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Improving Green Building Project Management Processes through the Lean Approach

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Abstract

Question: Using a Lean approach to classify issues, or wastes, experienced during the different design processes, what sustainability-related activities affect the project design development stage.

Purpose: **The objective of this paper is to** create a new lean-based approach to analyze the design process and quantify the negative effect of detected project-management issues on the project's main resources, categorized through three different variables: costs, time and sustainability.

Research Method: The research makes full use of a Lean approach intended as a standardized method to identify project wastes, classify the issues experienced during the different design processes and ultimately propose possible solutions for process optimization. The Lean approach was used as the basis to study four case studies wherein real projects were developed in different European countries under the LEED and BREEAM reference standards. The projects were analyzed against a set of guidelines developed by the Researchers with the aim of avoiding the replication of such issues in future projects. The analysis took into consideration all sustainability-related activities that affected the project design development.

Findings: By identifying and estimating the effects of each issue on the project variables, researchers could rank their negative impact on the project budget, schedule and level of sustainability. The ranking allowed isolating which issues, or categories of issues, had the worst impact on the overall project from both qualitative and quantitative points of view. These research goals were achieved through the implementation of the Lean method and philosophy.

Limitations: Among the main challenges related to time-variance analysis. Estimating the delay of single activities impact was sometimes difficult and ambiguous because it

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relied on other activities for which dependency could not be calculated. Limitations related to cost-variance analysis involved indirect costs that were difficult to estimate because they were neither related to any written document nor any formal activity or event of the project. The present research takes into consideration only four case-study projects and therefore the related conclusions cannot be generalized for all building projects.

Implications: Applying the ranking of the issues identifies to a real project development with limited resources, it would be possible to highlight which problems should be addressed first in order to avoid, or at least limit, their negative impact on the project establishing a set of guidelines for future projects.

Value for authors: This study sets the basis for several other research studies in relationship with green-building developments and lean approach.

Keywords: Lean Construction, Lean Thinking, Design, Green-Building; Development, Sustainability; Project Management; Waste

Paper type: Full paper.

INTRODUCTION

In recent years, several research studies have analyzed project management processes in order to optimize green-building projects using the Lean method (Lapinski et al., 2006). Within the construction environment, the Lean approach consists of a combination of operational research and practical development in design and construction with adaptations of Lean manufacturing principles. However, construction and manufacturing are two different fields. Construction is a project-based production process in which the project is, most of the times, the first and last of its kind and therefore a prototype whereas manufacturing production is a more standardized process. Lean Construction focuses on the achievement of concurrent and continuous improvements in all dimensions of the built and natural environment: design, construction, activation, maintenance, salvaging, and recycling (Abdelhamid et al., 2008). For the purpose of this study, researchers implemented the Lean approach as a standardized method to identify the project wastes, classify the issues experienced during the different design processes and ultimately propose possible solutions for the process optimization. On the other hand, it also represents a way to perceive the project-management tasks as a process that is not fixed in time and may be upgraded through identification of waste and continuous improvements. Such enhancements can be implemented when the same conditions of a process are repeated or, in other words, if the processes are standardized (Liker, 2004). From this perspective the implementation of international green-building standards like LEED or BREEAM gives the chance to look at the development of construction projects more as a product and less as a prototype (USGBC statistics, 2016).

In general, the Lean approach has been proven to lead to better results demonstrated in higher revenue generation and lower cost through the betterment and standardization of the different kind of production, service, and business processes. This has found application in all domains including construction project management. Following the results of a study developed by Koskela (1992, p.5): *"Construction has traditionally tried to improve competitiveness by making conversions incrementally more efficient. But* *judging from the manufacturing experience, construction could realize dramatic improvements simply by identifying and eliminating non conversion (non-value-adding) activities."* Almost simultaneously, Howell and Ballard (1994a and b) observed that the use of contacts and critical path methods to manager both project and production level progress was a major determinate to the health of construction project as well as a source of disconnect between plan (what should happen) and reality (what actually happen) (Ballard and Howell, 1994a). Therefore, the combination of Lean method and green-building standard could represent a possible way to improve the project management processes within a field, like the building industry, in which processes are rarely standardized. The term "construction" associated with the Lean approach refers to the entire industry and not the phase during which construction takes place (Abdelhamid et al., 2008). Therefore, Lean Construction approach encompasses and applies to the whole project-development process including owners, architects, designers, engineering, constructors, suppliers and final users.

The area of interest for the present research was narrowed down to projects developed at an international level and built within the European Union. Evidence of existing research studies related to Lean Construction takes into consideration projects developed within the Anglo-American construction process, which is different from the one implemented within the European Union (Quilty-Harper, 2011). In this scenario, more stakeholders are involved and local laws as well as European regulations establish new hierarchies within the entire construction and project development procedure leading to very fragmented processes (Guy and Moore, 2004). Such circumstances make the project management process more complex and more difficult to analyze. Therefore, the relationship between process integration and green-building design development may be a key-aspect for enhancing the efficiency of green-building design especially in conditions under which processes are very fragmented as in the European system (Pellicer et al., 2012).

Research goals.

This research utilizes the Lean approach to identify the project-management factors that negatively affects the green-building design process (Research Goal 1, RG1); this procedure was carried out for projects located within the European Community. The second Research Goal is to use the Lean approach to identify the events that cause them and propose specific countermeasures, or guidelines, for reducing their replication in future projects (RG2). After identifying a specific knowledge gap within the current knowledge environment researchers defined the process to carry out the research. This process was developed through the identification and analysis of a satisfactory number of case-study projects. The different types of "waste" (as defined under the Lean approach) affecting the development of the design phase were identified throughout the analysis of the case-study projects and then categorized in five categories of issues. Finally researchers quantified the impact of such waste on the entire-project development.

In order to achieve these goals, the paper is structured as follows. First, the point of departure of the research is set. Second, the research method is explained. Later, the results are shown, explained and discussed. Finally, conclusions are drawn, including the contributions, limitations and future lines of research.

