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Barriers to Adopting Lean Methodology in the Portuguese Construction Industry

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Abstract: The Lean methodology allows for the streamlining of management and production systems to reduce costs. In the case of the construction sector, the goal is to optimize processes, reduce waste, increase product quality, and increase client satisfaction. These have been areas where construction, as a sector, is struggling to deliver substantial results. Despite the potential benefits associated with Lean approaches, there has been significant resistance from the construction industry. The main objective of this research is to identify the barriers to applying Lean methodology in the Portuguese construction sector. This will contribute to understanding why Lean is not gaining traction among construction stakeholders and help to identify improvement areas replicable in similar markets. Initially, the barriers were identified based on a comprehensive literature review, and those barriers were evaluated based on their importance using a survey responded to by construction sector professionals. Based on the survey's results, 15 barriers were considered critical. Additionally, a combined ISM model and MICMAC analysis was developed to study the relations between these barriers and the driving and dependence power of each one of the critical barriers. The results obtained show that the main barriers are the lack of support and commitment from top management, a lack of organizational communication, a lack of communication and transparency between stakeholders, unsuitable organizational structures, a lack of adequate Lean awareness and understanding, management resistance to change, and employees' aversion to change and fear of new procedures.

Keywords: ISM; Lean methodology; MICMAC; mitigation measures

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1. Introduction

Construction represents 9% of the EU's GDP and 13% worldwide. The industry employs 7% of the global workforce [1,2]. In Portugal, the construction sector was 9.9% of the workforce and 5.9% of the country's GDP in 2008, but due to the economic crisis, its workforce share decreased to 6% in 2013, and its contribution to GDP fell to 3.5% in 2016. As of 2018, it employed 6.1% of the workforce and contributed 3.6% to the country's GDP. In 2021, the construction sector comprised 5% of Portugal's total GVA [3,4]. Although the economic relevance of the construction sector is well known, there have been several dimensions where the sector has not delivered substantial improvements, unlike other economic sectors.

These dimensions include the overall cost of projects, the level of productivity, the level of innovation, the duration of project completion, compliance with established deadlines, the number of defects and unconformities, the extent of rework required, the degree of customer satisfaction, and the troubling record of health and safety within the industry [5].

Most of these challenges are related to well-known problems in the construction sector, particularly the low level of industrialization and a suboptimal project organization and management model.

In the last few decades, different approaches have been followed, such as Total Quality Management (TQM), partnership relations, Business Process Reengineering (BPR), supply chain management, and Lean, to name a few. Although Lean has attracted some attention [5], a generalized adoption has been minimal.

The main objective of this research is to conduct an extensive examination of the factors hindering the successful adoption and implementation of Lean methodology within the construction sector in Portugal. The focus of this research is to identify the key barriers preventing the widespread acceptance of Lean methodology and to delve deeper into the interconnected nature of these barriers, exploring how they are related to each other and their effect on implementing Lean methodology. This will contribute to understanding why Lean is not gaining traction among construction stakeholders, and will help identify improvement areas replicable in similar markets, particularly in the European Union (EU) where there is an "open-market" model.

Through an in-depth analysis of the barriers, this research aims to gain a comprehensive understanding of what obstacles prevent the implementation of Lean in construction. This research also aims to suggest mitigation measures to overcome these identified challenges and promote the use of Lean methodology in the construction industry in Portugal.

This paper is organized as follows: after this introduction, Section 2 presents the literature review; Section 3 describes the methodology; Section 4 presents the results, followed by the main findings and discussion of the mitigation measures in Section 5; and Section 6 concludes.

2. Literature Review

2.1. General Definition

The Lean methodology is based on the Toyota Production System. The TPS is based on the complete elimination of waste. This system has two main characteristics: just-in-time production and autonomation. Just-in-time production means that each part of the car would only arrive at the assembly line exactly when needed and in the exact amount needed. Autonomation, also known as automation with a human touch, focuses on using autonomation machines equipped with an automatic stopping device that activates if a mistake occurs in production. This means that no faulty equipment is produced, and it is easier for the managers to become aware of machine problems, therefore allowing an improvement in such machines [6].

