

Article

Optimization of Green Building Design Processes: Case Studies within the European Union

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Abstract: Green buildings have recently become a key aspect of the construction field and bring along a renovation of the whole industry chain. Such changes introduce new challenges for all subjects involved, and designers are also affected by such issues, especially for the development of projects based on international green building standards. Within this scope, project management plays a key role in the optimization of the design phase. This research analyzes the design process of international projects from the project management perspective through a multiple case study approach, considering the sustainability-related tasks that negatively affect the project design development under two types of contractual approaches: Design-Build and Design-Bid-Build. It aims to identify whether the Design-Build or Design-Bid-Build process is the best solution for developing green building projects. Two case studies in Italy and two case studies in Spain are analyzed, and the effects of the project management issues are evaluated under three different points of view: Time, cost, and level of sustainability of the building. A poorly planned process for the achievement of the various green building features of the project can impact the project schedule and the budget, whereas, a poorly managed project could also negatively impact its green building features. Finally, this research also highlights the positive relationship between process integration and green building design development.

Keywords: design-bid-build; design-build; green building; lean; optimization; project

1. Introduction

Sustainability is a broad concept that reflects the resilience of the environment on human actions [1,2]. Over the years, the implementation of sustainability on processes, products, and services has been standardized through a variety of rating tools [3–5]. Within the global construction industry, sustainability is gaining momentum [6–8]. Furthermore, according to [9] (p. 1), “... an increased emphasis must be placed on the processes and competencies required to deliver high-performance buildings”. One of the main pillars for the development of high-performance (or green) buildings is process integration [1,10], considering the planning, design, construction, and operation phases of the facility lifecycle [5,11,12]. This way, during the last decade, green building projects have been using project management processes and tools [8,12,13].

Emerging research and education programs are focused on understanding all aspects of delivering high-performance (or green) projects to minimize waste, maximize value, and reduce costs [13–17]. This can be enhanced through project management, considering the application of knowledge, skills, tools, and techniques to project activities to meet the project requirements [18]. The primary challenge of project management is to achieve all of the project goals within given constraints, which are considered the scope, time, quality, and budget. The secondary challenge is to optimize the allocation

of necessary inputs and integrate them to meet pre-defined objectives [18]. During the last years, several research studies have analyzed project management processes to optimize green building projects focusing on various aspects, such as leadership factors [19,20], building information modelling implementation [12,21], lean construction [13,14], economic value [22], schedule performance [23], procurement approaches [24], rating systems [3], best practices [11], project-based organizations [25], processes [1], design teams [26], and design development [27,28].

The management of the design phase is especially critical within the facility lifecycle, as any later changes will produce cost overruns and delays [12,29]. Designers involved in the development of projects based on international green building standards face additional challenges, primarily the need for additional design time, uncertainty regarding special equipment and materials, inclusion of green requirements in the contractual specifications, and planning green activities within the general master plan [1,8,29]. In this scenario, the standardization of procedures through green building certification is appropriate [5,30]. This way, reference standards, such as Leadership in Energy and Environmental Design [31], or the British Research Establishment Environmental Assessment Method [32], have begun to be implemented as an international benchmark for the definition of common sustainable quality for buildings. LEED and BREEAM are the most used reference standards for green building worldwide [5,30] developed on the basis of the Anglo-American scenario. Furthermore, different methodologies and tools, such as life-cycle assessment, resource planning, green building reference standards, building information modeling, and others have been implemented in order to improve building sustainability [7,8,33], and it is important to coordinate such new tasks through appropriate project management processes [13–17].

Furthermore, case studies, interviews, standards, and data collection used for the majority of the accessed research articles related to project management and green building management are also mainly focused on the Anglo-American construction process [8,10,24,26]. In the European Union, the construction and project management processes differ from the Anglo-American approach [34,35]: There are European Union regulations that must be considered in every European country (local laws are subjected to these regulations too). Besides, more stakeholders are involved, i.e., the director of works acts as the representative of the owner during the construction phase, and the coordinator of health and safety is the person responsible for health and safety matters [36,37]. This way, the European scenario establishes new hierarchies within the whole construction and project development process. As in the United States, the most common contractual approaches in Europe are Design-Bid-Build and Design-Build [38,39]. The Design-Build approach is more integrated and collaborative than the Design-Bid-Build approach, not only in the United States but also in the European Union [24,35]. These considerations provided the research gap for the scope of this study: The implementation of Anglo-American protocols within the European reality could cause project management issues during the project design phase depending on the choice of contractual approach: Design-Bid-Build or Design-Build.

2. Research Goals

This study aims to analyze the project management issues that take place during the design process of green building projects. The scope of this research is focused on projects developed within the EU. The first goal of the research is to identify the project management factors affecting the green building design process within the EU regulations and context. This goal requires some steps to achieve:

- Identify a specific gap within the current body of knowledge;
- Define a feasible and adequate case study protocol to carry out this research;
- Identify and analyze a satisfactory number of case studies to develop the research;
- Categorize the project management issues affecting the green building design process.