POINT OF DEPARTURE.

Womack et al. (1990) frequently share what the group studying Toyota over the course of 5 years, circa 1985 to 1990, meant by the term Lean they used to describe what they observed as follows: "Creating value as defined by the customer by spending less time, human effort, capital expenditure, and space. This is achieved by identifying and removing non-value adding work from the value stream resulting in the product and/or service for the customer." As demonstrated by Liker (2004), the Lean approach takes into consideration the minimization of the so-called "process waste" within every possible activity, event or operation that, in spite of consuming any kind of resource, does not provide any added value to the product's final user. According to a recent study, the importance of green-building certification is rising; reference standards, such as LEED, are starting to be implemented as international benchmarks for the definition of common quality for buildings (Cotten, 2012). Different methods and approaches, such as life-cycle assessment, resource planning, green-building reference standards, building information modelling and others have been developed in relationship with building sustainability (Dahlmann and Veal, 2016) and it is important to coordinate such new tasks through appropriate project-management processes. Moreover, such green-building protocols are becoming a sort of over-national standardization systems because they don't withstand, but fall outside, the national laws (Orsi & Guillamón, 2016). According to the World Green Building Council, currently LEED and BREEAM are the most implemented green-building rating systems worldwide in terms of number of certified buildings and total certified projects area (USGBC Statistics, 2016).

Project management seeks to achieve all of the project goals within the given constraints which are considered to be scope, time, quality and cost (PMI, 2017). The secondary challenge is to optimize the allocation of necessary inputs and integrate them to meet pre-defined objectives (Kerzen and Saladis, 2013). For the scope of this work, researchers focused on the definition of quality which, at its most basic level, means meeting the needs of customers (PMI, 2017). However, as cited above, the implementation of green-building standards is directly connected with the definition of an international quality benchmark too (Cotten, 2012).

Accessed research related to project management and Lean management focuses on the Anglo-American construction process. However, within the European Union the construction and project management process is substantially different. More subjects are involved and local laws establish new hierarchies within the whole construction and project development process (Guy and Moore, 2004). Such concepts are still valid for the Lean Construction approach and all these considerations brought the researchers to identify the following research gap. The Lean approach may be implemented for the optimization of the project-management processes within the European construction system by identifying and minimizing the different types of process wastes. In order to do that, the implementation of some sort of design-process standardization procedure is needed, such as, the LEED and the BREEAM green-building standards.

RESEARCH METHOD.

Overall Method.

This research was developed using a qualitative research approach based on multiple case studies. According to Yin (2013), the exploratory approach is appropriate for investigating a phenomenon in its current scenario. Qualitative research aims towards analytical generalization, as opposed to statistical generalization which usually aims toward quantitative studies. Analytical generalization involves the extraction of abstract concepts from each unit of analysis. These concepts should be related to the theoretical grounds and be potentially applicable to other cases (Yin, 2013).

Therefore, to attain the two research goals (identifying the project-management factors that negatively affect the green-building design process as well as the events that cause them), several case-study projects were selected: (1) a pilot case-study, which allowed the design, implementation and testing of the case-study protocol; and (2) additional studies, which allowed the analysis of the project-management issues affecting the design process through the Lean approach. Explanation building and cross-case analysis were implemented (Yin, 2013) in order to determine the impact of each problem category on the different design processes that take place during the design phase of the building life cycle. This can be further reinforced by developing cross-case comparisons. Figure 1 shows the overall research method followed in this paper. The next sub-sections show the details of each of the stages of this research method.

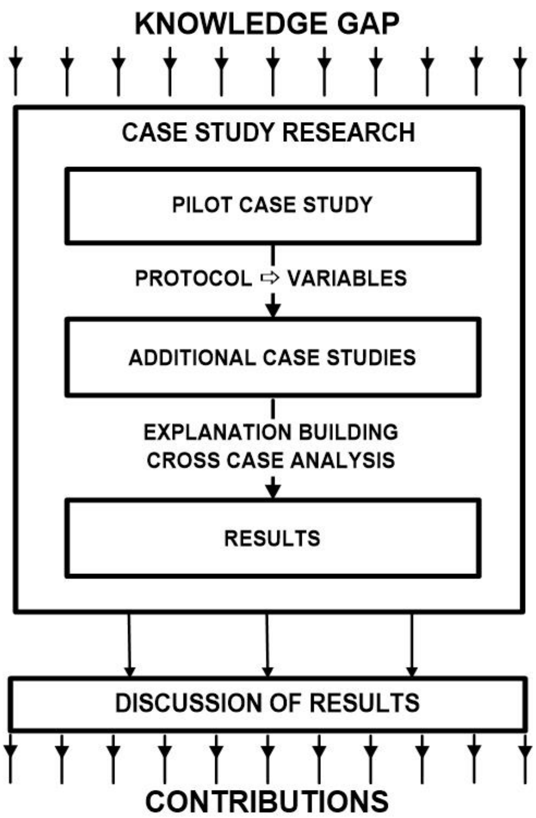

Figure 1: Research method.

Pilot Case Study.

According to Yin (2013), researchers should be sufficiently familiar with the study domain as to understand the main concepts that are relevant to the study in order to select the cases. Furthermore, they should also be able to interpret the information in real-time and adjust their data-collection activities accordingly to suit the case study. Therefore, as the first stage of the research method, a pilot case-study project was chosen in order to build a framework and test the protocol on the results obtained. The availability of information and the scenario required for the development of the research determined the choice of the case study (Yin, 2013). Within the scope of the pilot case study researchers focused on considering the major possible number of variables. The pilot case-study had to match with a sort of worst-case scenario for the development of the protocol that could be implemented to the major number of case studies similar to the original one. Therefore, the pilot case-study had to contain the major number of potential variables to be considered in the other case studies. This way, the project of a new school-complex in Italy certified under the LEED for Schools 2007 (LEED for Schools, 2007) reference standard was chosen as a pilot case-study; this project had a total budget of approximately €13.2 Million, and a total gross footprint of 6,000 m^2. In this instance, the worst case scenario is represented by a very fragmented design process developed by different subjects within the interested geographical areas using one of the two reference standards cited before. This first case study (the pilot) allowed the research to define the research protocol (Yin, 2013), as well as the response variables of the research relevant from the project-management perspective.