Koskela [7] established the principles of Lean Construction (LC). Koskela states that to successfully apply LC, the companies need to reduce the share of non-value-adding activities, with a value-adding activity being one that transforms material or information into what the client requires. Koskela's principles also include reducing product variability and cycle time (amount of time it takes to complete a process from start to finish). These two principles are interconnected and can be tackled by applying just-in-time production or reducing batch sizes. Increasing output flexibility is also important, as it helps organizations adapt to changing customer needs. Koskela also refers to the continuous need to pursue improvements and the importance of benchmarking to compare the company's processes to other companies in the market.

Womack and Jones [8] established the five principles of Lean thinking. The first principle is value identification. The authors state that the customer determines the value of a product and this can be related to price, quality, or capabilities. According to Dulaimi and Tamanas [9], construction must adopt a product-focused approach that allows a long-term dialogue to begin about the nature of value and the way the product delivers it. The customer wants a building that meets his needs while being cost-effective. Howell and Ballard [10] established that specifying value comes before design in the construction industry.

2.2. Barriers to Lean in the Construction Sector

The literature provides several studies that have identified the reasons behind the lack of LC implementation in the construction industry worldwide, with dozens of barriers being identified as part of the problem. This section will analyse the main contributions of past literature that have allowed us to identify the main barriers and create a new set of barriers to analyse for the specific case of the Portuguese construction sector.

Dulaimi and Tanamas [9] studied the requisites and barriers to implementing LC. For this study, managing directors and construction managers from selected Singapore ISO 9000-certified construction firms were interviewed. Based on the interview results, the authors concluded that most companies only applied certain aspects of LC and established the lack of commitment to change as the main barrier.

Sarhan and Fox [11] identified the barriers to implementing LC in the United Kingdom that justify the limited implementation of Lean in the country's construction industry. The authors conducted a survey to evaluate which barriers are critical. The barriers were evaluated between 1 and 5. The survey identified three barriers with results higher than 4 and considered them as critical barriers: the lack of Lean understanding (4.30), the lack of commitment from the top management (4.06), and culture and human attitudinal issues (4.04). The last barrier includes the lack of commitment from workers or ineffective communication.

Kumar and Kumar [12] surveyed the critical barriers to implementing Lean methodology in the Indian industry. The authors considered that Lean is used in India as an improvement tool instead of adopting Lean culture. The barriers identified were divided into seven categories: management, resource, knowledge, conflicts, employee, financial, and experience. Each group was evaluated between 1 (insignificant) and 5 (highly significant). The management group was considered the most important barrier (3.94), and experience was considered the least important (2.94).

Shang and Pheng [13] studied previous research on Lean barriers to determine which ones were barriers to implementing LC in China. For this study, twenty-two different barriers were analysed on a large-scale survey of ninety-one Chinese construction professionals: thirty-four general managers, twenty-three project managers, fifteen engineers, five contract managers, four quality managers, three regional managers, and seven professionals whose position was not stated. All the barriers were evaluated using a Likert Scale between 1 (insignificant) and 5 (highly significant). All twenty-two barriers obtained a result higher than 3, so the barriers were all considered significant. The results showed that the most important barriers were the lack of a long-term philosophy (3.85), the absence of a Lean culture in the organization (3.84), and subcontracting (3.84).

Cano et al. [14] identified the barriers and success factors to implementing LC, with 110 barriers identified during the literature review. The barriers and the success factors were divided into the following groups: people, organizational structure, supply chain, external value chain, internal value chain, and externalities. Based on interviews with 26 Colombian companies, it was concluded that only 56% of the barriers are present in the Colombian industry. This study considered stakeholders' lack of communication and transparency as the most significant barrier.