The second goal of this research is to investigate how the implementation of a Design-Build process could benefit the development of green building projects in comparison to a Design-Bid-Build one. This goal also requires the development of two other steps:

- Evaluate the impact of each project management issues on design processes;
- Investigate the relationship between process integration (Design-Bid-Build vs. Design-Build) and green building design development.

3. Research Method

3.1. Overall Approach

As stated previously, this research aims to analyze the project management issues occurring during the design process of green building projects, they apply either Design-Bid-Build or Design-Build contractual approaches within the EU. This research is carried out following the six main steps summarized in Figure 1. Each step of the research is briefly described as follows:

1. Literature review: To identify the knowledge gap;
2. Pilot case study: To define a feasible research protocol;
3. Selection of case studies: To identify suitable case studies;
4. Case study analysis: To analyze the case studies and to categorize the project management issues affecting the green building design process;
5. Cross-case analysis: To identify the impact of each project management issues on Design-Build and Design-Bid-Build processes;
6. Conclusions: To highlight the contributions, limitations, and recommendations of the research.

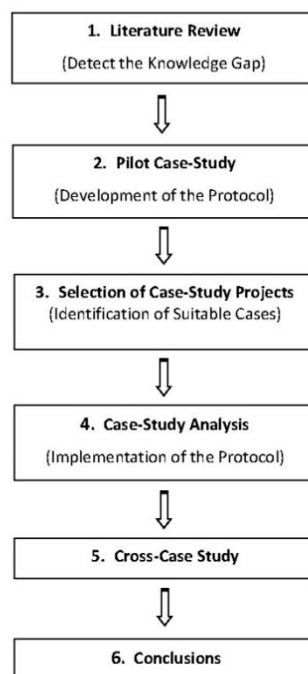


Figure 1. Research method.

3.2. Pilot Case Study

This research was carried out using a qualitative research approach based on multiple case studies. This exploratory approach is appropriate for investigating a phenomenon in its current state [40,41]. The unit of analysis selected for the purpose of this research is a process and, more specifically, the

process of design of a green building project. Researchers chose a pilot case study project to shape the draft of the research method in view of the development of the project and the outcomes obtained. The two main outputs of the pilot case study are the identification of the variables and the design of the research protocol [41]. The pilot project was also chosen purposively considering the availability of information and the scenario required for the development of the research [40,41]. Using the first project as a pilot case study, researchers aimed to consider the majority of possible variables. The case study had to be a worst-case scenario for the development of a protocol that could be valid for case studies similar to the original.

In this case, the worst-case scenario was a fragmented process developed within the European Union using one of the two referenced standards. The project of a new school complex in Italy, certified under the LEED standard [31], was chosen as the pilot case study project. This project involved a very fragmented design process developed by various stakeholders through the Design-Bid-Build procedure. This pilot case study considered three dependent variables: Time, cost, and sustainability. These three variables were chosen on the basis of the information collected throughout the pilot case study analysis (outcomes of interviews and documentation), as well as the literature review: Time [18], cost [18], and sustainability [9].

The process implemented for developing the pilot case study was sorted out by activities referred to as specific project-related jobs or events. Occasionally, researchers identified one or more project issues associated with some of these activities. Issues were identified using the concept of “waste,” as defined by the lean approach [42]: Any type of activity performed during the production process that, in spite of consuming resources, does not bring added value to the final product. Out of the seven types of waste defined for a typical lean process [42,43], researchers identified five applicable to the scope of this study: (1) Waiting (delays in the process), (2) movement of people, (3) extra-processing (re-manufacturing and activity reiteration), (4) costs (unforeseen expenses for project-related activities), and (5) defects (intended as project weaknesses that did not allow the team to reach the expected level of sustainability within the LEED or BREEAM certification). Only those types of waste that could be directly associated with project management jobs or events were taken into account. Lean construction literature usually considers two additional types of waste: Transportation of materials and inventory [42,43]. However, because of the empirical design phase focus of this study, no waste production activity was identified for these two types of waste and, therefore, they were not considered in this research.

Waste-related issues are the symptoms of project management challenges the authors were interested in [16,44,45]. Therefore, the ones initially identified during the case study were labeled and gathered in several categories of issues. The identification of such categories of issues during the pilot case study determined the independent variables of the present research:

- A. Lack integration between the technicians involved;
- B. Misunderstanding of Commissioning Authority’s tasks and processes;
- C. Lack of appropriate clauses in bid documentation;
- D. Systematic cuts to budget due to change orders and delays;
- E. Misunderstanding of the energy modeling role and processes in the building.

As stated previously, the protocol was one of the main outputs of the pilot case study. This protocol considered the research goals, the procedures to deal with the data (sources of data, access to design teams, data collection, confidentiality forms, and interviews) [41,46,47]. According to the protocol, the general manager, design project manager, and three key members of the design team should be interviewed following this protocol.

