BUG rating method Option 2 - Calculation method Internally illuminated exterior signage - do not exceed 200cd/m2 (nightime) and 2000cd/m2 (daytime)	1		

Source: Adapted by the author from LEED v4 reference guide.

There are three types of contribution of points over the category, 10%, 20%, and 30%. Organizing all the credits in an order of contribution, the credit that contributes the most in terms of points is Rainwater Management (30%), followed by Site Development and Heat Island Reduction (both with 20%), and finally, Site Assessment, Open Space and Light Pollution Reduction (all with 10%).

The difficulty of achievement of the credits from this category is shown in Figure 5.7. The credit that received the highest score is Rainwater management (100%), classified according to the team, as the most difficult or challenging credit to be achieved. After SS4, the most challenging credit is Site Development (91%), followed by Light Pollution Reduction (72%), Open Space (64%), and Site Assessment and Heat Island Reduction (both with 27%).

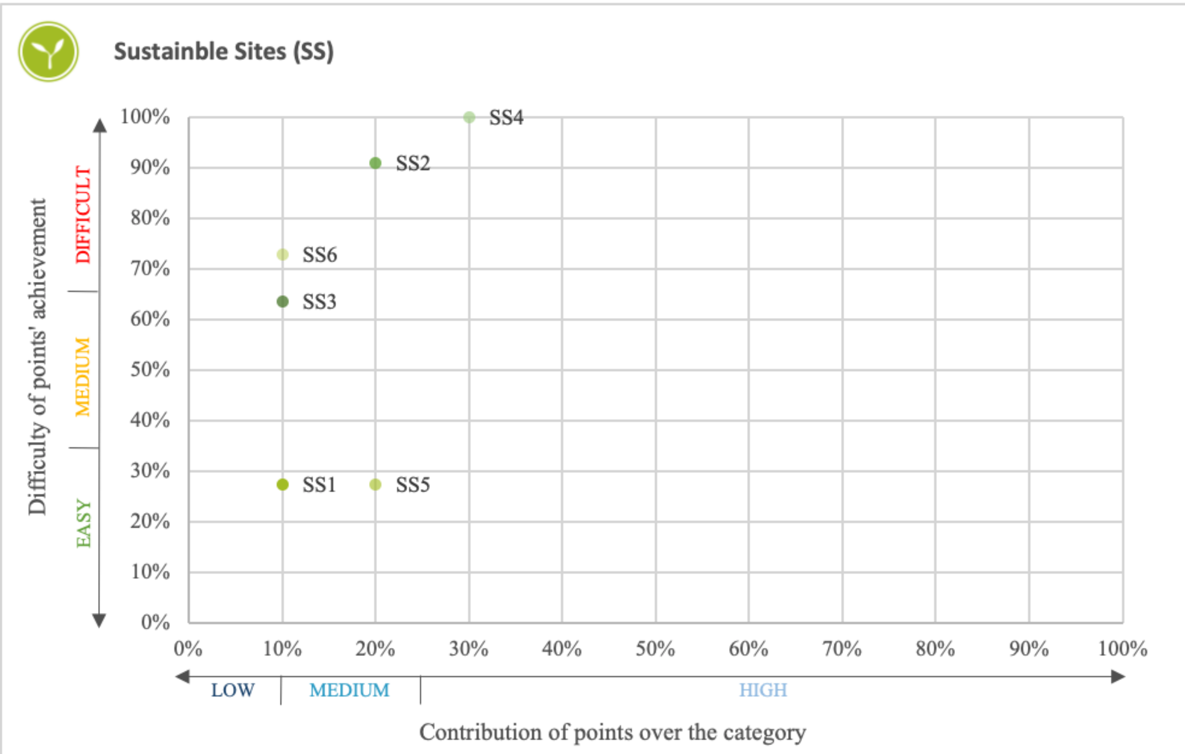
Figure 5.7 - Difficulty of achievement (SS



Source: Created by the author.

The relationship between the difficulty of achievement and points' contribution shows that SS4 is the most challenging credit to be achieved and also the one that contributes the most in terms of points, as can be seen in Figure 5.8. When analyzing the second most challenging credit to be achieved, SS2, it has a medium points' contribution over the Sustainable Sites category, together with credit SS5 (that is classified as easy achievement). Again, this shows that the difficulty of achievement and points' contributions are not directly related variables.

Figure 5.8 - Difficulty of achievement x Contribution of points (SS).



Source: Created by the author.

Regarding the influence that each credit of the Sustainable Sites category has on the cost, it has been perceived that only Heat Island Reduction (SS5) and Light Pollution Reduction (SS6) credits do not have an impact on the cost. Site Assessment (SS1), Site Development (SS2) and Open Space (SS3) impact the cost with a slight increase, while Rainwater Management (SS4) with a big increase on the cost of the project.

The increase in cost of Site Assessment credit (SS1) is related to extra consultancy, mostly for the topography and hydrology features that should be filled in the Site Assessment Worksheet. These costs should already be considered in the budget, but extra consultancy is required to assess the needed information requested by this credit. In the case of the Open Space credit (SS3), extra costs are linked to the vegetation and trees that should be acquired. However, it is a tiny increase if compared to the whole cost of the project. The big increase in cost for credit SS4 (Rainwater Management) is related to extra work (design, construction, more materials) that has to be done and acquired to achieve the credit requirement, which is difficult.

About the influence of the credits on the project schedule, it has been noticed that only Rainwater Management (SS4) credit impact the schedule with a slight increase in time. This delay can be related to the installation of the green infrastructure and approval with the municipality. All the other credits usually have no impact on the project schedule.

5.2.1.2.4 WATER EFFICIENCY

This category is composed of three prerequisites and four credits. In general, this category is considered to be of medium difficulty of achievement and low points' contribution to the overall rating system. All prerequisites and credits are from the LEED design stage submission. Only WE2 is eligible for exemplary performance.

The points' distribution is given in detail in the CrBS of Water Efficiency.

Table 5.6 - CrBS (WE).

Credits Breakdown Structure (CrBS)						
Category ID and name	**Credit ID and name**	**Sub credit**	**Description**	**Max points**	**Weight over the whole project**	**Weight over the category**
WE Water Efficiency				**11**	**10.0%**	
	Prereq		Outdoor Water Use Reduction		Required	
			Reduce outdoor water use through Noirrigation required or reduced irrigation			
	Prereq		Indoor Water Use Reduction		Required	
			Reduce indoor water consumption (building water use, and appliance and process water use)			
	Prereq		Building-Level Water Metering		Required	
			Install permanent water meters that measure the total potable water use for the building and associated grounds. Meter data must be compiled into monthly and annual summaries; meter readings can be manual or automated			
	1		Outdoor Water Use Reduction	2	1.8%	18.2%
		OR	Option 1 - No irrigation required	2		
			Option 2 - Reduced irrigation			
			50% reduction from baseline (prereq)	1		
			100% reduction from baseline (prereq)	2		

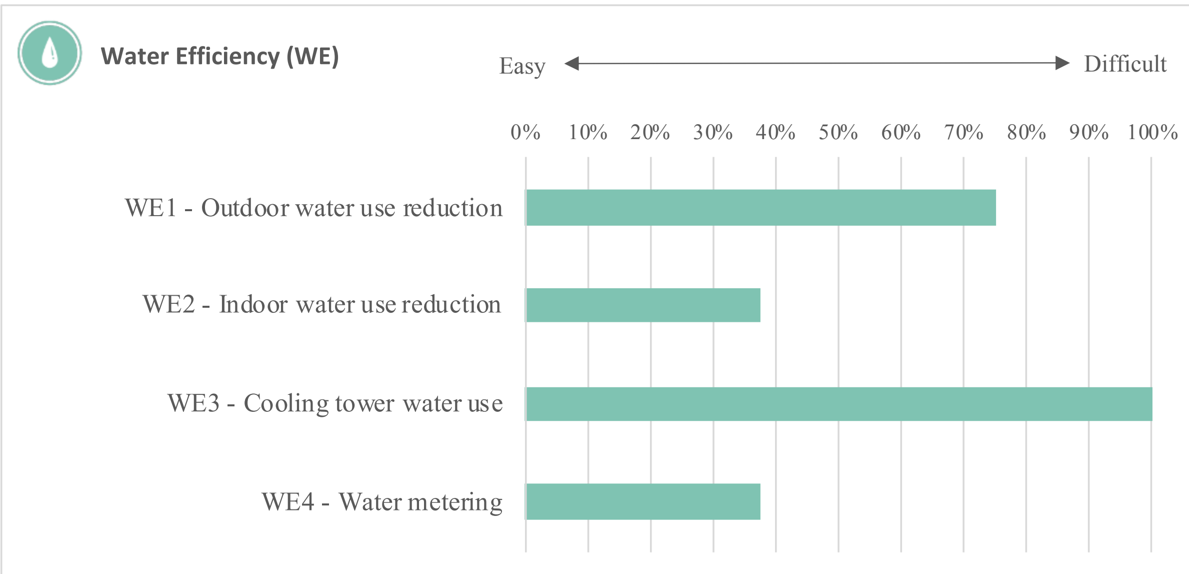
2	Indoor Water Use Reduction		6	5.5%	54.5%
	OR	25% reduction fixture and fitting water use from the baseline	1		
		30% reduction fixture and fitting water use from the baseline (prereq	2		
		35% reduction fixture and fitting water use from the baseline (prereq	3		
		40% reduction fixture and fitting water use from the baseline (prereq	4		
		45% reduction fixture and fitting water use from the baseline (prereq	5		
		50% reduction fixture and fitting water use from the baseline (prereq	6		
3	Cooling Tower Water Use		2	1.8%	18.2%
	OR	*Points for number of cooling tower cycles*			
		Maximum number of cycles achieved without exceeding any filtration levels or affecting operation of condenser water system (up to maximum of 10 cycles)	1		
		Achieve a minimum 10 cycles by increasing the level of treatment in condenser or make-up water OR Meet the minimum number of cycles to earn 1 point and use a minimum 20% recycled nonpotable water	2		
4	Water Metering		1	0.9%	9.1%
	AND	Install permanent water meters for two or more water subsystems (irrigation, indoor plumbing fixtures and fittings, domestic hot water, boiler, reclaimed water, other process water)	1		

Source: Adapted by the author from LEED v4 reference guide.

There are three types of points' contribution in the WE category, high, medium, and low. The credit Indoor Water Use Reduction is worth more than half of the Water Efficiency category points, with 54.5% of the points. Credits Outdoor Water Use Reduction and Cooling Tower Water Use have a medium contribution, both 18.2%. Finally, Water Metering credits with the lowest contribution of points in this category with 9.1%.

The difficulty of achievement is shown in Figure 5.9, where it is possible to see that the most challenging credit is Cooling Tower Water Use (100%), followed by Outdoor Water Use Reduction (75%), and Indoor Water Use Reduction and Water metering (both with 38%).

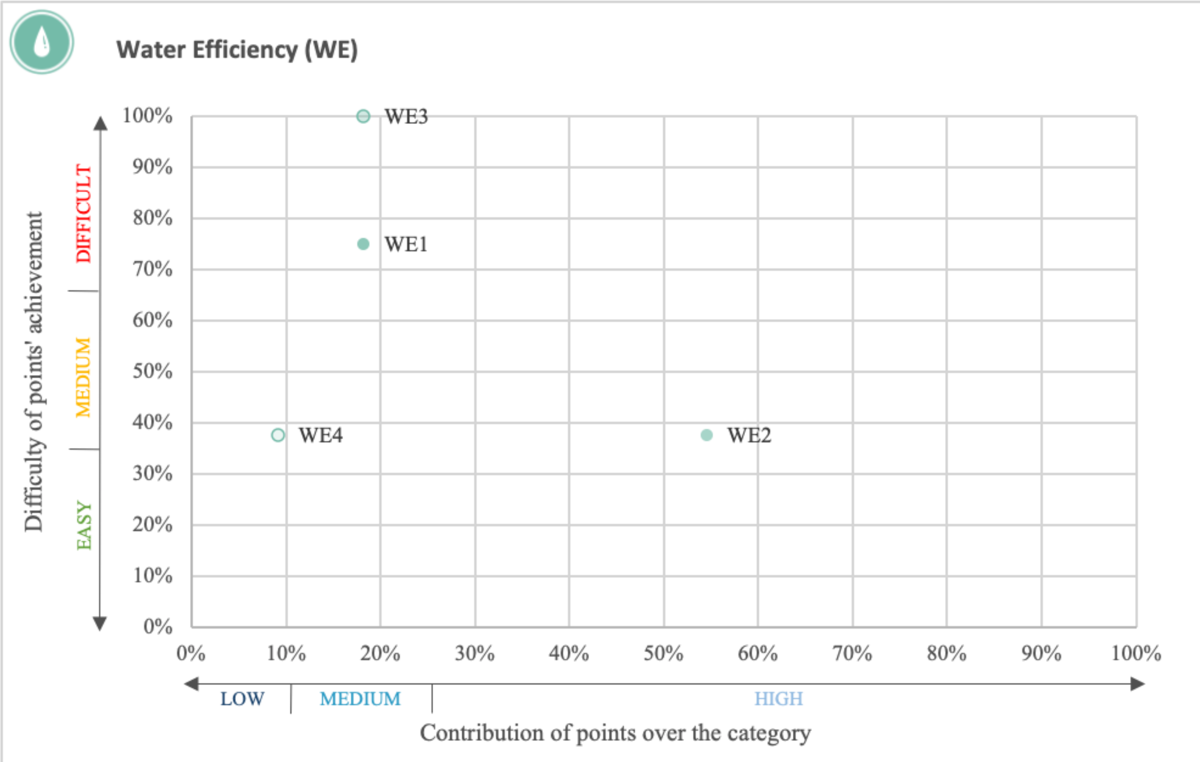
Figure 5.9 - Difficulty of achievement (WE).



Source: Created by the author.

The relationship between the difficulty of achievement and the points' contribution (Figure 5.10) shows that even though credit WE3 is the most difficult to achieve, it is not the one that contributes the most to the category in terms of points. The credit that contributes the most is Indoor Water Use Reduction (WE2), which is one of the easiest credits to be achieved.

Figure 5.10 - Difficulty of achievement x Contribution of points (WE).



Source: Created by the author.

Regarding the influence that each credit of the Water Efficiency category has on the cost, it has been perceived that only Indoor Water Use Reduction (WE2) does not impact the project's cost (and it is an easy credit). Credits WE1, WE3, and WE4 impact the cost with a slight increase in cost.

The increase in cost of credit Outdoor Water Use Reduction (WE1) is related to addition installation system management (control system for rain, a different irrigation type, to name a few). For the Cooling Tower Water Use, the increase could be related to the extra cost to insert a treatment to guarantee the required number of cycles. Moreover, for water metering (WE4), the increase is related to additional equipment that has to be installed and maintained.