The protocol followed for this pilot case study is displayed in Figure 2. Next, each of the steps of this protocol are explained in-depth. This explanation also includes the outcomes of the implementation of the protocol in this pilot case study.

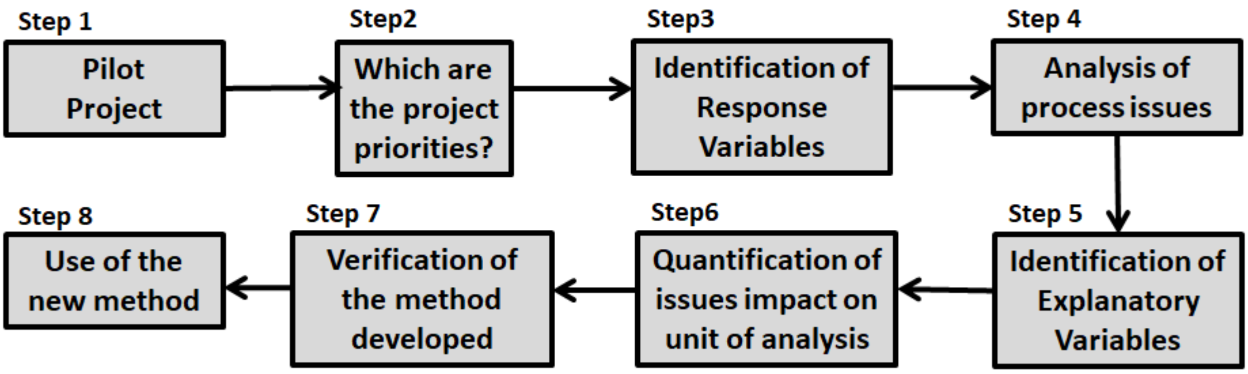

Figure 2: Graphical representation of the protocol followed in the pilot case study.

Step 1. The pilot case study was used to test the protocol that had to be applied later on other case-study projects. As unit of analysis, the researchers chose the project design phase of a public building. The reasons for choosing this project as the pilot case study were:

- It is a real building-related process embracing the different types of activities, but at the same time its broadness is comparable with the project resources.
- It is performed during a period of time that allows the study and not too far from the research-development phase.

- All related information and activities are well-documented and are accessible to the public by law.
- It is a LEED-certified building with a design-development process pursuing the LEED certification.

Step 2: the main research goal is the optimization of the process through the Lean approach and, following the definition of "lean" and "waste", researchers defined the case study priorities based on the client's needs. Researchers identified these priorities through a multiple set of interviews with the owners, analysis of the documentation and personal observation. The owner's concerns were related to cost and duration of the design process in relation to the final level of sustainability of the project.

Step 3: within this step researchers converted the factors that established the owner's priorities for the project into response variables that could be defined and measured. The first two factors, process duration and cost, were easily defined using the units of measurement typically implemented within the European construction market: Euros for the cost and number of workdays for duration. Researchers determined and analyzed the last factor following the definition of Cotton (2012) under which, the green-building reference standards, such as LEED, are implemented as international benchmark for the definition of common quality building standards. Thus, with the consent of the owner, the quality of the project was measured as the level of sustainability achieved through the application of the LEED and BREEAM protocols. As a result, researchers identified these three response variables: design-process cost (Euros); design-process duration (number of workdays); level of sustainability of the project (LEED/BREEAM credits). These response variables were used to control the project factors that were essential to the owner.

Step 4: the pilot case-study was sorted out by activities referred to specific sustainability-related tasks or events using scheduling-process and techniques (Harris, 1978). Occasionally, researchers identified some problems associated with such activities which affected one or more response variables. These problems were identified through interviews with the project technicians and/or the analysis of the project documentation. Finally all the activities associated with these problems were labeled as "issue-related activity". Since the issues originally identified during the pilot case study resulted to be the outcomes of the project management problems the researchers were focusing on (Fercoq et al. 2016; Salgin et al. 2016; Wesz et al. 2018), they were labelled and placed as "Issue Categories". Researchers gathered such issue-related activities together in different groups depending on the cause or, in other words, the sustainability-related task that generated them. As a result researchers identified five categories of issues related to the project:

- Lack of integration among technicians involved in the sustainability-related tasks.
- Misinterpretation of Commissioning Authority's activities.
- Unsuitable clauses in tender documents.
- Over-costs because of delays and change orders.
- Misunderstanding of the energy modelling process.

Step 5: after determining the categories of issues of the project, researchers focused on identifying the reasons why such issues happened. Thus, they started to analyze the problems through the Lean-methodology lens and more specifically by implementing the concept of “waste”. It is noteworthy to highlight that, within the Lean terminology, “waste” is not construction refuse and/or excess disposed items and materials as is often misunderstood. The term “waste” refers to the unproductive use of resources in the execution of work that is supposed to create value for the owner. Liker (2004) defines it as any type of activity performed during the process that in spite of consuming resources does not bring added value to the final product. Lean literature varies in accounting for the types of wastes where seven, eight, nine, and even more have been recognized. The key is to identify the waste and minimize or eliminate it (Koskela, 1992). Through the pilot-case analysis only six types of “waste” were identified and therefore considered: (1) waiting (delays in the process and unnecessary approval cycles); (2) motion (unnecessary trips or steps caused by design and implementation of work processes); (3) over-processing (unnecessary process steps); (4) inventory (backlog of work, excess materials or information); (5) defects (data errors, missing info; multiple collection, use, and management of information); and (6) overproduction (unneeded reports, production of un-requested tasks).