3.3. Selection of other Case Studies and Data Collection

To select the case studies, researchers should be sufficiently familiar with the study domain to understand the main concepts that are relevant to the study [40,41]. Moreover, researchers should be

able to interpret the information in real-time and adjust their data collection activities accordingly to suit the case study. Therefore, case studies selected had to fulfill these six requirements:

- Newly developed for tertiary-sector activities;
- Budget ranging between 5 and 15 million Euros;
- Footprint ranging between 2000 and 10,000 m²;
- Under certification by LEED or BREEAM;
- Comply with European Union directives;
- Accessibility to the stakeholders involved in the design phase.

The last requirement was key in order to make the research feasible. Researchers needed to identify the different stakeholders involved in each case study, as well as to communicate with them directly. Design processes had to be tracked down from the viewpoint of time (delays), cost (direct and indirect), and level of sustainability. Each case study had to be analyzed from the perspective of each of the three dependent variables and, therefore, information related to each variable had to be available, well-defined, and trackable throughout the whole process.

Considering those six requirements, the chosen case studies were the following:

1. School complex located in Trento (Italy), certified by LEED [31], with a total budget of approximately 13.2 Million Euros and a total gross footprint of 6000 m². This was the pilot case study;
2. Nursing home complex located in Volano (Italy), certified by LEED [31], with a total budget of approximately 11.0 million Euros and a total gross footprint of 5965 m²;
3. Office building located in Barcelona (Spain), certified by LEED [31], with a total budget of approximately 7.5 million Euros and a total gross square footprint of 3000 m²;
4. Office building located in Alicante (Spain), certified by BREEAM [32], with a total budget of approximately 14.0 million Euros and a total gross square footprint of 5885 m².

This last case study (#4) was the only one delivered using the Design-Build approach. The other three were delivered under the traditional method (Design-Bid-Build).

3.4. Case Study Analysis

Processes and activities implemented for project data collection were standardized during the development of the pilot case study protocol. Information proceeded from two main sources: Documentation [40] and interviews [46]. For both cases, the extrapolation of the required information followed the protocol, which was determined and verified during the pilot case study. Project management practices and specific software were implemented in different case studies. Documentation and interviews were standardized, and scheduling and estimating techniques were implemented, which allowed researchers to repeat the process for each case study [28,48]. Sustainability-related information and results were calculated on the basis of the green building reference standards used for each building certification process [31,32].

Dependent variables identified time, cost, and sustainability. Independent variables refer to the project issues, identified using the concept of waste. For each dependent variable, the total impact “I” of all “i” project issues were estimated as the sum of the impact of a specific independent variable on all the activities considered (see Equations (1), (2), and (3)).

$$I_d = \sum_1^n i_{An(d)} + \sum_1^n i_{Bn(d)} + \sum_1^n i_{Cn(d)} + \sum_1^n i_{Dn(d)} + \sum_1^n i_{En(d)}, \quad (1)$$

$$I_{\epsilon} = \sum_1^n i_{An(\epsilon)} + \sum_1^n i_{Bn(\epsilon)} + \sum_1^n i_{Cn(\epsilon)} + \sum_1^n i_{Dn(\epsilon)} + \sum_1^n i_{En(\epsilon)}, \quad (2)$$

$$I_S = \sum_1^n i_{An(S)} + \sum_1^n i_{Bn(S)} + \sum_1^n i_{Cn(S)} + \sum_1^n i_{Dn(S)} + \sum_1^n i_{En(S)}, \quad (3)$$

where “I” represents the impact of all different “i” issues interfering in different “n” activities of each “A” to “E” waste category, for dimensions of time “d”, costs “€” and sustainability “S”.

This research protocol was based on the pilot case study, and they followed an iterative process [49]. For each project-related decision, such as the selection of variables or data collection, researchers would first decide on a technique, then implement it in the field, later correcting any mistakes or errors and, finally, re-implement the protocol until obtaining acceptable results. With the term “acceptable,” researchers intended a result upon which all subjects involved would agree. If some data, information, or number could not be approved by all subjects, the process was adjusted and re-proposed [40].

The results of the correlation between independent and dependent variables were summarized in three different tables (one for each dependent variable) for each case study. The numbers resulting from the calculations of the different variable related activities were then turned into percentages related to the total of each dependent variable: Time, cost, and sustainability variances. As described later in more detail, the units of measurement considered for each of the three dependent variables were:

- Working days for the time variance: Considered as the additional working days of delay for the completion of critical and non-critical activities caused by project management issues;
- Euros for the cost variance: Considered as the extra costs paid by the owner and by all stakeholders involved caused by project management issues;
- LEED or BREEAM points for the sustainability variance: Considered as the unsuccessful achievement of the original green building score expected at the beginning of the project due to project management issues.