About the influence of the credits on the schedule of the project, it has been noticed that only Outdoor Water Use Reduction credit (WE1) influence the schedule of the project with a delay in the project's schedule.

5.2.1.2.5 ENERGY AND ATMOSPHERE

The EA category contains four prerequisites and seven credits. In general, this category is considered of difficult achievement and high points' contribution to the overall rating system. The first Prerequisite (Fundamental commissioning and verification) is from the construction stage submission, with credits EA1, EA4, and EA7. All the others are from the design stage submission. Only EA2 and EA5 are eligible for exemplary performance.

The points' distribution is given in detail in the CrBS of Energy and Atmosphere.

Table 5.7 - CrBS (EA).

Category ID and name	Credit ID and name	Sub credit	Description	Max points	Weight over the whole project	Weight over the category
Credits Breakdown Structure (CrBS)						
EA Energy and Atmosphere				**33**	**30.0%**	
	Prereq		Fundamental Commissioning and Verification	Required		
			Comissioning process scope (Cx activities for mechanical, electrical, plumbing, and renewable energy systems and assemblies - develope basis of design (BOD) and owner's project requirements (OPR)); Comissioning authority (with specific qualification), Current facilities requirements and operations and maintenance plan (prepare and maintain a current facilities requirements and operations and maintenance plan that contains the information necessary to operate the building efficiently			
	Prereq		Minimum Energy Performance	Required		
			Option 1 - Whole building energy simulation Option 2 - Prescriptive compliance: ASHRAE 50% advanced energy design guide Option 3 - Prescriptive compliance: Advanced buildings Core performance guide			
	Prereq		Building-Level Energy Metering	Required		
			Install building-level energy meters, or submeters that can be aggregated to provide building-level data representing total building energy consumption. Energy consumption must be tracked monthly			
	Prereq		Fundamental Refrigerant Management	Required		
			Do not use chlorofluorocarbon (CFC)-based refrigerants in new heating, ventilating, air-conditioning, and refrigeration (HVAC&R) systems. When reusing existing HVAC&R equipment, complete a comprehensive CFC phase-out conversion before project completion			
	1		Enhanced Commissioning	6	5.5%	18.2%
		AND / OR	Option 1 - Enhanced systems comissioning			
			OR: Path 1 - Enhanced comissioning	3		
			OR: Path 2 - Enhanced + Monitoring-based comissioning	4		
			Option 2 - Envelope comissioning	2		
	2		Optimize Energy Performance	18	16.4%	54.5%
		OR	Option 1 - Whole building energy simulation	up to 18		
			6% improvement in performance compared with baseline (prereq)	1		
			8% improvement in performance compared with baseline (prereq)	2		
			10% improvement in performance compared with baseline (prereq)	3		
			12% improvement in performance compared with baseline (prereq)	4		
			14% improvement in performance compared with baseline (prereq)	5		
			16% improvement in performance compared with baseline (prereq)	6		
			18% improvement in performance compared with baseline (prereq)	7		
			20% improvement in performance compared with baseline (prereq)	8		
			22% improvement in performance compared with baseline (prereq)	9		
			24% improvement in performance compared with baseline (prereq)	10		
			26% improvement in performance compared with baseline (prereq)	11		
			29% improvement in performance compared with baseline (prereq)	12		
			32% improvement in performance compared with baseline (prereq)	13		
			35% improvement in performance compared with baseline (prereq)	14		
			38% improvement in performance compared with baseline (prereq)	15		
			42% improvement in performance compared with baseline (prereq)	16		
			46% improvement in performance compared with baseline (prereq)	17		
			50% improvement in performance compared with baseline (prereq)	18		
			Option 2 - Prescriptive compliance: ASHARE advanced energy design guide (only eligeble if option 2 of Minimum energy performance prequesite was chosen). ASHARE 50% Advanced energy design guide for Small to Medium office buildings	Up to 5		
			Building envelope, opaque: roofs, walls, floors, slabs, doors, and continuous air barriers	1		
			Building envelope, glazing: vertical fenestration	1		
			Intertior lighting, inclusing daylighting and interior finishes	1		
			Exterior lighting	1		
			Plug loads, including equipment and controls	1		
	3		Advanced Energy Metering	1	0.9%	3.0%
		AND	Install advanced energy metering for all whole-building energy sources used by the building, and any individual energy end uses that represent 10% or more of the total annual consumption of the building	1		
	4		Demand Response	2	1.8%	6.1%
		OR	Case 1 - Demand response program available	2		
			Case 2 - Demand responde program not available but existent infrastructure for future use	1		

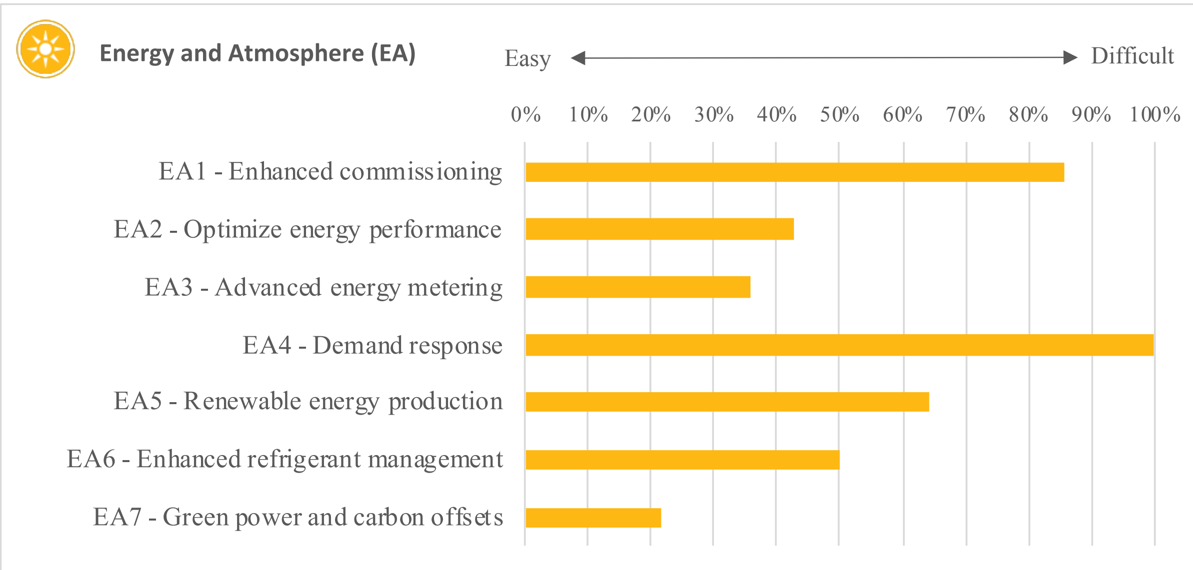
5	Renewable Energy Production		3	2.7%	9.1%
	OR	1% renewable energy	1		
		5% renewable energy	2		
		10% renewable energy	3		
		$\% = \frac{Equivalent\ cost\ of\ usable\ energy\ produced\ by\ the\ ren.energy\ system}{Total\ building\ annual\ energy\ cost}$			
6	Enhanced Refrigerant Management		1	0.9%	3.0%
	OR	Option 1 - No refrigerant or low-impact refrigerants	1		
		Option 2 - Calculation of refrigerant impact	1		
7	Green Power and Carbon Offsets		2	1.8%	6.1%
	OR	50% of total energy adressed by green power, RECs and/or offsets	1		
		100% of total energy adressed by green power, RECs and/or offsets	2		

Source: Adapted by the author from LEED v4 reference guide.

The contribution of points varies a lot in the Energy and Atmosphere category. Starting with Optimize Energy Performance credit (EA2), it can contribute to more than half of the total category points, with 54.5%. This credit points vary according to the percentage of improvement in performance compared to a baseline reference building. Therefore, it is possible that the contribution is not so high. If this credit's lowest performance is achieved, it contributes only to 3% of this category's points. The second credit that can contribute the most to this category is Enhanced Commissioning (EA1), with 18.2%. This credit is an improvement of the first prerequisite. Then, Renewable Energy Production (EA5) can achieve up to 9.1% with the maximum points, Demand Response (EA4) and Green Power and Carbon Offsets (EA7) can achieve up to 6.1%, and Advanced Energy Metering (EA3) and Enhanced Refrigerant Management (EA6) can achieve up to 3%.

The difficulty of achievement (Figure 5.11) shows that Demand Response (100%) is the most challenging credit of the Energy and Atmosphere category, followed by Enhanced Commissioning (86%), Renewable Energy Production (64%), Enhanced Refrigerant management (50%), Optimize Energy Performance (43%), Advanced Energy Metering (36%) and finally, Green Power and Carbon Offsets (21%).

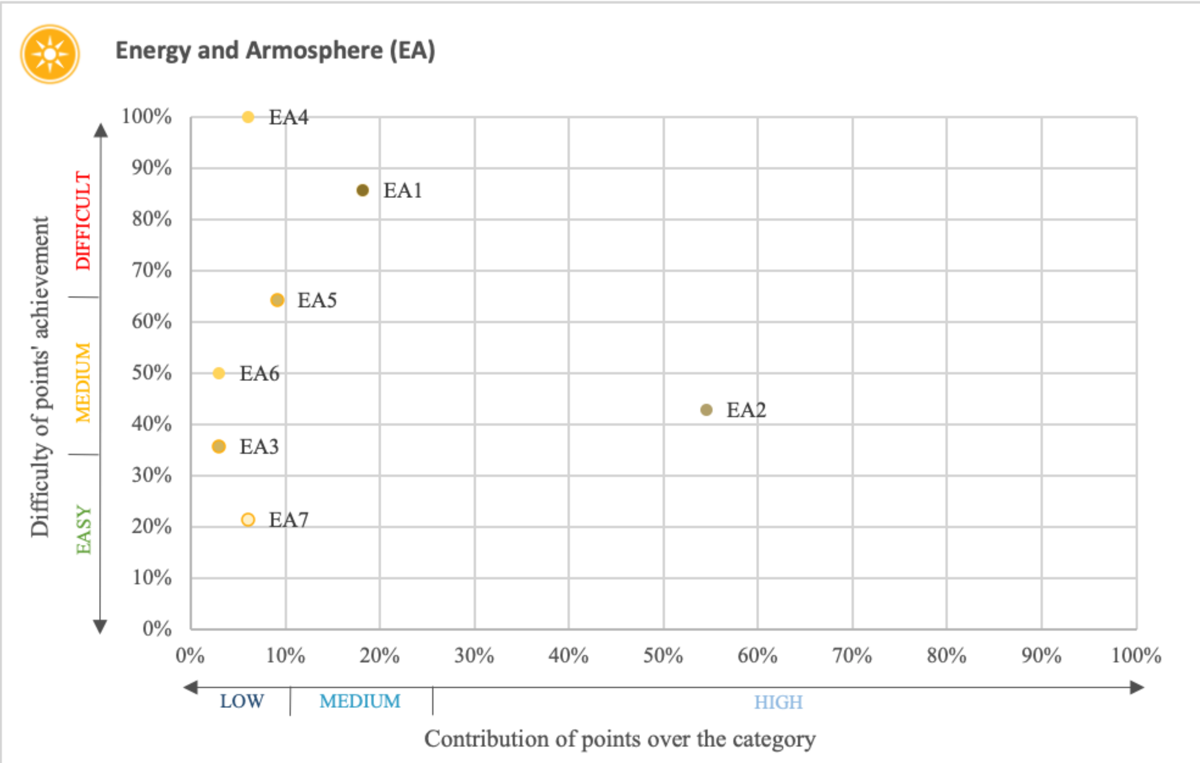
Figure 5.11 - Difficulty of achievement (EA).



Source: Created by the author.

According to the difficulty analysis, most of this category's credits are of medium or difficult achievement, and still, their contribution of points to the category is mostly low. By analyzing Figure 5.12, it is possible to see that the most challenging credit to achieve (EA4) has a very low contribution of points, together with four other credits (EA3, EA5, EA6, and EA7). The other credit of difficult achievement (EA1) has a medium contribution of points to the category, while EA2, a medium difficulty of achievement credit, can have a very high contribution of points. It is important to point out that the difficulty of achievement of credit EA2 (Optimize Energy Performance) increases according to the number of points it is wanted to achieve, to the improvement of energy performance.

Figure 5.12 - Difficulty of achievement x Contribution of points (EA).



Source: Created by the author.

Regarding the influence that each credit of Energy and Atmosphere category has on the cost, it has been perceived that all credits impact the cost in some way. This means that this category should be very well pre-assessed and assessed to guarantee that the project does not go overbudget. Credits EA1, EA2, EA3, and EA5 impact the cost with a big increase in price, while EA4, EA6, and EA7 impact a bit less, with a slight impact on the cost.

The increase in cost for the credits of the Energy and Atmosphere category is usually related to extra consultancy and additional materials and installation. For example, Enhanced Commissioning (EA1) requires extra consultancy and performance tests that, in the future, can have a return on investment, so maybe the increase in cost would not be extra if seen in the long term. The cost related to the Enhanced Refrigerant Management (EA6) will slightly increase if the proper refrigerant and equipment is not considered in initial design phase, meaning that all equipment will have to be changed in order to comply with the credit requirement.

About the influence of the credits on the schedule of the project, it has been noticed that the Enhanced Commissioning credit (EA1) can impact a lot the schedule of project, while

Advanced Energy Metering (EA3) impact a bit less with a slight impact. EA2, EA4, EA5, EA6 and EA7 usually do not impact the schedule of the project at all.

5.2.1.2.6 MATERIALS AND RESOURCES

The Material and Resources category contains two prerequisites and five credits. In general, this category is considered of difficult achievement and medium points' contribution to the overall rating system. Only the first Prerequisite (Storage and Collection of Recyclables) is from the design stage submission, the other pre-requisite and all credits are from the construction submission phase. All credits of this category are eligible for exemplary performance. The points' distribution is given in detail in the CrBS of Materials and Resources.

Table 5.8 - CrBS (MR).