Once the real-project issues had been determined (step 4) and the types of Lean wastes were recognized, researchers proceeded to the designation of the explanatory variables. The main idea was to match the detected types of project issues and Lean wastes with the Lean principles (Liker, 2004) that could have prevented them. Thus, the explanatory variables were identified as the Lean-principles that should have been implemented in order to avoid the formation of the Lean wastes for the project issues identified above. Out of fourteen Lean principles (Liker, 2004), only five were originally considered for the purpose of the pilot case-study:

- Principle 2: create continuous process flow to avoid hidden problems.
- Principle 5: build a culture of ‘stopping to fix problems’ to get quality right.
- Principle 6: standardized tasks are the foundation for continuous improvement and employee empowerment.
- Principle 7: use visual controls so no problems are hidden.
- Principle 9: grow leaders who thoroughly understand the work and live the philosophy.

The process implemented by researchers to link the project issues with the Lean-principles was developed on the basis of the interviews with the project technicians, the analysis of the project documentation and the literature review and it is explained in detail later.

<u>Step 6:</u> the project information considered useful for the scope of this research proceeded from two main sources: documentation and interviews. For both cases the process implemented for the collection and extrapolation of the data were standardized through the development of the protocol. Specific software and project-management approaches were implemented to obtain results related to cost and time facets. Both methods were standardized through the implementation of scheduling and estimating techniques, which allowed researchers to repeat the process for each case-study project (Russell-Smith et al., 2015). Sustainability-related information and results were calculated on the basis of the green-building reference standards used for each building certification process considering sustainability, in other words green-building-reference-standard score,

as a project priority (Horman, 2006). With this step researchers quantified the impact of the project issues on the unit of analysis (project design phase) differentiating the results on the basis of the response variables.

Step 7: the results obtained in the previous step (for the pilot case study) were validated by the research team using two different techniques: interviews (Woodside 2010) and research publications (Yin 2013). Interviewees, which were the subjects involved in the real-project development, had to agree upon the plausibility of the results, both from qualitative and quantitative points of view. They agreed on the issues and on the causes that determined them. In addition, researchers collected the results proceeding from the pilot case-study and published them through a research paper (Orsi and Guillén, 2016) that was publicly presented in 2016. Thus, the publication's outputs endorsed the validity of the method that could then be applied to a broader range of case studies.

Step 8: the research team then proceeded with the selection of other case studies based on the ideas and concepts explained above. The protocol developed through the pilot case-study was then implemented to three other real projects. Results proceeding from the qualitative analysis were divided, as for the pilot case-study, in two different categories: response variables and explanatory variables. Response variables identify the different fields investigated within the research and remained unchanged throughout the whole research: cost variance, time variance, and sustainability variance. The explanatory variables identify the types of Lean principles that could have prevented the project issues and, even though for the pilot case study only five were identified, by the end of the research project two others were considered:

- Principle 1: base the management decisions on long term philosophy.
- Principle 4: level out the workload.

Additional Case Studies.

Regarding the second stage of the research method, additional case studies have to be chosen in order to implement the protocol. All case-studies had to be analyzed through first-hand information and direct interaction with the subjects involved in the design process. They also had to be located within the European Union legal framework and be registered or certified under the LEED or BREEAM protocols. Researchers needed all information related to the design processes to be trackable and well defined from three different points of view: cost (direct and indirect), time (delays), and level of sustainability. From the building-type perspective all buildings had to have a similar budget (€5 to €15 Million), a similar size (3,000 m^2 – 6,000 m^2) and a similar scope, which was finally defined as new-development buildings for tertiary-sector activities. On the basis of these concepts researchers chose the following three additional case-studies:

- New Nursing Home Complex located in Volano (TN – Northern Italy), certified under LEED for Healthcare 2009 (LEED for Healthcare, 2009), with a total budget of approximately €11 Million and a total gross footprint of 5,965 m^2.
- New Office Building located in Barcelona (Spain), certified under the LEED protocol (LEED v.3, 2009) with a total budget of approximately €7.5 Million and a total gross square footprint of 3.000 m^2.

- New Office Building located in Alicante (Spain), certified under the BREEAM protocol (BREEAM Commercial, 2013) with a total budget of approximately €14 Million and a total gross square footprint of 5.885 m^2.

Throughout the research process the data collection and analysis procedure was developed following a consensus-based iterative process. The information related to each variable were collected by researchers through the protocol developed in the previous stage of the research and this method was implemented for each case study. However, such information were then double-checked with all subjects involved in the design process of each project and the final numbers were considered acceptable only when all such subjects would agree.

The project outcomes are the results of the correlation between explanatory and response variables. The final results of the research are summarized in three different matrices (one for each explanatory variable) for each case-study project. The numbers resulting from the calculations of the different variable-related activities are shown as percentages related to the total of each explanatory variable: cost, time, and sustainability.

Interviews with the subjects directly involved in the process demonstrated the validity of the partial results for each iteration. All interviewees agreed upon the plausibility of the results both from qualitative and quantitative points of view: they agreed on the types of issues and on the causes that determined them; quantitatively because the research results in terms of numbers coincided in order of size, with their expectations. For the purpose of this work, interviews played a key-role for both qualitative and quantitative estimate of the important information. All interviews were addressed to subjects directly involved in the project: technicians, owners, professionals, public clerks, council members and others. Table 1 shows the role of the interviewees consulted for each case-study.

Project / Subjects	School-complex project	Nursing-home project	Barcelona office project	Southern-Spain office project
Owner	X	X		
Owner's Employee	X	X	X	
Council Member	X			
Senior Architect	X	X		
Assistant Architect	X		X	X
Senior Mechanical Engineer	X	X		
Junior Mechanical Engineer		X	X	
Structural Engineer	X	X		
Project Manager				X
Assistant Project Manager				X
LEED AP	X	X	X	X
Commissioning Authority	X	X	X	
Energy Modeller	X		X	X
Owner's Consultant		X	X	X
General Contractor				X
Site Engineer				X

Table 1: Summary of the interviewees' categorization for each case-study project.