Khaba and Bhar [15] identified and analysed the critical barriers to Lean implementation in India. Based on experts' opinions, the authors identified thirteen barriers to LC. They established the barrier's hierarchy and the relations between barriers, evaluating the barriers' driving and dependence power using the ISM model and a MICMAC analysis.

Lodgaard et al.'s [16] study is based on twenty-eight interviews: four top managers, fourteen middle managers, and ten workers. These interviews showed that each group has different perspectives on the barriers to applying LC. The main difference is the importance given to Lean tools and practices that workers consider minor barriers while receiving more attention from the managers.

Bayhan et al. [17] conducted a study to help construction professionals better meet project requirements by identifying key enablers and impediments to Lean implementation in construction projects. The study suggests seven key enabler and barrier groups: financial, managerial, technical, workforce, culture, government, and communication. The study considered twenty-seven enablers and twenty-seven barriers. A survey was also created and given to Lean practitioners to rank the enablers and barriers according to their level of importance, from 1 to 5. The results showed that the lack of support from top management (4.61), a lack of Lean understanding (4.14), and a lack of information sharing (4.09) are the main barriers. The lack of government support was considered the least important barrier (3.04) but still significant.

Albalkhy and Sweis [18] identified and explained twenty-nine barriers and suggested a model to categorize the barrier's source. Four exogenous, five labour-related, three material-related, and seventeen internal environment-related barriers were categorized. The authors used the same thirty barriers to survey Jordan to study the barriers to LC. The survey was sent to 326 people: 41 owners, 107 consultants, and 178 contractors. The results obtained were similar for the three groups. For the owners and consultants, the lack of support from top management was the main barrier. Consultants evaluated this barrier with 4.05 and the owners with 4.12. The contractors considered stakeholders' lack of involvement and transparency the most important barrier (4.02).

2.3. Relations between Barriers

Khaba and Bhar [15] conducted a comprehensive study investigating the connections between various barriers to implementing the Lean methodology in construction. The study specifically looked at 13 different barriers that organizations may face when attempting to implement Lean principles:

Khaba and Bhar [15] established the relations between barriers and ordered the barriers by their driving power. Khaba and Bhar [15] defined driving power as the total number of barriers that a barrier helps achieve (including itself) and the dependence power of a barrier as the number of barriers that help achieve it. By analysing the barriers' driving power, the Authors placed them in four quadrants:

- Quadrant I—for autonomous variables characterized by their weak driving power and dependence.
- Quadrant II—for dependent barriers. These barriers have weak driving power but strong dependence.
- Quadrant III—for linkage variables. These barriers have strong driving power and strong dependence power.
- Quadrant IV—for independent barriers. These are the most important barriers, as they have strong driving power and weak dependence power.

2.4. Summary of Main Barriers

Based on the literature, the Authors created and classified a list of the main barriers summarized in Table 1.

Table 1. Barriers to adopt Lean Construction.

Code	Barrier	References
	Financial Barriers	
B1	Not recognizing the financial advantage	Kumar and Kumar [12], Khaba and Bhar [15], and Albalkhy and Sweis [18]
B2	Implementation cost	Sarhan and Fox [11], Khaba and Bhar [15], Bayhan et al. [17], and Albalkhy and Sweis [18]
	Communicational Barriers	
B3	Lack of organizational communication	Dulaimi and Tanamas [9], Sarhan and Fox [11], Kumar and Kumar [12], and Bayhan et al. [17]
B4	Lack of communication and transparency between stakeholders	Bayhan et al. [17] and Albalkhy and Sweis [18]
B5	Unsuitable organizational structure	Shang and Pheng [13] and Albalkhy and Sweis [18]