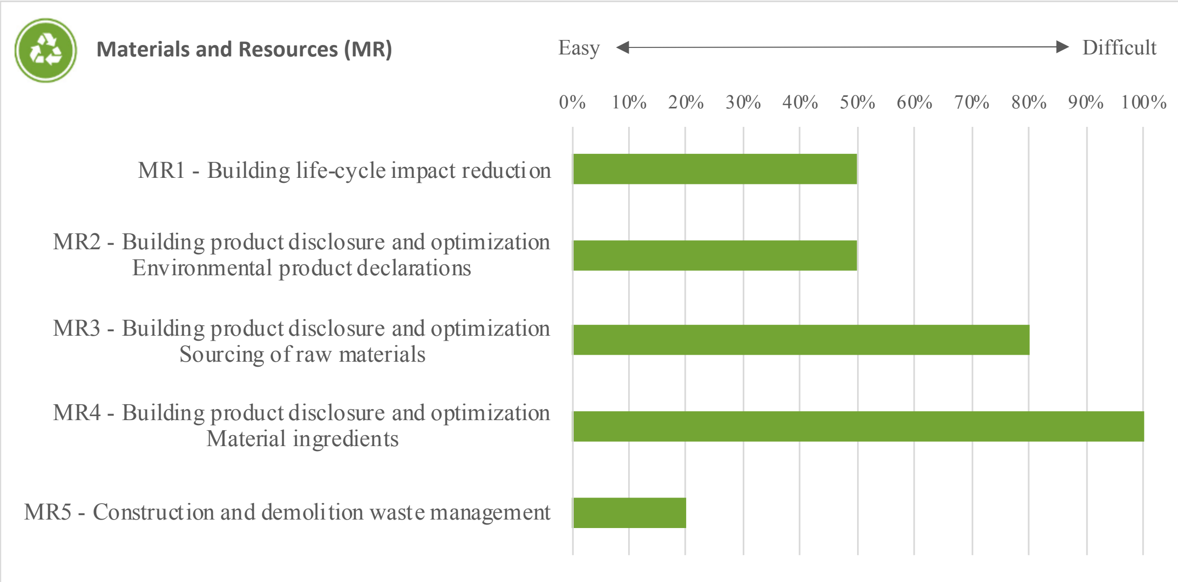
Credits Breakdown Structure (CrBS)						
Category ID and name	**Credit ID and name**	**Sub credit**	**Description**	**Max points**	**Weight over the whole project**	**Weight over the category**
MR Materials and Resources				**13**	**11.8%**	
	Prereq		Storage and Collection of Recyclables	Required		
			Provide dedicated areas accessible to waste haulers and building occupants for the collection and storage of recyclable materials for the entire building			
	Prereq		Construction and Demolition Waste Management Planning	Required		
			Develop and implement a construction and demolition waste management plan			
	1		Building Life-Cycle Impact Reduction	5	4.5%	38.5%
		OR	Option 1 - Historic building reuse	5		
		OR	Option 2 - Renovation of abandoned or blighted building	5		
		OR	Option 3 - Building and material reuse			
		OR	(OR) 25% of completed project surface area reused	2		
		OR	(OR) 50% of completed project surface area reused	3		
		OR	(OR) 75% of completed project surface area reused	4		
		OR	Option 4 - Whole-building life cycle assessment	3		
	2		Building Product Disclosure and Optimization - Environmental Product Declaratio	2	1.8%	15.4%
		AND /OR	Option 1 - Environmental product declaration (EPD)	1		
		AND /OR	Option 2 - Multi-attribute optimization	1		
	3		Building Product Disclosure and Optimization - Sourcing of Raw Materials	2	1.8%	15.4%
		AND /OR	Option 1 - Raw material source and extraction reporting	1		
		AND /OR	Option 2 - Leadership extraction practices	1		
	4		Building Product Disclosure and Optimization - Material Ingredients	2	1.8%	15.4%
		AND / OR	Option 1 - Material ingredient reporting	1		
		AND / OR	Option 2 - Material ingredient optimization	1		
		AND / OR	Option 3 - Product manufacturer supply chain optimization	1		
			Product compliant with both option 2 and 3 may only be counted once			
	5		Construction and Demolition Waste Management	2	1.8%	15.4%
		OR	Option 1 - Diversion			
		OR	Path 1 - Divert 50% and three material streams	1		
		OR	Path 2 - Divert 75% and four material streams	2		
		OR	Option 2 - Reduction of total waste material	2		

Source: Adapted by the author from LEED v4 reference guide.

The first credit, Building Life-cycle Impact Reduction (MR1), can contribute up to 38.5% with the category's points. All the other credits contribute up to 15.4%. In this category, the credits' contribution can vary depending on the chosen sub credits.

The difficulty of achievement (Figure 5.13) shows that Material ingredients (100%) is the most challenging credit of the Materials and Resources category, followed by Sourcing of raw materials (80%), Building life cycle impact reduction and Environmental product declarations (both with 50%), and Construction and demolition waste management (20%).

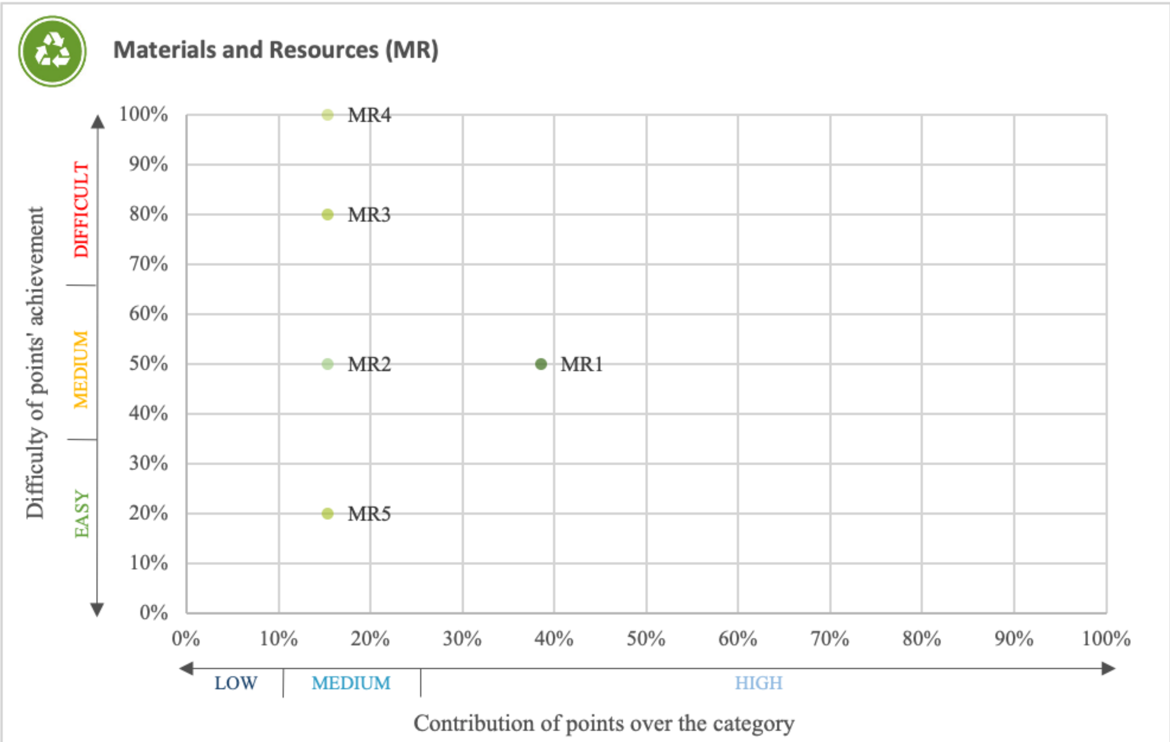
Figure 5.13 - Difficulty of achievement (MR).



Source: Created by the author.

According to the contribution of points, most of this category's credits are of medium contribution, and their difficulty of achievement vary a lot. By analyzing Figure 5.14, it is possible to see that the most challenging credit (MR4) has a medium contribution of points, together with three other credits of this category (MR3, MR2, and MR5). The other credit, that has a high contribution in terms of points (MR1), is categorized as medium difficulty of achievement.

Figure 5.14 - Difficulty of achievement x Contribution of points (MR).



Source: Created by the author.

It has been observed that three credits impact the cost, all with a slight increase: Building life cycle impact reduction (MR1), Sourcing of raw materials (MR3), and Material ingredients (MR4). The increase in cost in this category is usually related to decisions made in the design phase that did not consider a LEED perspective. In some cases, the decision to pursue the LEED certification happens after materials or contractors were selected, and if LEED requirements were not taken into account, an increase in cost is likely to happen. However, when the design team is familiar with LEED requirements (previous experience) or LEED assessment is part of the project since the basic design, this increase is unlikely to happen.

Regarding the influence of the credits on the schedule of the project, it has been noticed that Construction and Demolition waste management (MR5) can slightly impact the schedule of project.

5.2.1.2.7 INDOOR ENVIRONMENTAL QUALITY

The Indoor Environmental Quality (EQ) category contains two prerequisites and nine credits (Table 5.9). In general, this category is considered of difficult achievement and medium points' contribution to the overall rating system. All prerequisites and most of the credits are from the design submission phase, only credits EQ2, EQ3, and EQ4 are from the construction submission phase. Only credits EQ1, EQ2 and EQ8 are eligible for exemplary performance.

Table 5.9 - CrBS (EQ).

Credits Breakdown Structure (CrBS)						
Category ID and name	**Credit ID and name**	**Sub credit**	**Description**	**Max points**	**Weight over the whole project**	**Weight over the category**
EQ Indoor Environmental Quality				**16**	**14.5%**	
	Prereq		Minimum Indoor Air Quality Performance	Required		
			Meet the requirements for ventilation (mechanical and natural) and monitoring			
	Prereq		Environmental Tobacco Smoke Control	Required		
			Prohibit smoking inside the building			
	1		Enhanced Indoor Air Quality Strategies	2	1.8%	12.5%
		AND /OR	Option 1 - Enhanced IAQ strategies	1		
			Option 2 - Additional enhanced IAQ strategies	1		
	2		Low-Emitting Materials	3	2.7%	18.8%
		OR	Option 1- Product category calculations	Up to 3		
			Compliant category - New construction without furniture			
			2	1		
			4	2		
			5	3		
			Compliant category - New construction with furniture			
			3	1		
			5	2		
			6	3		
			Option 2 - Budget calculation method	Up to 3		
			Total percentage of compliance			
			≥ 50% and < 70%	1		
			≥ 70% and < 90%	2		
			≥ 90%	3		
	3		Construction Indoor Air Quality Management Plan	1	0.9%	6.3%
		AND	Develop and implement an indoor air quality (IAQ) management plan for the construction and preoccupancy phases of the building	1		
	4		Indoor Air Quality Assessment	2	1.8%	12.5%
		OR	Option 1- Flush-out			
			OR: Path 1 - Before occupancy	1		
			Path 2 - During occupancy	1		
			Option 2 - Air testing	2		

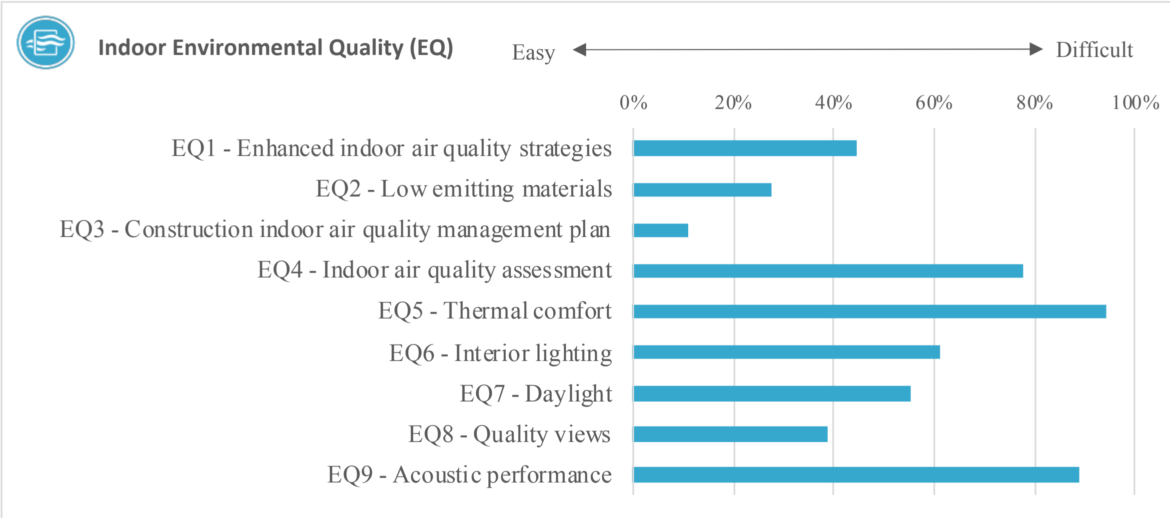
5	Thermal Comfort		1	0.9%	6.3%
	AND	Thermal comfort design			
		OR: Option 1 - Meet requirements of ASHRAE Standard 55-2010			
		OR: Option 2 - Meet requirements of ISO and CEN Standards			
		Thermal comfort control	1		
		Provide individual thermal comfort controls for at least 50% of individual occupant spaces. Provide group thermal comfort controls for all shared multioccupant spaces.			
6	Interior lighting		2	1.8%	12.5%
	AND / OR	Lighting control	1		
		Lighting quality	1		
7	Daylight		3	2.7%	18.8%
	OR	Option 1 - sDA and ASE			
		$sDA_{300/50\%} \geq 55\%$	2		
		$sDA_{300/50\%} \geq 75\%$	3		
		$ASE_{1000,250} \leq 10\%$			
		Option 2 - Illuminance calculations - demonstrate throuhgh computer modeling Illuminance levels between 300 - 3000lux for 9am and 3pm on clear sky and equinox.			
		75% of regulaly occupied floor area	1		
		90% of regurlarly occupied floor area	2		
		Option 3 - Measurement - Achieve illuminance levels for two selected months between 300 - 300lux for any hour between 9am and 3pm.			
		75% of regularly occupied floor area	2		
		90% of regurlarly occupied floor area	3		
8	Quality Views		1	0.9%	6.3%
	AND	Achieve a direct line of sight to the outdoors via vision glazing for 75% of all regularly occupied floor area. Additionally, 75% of all regularly occupied floor area must have at least two other conditions. Views to interior atria may be used to meet up 30% of the required area	1		
9	Acoustic Performance		1	0.9%	6.3%
	AND	Meet requirements for HVAC background noise, sound isolation, reverberation time, and sound reinforcement and masking systems	1		

Source: Adapted by the author from LEED v4 reference guide.

There is no credit in this category that has a high contribution in terms of points to the rating system. The credits that contribute the most are Low emitting materials (EQ2) and Daylight (EQ7) with 18.8% each, followed by Enhanced indoor air quality strategies (EQ1), Indoor air quality assessment (EQ4), and Interior lighting (EQ6), each one with 12.5%. Finally, all the other credits contribute to 6.3% each. The credits' contribution can also vary depending on the chosen sub credits, so the maximum number of points is not always achieved.