Cross Case Analysis.

The study was carried out following the explanation building approach and the cross-case analysis procedure (Yin, 2013). Explanation building focuses on analyzing the case study data by building an explanation about the case (Yin, 2009). For the purpose of this study, researchers highlighted a whole set of cause-effect relationships (Miles and Huberman, 1994), between the cause (response variables) and their effects on the project (explanatory variables). The procedure was developed through an iterative process based on the initial predictions which were then compared against the case study evidence. In some cases, the predictions taken as initial references were modified on the basis of the results obtained and/or of additional evidence found throughout the research. The process was iterated until researchers obtained a satisfactory match for different aspects of the research. The process was considered to be satisfactory when all subjects involved unanimously agreed upon the results obtained.

The final stage of the research was to conduct a comparative process of the selected case-studies based on the replication logic under which each case had to be selected (predicting similar results). This way, both explanation building and cross-case analysis methods, can generate theoretical frameworks and formal propositions (Barratt et al., 2011). Following such ideas researchers established a first direct approach through the identification and analysis of a pilot case-study and then verifying the results through a cross-case analysis related to the other case-study projects. Therefore researchers first used the variables (explanatory and response) identified through the pilot case-study and then modified them depending on the results of the other case-studies. As a final result the original response variables were not modified because considered appropriate by the research team. However, other explanatory variables were found throughout the analysis of the other case-studies and, therefore, they were added to the ones originally identified for the pilot case-study.

RESULTS AND DISCUSSION.

Case-study analysis: response variables.

Each response variable cited above was analyzed separately for the scope of this study. Researchers developed a specific method of analysis for each of the three variables on the basis of the Lean approach. The main idea was to identify and quantify the impact of eventual process wastes, as defined under the Lean approach, within the unit of analysis of the study.

First response variable: time variance.

The first response variable considered was the time variance, that is, the total amount of time lost due to sustainability-related problems which turned out to be related with the following types of Lean waste: waiting, over processing, defects and inventory. The duration of such wastes for this variable was estimated on the basis of the Gantt-diagram results developed using the software Microsoft Project. Only sustainability-related activities and project milestones were considered for the purpose of the present research. Sustainability-related problems, caused by the Lean wastes cited above, were accounted as normal activities with predecessors and successors and their duration was estimated on the basis of the data previously collected through project documentation and interviews. Researchers identified all these Lean-waste-related activities under the time-variance perspective and then highlighted the activities affected by such wastes. Within the Gantt diagram, researches used different colors to classify normal activities (blue), sustainability-related activities (green), Lean wastes related to sustainability (red), activities affected by Lean wastes (orange) and project-management-related activities (yellow). Researchers calculated the critical path following the main scheduling and project-management concepts (Harris, 1978) along with free-float and total-float of each activity. The total time variance of the project was calculated as the sum of all delays beyond the total float margin of each sustainable-related activity directly or indirectly affected by the types of Lean-wastes described above.

Second response variable: cost variance.

Following the Lean-based analysis each type of process waste described above caused some sort of additional cost in the process. In some cases this was produced by extra activities that had to be provided in order to fix or solve the process issues. In other cases the generation of unnecessary lead times and waiting brought to the loss of opportunities for fulfilling the project scopes. Therefore, researchers considered two types of costs related to Lean-wastes: direct and indirect costs. With the term "direct costs" researchers identified all expenses that determined an extra cash-flow output for the client. Lean-process-wastes that generated the direct costs were: over-processing, defects, and overproduction. With the term "indirect costs" researchers recognized two types of expenses:

- Additional costs that did not cause an extra cash-flow output for the client but had to be paid off by technicians involved in the project in order to fulfill the requirements of the expected product.
- Additional costs caused by the effects the Lean-wastes which affected third parties and later project development phases.

Lean-process-wastes that generated the indirect-cost category were: waiting, motion and excess of inventory. All costs were estimated in Euros either through interviews or project documentation.

Third response variable: sustainability variance.

The sustainability variance was estimated on the basis of the green-building protocol implemented for obtaining the green-building certification of each project. The protocol represented for researchers a tangible and standardized evaluation method of the green-building features of the project through which measuring its level of sustainability. The difference between the LEED (or BREEAM) points initially estimated through the protocol checklists and the final result of the certification determined the sustainability variance of the project. From this point of view it is important to notice that all types of Lean waste cited above contributed to the loss of green-building points. However, for the purpose of this study, researchers highlighted three major causes of variance among all types of Lean waste: waiting; over-processing and defects.

Case-study analysis: explanatory variables.

The explanatory variables for the purpose of this research were defined by linking the detected project issues with the types of Lean wastes and, consequently, with the Lean principles that could have limited them. This process was made through the analysis of the project data, literature review and on the basis of interviews and project documentation as described in the previous chapters. The relationship between each Lean principle and the project issues is described below.

Principle 1: base the management decisions on long term philosophy.

In some cases the owner or the project manager decided to take actions to solve imminent problems without planning the next steps on a long-term basis. For example, poor bid clauses referred to sustainability were detected in some case-studies. This happened because the owner required the bid only to assess the financial aspects of the project shifting the sustainability aspects to future steps. As a result, not all aspects of sustainability were properly assessed during the bid-clauses formulation, the clauses related to the production of LEED/BREEAM documentation were not considered and this lead to an additional cost claimed by the design company later on during the design development.

Principle 2: create continuous process flow to avoid hidden problems.

The lack of constant relationship between professionals along with a partial understanding of each other's tasks were the reasons why some problems remained hidden until the last project phases. For example, in some cases the owner did not understand the importance of the Commissioning Authority (CxA) which was not brought to the attention of the project team until the very last phases of the design. As a result, the CxA could not examine the project until the end of the design, when all shop drawings, estimates, bid specification and related documents had already been approved and closed. This generated extra costs and a loss of sustainability points for the project.