Table 1. *Cont.*

Code	Barrier	References
Barriers related to Input Factors (labor and material)		
B6	Employees' aversion to change and fear of new procedures	Kumar and Kumar [12], Shang and Pheng [13], Cano et al. [14], Bayhan et al. [17], and Albalkhy and Sweis [18]
B7	High turnover of the workforce	Shang and Pheng [13] and Albalkhy and Sweis [18]
B8	Low-skilled workforce with a lack of education	Dulaimi and Tanamas [9], Bayhan et al. [17], and Albalkhy and Sweis [18]
B9	Lack of Lean consultants and trainers	Khaba and Bhar [15]
B10	Inadequate delivery performance and material delivery delays	Shang and Pheng [13] and Albalkhy and Sweis [18]
B11	The lack of prefabrication and the limited usage of off-site construction techniques	Shang and Pheng [13] and Albalkhy and Sweis [18]
B12	Lack of long-term relationships with suppliers	Albalkhy and Sweis [18]
Barriers related to Management		
B13	Lack of green initiatives that reduce waste	Khaba and Bhar [15]
B14	Lack of identification and control of waste in the project and in the company	Cano et al. [14] and Albalkhy and Sweis [18]
B15	Lack of support and commitment from top management	Sarhan and Fox [11], Kumar and Kumar [12], Shang and Pheng [13], Cano et al. [14], Lodgaard and Ingvaldsen [16], Bayhan et al. [17], and Albalkhy and Sweis [18]
B16	Lack of adequate Lean awareness and understanding	Sarhan and Fox [11], Kumar and Kumar [12], Shang and Pheng [13], Cano et al. [14], Khaba and Bhar [15], Lodgaard and Ingvaldsen [16], Bayhan et al. [17], and Albalkhy and Sweis [18]
B17	Management resistance to change	Shang and Pheng [13], Khaba and Bhar [15], Bayhan et al. [17], and Albalkhy and Sweis [18]
B18	Lack of planning for quality	Khaba and Bhar [15] and Albalkhy and Sweis [18]
B19	Lack of understanding of customer needs	Sarhan and Fox [11], Khaba and Bhar [15], and Albalkhy and Sweis [18]
B20	Absence of long-term planning	Dulaimi and Tanamas [9], Kumar and Kumar [12], Shang and Pheng [13], Bayhan et al. [17], and Albalkhy and Sweis [18]
Technical Barriers		
B21	Lack of performance measurement systems	Sarhan and Fox [11], Khaba and Bhar [15], and Albalkhy and Sweis [18]
B22	Lack of knowledge of new technologies (BIM)	Sarhan and Fox [11] and Khaba and Bhar [15]
Exogenous Barriers		
B23	Excessive bureaucracy and inflexible licensing and approvals	Shang and Pheng [13], Bayhan et al. [17], and Albalkhy and Sweis [18]
B24	Lack of government support	Shang and Pheng [13], Khaba and Bhar [15], Bayhan et al. [17], and Albalkhy and Sweis [18]
B25	Fragmentation and subcontracting	Dulaimi and Tanamas [9], Sarhan and Fox [11], Shang and Pheng [13], and Khaba and Bhar [15]
B26	Lack of "design-build" procurement models	Sarhan and Fox [11] and Albalkhy and Sweis [18]
B27	Cultural differences in Western countries	Cano et al. [14] and Khaba and Bhar [15]

3. Methodology

3.1. Overall Methodology

To evaluate the importance of each barrier, a survey was conducted, obtaining 99 responses. Out of the 99 respondents, 12 were clients, 57 were consultants, and 30 were contractors. The results were thoroughly analysed and validated using the statistical methods explained in this chapter.

With two industry experts' help, the barriers' interrelationships were determined, allowing the development of the ISM method and MICMAC analysis. Combining the barriers' interrelationships and hierarchal structure, resulting from the ISM model, with their driving and dependence powers, from the MICMAC analysis, permits leveraging the discussion of the importance of the barriers and their relationships in adopting Lean [19]. The stages to achieve these relations were detailed in this chapter. Figure 1 represents the flowchart of the research stages in this research.