The difficulty of achievement chart (Figure 5.15) shows that Thermal comfort (94%) is the most challenging credit of the Indoor Environmental Quality category, followed by Acoustic performance (89%), Indoor air quality assessment (78%), Interior lighting (61%), Daylight (56%), Enhanced indoor air quality strategies (44%), Quality views (39%), Low emitting materials (28%), and Construction indoor air quality management plan (11%).

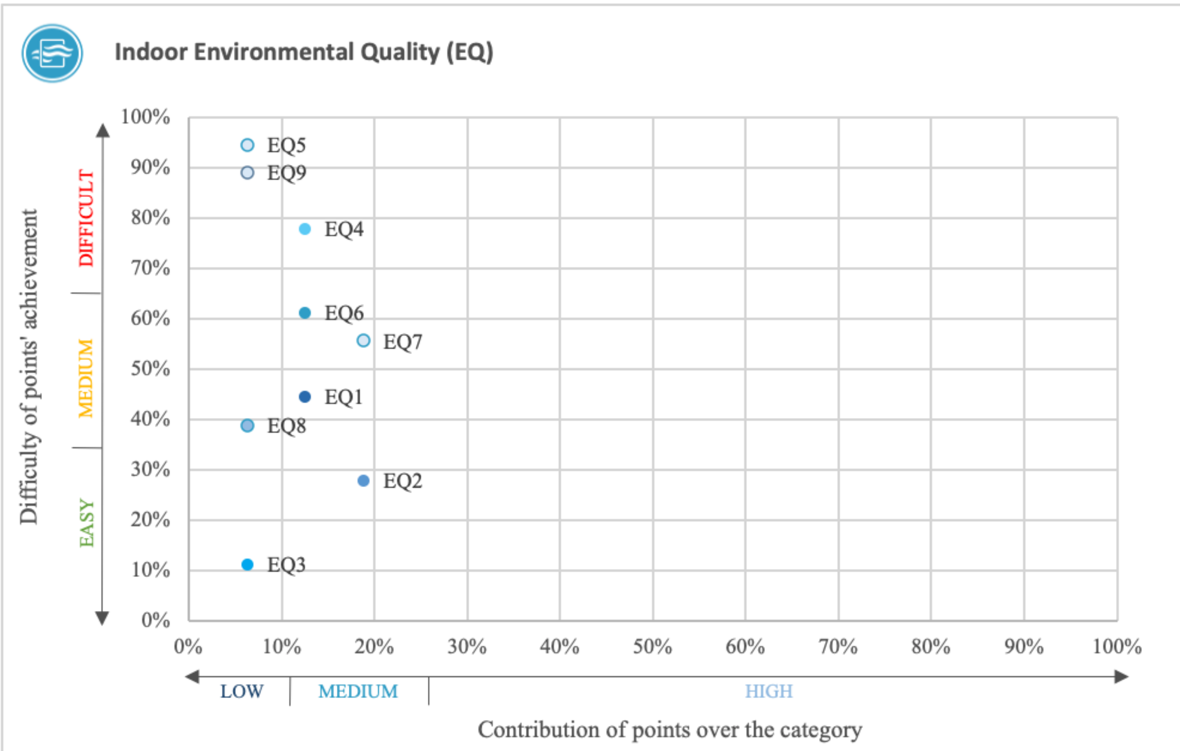
Figure 5.15 - Difficulty of achievement (EQ).



Source: Created by the author.

According to the contribution of points, there is no credit of high contribution of points, they are all spread between medium or low. By analyzing Figure 5.16, it is possible to see that the two most challenging credits (EQ5 and EQ9) have a low contribution of points. The credit EQ4, which is also of difficult achievement, has a medium contribution of points. The credits classified as medium difficulty of achievement have both a low (EQ8) and a medium contribution of points (EQ6, EQ7, and EQ1). Finally, the easy credits have both a low (EQ3) and medium (EQ2) contribution of points.

Figure 5.16 - Difficulty of achievement x Contribution of points (EQ).



Source: Created by the author.

Most of the credits of this category influence the cost and the schedule of the project somehow. Six out of the nine credits impact the cost, and four out of the nine credits impact the schedule.

Credits EQ1, EQ5, EQ6, EQ7, and EQ9 can slightly impact the cost, and credit EQ4 can greatly impact it. The big increase related to Indoor air quality assessment (EQ4) is due to extra consultancy and the cost of electricity because of the performance tests. Thermal comfort increases the project's cost because an individual thermal comfort controller would have to be added, which is feasible when the plan has closed spaces; however, it becomes more difficult and more expensive when an open plan is considered. This category's acoustic performance is associated with HVAC background noise, interior walls, slabs, to name a few examples. This credit is not associated with the building envelope, which is considered in the energy and atmosphere category. Therefore, to guarantee the required acoustic performance, high performing materials and equipment should be considered, increasing the cost of the project.

Regarding the influence of the credits on the schedule of the project, EQ2, EQ5 and EQ9 can slightly delay the project's schedule, while EQ4 can result in a bigger delay. Some of these delays are related to the performance tests on site, or to decisions that had to be changed during the project.

5.2.1.2.8 INNOVATION

The Innovation (IN) category does not have prerequisites and has two credits (Table 5.10). This category is considered of easy achievement and low points' contribution to the overall rating system. The credits can be both from the design or construction submission phase, and none of the credits are eligible for exemplary performance.

Table 5.10 - CrBS (IN).

Credits Breakdown Structure (CrBS)						
Category ID and name	**Credit ID and name**	**Sub credit**	**Description**	**Max points**	**Weight over the whole project**	**Weight over the category**
IN Innovation				**6**	**5.5%**	
	1 Innovation			5	4.5%	83.3%
		AND / OR	Option 1 - Innovation			
			Achieve significant, measurable environmental performance using a strategy not addressed in the LEED green building rating system. Identify: 1)The intent of the proposed innovation; 2) Proposed requirement for compliance; 3) Proposed submittals to demonstrate compliance; 4) The design approach or strategies used to meet the requirements.	1		
			Option 2 - Pilot			
			Achieve one credit from USGBC's LEED Pilot credit library	1		
			Option 3 - Additional strategies			
			Innovation	1 to 3		
			Pilot	1 to 3		
			Exemplary performance (An exemplary performance point is typically earned for achieving double the credit requirements or the next incremental percentage threshold.)	1 to 2		
		To achieve all five innovation points, a project team must achieve at least one pilot credit, at least one innovation credit and no more than two exemplary performance credits.				
	2 LEED Accredited Professional			1	0.9%	16.7%
			At least one principal participant of the project team must be a LEED AP with a speciality appropriate for the project	1		

Source: Adapted by the author from LEED v4 reference guide.

The Innovation (IN1) credit of this category has a high contribution in terms of points (83.3%) and it is classified as difficult achievement. While LEED Accredited professional has a medium contribution (16.7%) of points and is classified as easy achievement.

None of these credits influence the project cost, neither the project's schedule. It has been observed by the LEED APs that in some cases, it could happen a slightly decrease in time due to the experience that a LEED AP has and brings to the project, facilitating all the processes, mainly if this professional in following the project since the conceptual design.

5.2.1.2.1 REGIONAL PRIORITY

The Regional priority (RP) category does not have prerequisites and has four credits that vary depending on the location of the project. This category is considered of easy achievement and low points' contribution to the overall rating system. The credits can be both from the design or construction submission phase, and none of the credits are eligible for exemplary performance.

The regional Green Building Council and Chapters identify six regional priority credits for each location, as being credits that have additional regional importance for the project's region. The project can earn up to four of the six regional priority credits (USGBC, 2019b).

Table 5.11 - CrBS (RP).

Credits Breakdown Structure (CrBS)						
Category ID and name	Credit ID and name	Sub credit	Description	Max points	Weight over the whole project	Weight over the category
RP Regional Priority				**4**	**3.6%**	
			To provide an incentive (a bonus point) for the achievement of credits that address geographically specific environmental, social equity, and public health priorities. A project can achieve up to 4 options.			
	1		Regional Priority: Specific Credit	1	0.9%	25.0%
	2		Regional Priority: Specific Credit	1	0.9%	25.0%
	3		Regional Priority: Specific Credit	1	0.9%	25.0%
	4		Regional Priority: Specific Credit	1	0.9%	25.0%

Source: Adapted by the author from LEED v4 reference guide.

The points' contribution to the Regional Priority category is equally distributed (Table 5.11); each one contributes to 25%. The difficulty of achievement of these regional priority credits will follow the specific credit difficulty analysis, and the same logic is taken for the impact on cost and schedule.

As an example, the regional priority credits for a project in Milan are listed below. Each credit is followed by the difficulty of achievement, the impact on cost, and the impact on schedule, respectively.

- Reduced parking footprint: Easy / None / None
- Daylight: Medium / Slight increase / None
- Sensitive land protection: Medium / None / None
- Green vehicles: Medium / Slight increase / None
- Light pollution reduction: Difficult / None / None
- Outdoor water use reduction: Difficult / Slight increase / Slight increase

5.2.2 - GREEN BIM - BEP FOR LEED

The BIM Execution Planning guide has a five-step procedure that will define the BIM deliverables to implement BIM in a project successfully. The BIM Plan is the most indicated way to adopt BIM in a project. It is a complete and complicated procedure that has to be “developed in early stages of a project; continually developed as additional participants are added to the project; and monitored, updated, and revised as needed throughout the implementation phase of the project” (Messner et al., 2020).

The objective of the BIM Plan is to “stimulate planning and direct communication among the project team members during the early phases of a project”. Moreover, the BIM plan cannot be developed in isolation and has to include actors from all organizations with significant roles involved in the project (Messner et al., 2020).

The five-step is a long process that has to be developed and continuously improved. Due to the limited time and resources available for this thesis's development, it has been decided to develop the first step of the BIM Plan (1. Goals) and part of the second (2. Model Uses). As seen in the theoretical foundation, the identification of BIM Model Uses is also a five-step procedure, but only the first step will be developed (1. Identify Model Uses).

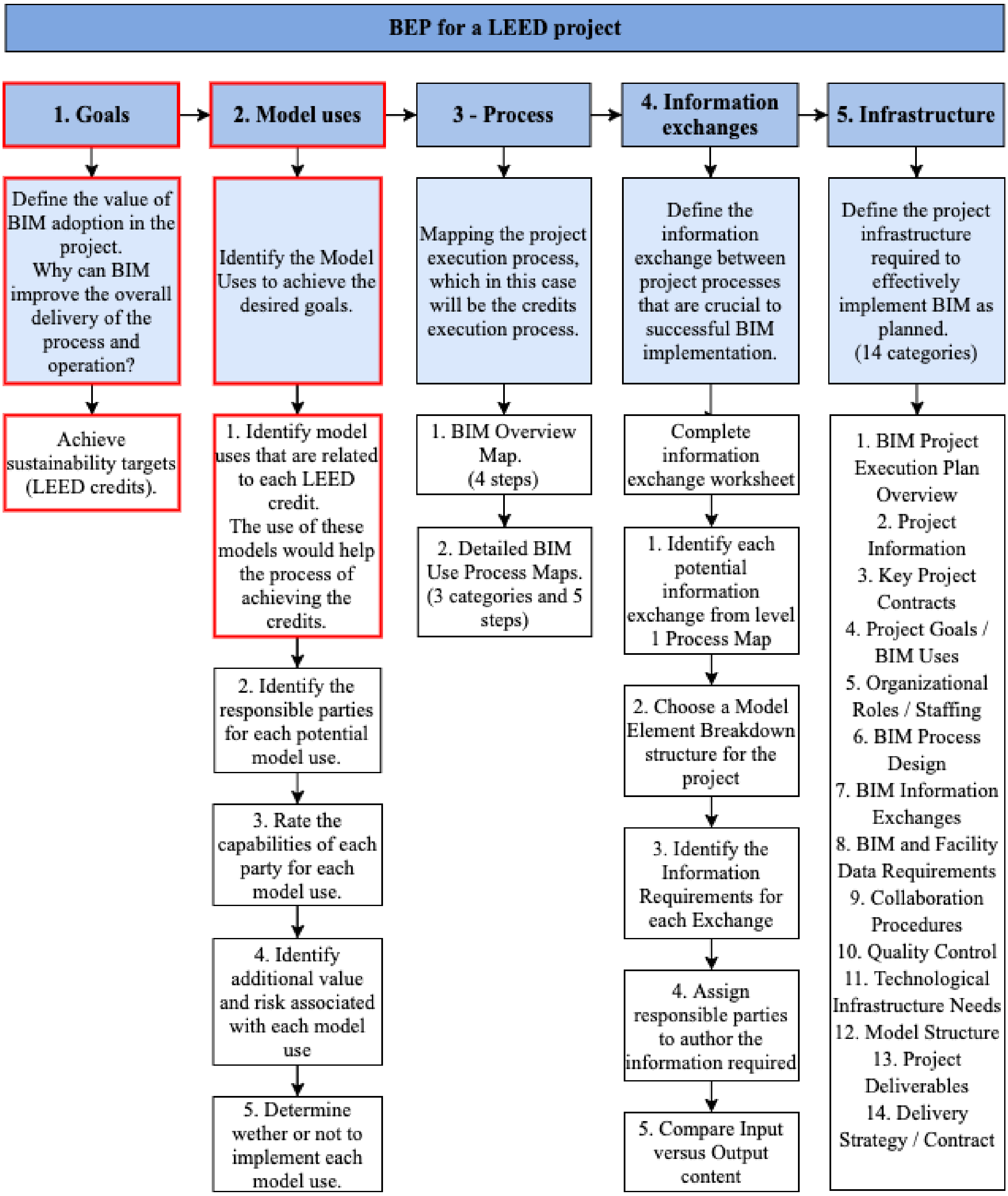
In addition to the Model Uses identification, BIM parameters that could be inserted in the model are also indicated. Identifying BIM Use cases and parameters will help the actors of a project better delineate deliverables, understand how to achieve some LEED goals in a better way, therefore facilitating the assessment process of a LEED project. Nevertheless, it is highly indicated to develop the complete BIM Plan procedure to adopt BIM in a project correctly.

The main idea here is to determine BIM Uses and parameters that will be needed during the LEED assessment process, or in other words, link what information of a project will have to be accessed by the LEED AP in order to prepare all the documentation required for the LEED submission. The identification of these uses will improve the LEED assessment process. The time needed to prepare the documentation will be reduced because it will be easier to access the information. Moreover, the information inserted in the model will be consistent.

It has been seen that the Model Uses proposed by Penn State University in the BIM Execution Planning Guide are twenty-five. However, the authors of the PSU BEP guide affirm that there are many more potential uses, and that the identification of the uses should not be limited to the ones listed by them. For this reason, in addition to the Model Uses proposed by PSU, other Model Uses suggested by Harvard University (Harvard University Construction Management Council, 2012) and by the BIM Excellence initiative (Succar, 2017) will also be considered.