Principle 4: level out the workload.

The projects that suffered more issues were also the ones with a fluctuating level of workload. The project scheduling was often interrupted by unproductive trances (waiting) which later led to delays, work overload and lack of detail in performing the job tasks.

Principle 5: build a culture of 'stopping to fix problems' to get quality right.

In some cases the owner and/or project manager did not implement a philosophy to prevent future problems but only to fix the imminent ones. Such projects turned out to be the ones suffering more delays, extra costs and loss of sustainability points. The lack of issue prevention along with poor activity planning by the team shifted the recognition of specific solutions to later project phases, increasing the costs and lowering the project quality. This issue was predicted earlier on through the literature review (Construction Users Roundtable, 2004) and was then confirmed by the data analysis and the final results.

Principle 6: standardized tasks.

The lack of common protocols and standards related to the development of single tasks often led to delays and loss of resources. Every project phase was developed as a prototype on the basis of customized processes and actions. Thus, each phase demanded a preliminary period of education and team coordination. In some cases, this problem associated with the turnover of the public owner due to new elections caused massive delays and the need to re-establish the whole management process.

Principle 7: use visual controls so no problems are hidden.

The projects that didn't follow the Integrated Project Delivery process were developed by professionals that were physically detached from one another.

Comprehensive meetings with all the team members were held periodically on a monthly basis. However, the lack of connection between professionals (e.g., structural engineer, mechanical engineer and architect) often led to project errors that would be eventually identified during the following meetings but that required additional rework and resources.

Principle 9: grow leaders who thoroughly understand the work and live the philosophy.

The lack of implementation of this principle is a problem that researchers detected in several case-studies. In fact, through interviews and document analysis, researchers detected that the project sustainability was considered by the owners mainly as a secondary project factor. On the contrary of Horman's idea (2006), they thought that sustainability could be treated separately from the rest of the project simply by hiring external consultants independently. In spite of the efforts of some specialist the owners of two projects didn't change their approach and this lead to a substantial loss of sustainability points, extra costs and delays.

TIME-VARIANCE ANALYSIS								
DETECTED ISSUES / LEAN PRINCIPLES	CASE-STUDY PROJECT	Lack of integration between technicians	Commissioning Authority tasks & process	No appropriate clauses in bid documentation	Systematic cuts to project budget	Energy Modelling role and process	SUB TOTAL	TOTAL (Days)
Principle 1 (E.g. No long-term philosophy and defects in bid and early stages)	School Complex						0	18
	Nursing Home			18			18	
	Bld. Barcelona						0	
	Bld. South Spain						0	
Principle 2 (E.g. No process flow for CxA ,OPR, BOD)	School Complex						0	22
	Nursing Home		16				16	
	Bld. Barcelona		6				6	
	Bld. South Spain						0	
Principle 4 (E.g. Workload not levelled and extra-personell costs)	School Complex						0	10
	Nursing Home	4	2			4	10	
	Bld. Barcelona						0	
	Bld. South Spain						0	
Principle 5 (E.g. No stop to fix problems and re-work)	School Complex						0	49
	Nursing Home	5	14			30	49	
	Bld. Barcelona						0	
	Bld. South Spain						0	
Principle 6 (E.g. No standard tasks, incorrect processing and change orders)	School Complex	6		90	16		112	140
	Nursing Home		7		21		28	
	Bld. Barcelona						0	
	Bld. South Spain						0	
Principle 7 (E.g. No visual control and defects in project)	School Complex			38	7		45	81
	Nursing Home	12			11		23	
	Bld. Barcelona				5	8	13	
	Bld. South Spain						0	
Principle 9 (E.g. Leaders not prepared, hidden issues for	School Complex		5				5	40
	Nursing Home	16			8	7	31	
	Bld. Barcelona	1			1	2	4	
	Bld. South Spain						0	
TOTAL		44	50	146	69	51		

Table 2a: Results obtained for each case-study in relationship with response variable n. 1 "Time".

The different types of waste detected within the different design processes were classified through the Lean principles cited above (explanatory variables). The categories of issues identified were the symptoms of the lean wastes that generated them or, in other words, the lack of the lean principles that generated them. Therefore researchers classified the project outputs with different tables, one for each response variable, considering both the categories of issues and the lean principles. This process was carried out for each response variable: time, cost and sustainability. The results of this work are summarized in Tables 2a, 2b, and 2c and quantify the impact of the detected issue categories in relationship with the explanatory variables.

COST-VARIANCE ANALYSIS - Direct Costs								
DETECTED ISSUES / LEAN PRINCIPLES	CASE-STUDY PROJECT	Lack of integration between technicians	Commissioning Authority tasks & process	No appropriate clauses in bid documentation	Systematic cuts to project budget	Energy Modelling role and process	SUB TOTAL	TOTAL (€)
Principle 1 (E.g. No long-term philosophy and defects in bid and early stages)	School Complex						**0**	**5000**
	Nursing Home			5000			**5000**	
	Bld. Barcelona						**0**	
	Bld. South Spain						**0**	
Principle 2 (E.g. No process flow for CxA ,OPR, BOD)	School Complex						**0**	**10500**
	Nursing Home		8000				**8000**	
	Bld. Barcelona		2500				**2500**	
	Bld. South Spain						**0**	
Principle 5 (E.g. No stop to fix problems and re-work)	School Complex		14000	10000		8000	**32000**	**32000**
	Nursing Home						**0**	
	Bld. Barcelona						**0**	
	Bld. South Spain						**0**	
Principle 6 (E.g. No standard tasks, incorrect processing and change orders)	School Complex						**0**	**31500**
	Nursing Home		30000				**30000**	
	Bld. Barcelona			1500			**1500**	
	Bld. South Spain						**0**	
Principle 7 (E.g. No visual control and defects in project)	School Complex	4000		8000	6000		**18000**	**34100**
	Nursing Home				5000		**5000**	
	Bld. Barcelona				7500	3600	**11100**	
	Bld. South Spain						**0**	
Principle 9 (E.g. Leaders not prepared, hidden issues for	School Complex	4000					**4000**	**44500**
	Nursing Home			30000			**30000**	
	Bld. Barcelona	7500			1500	1500	**10500**	
	Bld. South Spain						**0**	
TOTAL		**15500**	**54500**	**54500**	**20000**	**13100**		
COST-VARIANCE ANALYSIS - Indirect Costs								
Principle 4 (E.g. Workload not levelled and extra-personell costs)	School Complex							**29830**
	Nursing Home	2500	500	500	1000	500	**5000**	
	Bld. Barcelona	300	600		300		**1200**	
	Bld. South Spain						**0**	
Principle 5 (E.g. No stop to fix problems and re-work)	School Complex	500		500	1000	500	**2500**	**15700**
	Nursing Home			1200		10000	**11200**	
	Bld. Barcelona	2000					**2000**	
	Bld. South Spain						**0**	
Principle 7 (E.g. No visual control and defects in project)	School Complex				3500	4000	**7500**	**14130**
	Nursing Home	3230			3400		**6630**	
	Bld. Barcelona						**0**	
	Bld. South Spain						**0**	
TOTAL		**3230**	**0**	**0**	**6900**	**4000**		