Furthermore, the protocol developed during the pilot case study project was verified by the researchers through two different techniques: Interviews [46] and previous research [41]. Interviews helped with the subjects directly involved in the process and unanimously demonstrated the validity of the results. 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.

Following [41], this study was developed considering the cross-case analysis approach based on the implementation of a specific theory. As stated previously, the unit of analysis of this research is the process of design of a green building project. The comparative process of the case studies implemented for this research was based on replication logic, under which each case had to be selected to predict similar results.

3.5. Cross-Case Study

In addition to the general strategies described above, two other techniques were also implemented to analyze the case study evidence: Explanation building and cross-case analysis [41]. Explanation building focuses on analyzing the case study data by building an explanation. In this context, the researchers focused on developing a set of causal links on how or why something happened [40]. The process was iterative and involved the use of initial predictions and their comparison against the case study evidence [47]. Then, based on any variances, the initial predictions were revised and compared against additional evidence. This process was repeated until a satisfactory match was obtained for different aspects of the present research [40,41]. The process was considered to be satisfactory when all subjects involved agreed upon the results obtained.

Evidence proves that case studies that implement both direct-case and cross-case analyses are more effective at generating theoretical frameworks and formal propositions than studies using only one of the two approaches [50]. On the basis of these concepts, researchers focused on developing a direct approach through the use of one pilot case study and corroborating it afterward using cross-case analysis with the other case study projects. For such goals, the researchers first implemented the variables (dependent and independent) found for the pilot case study, then adjusted them depending on

the results obtained from the other case studies [51]. In this stage of the research process, the comparison between cases also focused on the different levels of project delivery integration: Design-Bid-Build vs. Design-Build contracts. Furthermore, researchers referred to the LEED and BREEAM protocols only as standardized definitions of sustainability, and not as absolute evaluation methods for building sustainability. The fact of referring to common reference standards throughout different projects allowed having a common baseline for defining the concept of sustainability and, therefore, evaluating all projects using the same metrics.

4. Results and Discussion

4.1. Case Study Analysis

Results were grouped into three dependent variables: Time, cost, and sustainability. The total amount of time lost due to sustainability-related problems were estimated on the basis of the bar-chart schedule results developed using the software, Microsoft Project. Within the bar-chart, sustainability-related problems previously identified by the researchers were counted 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. Different colors were used to classify normal activities (blue), sustainability-related activities (green), sustainability-related problems (red), project-management-related problems (orange), and project-management-related activities (yellow). Not all project activities were considered for the purpose of the present research, only sustainability-related activities and project milestones.

A critical path was then calculated on the basis of the scheduling and project management concepts [18], along with the free-float and total-float of each activity. The duration of all sustainability-related problems included on the project's critical path accounted for the total project delay. The duration of all sustainability-related problems of the whole project bar-chart accounted for the total loss of time, as represented in Figure 2.

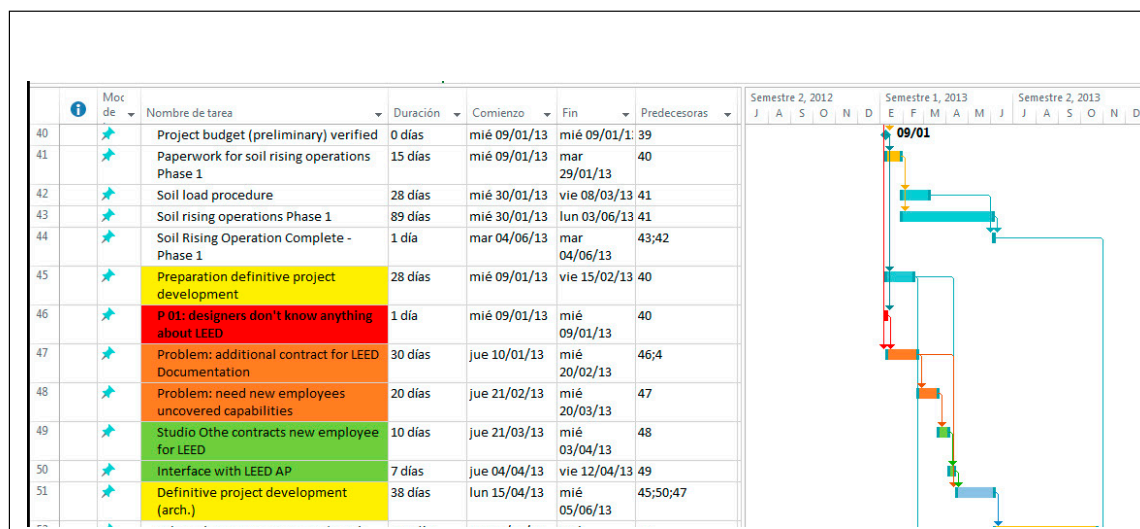


Figure 2. Gantt chart showing sustainability-related problems (red), project-management-related problems (orange), sustainability-related activities (green), and project management-related activities (yellow).