Figure 5.17 shows the steps of the BIM Plan. For the adaptation of the BEP for LEED in this thesis, only the steps circled in red will be developed. Further research can be developed in the future regarding this to propose a more complete inclusion of LEED into BIM Plans.

Figure 5.17 - PSU BEP procedure (adapted).



Source: Adapted from (Messner et al., 2020).

According to the steps demonstrated in Figure 5.17, the first step is to define the value of BIM adoption in the project: "Why can BIM improve the overall delivery of the process and operation?" The concept of Green BIM has been previously explained in this thesis; therefore, the three pillars of Green BIM defined by Gandhi and Jupp (2013) could help to answer to this question.

- Integrated design processes;
- Environmentally sustainable design principles; and
- Optimization of Green building certification credits.

The use of BIM assists the sustainable design processes and improves the sustainability assessment of the LEED certification. So, the goal for using BIM is to achieve sustainability targets, which, in this case, are the credits of the LEED BD+C NC v4 rating system.

The second step of the plan is to identify the Model Uses and parameters to achieve the goal, more precisely, the LEED credits. Table 5.12 shows the identified BIM Model Uses and the BIM parameters for each credit of the LEED certification. In some cases, no Model Use or Parameter has been identified, and not applicable (n/a) has been written instead.

Table 5.12 - BIM Model Uses and Parameters.

Categories and Credits		Model Uses	Parameters
Integrative Process			
1	Integrative Process	Analyze Energy Performance	Type of room space (according to ASHRAE 90.1-2010); Occupancy of rooms
Location and Transportation			
1	LEED for Neighborhood Development Location	n/a	n/a
2	Sensitive Land Protection	Analyze site selection criteria	n/a
3	High Priority Site	Analyze site selection criteria	n/a
4	Surrounding Density and Diverse Uses	Capture existing conditions	n/a
5	Access to Quality Transit	n/a	n/a
6	Bicycle Facilities	Author design / Parking logistics planning	Building occupancy (regular/visiting occupants); Number of residential units (if the case); Type of bicycle storage (long term/short term)
7	Reduced Parking Footprint	Author design / Parking logistics planning	Parking capacity of the project (including outside project boundary that is used by occupants); Type of parking space (regular or preferred/carpool);
8	Green Vehicles	Author design / Parking logistics planning	Type of parking space (regular or green vehicles/green vehicles with ESVE)
Sustainable Sites			
Prereq	Construction Activity Pollution Prevention	n/a	n/a
1	Site Assessment	Analyze site selection criteria; Capture existing conditions; Climate Analyzes	n/a
2	Site Development - Protect or Restore Habitat	n/a	n/a
3	Open Space	Author design; Landscape modeling	Total site area; total outdoor area; total vegetated area; identify the vegetation types;
4	Rainwater Management	Hydrological systems modeling	n/a
5	Heat Island Reduction	Author design; Architectural modeling	Solar reflectance (SR) and solar reflectance index (SRI) of materials (mainly paving and roofing materials)
6	Light Pollution Reduction	Analyze lighting performance	Link photometric data to the material; BUG rating information of the luminary (uplight and light

Categories and Credits		Model Uses	Parameters
			trespass) or percentage of total lumens emitted above horizontal (uplight) and vertical (trespass)
Water Efficiency			
Prereq	Outdoor Water Use Reduction	Irrigation systems modeling	n/a
Prereq	Indoor Water Use Reduction	Hydraulic systems modeling	Link datasheet of objects, if modeled (fixtures, fittings, appliances)
Prereq	Building-Level Water Metering	Monitor system performance; Monitor Assets	n/a
1	Outdoor Water Use Reduction	Irrigation systems modeling	n/a
2	Indoor Water Use Reduction	Hydraulic systems modeling	Link datasheet of objects, if modeled (fixtures, fittings, appliances)
3	Cooling Tower Water Use	n/a	n/a
4	Water Metering	Monitor system performance; Monitor Assets	n/a
Energy and Atmosphere			
Prereq	Fundamental Commissioning and Verification	Handover and commissioning; Design documents (OPR/BOD)	Occupancy schedule of rooms; set points of HVAC system; equipment run-time schedule;
Prereq	Minimum Energy Performance	Analyze energy performance	Type of room space (according to ASHRAE 90.1-2010); Occupancy of rooms; Occupancy schedule of rooms; U-values; g-values; Tvis; R-values opaque elements; link HVAC equipment data sheet (i.e. efficiency value)
Prereq	Building-Level Energy Metering	Monitor system performance; Monitor assets	n/a
Prereq	Fundamental Refrigerant Management	n/a	n/a
1	Enhanced Commissioning	Handover and commissioning	n/a
2	Optimize Energy Performance	Analyze energy performance	Type of room space (according to ASHRAE 90.1-2010); Occupancy of rooms; Occupancy schedule of rooms; U-values; g-values; Tvis; R-values opaque elements; link HVAC equipment data sheet (i.e. efficiency value)
3	Advanced Energy Metering	Monitor system performance; Monitor Assets	n/a
4	Demand Response	n/a	n/a
5	Renewable Energy Production	Analyze energy performance	n/a
6	Enhanced Refrigerant Management	n/a	n/a
7	Green Power and Carbon Offsets	n/a	n/a
Materials and Resources			
Prereq	Storage and Collection of Recyclables	n/a	n/a
Prereq	Construction and Demolition Waste Management Planning	Author construction site logistics model (focus on	n/a

Categories and Credits		Model Uses	Parameters
		waste); Construction waste management	
1	Building Life-Cycle Impact Reduction	Life-Cycle Assessment	n/a
2	BPDO - Environmental Product Declarations	Author cost estimate	Link EPD to the materials
3	BPDO - Sourcing of Raw Materials	Author cost estimate	Link CSR / extraction report to the materials
4	BPDO - Material Ingredients	Author cost estimate	Link product datasheet to the material (There are several options of material declarations considered for the achievement of this credit, by having the exact data sheet would already facilitate the process for the investigation.)
5	Construction and Demolition Waste Management	Author construction site logistics model (focus on the waste); Construction waste management	n/a
Indoor Environmental Quality			
Prereq	Minimum Indoor Air Quality Performance	Analyze air quality performance; HVAC systems modeling	Room area, occupancy of room; type of building and/or room space; Building category; floor area per person (can be calculated with area of room and occupancy); Occupancy schedule of room; Activity and clothing level of room;
Prereq	Environmental Tobacco Smoke Control	n/a	n/a
1	Enhanced Indoor Air Quality Strategies	Analyze air quality performance; HVAC systems modeling	n/a
2	Low-Emitting Materials	Author design; Architectural modeling; Author cost estimate	Link product datasheet to the material/surface (information required is related to General Emissions Evaluation and VOC content requirements for wet applied surfaces) - Analyzed categories: interior paints and coatings, interior adhesives and sealants, flooring, composite wood, ceiling, walls, thermal and acoustic insulation, furniture, exterior applied products (the last one only for healthcare and schools).
3	Construction Indoor Air Quality Management Plan	Analyze air quality performance; HVAC systems modeling	n/a
4	Indoor Air Quality Assessment	n/a	n/a

Categories and Credits		Model Uses	Parameters
5	Thermal Comfort	Analyze thermal comfort performance; Author design; Architectural modeling;	For thermal comfort design: Occupancy of rooms; type of building and/or room space; Building category; Occupancy schedule of room; Activity and clothing level of room;
6	Interior lighting	Analyze lighting performance	Link photometric data to the material (luminance; CRI, rated life in hours)
7	Daylight	Analyze lighting performance	Glass (window/façade) data sheet or input SHG, Tvis, parameters, glazing ratio; Room orientation; Type of room space; Occupancy schedule of room; Materials surface reflectance, roughness, specularity;
8	Quality Views	Author design; Architectural Modeling	n/a
9	Acoustic Performance	Analyze acoustic performance	Type of room space; Occupancy of rooms;
Innovation			
1	Innovation	n/a	n/a
2	LEED Accredited Professional	n/a	n/a
Regional Priority			
1	Regional Priority: Specific Credit	Depend on the project location. Follow parameters of the specific credit.	
2	Regional Priority: Specific Credit	Depend on the project location. Follow parameters of the specific credit.	
3	Regional Priority: Specific Credit	Depend on the project location. Follow parameters of the specific credit.	
4	Regional Priority: Specific Credit	Depend on the project location. Follow parameters of the specific credit.	

Source: Created by the author.

5.2.3 - CONCLUSION

This stage discussed the second and third specific objectives of this thesis.

The second specific objective (Investigate the LEED BD+C NC v4 rating system, its difficulties, and impacts on the project) has been achieved by applying and analyzing a questionnaire that was answered by the sustainability engineers of Jacobs Italia S.p.A. This part showed that it is crucial that the sustainability team participates in the design process from the initial stages due to the impacts that some credits can have on the overall project. It has been mentioned by the sustainability consultancy team that usually when a project arrives to them, the sustainability goals of the project have already been defined, which is not the best situation. Defining the sustainability goals of the project in collaboration with the sustainability experts will improve the design stage's performance and avoid many changes during the design phase that would have to be done because the decisions were not taken considering the LEED requirements.

The third specific objective has been accomplished considering the literature, theoretical foundation, and discussions with Jacobs' LEED APs. The identification of BIM Use cases and parameters to enhance methods has been done, and it is concluded that this identification related to LEED credits has to be considered in the BEP of a sustainable project to better execute the sustainability assessment. It is crucial that the designers know what information will be used in the future so that the model has reliable and useful information that will facilitate the LEED assessment and pre-assessment process.

5.3 - PROPOSAL (STAGE 3)

This stage presents the main objective of the thesis. The section 5.3.1 presents the developed framework that considered specific objectives two and three of this thesis, and then, section 5.3.2 presents a dynamic ranking that will help project teams to define their priorities according to the project requirements and constraints.

5.3.1 - GREEN BIM FRAMEWORK

The proposed framework has been developed to improve the management of LEED projects and help future project teams better define the project's sustainability targets considering the LEED credits and requirements since the project's initial phases. The decisions related to the LEED credits are tailored by the project objectives, features and available budget, that is why it is important to understand the difficulty of each credit, its points' contribution, and the related impacts on the project. Moreover, preparing a BIM Plan to enhance the quality of the BIM adoption in the project is very important. When the project seeks a Green Building certification, it is crucial that this plan considers the LEED requirements and that the designers know what information will be needed for the sustainability assessment.

This Green BIM framework puts together the results of specific objectives two and three of this thesis and provides a foundation for the sustainable building process. Thus, helping teams to understand important aspects regarding a project's sustainability assessment.

A short demonstration of the framework is given in Table 5.13 to clarify what information is included in the framework. The complete framework is presented in the APPENDIX B - GREEN BIM FRAMEWORK.

Table 5.13 - Green BIM framework (preview).

Categories and Credits		Difficulty of achievement	Points' contribution	Impact on cost	Impact on schedule	Model Uses	Parameters
Integrative Process		EASY	LOW				
1	Integrative Process	easy	low	none	none	Analyze Energy Performance	Type of room space (according to ASHRAE 90.1-2010); Occupancy of rooms

Source: Created by the author.

This framework does not remove the importance of having an Accredited Professional in the team; instead, it helps other actors from the design and construction teams understand the sustainability assessment process, facilitating and improving the whole processes' performance. It is highly recommended to define the project's sustainability targets in collaboration with the main actors, mainly with the sustainability professionals.

5.3.2 - DYNAMIC RANKING

A dynamic ranking has been developed considering the UNDERSTANDING LEED section's results. This ranking is called dynamic because it gives the project's team the possibility to classify the LEED credits according to the project priorities and constraints. Concisely, the credits dynamic ranking will classify the credits that are more likely to be achieved/invested on depending on what the team considers to be more significant for that project. This 'significance' is based on the four analyzed variables of the UNDERSTANDING LEED section, with the alternatives that appear in the APPENDIX B - GREEN BIM FRAMEWORK.

The variables and alternatives are summarized in Table 5.14:

Table 5.14 - Variables and alternatives.

Variables	**Difficulty of achievement**	**Points' contribution**	**Impact on cost**	**Impact on schedule**
Alternatives	Easy	Low	None	None
	Medium	Medium	Slight increase	Slight increase
	Difficult	High	Big increase	Big increase

Source: Created by the author.

Counting the four variables and their alternatives, there are a total of 81 possible combinations that could be considered in the ranking. The combination can be calculated according to the following: *Total combinations = 3 x 3 x 3 x 3 = 81*. Even though there are 81 possible combinations, only the 23 combinations that appear in the Green BIM framework credits will be considered for the dynamic ranking because those are the results of the research carried out with the experienced LEED APs of Jacobs.

The ranking preparation process will be described and explained through the use of an example. The credits dynamic ranking will be assessed by multiplying values that will be assigned to each alternative. These values will vary according to priorities that the team will have to set, depending on the project's goals and constraints. In this example case, the higher the credit assessment, the best, the more likely it is to achieve/invest on that credit.

The process is divided into two parts: the first is related to the importance given to the variable, and the second is related to the priority given to the alternative. See Table 5.14 to recall what the variables and alternatives are.

The importance given to the variable: It is likely that one of the variables has a higher weight to the project than another. Therefore, if the team considers one variable more important than others, the value given to the alternatives of that variable will have to be balanced according to this importance.

For the ranking example given, the *point's contribution* variable has higher importance than the *difficulty of achievement* of a credit. Moreover, it is preferred to have an *increase in the schedule* than to have an *increase in the cost*. By defining this level of importance between the variables, the team will be able to assign values to the alternatives that enhance the credit assessment considering the project's priorities.

The priority given to the alternative: The team will have to ask itself: *What alternative of this variable does the team consider a priority for this project?* This question must be asked for all the variables. For the ranking example given, the answers are the following:

- **Difficulty of achievement:** The priority is to achieve *Easy* credits first, then *Medium*, then *Difficult* credits. This means that a higher value will be assigned to the *Easy* alternative, then a lower value to the *Medium* one, and an even lower value to the *Difficulty* alternative.
- **Points' contribution:** The priority is to achieve *High* points' contribution credits first, then *Medium*, then *Low* points' contribution. This means that a higher value will be assigned to the *High* alternative, then a lower value to the *Medium* one, and an even lower to the *Low* alternative.
- **Impact on cost:** When there is a cut in the budget in a project, the cut usually happens on the sustainability part. Therefore, this ranking example intends to focus on credits that do not impact cost unless they have a considerable contribution of points. It is essential to discuss this alternative with the LEED assessment team because many other aspects of the project can influence the cost, including delay in the schedule and problems with the denial of documentation during the LEED submission phases, that can be followed by an appeal of the credit that has been denied (which costs around $500 per appeal). Therefore, the priority is to achieve credits that have no impact on the cost. This means that a higher value will be assigned to the *None* alternative, then a lower value to the *Slight increase* one, and an even lower to the *Big increase* alternative.
- **Impact on schedule:** The priority is to achieve credits that have no impact on the schedule. This means that a higher value will be assigned to the *None* alternative, then a lower value to the *Slight increase* one, and an even lower to the *Big increase* alternative.