Table 2b: Results obtained for each case-study in relationship with response variable "Costs".

SUSTAINABILITY-VARIANCE ANALYSIS								
DETECTED ISSUES / LEAN PRINCIPLES	CASE-STUDY PROJECT	Lack of integration between technicians	Commissioning Authority tasks & process	No appropriate clauses in bid documentation	Systematic cuts to project budget	Energy Modelling role and process	SUB TOTAL	TOTAL (Green Points)
Principle 1 (E.g. No long-term philosophy and defects in bid and early stages)	School Complex						0	0
	Nursing Home						0	
	Bld. Barcelona						0	
	Bld. South Spain						0	
Principle 2 (E.g. No process flow for CxA ,OPR, BOD)	School Complex						0	1
	Nursing Home		1				1	
	Bld. Barcelona						0	
	Bld. South Spain						0	
Principle 4 (E.g. Workload not levelled and extra-personell costs)	School Complex						0	0
	Nursing Home						0	
	Bld. Barcelona						0	
	Bld. South Spain						0	
Principle 5 (E.g. No stop to fix problems and re-work)	School Complex					5	5	10
	Nursing Home				1	4	5	
	Bld. Barcelona						0	
	Bld. South Spain						0	
Principle 7 (E.g. No visual control and defects in project)	School Complex				1		1	4
	Nursing Home	1			1		2	
	Bld. Barcelona					1	1	
	Bld. South Spain						0	
Principle 6 (E.g. No standard tasks, incorrect processing and change orders)	School Complex	1	1		2		4	11
	Nursing Home	1			2	3	6	
	Bld. Barcelona			1			1	
	Bld. South Spain						0	
Principle 9 (E.g. Leaders not prepared, hidden issues for	School Complex						0	1
	Nursing Home						0	
	Bld. Barcelona					1	1	
	Bld. South Spain						0	
TOTAL		3	2	1	7	14		

Table 2c: Results obtained for each case-study in relationship with response variable "Sustainability".

The tables 2a, 2b and 2c allowed the researchers analyzing the different projects from the lean perspective. The sum of the problem's impacts on the project considering the categories of issues (vertical sum) determines the impact of each category of issue on the whole project defining which were the project activities that most affected the project. On the other side, the sum of the problem's impacts from the point of view of the explanatory variables (horizontal sum) defines which problems affected the process at a management level. Results proceeding from the explanatory-variables analysis (horizontal sum) show how much the lack of implementation of each Lean principle impacted the project. In table 3, researchers gathered all response-variables results on the basis of each explanatory variable (or lean-principle detected). This table shows the impact of each lean principle on the project response variables and offers an overall vision of which principles should be addressed in order to minimize the impact of the detected issues on the project.

As an overall result, researchers highlight what follows:

- The lack of standardized tasks and incorrect processing was a major issues for all the projects from the time and sustainability perspective causing 140 days of delay and the loss of 11 sustainability points overall.
- From the cost perspective, the lack of visual control, avoiding to stop to fix the problems (with consequent rework) and the presence of hidden issues

throughout the process were the main causes of added project costs adding respectively €48,230, €47,700 and €44,500, respectively, to the original budgets.

DETECTED ISSUES / LEAN PRINCIPLES	VARIABLE N. 1 TIME TOTAL (Days)	VARIABLE N. 2 COSTS TOTAL (€)	VARIABLE N. 3 SUSTAINABILITY TOTAL (Green Points)
Principle 1 (E.g. No long-term philosophy and defects in bid and early stages)	18	5000	0
Principle 2 (E.g. No process flow for CxA ,OPR, BOD)	22	10500	1
Principle 4 (E.g. Workload not levelled and extra-personell costs)	10	29830	0
Principle 5 (E.g. No stop to fix problems and re-work)	49	47700	10
Principle 6 (E.g. No standard tasks, incorrect processing and change orders)	140	31500	11
Principle 7 (E.g. No visual control and defects in project)	81	48230	4
Principle 9 (E.g. Leaders not prepared, hidden issues for LEED/BREEAM docs)	40	44500	1

Table 3: Summary showing the impact of each explanatory variable on the project response variables.

CONCLUSIONS.

Completion of the research objectives.

Following the research objectives described previously, researchers adapted the Lean method to identify the project-management issues that negatively affected the green-building design process (RG1). This objective was achieved twice: (1) using the definition of the explanatory variables during the analysis of the prototype project; and (2) during the analysis of the results obtained from all the case-study projects analyzed. This objective required a certain number of intermediate steps which are described in Table 4.