The first research method employed in this dissertation is survey research. This method is used to establish a list of critical barriers that are encountered when implementing LC in Portugal. Survey research enables the collection of data from many participants, providing a broad perspective on the critical barriers. This survey was sent to several

Architecture, Civil Engineering, and Construction (AEC) Portuguese sector professionals in November 2022. The respondents were asked to evaluate each barrier using a Likert scale in this survey. This scale ranges from 1 (not important) to 5 (extremely important) and allows respondents to indicate their level of agreement or disagreement with a statement or question. To ensure the validity of the Likert scale, it is crucial to assess its internal consistency using a statistical measure known as Cronbach's alpha [20]. To ensure consistency, the alpha must be at least 0.7 to be satisfactory. Anything above 0.8 is considered good, and above 0.9 is desirable for clinical applications [20].

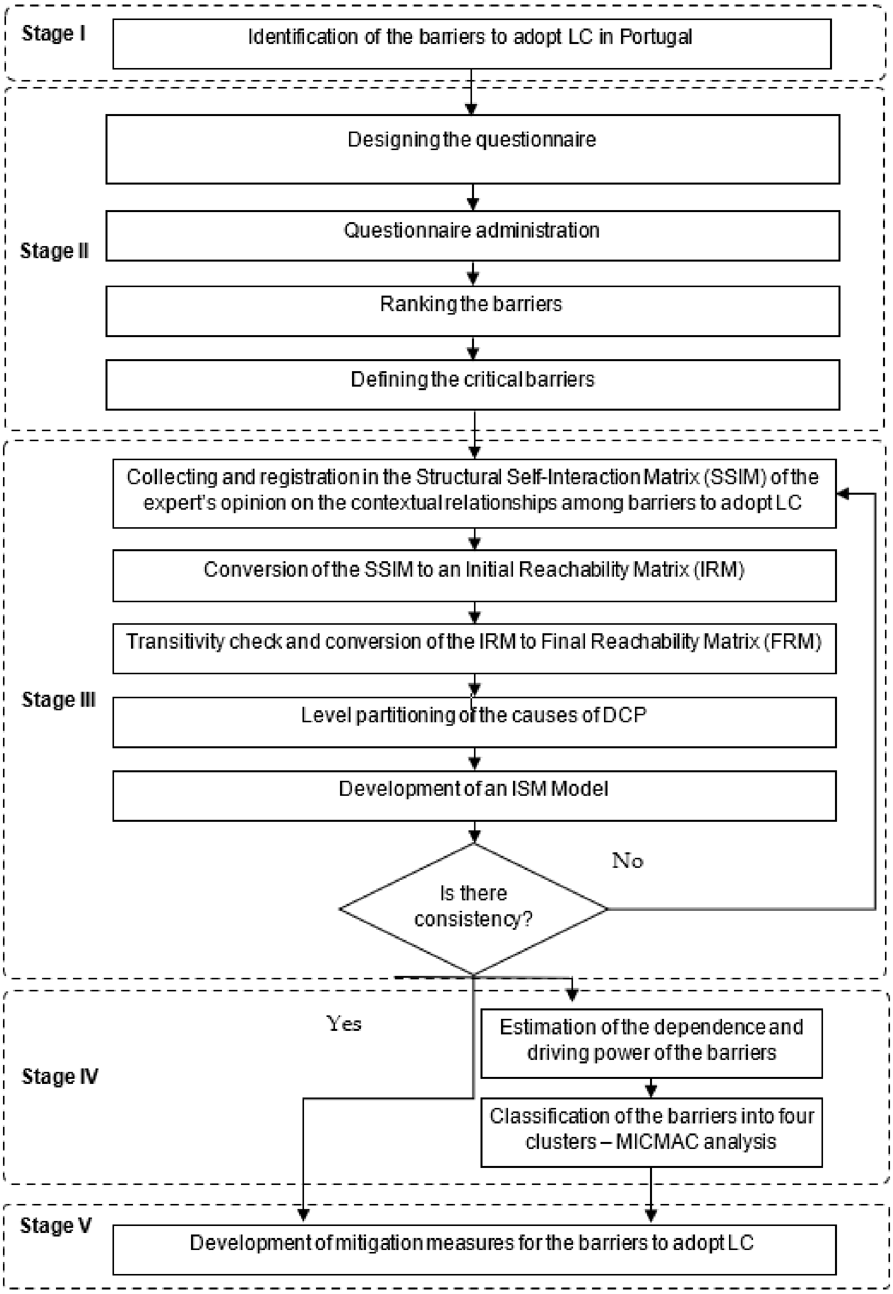

Figure 1. Research method stages.