After defining the priorities, it will be possible to assign the values of each alternative. For the example given, the values of each alternative are shown in Table 5.15. It is possible to see that the values are balanced between the variables. When difficulty of achievement values is compared to points' contribution, it is seen that the second has a higher weight over the assessment result. And when the increase in schedule (slight or big) is compared to the increase in cost (slight or big), it is observed that cost it is preferred to have increase in schedule than in cost. The fact that the values of slight or big, both for cost and schedule, are lower than one, means that the final assessment of the credit will be lowered due to the increase. However, if that increase if accompanied by a high points' contribution, the credit assessment will still be appreciated because it has been said that 'this ranking example intends to focus on credits that do not impact cost unless they have a considerable contribution of points.

Table 5.15 - Dynamic ranking example - Alternative values.

Difficulty of achievement	A	Points' contribution	B	Impact on cost	C	Impact on schedule	D
Easy	3.00	Low	2.00	None	1.00	None	1.00
Medium	2.00	Medium	5.00	Slight increase	0.10	Slight increase	0.15
Difficult	1.00	High	10.00	Big increase	0.05	Big increase	0.10

Source: Created by the author.

As previously said, the ranking will be assessed by multiplying the given values, which will result in a final credit assessment.

$$Assessment = A \times B \times C \times D$$

A – Value assigned to the alternative of Difficulty of achievement

B – Value assigned to the alternative of Points' contribution

C – Value assigned to the alternative of Impact on cost

D – Value assigned to the alternative of Impact on schedule

Considering the combinations presented on the Green BIM framework and the values given according to the project's priorities, each credit will be assessed with one value.

The assessment calculations have been done using Microsoft Excel. The file has been prepared to automatically link the assigned values (A, B, C, and D) with the correct alternative and calculate the final assessment. The only manual work that has to be done is the assignment of A, B, C, and D alternative values and the application of a filter on the assessment to sort the credits from the highest value to the lowest. A screenshot of the calculation speadsheet is shown in Figure 5.18.

Figure 5.18 - Credit dynamic ranking.

CREDITS DYNAMIC RANKING							
Difficulty of achievement	A	Points' contribution	B	Impact on cost	C	Impact on schedule	D
Easy	3.00	Low	2.00	None	1.00	None	1.00
Medium	2.00	Medium	5.00	Slight increase	0.10	Slight increase	0.15
Difficult	1.00	High	10.00	Big increase	0.05	Big increase	0.10

Categories and Credits		Points	Difficulty of achievement	A	Points' contribution	B	Impact on cost	C	Impact on schedule	D	Assessment
4	Surrounding Density and Diverse Uses	5	easy	3.00	high	10.00	none	1.00	none	1.00	30.00

Source: Created by the author.

Finally, the final assessment of all credits, when organized from the highest assessment to the lowest, for this example, will give the ranking shown in Table 5.16.

Table 5.16 - Ranking (example).

Categories and Credits		LEED points	Difficulty of achievement	Points' contribution	Impact on cost	Impact on schedule	Assessment
4	Surrounding Density and Diverse Uses	5	easy	high	none	none	30.00
5	Access to Quality Transit	5	easy	high	none	none	30.00
2	Indoor Water Use Reduction	6	medium	high	none	none	20.00
5	Heat Island Reduction	2	easy	medium	none	none	15.00
2	LEED Accredited Professional	1	easy	medium	none	none	15.00
1	LEED for Neighborhood Development Location	16	difficult	high	none	none	10.00
2	BPDO - Environmental product	2	medium	medium	none	none	10.00
1	Innovation	1	difficult	high	none	none	10.00
1	Integrative Process	1	easy	low	none	none	6.00

	Categories and Credits	LEED points	Difficulty of achievement	Points' contribution	Impact on cost	Impact on schedule	Assessment
7	Reduced Parking Footprint	1	easy	low	none	none	6.00
3	Construction Indoor Air Quality Management Plan	1	easy	low	none	none	6.00
3	High Priority Site	2	difficult	medium	none	none	5.00
2	Sensitive Land Protection	1	medium	low	none	none	4.00
8	Quality Views	1	medium	low	none	none	4.00
6	Light Pollution Reduction	1	difficult	low	none	none	2.00
1	Building Life-Cycle Impact Reduction	5	medium	high	slight increase	none	2.00
5	Construction and Demolition Waste Management	2	easy	medium	none	slight increase	1.50
2	Low-Emitting Materials	3	easy	medium	none	slight increase	1.50
2	Optimize Energy Performance	18	medium	high	big increase	none	1.00
1	Enhanced Indoor Air Quality Strategies	2	medium	medium	slight increase	none	1.00
6	Interior lighting	2	medium	medium	slight increase	none	1.00
7	Daylight	3	medium	medium	slight increase	none	1.00
1	Site Assessment	1	easy	low	slight increase	none	0.60
7	Green Power and Carbon Offsets	2	easy	low	slight increase	none	0.60
2	Site Development - Protect or Restore Habitat	2	difficult	medium	slight increase	none	0.50
3	Cooling Tower Water Use	2	difficult	medium	slight increase	none	0.50
3	BPDO - Sourcing of Raw Materials	2	difficult	medium	slight increase	none	0.50
4	BPDO - Material Ingredients	2	difficult	medium	slight increase	none	0.50
8	Green Vehicles	1	medium	low	slight increase	none	0.40
3	Open Space	1	medium	low	slight increase	none	0.40
4	Water Metering	1	medium	low	slight increase	none	0.40
6	Enhanced Refrigerant Management	1	medium	low	slight increase	none	0.40
4	Demand Response	2	difficult	low	slight increase	none	0.20
5	Renewable Energy Production	3	medium	low	big increase	none	0.20
4	Rainwater Management	3	difficult	high	big increase	slight increase	0.05
1	Outdoor Water Use Reduction	2	difficult	medium	slight increase	slight increase	0.05
6	Bicycle Facilities	1	difficult	low	slight increase	slight increase	0.02

	Categories and Credits	LEED points	Difficulty of achievement	Points' contribution	Impact on cost	Impact on schedule	Assessment
3	Advanced Energy Metering	1	medium	low	big increase	slight increase	0.02
5	Thermal Comfort	1	difficult	low	slight increase	slight increase	0.02
9	Acoustic Performance	1	difficult	low	slight increase	slight increase	0.02
1	Enhanced Commissioning	6	difficult	medium	big increase	big increase	0.01
4	Indoor Air Quality Assessment	2	difficult	medium	big increase	big increase	0.01

Source: Created by the author.

The ranking shown in Table 5.16 is valid for a project that has certain priorities, as explained throughout the given example. However, if another project has different priorities, it is possible to redefine the values assigned to the alternatives, thus reassessing the ranking.

For example, if a project aims at achieving the easiest credits first regardless of its points' contribution, the values assigned to the alternatives of the *Difficulty of achievement* variable should receive a higher weight. Another example, if a project team is mostly worried about not having any delays because it is facing a tight schedule, regardless of how much the achievement of those credits would impact the cost, then the values assigned to the increase in schedule would have to be lowered in order to reduce the final credit assessment.

5.3.3 - CONCLUSION

The third and final stage achieved the thesis' main objective, which was the proposal of a framework that helps to improve the management of LEED BD+C NC v4 projects.

The proposed framework, called Green BIM, presents information gathered during the investigation of the specific objectives: the difficulties, points' contribution, and impacts of LEED; and the use of BIM to enhance the methods. Moreover, the Green BIM framework's information has allowed the author to develop a tool, called dynamic ranking, to rank the credits according to an assessment that depends on the project's priorities and constraints.

This framework and ranking tool improve the management of the LEED projects because it helps other project actors understand aspects related to the sustainability assessment processes. The framework points out interesting features of the LEED credits empowering other actors to increase their LEED credits knowledge. The dynamic ranking tool facilitates the process of setting sustainability credits to the project based on some characteristics. It is known that those features present in the framework are not all that matters to set the LEED credits; however, the framework helps teams to have an overview of the situation based on the project's priorities. The presence of a sustainability engineer or LEED AP is essential during the whole design and construction process, however, as important as that is that other actors understand the requirements, the difficulties, and the impacts that LEED credits can have on the project. In this way, the collaboration between all parties of the project is enhanced, resulting in an overall improvement of the project's performance.

6 - CONCLUSION

This chapter summarizes the research's main results and suggests future studies related to Green Construction Project Management.

Green construction project management is a topic that has gained attention over the last years, mainly over the last decade. New methods, techniques, and tools are being investigated to improve the management of projects that account for sustainability, technology, and digitalization in its scope. The use of an appropriate management method brings several benefits to the entire production chain; however, finding a suitable method is not easy. Based on the theoretical background and literature review, this thesis intended to propose a framework to improve the management of sustainable building projects that are seeking the LEED certification. Three specific objectives have been defined as a way to design the achievement of the main objective.

The exploration of the literature has pointed out that to improve green construction project management, engineering companies must consider sustainability in its culture and its strategic plan. Moreover, since sustainability and technology are always advancing, it is essential that a philosophy of continuous improvement guides the companies' management practices and the employees. With that knowledge in mind, an investigation has been performed on Jacobs' current management practices, which is one of the leading engineering companies in the world. The results showed that the company adopts a sustainable project management approach and has sustainability as a solid foundation of its culture and strategy. Furthermore, the case study has identified that the current management practices of the engineering processes follow mostly the traditional project management methodology. However, lean principles are observed in the team's daily routine, but due the involvement of several other teams, full incorporation of the principles is not yet possible.

The second and third specific objectives were achieved throughout collaboration with Jacobs Italia S.p.A. and resulted in two main points. The definition of a project's sustainability targets is an important initial stage that is better defined if the main actors know the LEED requirements. Therefore, it is crucial that the sustainability team participates in the design process since the initial design phases in order to set the targets and minimize the impact that the LEED requirements have on the project, and that the other members of the project understand these requirements to boost the performance of the project. Moreover, to enhance the methods adopted during the design and construction phases, such as the use of BIM, it is essential that the designers know what information will be used in the future so that the model has reliable and useful information, thus facilitating the LEED assessment process.

Finally, the Green BIM framework put together information that helps other project members understand aspects of the LEED assessment processes. The Green BIM framework listed the difficulty of achievement, points' contribution, the impacts on cost, impacts on schedule, possible BIM Model Uses, and BIM parameters of each credit of the LEED BD+C NC v4. With that information, a tool called dynamic ranking was developed, allowing a project's team to rank the LEED credits according to the project's priorities. Therefore, improving the management of LEED BD+C NC v4 projects and facilitating the definition of the project's sustainability targets. The main goal of this thesis has been achieved, and with the use of the framework and the developed tool, the collaboration between all parties involved in a sustainable building project is enhanced, resulting in an overall improvement of the project's performance.

Green Construction Project Management is an area of study with several opportunities for future studies. The first suggestion is to further investigate the BIM Model Uses and parameters through practical applications. The second suggestion is more focused on the project management side of the topic. It is recommended to investigate the risk management of sustainable projects. Risk management can be linked to various issues. A particular one that has been receiving attention in the construction sector is assessing risks related to cybersecurity in sustainable and smart buildings.

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APPENDIX A - CREDIT BREAKDOWN STRUCTURE

Credits Breakdown Structure (CrBS)

Category ID and name	Credit ID and name		Sub credit	Description	Max points	Weight over the whole project	Weight over the category
IP Integrative Process					**1**	**0.9%**	
	1	Integrative Process			1	0.9%	100.0%
			AND	Energy related systems Discovery - simple box energy modeling analysis that explores how to reduce energy loads. Assess at least two of the listed potential strategies Implementation - Document how the above analysis informed design and building form decisions in the project's OPR and BOD and the eventual design of the project Water related systems Discovery - Perform a preliminary water budget analysis that explores how to reduce potable water loads. Assess and estimate the project's potential nonpotable water supply sources and water demand volumes Implementation - Document how the above analysis informed design and building form decisions in the project's OPR and BOD and the eventual design of the project. Dem- onstrate how at least one on-site nonpotable water supply source was used to reduce the burden on municipal supply or wastewater treatment systems by contributing to at least two of the water demand components listed. Demonstrate how the analysis informed the design of the project	1		
LT Location and Transportation					**16**	**14.5%**	
	OR LEED for neighborhood development location credit OR all the other						
	1	LEED for Neighborhood Development Location			16	14.5%	100.0%
		Boundary of a development certified under LEED ND v4 rating system					
			OR	Certified	8		
				Silver	10		
				Gold	12		
				Platinum	16		
	2	Sensitive Land Protection			1	0.9%	6.3%
			OR	Option 1- Locate the development footprint on land that has been previously developed	1		
				Option 2 - Locate the development footprint on land that has been previously developed or that does not meet some criteria for sensitive land	1		
	3	High Priority Site			2	1.8%	12.5%
			OR	Option 1- Historic district	1		
				Option 2 - Priority designation	1		
				Option 3 - Brownfield remediation	2		
	4	Surrounding Density and Diverse Uses			5	4.5%	31.3%
			AND/OR	Option 1 - Surrounding density			
				Combined Density (5050 sqm/hectare of buildable land)	2		
				Combined Density (8035 sqm/hectare of buildable land)	3		
				Separate residential and non residential (17.5DU/hectare or 0.5 FAR)	2		
				Separate residential and non residential (30DU/hectare or 0.8 FAR)	3		
				Option 2 - Diverse use			
				800m distance to 4 to 7 other publicly diverse use	1		
				800m distance to 8+ other publicly diverse use	2		
	5	Access to Quality Transit			5	4.5%	31.3%
			OR	Minimum daily transit service for projects with multiple transit types			
				72 weekday trips / 40 weekend day trips	1		
				144 weekday trips / 108 weekend day trips	3		
				360 weekday trips / 216 weekend day trips	5		
				Minimum daily transit service for projects with commuter rail or ferry			
				24 weekday trips / 6 weekend day trips	1		
				40 weekday trips / 8 weekend day trips	2		
				60 weekday trips / 12 weekend day trips	3		
		Projects served with 2+ routes such that no one route provides more than 60% of the documented levels, may earn an extra point (up to the max)			1		