Cost analysis was divided into two categories: Direct and indirect costs. The term “direct costs” identifies all expenses caused by the sustainability-related challenges that the owner had to bear in addition to the original project budget to complete the design process. The term “indirect costs” identifies two types of costs: (1) Additional costs caused by sustainability-related problems that technicians involved in the project had to bear with no additional compensation to their professional fee for

developing the expected product, and (2) additional costs caused by the effects of sustainability-related problems, which affected third parties and later, project development phases. All costs were estimated in Euros, either through interviews or project documents.

Results for sustainability-related points were estimated on the basis of green building standards and taking the whole possible score identified at the beginning of the project as a reference. The researchers focused on all LEED or BREEAM points that finally could not be achieved due to project management issues related with sustainability (categories A to E cited above). Before starting the design phase, the project team estimated a possible score, filling up a preliminary checklist, including the design and construction stages. During the design stage, the project team realized that not all credits could be fulfilled, some of them due to proper project features and others due to project management related issues. The results for each case study (#1, #2, #3, and #4) are summarized in Tables 1–4, respectively.

Table 1. Results of case study #1 (school complex)

	Lack of Integration	Commissioning Authority Tasks	No Appropriate Clauses in Bid Documentation	Reduction of Project Budget	Energy Modelling	TOTAL	%
Additional Time (Working Days)	9	5	128	23	0	165	30.0
Indirect Additional Costs (€)	500	0	500	4500	4500	10,000	4.2
Direct Additional Costs (€)	8000	14,000	18,000	6000	8000	54,000	22.4
Green Value (LEED points)	1	1	0	3	5	10	11.8

Table 2. Results of case study #2 (nursing-home project)

	Lack of Integration	Commissioning Authority Tasks	No appropriate Clauses in Bid Documentation	Reduction of Project Budget	Energy Modeling	TOTAL	%
Additional Time (Working Days)	37	39	18	40	41	175	29.2
Indirect Additional Costs (€)	5730	500	1700	4400	10,500	22,830	8.3
Direct Additional Costs (€)	0	38,000	35,000	5000	0	78,000	28.3
Green Value (LEED points)	2	1	0	4	7	14	16.3

Table 3. Results of case study #3 (office building in Barcelona)

	Lack of Integration	Commissioning Authority Tasks	No appropriate Clauses in Bid Documentation	Reduction of Project Budget	Energy Modeling	TOTAL	%
Additional Time (Working Days)	1	6	0	6	10	23	4.9
Indirect Additional Costs (€)	2300	600	0	300	0	3200	6.7
Direct Additional Costs (€)	7500	2500	1500	9000	5100	25,600	53.4
Green Value (LEED points)	0	0	1	0	2	3	3.6

Table 4. Results of case study #4 (office building in Alicante)

	Lack of Integration	Commissioning Authority Tasks	No appropriate Clauses in Bid Documentation	Reduction of Project Budget	Energy Modeling	Other Non-Related	TOTAL	%
Additional Time (Working Days)	0	0	0	0	0	0	0	0
Indirect Additional Costs (€)	0	0	0	0	0	0	0	0
Direct Additional Costs (€)	0	0	0	0	0	0	0	0
Green Value (LEED points)	0	0	0	0	0	-4	-4	-4.7

Categories of project waste (independent variables) occurred during the design process and may be linked to time, direct costs, indirect costs, and green building values (dependent variables). The tables highlight the project factors that caused project wastes or losses (not gains), in terms of time, cost, and sustainability. In case #4, no waste in the project was detected, thus, the zeros in Table 4. However, it instead gained sustainability points throughout the process. According to the technicians and other stakeholders involved in the process, this gain was unexpected and could not be related to any variable considered for the development of this study. Considering that Tables 1–4 display the “waste” of each dependent variable, as stated previously, gaining four BREEAM points of sustainability must be represented as a negative result in Table 4. Hence, they have been introduced in the Table as an “other non-related” variable.

Waste-related issues identified (independent variables) are:

- Lack of integration between the technicians involved and bad-timing for green building activities: The project design team was formed by veteran technicians accustomed to developing the project following the development process ruled by the Italian legislation, already based on EU regulations. LEED imposed the overlap of project activities through a more integrated process, generating problems between technicians [1,26], as everyone had to participate in each other’s part of the project. This fact, along with other misunderstandings, generated friction between the participants involved, slowing down the whole design process [19,29], and threatening the achievement of the LEED credits.
- Misunderstanding of Commissioning Authority’s activities and process: The Commissioning Authority is, in brief, a consultant hired by the owner, responsible for ensuring that the design and construction of the mechanical components comply with the owner’s requirements and expectations [3]. The design team leader did not bring in the Commissioning Authority until the very last phases of the design. Thus, the design was not exposed to the analysis of the Commissioning Authority until the end of the design, when all shop drawings, estimates, bid specifications, and related documents had already been approved and closed. Within the European system, project-related documents, estimates, and specifications are developed by designers, not by general contractors. To avoid change orders during the construction phase, the Commissioning Authority should always be hired during the design process. This did not happen in the nursing home project (#2) where, for example, the Commissioning Authority could not insert proper clauses for the activities that had to be performed during the construction stage, causing an estimated extra cost of 30,000 Euros during the construction phase.
- No appropriate clauses in bid documentation: Poor bid clauses refer to sustainability-related issues that were detected in some case studies. Because of the owner’s inexperience or technician’s misunderstanding, not all aspects of sustainability were properly assessed during bid clause formulation [1,24]. For example, in one case, the clauses related to the production of LEED documentation were not considered, which led to an additional cost of 30,000 Euros claimed by

the design company (case #2). In case #1, the development of inexact clauses, such as the reference to the wrong standard, led to the redefinition of the whole bid documentation, with an added cost of 5000 Euros for consulting services and bureaucracy.

- Systematic cuts to budget due to change orders and delays: The more delays that affect the design phase, the higher the costs of material, labor, and equipment increase, and, consequently, the shorter the budget becomes. As a result, for projects suffering severe delays at each design step, the team had to apply cuts and re-define the original design, which also affected the green building points of the project [23].
- Misunderstanding of the energy modeling role and process: As for the Commissioning Authority, technicians did not quite understand the importance and the development process of the energy modeling until the final design phases [10]. In some cases (#1 and #2), energy modeling was not considered in the initial bid clauses due to the owner's decision, thus, no one was formally appointed as Energy Modeler when the contract was signed. Mechanical engineers took over the task during the design phase, but they did not have experience in developing energy modeling for LEED. By the end of the final design stage, technicians realized they were not able to do it. An external professional Energy Modeler was contracted by the engineering firm with an additional cost of 10,000 Euros. However, by the time the simulation was ready, the final design had already been approved, along with the project estimate, and the construction bid had already been published. The energy simulation did not match the expected results [10]. However, no changes could be made as the project had already been approved and bid out. This problem, apart from generating extra costs during the design process, avoided the achievement of several points under the energy-efficiency credit.

4.2. Cross-Case Analysis

After completing the analysis on the different case studies, the research team focused on comparing the results obtained, separating the analysis for each dependent variable (time, cost, and sustainability), as suggested by [41]. Each of them is analyzed in the following paragraphs.

4.2.1. First Dependent Variable: Time

From the time variance perspective, there is a substantial difference between the first two case studies (#1 and #2) and the other two (#3 and #4). While the school (#1) and the nursing home (#2) projects suffered a delay of almost 30%, both office buildings (#3 and #4) were completed with a delay of less than 5%. According to the results and information retrieved through the interviews and document analysis, the cause of this problem was the process fragmentation, as defined under the lean approach [42,43,52]. Each subject would interact with the other ones occasionally on a random-schedule basis when a problem occurred. Therefore, the process integration was done on the basis of an interventionist, not a prevention procedure.

The scheduling was developed at the beginning of the work by technicians, and it was later validated by the owner. However, it was neither accurate nor detailed [17,48]. As a result, the planning tasks related to several activities that remained uncovered. The process that appeared to be fluent presented several gaps, which remained hidden during the design phase [17,23]. Thus, such problems that may be solved without difficulties became hidden problems that would eventually come to the surface by the time they needed to be solved, turning activities from important to urgent [15]. This would suddenly drain resources and, consequently, impact the entire schedule.

One key difference between the first two case studies (#1 and #2) and the other two (#3 and #4) was the perception of the importance of time. According to the information retrieved during the case analysis, in different case studies, the participants involved, along with the owner, gave different priority to the time variable. Out of the three dependent variables identified by the researchers, not all of them had the same importance throughout the process. In many cases, the owner had to solve problems by managing time, cost, and sustainability. The first two cases (#1 and #2) were publicly

funded. Hence, the time and sustainability variables were often sacrificed to the benefit of the cost variable [22,25]. Moreover, in such cases, often the time variable appeared to be considered as the least important of the three. On more than one occasion, during the school (#1) and the nursing home (#2) projects, the decision-making process for the issue of missing a sustainability-related activity/service, was solved choosing one of these alternatives: (a) Adding more resources and, therefore, increasing costs (schedule-crashing), (b) avoiding the sustainability-related benefit, and (c) providing the missing service and delaying other activities.

Most of the time, the last option was chosen. The lack of importance given to the time variable is demonstrated by the delays suffered during the completion of the first two case studies (#1 and #2). Each of them experienced a delay between 165 and 175 working days only for sustainability-related activities. This fact alone highlights the propensity of project owners to sacrifice the time variable to the optimization of the variable related to sustainability. This fact shows a specific hierarchy for the first two public-owned projects, in which the project budget could not be varied, and therefore, remains the first priority. Sustainability may be varied, but if the problem can be solved by adding time, the owner would rather wait. Thus, the hierarchy of dependent variables for the first two projects is the following: (1) Cost, (2) sustainability, and (3) time.