3.2. Survey

The survey was conducted in November 2022, obtaining 99 answers from clients, consultants, and contractors, as shown in Table 2. The questionnaire administered to this study's participants was carefully crafted and divided into three separate and distinct sections. Each section was designed to elicit specific information from the respondents to understand their perspectives and experiences comprehensively.

Table 2. Number of responses from each group.

Group	Number of Responses	Frequency (%)
Clients	12	12%
Consultants	57	58%
Contractors	30	30%

The first section of the questionnaire focused on gathering information about the respondent's background and profile. This included questions about the respondent's occupation, years of experience in the construction sector, and whether the respondent has had any prior experience with the Lean methodology. The second section of the questionnaire was designed to inquire about the size of the company by which the respondents were employed. The final section of the questionnaire aimed to measure the respondent's opinions on the obstacles to successfully implementing Lean Construction in Portugal. In this section, the respondents evaluated each barrier using a Liker Scale. Overall, the questionnaire was designed to gather a wide range of information from the participants to gain a comprehensive understanding of their perspectives and experiences regarding the implementation of LC in Portugal.

Of the 99 respondents, only a small percentage, 17 in total, had prior experience with the Lean methodology. This information is crucial as it indicates that most of the participants were not familiar with the principles and practices of LC, which may have affected their responses to the questions related to the implementation of LC in Portugal. Regarding the years of experience in the sector, the numbers are shown in Table 3.

Table 3. Respondent's years of experience in the sector.

Years of Experience in the Sector	Number of Responses	Frequency (%)
≤5 years	12	12%
6 to 10 years	10	10%
11 to 19 years	20	20%
≥20 years	57	58%

It is imperative to have a sample size of respondents that surpasses 44 to draw valid and dependable statistical inferences with an adequate degree of assurance. This follows the research carried out by Forza [21], who asserts that a sample size of this proportion is essential for achieving a statistical power (β) of 0.8 at a critical level (α) of 0.05. This examination procured 99 responses by administering a questionnaire, which fulfils the criteria necessary for the conduct of statistical examinations, as stipulated by the study of Forza [21].

3.3. Statistical Analysis

A statistical analysis utilizing two methodologies was executed to evaluate the responses garnered from the various groups: Analysis of Variance (ANOVA) and Spearman's correlation coefficient. ANOVA is a statistical technique employed to examine the equality of means among two or more groups. The methodology contrasts the means of the various groups to ascertain if there are any statistically significant disparities between them. The null hypothesis posits that the means of all groups are equal, while the alternative hypothesis postulates that the mean of at least one group is distinct from the others. ANOVA allows us to determine if the differences between the groups are statistically significant and, thus, potentially meaningful [21].

Spearman's correlation coefficient assesses the strength and direction of a monotonic relationship between two variables. It varies from -1 to 1, where -1 represents a strong negative correlation, 0 indicates no relationship, and 1 indicates a strong positive correlation. Unlike Pearson's correlation, Spearman's can be used for non-normal distributions, and coefficients for non-normal data should be calculated from ranks, not values. Akoglu [22] states that values from 0.4 to 0.6 indicate moderate relations and values from 0.7 to 1 indicate strong relations.