6		Bicycle Facilities	1	0.9%	6.3%
	AND	Bicycle network Bicycle storage and shower rooms (varies if commercial, residential, mixed use)	1		
7		Reduced Parking Footprint	1	0.9%	6.3%
		Do not exceed the minimum local code requirements for parking capacity. Provide parking capacity that is a percentage reduction below the case retios recommended by the Parking Consultants Council as shown in the Institute of Transportation Engineers' Transportation Planning Handbook, 3rd edition, Tables 18-2 through 18-4.			
	OR	Case 1 - Baseline location - Achieve 20% reduction of parking capacity (for projects that didn't earn point in LT4 and LT5)	1		
		Case 2 - Dense and/or transit served location - Achieve 40% reduction of parking capacity (for projects that earned one or more points in LT4 and LT5)			
		Credit calculations should include all existing and new off-street parking spaces that are leased or owned by the project, even when outside the project boundary. Pooled parking share should be accounted. Prefered carpool parking 5% of the total parking after reductions (not required if no off-street parking is provided.			
8		Green Vehicles	1	0.9%	6.3%
	AND one opt	Preferred parking - 5% of all parking spaces for Green vehicles or discounted parking rate of 20% for green vehicles	1		
		Option 1 - Electric vehicle charging - install in 2% of all parking spaces			
		Option 2 - Liquid, gas, or battery facilities			
SS		**Sustainable Sites**	**10**	**9.1%**	
Prereq		Construction Activity Pollution Prevention		Required	
		Create and implement an erosion and sedimentation control plan for all construction activities with description of implemented measures. Apply for construction general permit			
1		Site Assessment	1	0.9%	10.0%
	AND	Complete and document a site survey or assessment including: topography, hydrology, climate, vegetation, soils, human use, human health effects. Demonstrate the relationship between site features and project design	1		
2		Site Development - Protect or Restore Habitat	2	1.8%	20.0%
	AND 1opt	Preserve and protect from development and construction 40% of the natural greenfield, if existed			
		Option 1 - On-site restoration of 30% of all site identified as previously disturbed	2		
		Option 2 - Provide financial support to a local conservation organization or recognized land trust (equivalent to U$4/sqm of total site area)	1		
3		Open Space	1	0.9%	10.0%
	AND	Provide outdoor space > 30% of total site area (including building footprint). A minimum of 25% of that outdoor space must be vegetaded. The outdoor space must follow some criteria	1		
4		Rainwater Management	3	2.7%	30.0%
	OR	Option 1 - Percentile of rainfall events			
		Path 1 - 95% percentile of regional or local rainfall events using low-impact development (LID) and green infrastructure	2		
		Path 2 - 98% percentile of regional or local rainfall events using low-impact development (LID) and green infrastructure	3		
		Path 3 - Zero lot line projects in urban areas with a minimum density of 1.5 FAR - 85% percentile of regional or local rainfall events using low-impact development (LID) and green infrastructure	3		
		Option 2 - Natural land cover conditions	3		
5		Heat Island Reduction	2	1.8%	20.0%
	OR	Option 1- Nonroof and roof - Use a combination of nonroof measures, high-reflectance roof, vegetaded roof that respects the formula below $\frac{\text{Area of Nonroof Measures}}{0.5} + \frac{\text{Area of High-Reflectance Roof}}{0.75} + \frac{\text{Area of Vegetated Roof}}{0.75} \geq \text{Total Site Parking Area} + \text{Total Roof Area}$	2		
		Option 2 - Parking under cover - A minimum of 75% of parking spaces under cover with the following criteria: three year aged SRI of at least 32; be a vegetaded rood; or be covered by energy generation systems	1		

6			Light Pollution Reduction	1	0.9%	10.0%
	AND		Uplight - do not exceed the ratings	1		
		OR	Option 1 - BUG rating method			
			Option 2 - Calculation method			
			Trespass - do not exceed the ratings			
		OR	Option 1 - BUG rating method			
			Option 2 - Calculation method			
			Internally illuminated exterior signage - do not exceed 200cd/m2 (nightime) and 2000cd/m2 (daytime)			
WE	**Water Efficiency**			**11**	**10.0%**	
Prereq			Outdoor Water Use Reduction	Required		
			Reduce outdoor water use through Noirrigation required or reduced irrigation			
Prereq			Indoor Water Use Reduction	Required		
			Reduce indoor water consumption (building water use, and appliance and process water use)			
Prereq			Building-Level Water Metering	Required		
			Install permanent water meters that measure the total potable water use for the building and associated grounds. Meter data must be compiled into monthly and annual summaries; meter readings can be manual or automated			
1			Outdoor Water Use Reduction	2	1.8%	18.2%
	OR		Option 1 - No irrigation required	2		
			Option 2 - Reduced irrigation			
			50% reduction from baseline (prereq)	1		
			100% reduction from baseline (prereq)	2		
2			Indoor Water Use Reduction	6	5.5%	54.5%
	OR		25% reduction fixture and fitting water use from the baseline	1		
			30% reduction fixture and fitting water use from the baseline (prereq	2		
			35% reduction fixture and fitting water use from the baseline (prereq	3		
			40% reduction fixture and fitting water use from the baseline (prereq	4		
			45% reduction fixture and fitting water use from the baseline (prereq	5		
			50% reduction fixture and fitting water use from the baseline (prereq	6		
3			Cooling Tower Water Use	2	1.8%	18.2%
	OR		*Points for number of cooling tower cycles*			
			Maximum number of cycles achieved without exceeding any filtration levels or affecting operation of condenser water system (up to maximum of 10 cycles)	1		
			Achieve a minimum 10 cycles by increasing the level of treatment in condenser or make-up water OR Meet the minimum number of cycles to earn 1 point and use a minimum 20% recycled nonpotable water	2		
4			Water Metering	1	0.9%	9.1%
	AND		Install permanent water meters for two or more water subsystems (irrigation, indoor plumbing fixtures and fittings, domestic hot water, boiler, reclaimed water, other process water)	1		
EA	**Energy and Atmosphere**			**33**	**30.0%**	
Prereq			Fundamental Commissioning and Verification	Required		
			Comissioning process scope (Cx activities for mechanical, electrical, plumbing, and renewable energy systems and assemblies - develope basis of design (BOD) and owner's project requirements (OPR)); Comissioning authority (with specific qualification), Current facilities requirements and operations and maintenance plan (prepare and maintain a current facilities requirements and operations and maintenance plan that contains the information necessary to operate the building efficiently			
Prereq			Minimum Energy Performance	Required		
			Option 1 - Whole building energy simulation			
			Option 2 - Prescriptive compliance: ASHRAE 50% advanced energy design guide			
			Option 3 - Prescriptive compliance: Advanced buildings Core performance guide			
Prereq			Building-Level Energy Metering	Required		
			Install building-level energy meters, or submeters that can be aggregated to provide building-level data representing total building energy consumption. Energy consumption must be tracked monthly			
Prereq			Fundamental Refrigerant Management	Required		
			Do not use chlorofluorocarbon (CFC)-based refrigerants in new heating, ventilating, air-conditioning, and refrigeration (HVAC&R) systems. When reusing existing HVAC&R equipment, complete a comprehensive CFC phase-out conversion before project completion			
1			Enhanced Commissioning	6	5.5%	18.2%
	AND / OR		Option 1 - Enhanced systems comissioning			
		OR	Path 1 - Enhanced comissioning	3		
			Path 2 - Enhanced + Monitoring-based comissioning	4		
			Option 2 - Envelope comissioning	2		

2		Optimize Energy Performance	18	16.4%	54.5%
	OR	Option 1 - Whole building energy simulation	up to 18		
		6% improvement in performance compared with baseline (prereq)	1		
		8% improvement in performance compared with baseline (prereq)	2		
		10% improvement in performance compared with baseline (prereq)	3		
		12% improvement in performance compared with baseline (prereq)	4		
		14% improvement in performance compared with baseline (prereq)	5		
		16% improvement in performance compared with baseline (prereq)	6		
		18% improvement in performance compared with baseline (prereq)	7		
		20% improvement in performance compared with baseline (prereq)	8		
		22% improvement in performance compared with baseline (prereq)	9		
		24% improvement in performance compared with baseline (prereq)	10		
		26% improvement in performance compared with baseline (prereq)	11		
		29% improvement in performance compared with baseline (prereq)	12		
		32% improvement in performance compared with baseline (prereq)	13		
		35% improvement in performance compared with baseline (prereq)	14		
		38% improvement in performance compared with baseline (prereq)	15		
		42% improvement in performance compared with baseline (prereq)	16		
		46% improvement in performance compared with baseline (prereq)	17		
		50% improvement in performance compared with baseline (prereq)	18		
		Option 2 - Prescriptive compliance: ASHARE advanced energy design guide (only eligeble if option 2 of Minimum energy performance prequesite was chosen). ASHARE 50% Advanced energy design guide for Small to Medium office buildings	Up to 5		
		Building envelope, opaque: roofs, walls, floors, slabs, doors, and continuous air barriers	1		
		Building envelope, glazing: vertical fenestration	1		
		Intertior lighting, inclusing daylighting and interior finishes	1		
		Exterior lighting	1		
		Plug loads, including equipment and controls	1		
3		Advanced Energy Metering	1	0.9%	3.0%
	AND	Install advanced energy metering for all whole-building energy sources used by the building, and any individual energy end uses that represent 10% or more of the total annual consumption of the building	1		
4		Demand Response	2	1.8%	6.1%
	OR	Case 1 - Demand response program available	2		
		Case 2 - Demand responde program not available but existent infrastructure for future use	1		
5		Renewable Energy Production	3	2.7%	9.1%
	OR	1% renewable energy	1		
		5% renewable energy	2		
		10% renewable energy	3		
		% = h .			
6		Enhanced Refrigerant Management	1	0.9%	3.0%
	OR	Option 1 - No refrigerant or low-impact refrigerants	1		
		Option 2 - Calculation of refrigerant impact	1		
7		Green Power and Carbon Offsets	2	1.8%	6.1%
	OR	50% of total energy adressed by green power, RECs and/or offsets	1		
		100% of total energy adressed by green power, RECs and/or offsets	2		
MR		**Materials and Resources**	**13**	**11.8%**	
Prereq		Storage and Collection of Recyclables		Required	
		Provide dedicated areas accessible to waste haulers and building occupants for the collection and storage of recyclable materials for the entire building			
Prereq		Construction and Demolition Waste Management Planning		Required	
		Develop and implement a construction and demolition waste management plan			
1		Building Life-Cycle Impact Reduction	5	4.5%	38.5%
	OR	Option 1 - Historic building reuse	5		
		Option 2 - Renovation of abandoned or blighted building	5		
		Option 3 - Building and material resuse			
		OR: 25% of completed project surface area reused	2		
		50% of completed project surface area reused	3		
		75% of completed project surface area reused	4		
		Option 4 - Whole-building life cycle assessment	3		
2		Building Product Disclosure and Optimization - Environmental Product Declaratio	2	1.8%	15.4%
	AND/OR	Option 1 - Environmental product declaration (EPD)	1		
		Option 2 - Multi-attribute optimization	1		

			Points		
3	Building Product Disclosure and Optimization - Sourcing of Raw Materials		2	1.8%	15.4%
	AND /OR	Option 1 - Raw material source and extraction reporting	1		
		Option 2 - Leadership extraction practices	1		
4	Building Product Disclosure and Optimization - Material Ingredients		2	1.8%	15.4%
	AND / OR	Option 1 - Material ingredient reporting	1		
		Option 2 - Material ingredient optimization	1		
		Option 3 - Product manufacturer supply chain optimization	1		
	Product compliant with both option 2 and 3 may only be counted once				
5	Construction and Demolition Waste Management		2	1.8%	15.4%
	OR	Option 1 - Diversion			
		Path 1 - Divert 50% and three material streams	1		
		Path 2 - Divert 75% and four material streams	2		
		Option 2 - Reduction of total waste material	2		
EQ	**Indoor Environmental Quality**		**16**	**14.5%**	
Prereq	Minimum Indoor Air Quality Performance		Required		
	Meet the requirements for ventilation (mechanical and natural) and monitoring				
Prereq	Environmental Tobacco Smoke Control		Required		
	Prohibit smoking inside the building				
1	Enhanced Indoor Air Quality Strategies		2	1.8%	12.5%
	AND /OR	Option 1 - Enhanced IAQ strategies	1		
		Option 2 - Additional enhanced IAQ strategies	1		
2	Low-Emitting Materials		3	2.7%	18.8%
	OR	Option 1- Product category calculations	Up to 3		
		Compliant category - New construction without furniture			
		2	1		
		4	2		
		5	3		
		Compliant category - New construction with furniture			
		3	1		
		5	2		
		6	3		
		Option 2 - Budget calculation method	Up to 3		
		Total percentage of compliance			
		≥ 50% and < 70%	1		
		≥ 70% and < 90%	2		
		≥ 90%	3		
3	Construction Indoor Air Quality Management Plan		1	0.9%	6.3%
	AND	Develop and implement an indoor air quality (IAQ) management plan for the construction and preoccupancy phases of the building	1		
4	Indoor Air Quality Assessment		2	1.8%	12.5%
	OR	Option 1- Flush-out			
		OR Path 1 - Before occupancy	1		
		Path 2 - During occupancy	1		
		Option 2 - Air testing	2		
5	Thermal Comfort		1	0.9%	6.3%
	AND	Thermal comfort design			
		OR Option 1 - Meet requirements of ASHRAE Standard 55-2010			
		Option 2 - Meet requirements of ISO and CEN Standards			
		Thermal comfort control	1		
		Provide individual thermal comfort controls for at least 50% of individual occupant spaces. Provide group thermal comfort controls for all shared multioccupant spaces.			
6	Interior lighting		2	1.8%	12.5%
	AND / OR	Lighting control	1		
		Lighting quality	1		
7	Daylight		3	2.7%	18.8%
	OR	Option 1 - sDA and ASE			
		$sDA_{300/50\%} \geq 55\%$	2		
		$sDA_{300/50\%} \geq 75\%$	3		
		$ASE_{1000,250} \leq 10\%$			
		Option 2 - Illuminance calculations - demonstrate throuhgh computer modeling Illuminance levels between 300 - 3000lux for 9am and 3pm on clear sky and equinox.			
		75% of regularly occupied floor area	1		
		90% of regurlarly occupied floor area	2		