In contrast, according to the information retrieved, for the other two projects analyzed (#3 and #4), time was a major issue. Stakeholders interviewed for these cases declared that the schedule deadline was included as a major contractual clause from the beginning of the design phase and, therefore, any delay would be considered as an exception, almost the same way as a contractual breach. This different perception of the importance of time within the process development, as well as the different management associated with it, led the projects to have different delays both from the variance perspective, as well as in absolute value. The first two projects registered a delay between 29.2% and 30.5% in terms of variance. However, the private-owned projects suffered a delay ranging from 0.0% to 4.9%.

4.2.2. Second Dependent Variable: Cost

The cost variance also registered substantial differences from case to case. The only project that suffered a substantially lower cost increment was the one developed in southern Spain (#4) through the Design-Build procedure. Results do not demonstrate a linear relationship between the magnitude of the cost variance and the magnitude of the project budget. Therefore, the research highlights the lack of linearity between the level of integration and cost variance when applying the Design-Bid-Build system. In other words, this study does not indicate that a better level of integration within the Design-Bid-Build system, as reported for case study #3, which necessarily leads to a lower cost variance in terms of percentages.

A different perspective has to be implemented for the Design-Build process (case study #4), in which the cost variance result was zero. This project is the only one that was completed on time and under budget. Therefore, regarding the cost-independent variable, it was concluded that:

- The level of integration within a Design-Bid-Build process affects the cost variance of the design phase from a non-linear perspective;
- For a Design-Bid-Build process, the cost variance results are lower in terms of absolute values for projects implementing a higher level of integration;
- For a Design-Bid-Build process, the cost variance results are higher in terms of percentages for small projects even when implementing a higher level of integration;
- For a Design-Build process, the cost variance resulted to be zero.

Notably, in terms of absolute values, the projects that suffered the greatest cost variance were the ones in which the variable “cost” was the most important of the three [22,25]. As already cited above for the time variance, each project owner had a different order of priorities for each of the three dependent variables. For the school (#1) and the nursing home (#2) projects, the most important

variable was always the “cost”, mainly because, as explained, it depended on public funding, which had already been approved and could not be changed. However, these projects also had “time” as the least important variable and, according to this analysis, these two variables are heavily related to one another. Most of the issues that generated the cost variance depended on delays, which imposed change orders, project re-manufacturing tasks, and other expensive activities [48]. Therefore, it is important to note that cost variance and time variance depend on each other. From a project management perspective, as well as during the design phase of a green building project, time is money.

4.2.3. Third Dependent Variable: Sustainability

For all projects developed under the Design-Bid-Build process (#1, #2, and #3), project sustainability was never considered a priority. Even when in multiple interviews, where owners and technicians committed to sustainability, this was often put aside when cost-related problems arose. Out of these three, none of the project budgets was ever modified for a sustainability-related problem, and this had severe consequences on the final level of the sustainability of the project. According to [9], a key aspect of the delivery of high-performance and sustainable building is the process integration and the focus on sustainability as a primary requirement, second to no others. This was fulfilled only for case study #4 and, according to the gathered information, it may depend on a different perception of the project.

All projects analyzed for the purpose of this study had to adjust the procedure to the new project conditions or requirements, which was determined by various factors. However, the research team noticed a substantial difference between the way this procedure was developed in the last project (#4) versus the other three. For the BREEAM score upgrade, the design team implemented the so-called “schedule-crashing” practice [53], under which, having a greater amount of work with a fixed deadline, the company decides to put more money into the project and accelerate the process when possible. In the other projects, the system was more a push system, where the completion of activities was scheduled at the time they were about to start, not before [47,48]. For example, in case study #2 the owner would wait for the response of the Water Resources Department before scheduling other activities. No master scheduling plan was implemented. Moreover, for sustainability, there was no effort to prevent problems, but to solve them as they came. The results obtained highlight the strong relationship between project management and project sustainability. Not only do the sustainability-related activities have a substantial impact on the project management process, but also the way the project management process is performed. In other words, a poorly planned process for the achievement of the various green building features of the project would cause an impact on the project costs and schedule. However, alternatively, a poorly managed project would also negatively impact its green building features.

It is important to note that, for the purposes of this work, the research team did not consider the final LEED or BREEAM certification achieved by each building, only the level of sustainability itself. In other words, both standards were implemented as tools to quantify the concept of sustainability for buildings. Therefore, the results of the present study focus on how much sustainability a building could lose regardless of the level of green building standard achieved. Nevertheless, the loss of sustainability points suffered by the school (#1) and the nursing home (#2) projects was so significant that it determined a lower rating on both final building certifications.