By analyzing and properly arranging the research outputs, researchers managed to implement the Lean method to analyze the factors that had a negative impact on the process. As a result, they identified the causes that initiated them and using the Lean method as a guideline they proposed specific countermeasures for reducing their replication in future projects (RG2). In fact, by looking at tables 2a through 2c, the results listed under the "Total" column on the right give the researchers the magnitude of the impact of each type of Lean waste detected within the different projects. This finding has a double beneficial output to the eyes of future project developments. On the one hand, it highlights which Lean wastes caused the majority of issues and therefore where resources should be directed in order to avoid the most impactful ones. On the other, such Lean wastes have been already analyzed and codified and therefore specific countermeasures have already been investigated. Knowing which types of wastes could negatively affect a design-development process could help identifying which countermeasures should be applied in order to avoid them.

Research Goal 1 - Research steps	How it was achieved
Identify a specific gap within the current research and knowledge environment;	A specific process of literature review was developed focusing on the main research fields and objectives.
Define a feasible and adequate method to carry out this research;	On the basis of the literature review and the information collected through interviews, documents and observations, researchers developed a new methodology through the analysis of a prototype case-study project.
Identify and analyze a satisfactory number of case studies in order to develop the research;	Three other case-study projects were identified and analyzed for the purpose of the present research following the method developed for the prototype case.
Identify and categorize the types of "waste", as defined under the Lean method, affecting the development of the design phase of the case-studies.	A specific categorization of project-management issues was developed through the identification of Explanatory and Response variables and the implementation of the Lean approach.
Quantify the impact of such wastes on the whole project development.	The impact of each problem category was estimated from a qualitative and quantitative point of view through the use of interviews, project documentation and observations.

Table 4: Research-process steps implemented toward the achievement of Research Goal no.1.

Findings.

The present research led to an entire set of findings that can be considered complementary to the main research objectives described above. The findings can be described as follows:

- Researchers found and implemented a new method for the betterment of project-management processes within green-building developments through the implementation of the Lean approach;
- The new method proved that, as anticipated by Koskela (1992), within the construction industry important improvements could be identified simply by analyzing non value-adding activities instead of improving competitiveness and activity-related efficiency;
- The research study analyzed the issue not only from a qualitative but also from a quantitative perspective and estimated the extent of impact on design-process costs, schedule and building sustainability.

- Through table 4, the study provides a practical classification of real project issues caused by the lack of implementation of the lean-principles cited above. From the perspective of a project manager, who would have limited resources to address all possible project issues, this may help him identifying the lean-problems to be addressed first in order to prevent project extra costs, delays and loss of sustainability-related points.

Limitations.

The present research has several limitations that could be described as follow:

- Limitations related to time-variance analysis. Even if researchers selected on purpose case studies developed almost simultaneously with the present research, the lack of a common protocol for the collection and storage of research-related data established prior to the project start determined a quantitative level of uncertainty. Estimating the delay of single activities impact was sometimes difficult and ambiguous because it relied on other activities for which dependency could not be calculated. Therefore, for the purpose of this research, activities with undefined scheduling features were considered to be part of groups of activities (milestones) whose start and ending point could be determined collectively.
- Limitations related to cost-variance analysis. Indirect costs impacts were difficult to estimate because they were neither related to any written document nor any formal activity or event of the project. Researchers only analyzed the cost of the problems they had related information about. There might have been other extra costs that were not considered because nobody captured them and so researchers did not even know of their existence. Researchers could not estimate the cost of not using the money allocated for the project during a medium-large period of time. The case-studies refer to public projects funded by public entities. Delays in design phase completion and consequently construction phase start represent a loss for the funding entity which cannot use nor invest the money allocated for the entire project (opportunity cost).
- Limitations related to sustainability-variance analysis. For the purpose of the present work, researchers took into consideration only two green-building protocols, LEED and BREEAM which are currently the most used at an international level for number of certified buildings and square meters. However, these protocols represent only a fraction of the green-building construction market and therefore results of the present research have to be considered relevant to these protocols.
- General limitations of the research study. The present research takes into consideration only four case-study projects and therefore the related conclusions cannot be generalized for all building projects. All case-study projects analyzed for the purpose of this research were similar in terms of building type, budget and, more generally, business segment. It is not clear if the values obtained for each of the independent variables would not vary in case of different projects in terms of use, dimensions and budget. The idea of avoiding the causes that determined the problems mentioned above is a

necessary but may not be sufficient condition to avoid the waste. Researchers do not have evidence that such waste can be fully avoided. In order to validate this thesis, researchers would need to analyze other projects where appropriate means and resources are implemented in order to prevent wastes listed above.

Recommendations for future research.

This study sets the basis for several other researches in relationship with green-building developments and lean approach. Among them researchers suggest the following ones:

- Extend the research to a wider set of building types: the research method described within could be applied to a wider set of buildings in terms of use, dimensions and geographical location.
- Extend the research to different types of green-buildings: the definition of "sustainability", hereby identified through the implementation of the LEED and BREEAM protocols, could be extended to other types of reference standards and/or definitions.
- Validation of the study results and final guidelines: further research studies could focus on the practical implementation of the guidelines proposed by this study. As explained in section 5.3 above, the present study focused on identifying the issues proceeding from real projects and linking them with different principles of the lean approach. The lack of specific lean principles causes one or more project issues. However, it is not clear if the implementation of such lean principles could fully or partially prevent the impact of the project issues identified by researchers. A case-study analysis based on real projects implementing the guidelines hereby proposed by researchers could validate, or not, this whole study and its research method. It is possible to state that taking the principles discussed in the paper into account should generally result in better time, cost, and sustainability performance even though we are unable to state the exact magnitude and/or percentage.

DATA AVAILABILITY STATEMENT

Some or all data, models, or code used during the study were provided by a third party. Direct requests for these materials may be made to the provider as indicated below:

- Information related to the Volano School Project: please contact the Municipality of Volano. info@comune.volano.tn.it
- Information related to the Opera Romani Nursing Home: please contact Opera Romani. info@operaromani.it

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