				Points		
			Option 3 - Measurement - Achieve illuminance levels for two selected months between 300 - 300lux for any hour between 9am and 3pm.			
			75% of regularly occupied floor area	2		
			90% of regurlarly occupied floor area	3		
	8	Quality Views		1	0.9%	6.3%
		AND	Achieve a direct line of sight to the outdoors via vision glazing for 75% of all regularly occupied floor area. Additionally, 75% of all regularly occupied floor area must have at least two other conditions. Views to interior atria may be used to meet up 30% of the required area	1		
	9	Acoustic Performance		1	0.9%	6.3%
		AND	Meet requirements for HVAC background noise, sound isolation, reverberation time, and sound reinforcement and masking systems	1		
IN	**Innovation**			**6**	**5.5%**	
	1	Innovation		5	4.5%	83.3%
		AND / OR	Option 1 - Innovation			
			Achieve significant, measurable environmental performance using a strategy not addressed in the LEED green building rating system. Identify: 1)The intent of the proposed innovation; 2) Proposed requirement for compliance; 3) Proposed submittals to demonstrate compliance; 4) The design approach or strategies used to meet the requirements.	1		
			Option 2 - Pilot			
			Achieve one credit from USGBC's LEED Pilot credit library	1		
			Option 3 - Additional strategies			
			Innovation	1 to 3		
			Pilot	1 to 3		
			Exemplary performance (An exemplary performance point is typically earned for achieving double the credit requirements or the next incremental percentage threshold.)	1 to 2		
		To achieve all five innovation points, a project team must achieve at least one pilot credit, at least one innovation credit and no more than two exemplary performance credits.				
	2	LEED Accredited Professional		1	0.9%	16.7%
			At least one principal participant of the project team must be a LEED AP with a speciality appropriate for the project	1		
RP	**Regional Priority**			**4**	**3.6%**	
		To provide an incentive (a bonus point) for the achievement of credits that address geographically specific environmental, social equity, and public health priorities. A project can achieve up to 4 options.				
	1	Regional Priority: Specific Credit		1	0.9%	25.0%
	2	Regional Priority: Specific Credit		1	0.9%	25.0%
	3	Regional Priority: Specific Credit		1	0.9%	25.0%
	4	Regional Priority: Specific Credit		1	0.9%	25.0%
			Total Possible Points:	**110**		

APPENDIX B - GREEN BIM FRAMEWORK

Categories and Credits		Difficulty of achievement	Points' contribution	Impact on cost	Impact on schedule	Model Uses	Parameters
Integrative Process		EASY	LOW				
1	Integrative Process	easy	low	none	none	Analyze Energy Performance	Type of room space (according to ASHRAE 90.1-2010); Occupancy of rooms
Location and Transportation		MEDIUM	MEDIUM				
1	LEED for Neighborhood Development Location	difficult	high	none	none	n/a	n/a
2	Sensitive Land Protection	medium	low	none	none	Analyze site selection criteria	n/a
3	High Priority Site	difficult	medium	none	none	Analyze site selection criteria	n/a
4	Surrounding Density and Diverse Uses	easy	high	none	none	Capture existing conditions	n/a
5	Access to Quality Transit	easy	high	none	none	n/a	n/a
6	Bicycle Facilities	difficult	low	slight increase	slight increase	Author design / Parking logistics planning	Building occupancy (regular/visiting occupants); Number of residential units (if the case); Type of bicycle storage (long term/short term)
7	Reduced Parking Footprint	easy	low	none	none	Author design / Parking logistics planning	Parking capacity of the project (including outside project boundary that is used by occupants); Type of parking space (regular or preferred/carpool);
8	Green Vehicles	medium	low	slight increase	none	Author design / Parking logistics planning	Type of parking space (regular or green vehicles/green vehicles with ESVE)
Sustainable Sites		MEDIUM	LOW				
Prereq	Construction Activity Pollution Prevention					n/a	n/a
1	Site Assessment	easy	low	slight increase	none	Analyze site selection criteria; Capture existing conditions; Climate Analyzes	n/a
2	Site Development - Protect or Restore Habitat	difficult	medium	slight increase	none	n/a	n/a
3	Open Space	medium	low	slight increase	none	Author design; Landscape modeling	Total site area; total outdoor area; total vegetated area; identify the vegetation types;

Categories and Credits		Difficulty of achievement	Points' contribution	Impact on cost	Impact on schedule	Model Uses	Parameters
4	Rainwater Management	difficult	high	big increase	slight increase	Hydrological systems modeling	n/a
5	Heat Island Reduction	easy	medium	none	none	Author design; Architectural modeling	Solar reflectance (SR) and solar reflectance index (SRI) of materials (mainly paving and roofing materials)
6	Light Pollution Reduction	difficult	low	none	none	Analyze lighting performance	Link photometric data to the material; BUG rating information of the luminary (uplight and light trespass) or percentage of total lumens emitted above horizontal (uplight) and vertical (trespass)
Water Efficiency		MEDIUM	LOW				
Prereq	Outdoor Water Use Reduction					Irrigation systems modeling	n/a
Prereq	Indoor Water Use Reduction					Hydraulic systems modeling	Link datasheet of objects, if modeled (fixtures, fittings, appliances)
Prereq	Building-Level Water Metering					Monitor system performance; Monitor Assets	n/a
1	Outdoor Water Use Reduction	difficult	medium	slight increase	slight increase	Irrigation systems modeling	n/a
2	Indoor Water Use Reduction	medium	high	none	none	Hydraulic systems modeling	Link datasheet of objects, if modeled (fixtures, fittings, appliances)
3	Cooling Tower Water Use	difficult	medium	slight increase	none	n/a	n/a
4	Water Metering	medium	low	slight increase	none	Monitor system performance; Monitor Assets	n/a
Energy and Atmosphere		DIFFICULT	HIGH				
Prereq	Fundamental Commissioning and Verification					Handover and commissioning; Design documents (OPR/BOD)	n/a
Prereq	Minimum Energy Performance					Analyze energy performance	Type of room space (according to ASHRAE 90.1-2010); Occupancy
Prereq	Building-Level Energy Metering					Monitor system performance; Monitor assets	
Prereq	Fundamental Refrigerant Management					n/a	

Categories and Credits		Difficulty of achievement	Points' contribution	Impact on cost	Impact on schedule	Model Uses	Parameters
1	Enhanced Commissioning	difficult	medium	big increase	big increase	Handover and commissioning	Occupancy schedule of rooms; set points of HVAC system; equipment run-time schedule;
2	Optimize Energy Performance	medium	high	big increase	none	Analyze energy performance	Type of room space (according to ASHRAE 90.1-2010); Occupancy of rooms; Occupancy schedule of rooms; U-values; g-values; Tvis; R-values opaque elements; link HVAC equipment data sheet (i.e. efficiency value)
3	Advanced Energy Metering	medium	low	big increase	slight increase	Monitor system performance; Monitor Assets	n/a
4	Demand Response	difficult	low	slight increase	none	n/a	n/a
5	Renewable Energy Production	medium	low	big increase	none	Analyze energy performance	n/a
6	Enhanced Refrigerant Management	medium	low	slight increase	none	n/a	Type of room space (according to ASHRAE 90.1-2010); Occupancy of rooms; Occupancy schedule of rooms; U-values; g-values; Tvis; R-values opaque elements; link HVAC equipment data sheet (i.e. efficiency value)
7	Green Power and Carbon Offsets	easy	low	slight increase	none	n/a	n/a
Materials and Resources		DIFFICULT	MEDIUM				
Prereq	Storage and Collection of Recyclables					n/a	n/a
Prereq	Construction and Demolition Waste Management Planning					Author construction site logistics model (focus on waste); Construction waste management	n/a
1	Building Life-Cycle Impact Reduction	medium	high	slight increase	none	Life-Cycle Assessment	n/a
2	BPDO - Environmental product	medium	medium	none	none	Author cost estimate	Link EPD to the materials
3	BPDO - Sourcing of Raw Materials	difficult	medium	slight increase	none	Author cost estimate	Link CSR / extraction report to the materials

Categories and Credits		Difficulty of achievement	Points' contribution	Impact on cost	Impact on schedule	Model Uses	Parameters
4	BPDO - Material Ingredients	difficult	medium	slight increase	none	Author cost estimate	Link product datasheet to the material (There are several options of material declarations considered for the achievement of this credit, by having the exact data sheet would already facilitate the process for the investigation.)
5	Construction and Demolition Waste Management	easy	medium	none	slight increase	Author construction site logistics model (focus on the waste); Construction waste management	n/a
Indoor Environmental Quality		DIFFICULT	MEDIUM				
Prereq	Minimum Indoor Air Quality Performance					Analyze air quality performance; HVAC systems modeling	Room area, occupancy of room; type of building and/or room space; Building category; floor area per person (can be calculated with area of room and occupancy); Occupancy schedule of room; Activity and clothing level of room;
Prereq	Environmental Tobacco Smoke Control					n/a	n/a
1	Enhanced Indoor Air Quality Strategies	medium	medium	slight increase	none	Analyze air quality performance; HVAC systems modeling	n/a
2	Low-Emitting Materials	easy	medium	none	slight increase	Author design; Architectural modeling; Author cost estimate	Link product datasheet to the material/surface (information required is related to General Emissions Evaluation and VOC content requirements for wet applied surfaces) - Analyzed categories: interior paints and coatings, interior adhesives and sealants, flooring, composite wood, ceiling, walls, thermal and acoustic insulation, furniture, exterior applied products (the last one only for healthcare and schools).
3	Construction Indoor Air Quality Management Plan	easy	low	none	none	Analyze air quality performance; HVAC systems modeling	n/a
4	Indoor Air Quality Assessment	difficult	medium	big increase	big increase	n/a	n/a

Categories and Credits		Difficulty of achievement	Points' contribution	Impact on cost	Impact on schedule	Model Uses	Parameters
5	Thermal Comfort	difficult	low	slight increase	slight increase	Analyze thermal comfort performance; Author design; Architectural modeling;	For thermal comfort design: Occupancy of room; type of building and/or room space; Building category; floor area per person (can be calculated with area of room and occupancy); Occupancy schedule of room; Activity and clothing level of room;
6	Interior lighting	medium	medium	slight increase	none	Analyze lighting performance	Link photometric data to the material (luminance; CRI, rated life in hours)
7	Daylight	medium	medium	slight increase	none	Analyze lighting performance	Glass (window/façade) data sheet or input SHG, Tvis parameters, glazing ratio; Room orientation; Type of room space; Occupancy schedule of room; Materials surface reflectance, roughness, specularity;
8	Quality Views	medium	low	none	none	Author design; Architectural Modeling	n/a
9	Acoustic Performance	difficult	low	slight increase	slight increase	Analyze acoustic performance	Type of room space; Occupancy of room;
Innovation		EASY	LOW				
1	Innovation	difficult	high	none	none	n/a	n/a
2	LEED Accredited Professional	easy	medium	none	none	n/a	n/a
Regional Priority		EASY	LOW				
1	Regional Priority: Specific Credit	All credits have a medium contribution of points. The other variables change according to the project's location. Once location is known, the other variables will follow the specific credits.				Depend on the project location. Follow parameters of the specific credit.	
2	Regional Priority: Specific Credit						
3	Regional Priority: Specific Credit						
4	Regional Priority: Specific Credit						

ANNEX A - CHECKLIST PRISMA 2009

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

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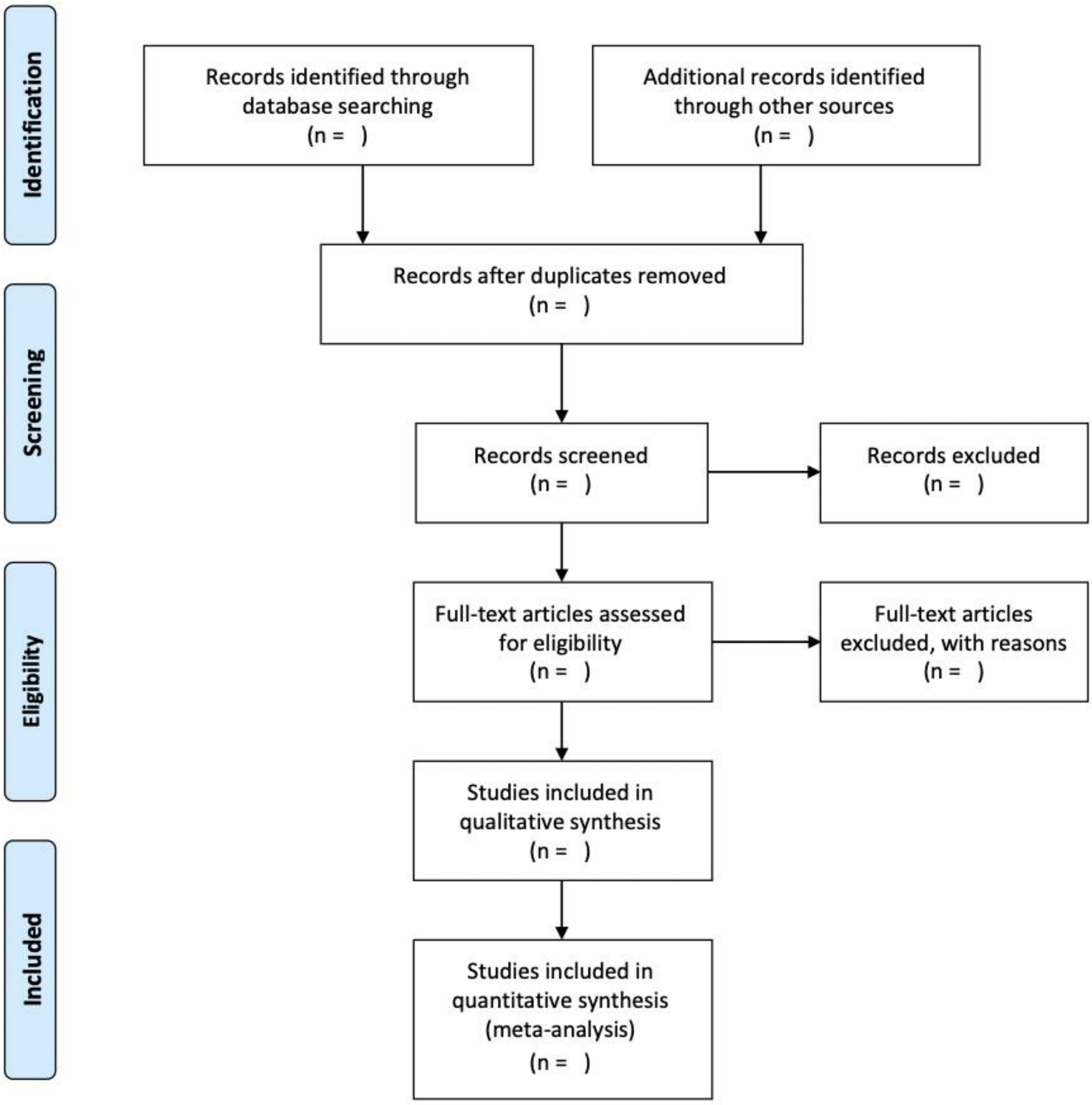
ANNEX B - PRISMA FLOW DIAGRAM

PRISMA 2009 Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*
The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

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