4.2.4. Cross-Case Analysis: General Considerations

The Design-Bid-Build projects (#1, #2, and #3) were affected by processes not leveled and lacked integration. All the case studies analyzed for the purpose of this research and that suffered the most severe issues for all three dependent variables were developed through the Design-Bid-Build process and presented, as primary causes, a lack of integration between technicians and the poor organization of the process-leveling activities. The only project developed through the Design-Build procedure that did not suffer any of the problems experienced in the other case studies. This highlights the potential improvement of process integration through the implementation of the Design-Build method [24].

On the other hand, the project manager takes responsibility for all project activities, including the sustainability-related ones. Many potential issues of the projects analyzed were prevented by the correct behavior of the project manager, who could manage both technical and sustainability-related activities. This highlights the importance of integration, not only from the viewpoint of physical workspaces and/or procedures, but also from a knowledge perspective [39,47,52]. According to the information retrieved by interviewees, the success of delivering an integrated design process also depended on the capability of preventing mistakes and each subject specializing in one particular construction field. Often each subject did not realize the presence of a mistake until another technician came in. The presence of one subject supervising the process with a multi-disciplinary knowledge avoided many potential issues.

Furthermore, process integration and interdisciplinary roles play a key role for the whole process optimization. All subjects involved in the process should blend in the team in early phases, and project issues should be brought to the attention of all technicians in order to have a multi-disciplinary problem-solving procedure. This concept, which strongly reflects a more integrated project delivery approach, should interest all main project activities, such as scheduling, estimating, management, engineering, and sustainability.

5. Conclusions

Implementation of Anglo-American protocols, such as BREAAAM or LEED, within the European reality, arise project management issues during the project design phase. These issues are generally linked to variables such as time, costs, and green building values. This research has highlighted four main problems that affect the design process:

- Green building activities overlap with regular project management activities, generally with bad timing. This causes misunderstanding between technicians, and it reflects a lack of integration of the design team;
- Change orders and delays cause systematic cuts to budget due and re-definition of the original design, affecting the green building points of the project too;
- There is a lack of appropriate clauses regarding sustainability in bid documentation. This often leads to the redefinition of the documents, adding cost due to consulting services and bureaucracy;
- Key stakeholders are hired very late in the process. The main examples are the Energy Modeler and the Commissioning Authority. Thus, verification that the energy model and the mechanical components comply with the owner's requirements cannot be done properly during the design phase.

Therefore, on the one hand, a poorly planned process for the achievement of the various green building features of the project could impact the project schedule and the budget. On the other hand, a poorly managed project could also negatively impact its green building features.

Furthermore, another important contribution of this research is that it identifies a positive relationship between process integration and implementation of sustainability through well-recognized standards such as LEED or BREEAM in the development of green building projects. Integration can be understood as physical integration, where all stakeholders interact first-hand with each other and are directly exposed to potential issues. It can also be understood as timely integration, where stakeholders interact on a frequent basis and solve the problems as they arise. This concept of integration in relationship with the development of green building projects has a great potential impact on business. As building developments become more and more international, the green building reference standards are growing as a global benchmark for establishing the quality of buildings. For such international projects, this research demonstrates the importance of process integration, which could possibly prevent some major problems that may occur if conditions similar to the case studies are replicated. The relationship between process integration and optimization of sustainability features

in green building developments serves as guidance for international projects developed through a highly fragmented process.

The case study analysis focuses on the comparison of projects developed through the two main procedures currently available worldwide, the Design-Bid-Build and the Design-Build. Several studies have already demonstrated the benefits of the Design-Build versus the Design-Bid-Build approach for general project management purposes due to its higher level of integration. This research demonstrates the positive relationship between process integration and green building design development. Therefore, on the basis of the literature review and of the results obtained, this research also establishes that the Design-Build approach is a more suitable procedure for green building developments.

This research, being exploratory, has several limitations regarding the analysis of time, cost, and sustainability. Estimating the delay of single activities was sometimes difficult and ambiguous as it depended on other activities. By matching data coming from interviews and project documentation, the authors determined the duration, floats, predecessors, and successors of each activity. However, in some cases, the bureaucratic and management processes were so complicated that none of the stakeholders involved knew what each activity depended on. The reason for this was the lack of integration and coordination of the process. Therefore, for the purpose of this research, activities with undefined scheduling features were not considered individually, but as part of groups of activities (milestones) whose start and end points could be determined univocally.

Future research studies may include more detailed analysis for estimating time and cost. Furthermore, to validate the results obtained, future research should be carried out on the basis of other standards than LEED and BREEAM. Additional studies may also consider extending the research to other European Union countries where construction culture and design and construction processes may be different from Italy and Spain. Different project and owner types could also be taken into consideration. Finally, a generalizable survey instrument could be generated to check the level of project delivery integration in green buildings.

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