3.4. Interpretive Structural Modelling

Interpretive Structural Modelling (ISM) is a flexible analytical method that enables comprehension of the interconnections between the various components in a system. The approach, which applies to various domains, including engineering, management, and social sciences, aims to identify key drivers shaping system structures and comprehend their interplay. By identifying the factors that have the most significant impact on the system, ISM provides researchers and practitioners with a roadmap to direct their efforts toward the most impactful areas, leading to more meaningful and practical improvements. Additionally, ISM makes it possible to identify leverage points to improve the system by understanding the interconnections between the key drivers. These leverage points can significantly enhance the system's performance through synergistic effects. The ISM methodology has been extensively researched and validated, as numerous studies have shown its effectiveness in understanding relationships and guiding improvements [15,23,24].

3.4.1. Structural Self-Intersection Matrix

Khaba and Bhar [15] and Eswarlal et al. [25] define the steps needed for the ISM methodology. The first step is to define the critical barriers that will be studied. The results of the survey define these barriers. With the list of barriers defined, the next step is to establish the relations between the barriers. In this step, every duo of barriers is evaluated using the following criteria:

- *V*—variable *i* has a direct impact on variable *j*;
- *A*—variable *j* has a direct impact on variable *i*;
- *X*—variable *i* and variable *j* have a mutual influence on each other;
- *O*—variable *i* and variable *j* do not affect one another.

The next step is to create the structural self-interaction matrix (SSIM). The SSIM is a matrix representing the relationships between different barriers being studied in a system. It is a matrix that highlights how each barrier affects the other barriers in the system.

3.4.2. Reachability Matrix

An Initial Reachability Matrix (IRM) is created from the SSIM by replacing each cell entry with either 1 or 0 following these criteria:

- *V* entry, the (*i*,) cell should be replaced with 1, and the corresponding (*j*, *i*) cell replaced with 0;
- *A* entry, the (*i*,) cell should be replaced with 0, and the corresponding (*j*, *i*) cell replaced with 1;
- *X* entry, both (*i*,) cells should be replaced with 1;
- *O* entry, both (*i*,) cells should be replaced with 0.

The IRM leads to the creation of the Final Reachability Matrix (FRM), which provides a more in-depth look at the indirect relationships between barriers in a system. The creation of the FRM begins with the IRM analysis and transitive reduction in relationships represented by a 1. Transitive reduction eliminates indirect relationships between variables that are not directly connected but are deducible through other relationships. As a result, the FRM will feature a relationship between A and C, even if there is no direct relationship between A and C in the IRM if barrier A directly relates to barrier B and barrier B relates to barrier C. This process is repeated for all relationships represented by a 1 in the IRM to form the FRM.

3.4.3. Level Partitioning

After completing the reachability matrix, the barriers will be divided into levels. To establish the relative relevance of each barrier, the technique of dividing them into various tiers is used. Three sets are created to split barriers into suitable levels efficiently. These sets are the intersection set, the reachability set, and the antecedent set. The reachability set includes the barrier in question and all barriers that are dependent on it. The antecedent set includes the barrier and all that affect or influence it. Lastly, the intersection set combines the reachability set and the antecedent set, representing the barriers that are both dependent on and affect the original variable. In the ISM hierarchy, barriers with the same reachability and intersection are designated as level I or top-level barriers. The process of determining the remaining levels is iterative, in which variables from the previous level are eliminated until all have been assigned to a level. Barriers in level 1 are on top of the ISM hierarchy and do not influence the other barriers. In the higher levels, the barriers are at the bottom of the ISM hierarchy and have a higher influence on the other variables.

3.4.4. ISM Model

Creating a directed graph based on the contextual linkages found in the reachability matrix is the method's sixth stage. Any transitive linkages that might be present in the reachability matrix are eliminated from the graph in this stage. Transitive links refer to indirect relationships between variables that are not directly connected but can be inferred through a chain of other relationships. Removing these links helps to simplify the graph and make it more accurate. Once the transitive links have been removed, an ISM model is generated by replacing the variable nodes in the graph with statements that describe the relationships between them. This model is then reviewed in the final step to ensure consistency and eliminate any unnecessary relations that may have been included. This step is critical to guaranteeing the final model's accuracy and reliability. To ensure a consistent and well-formed model, the needed adjustments are made.

3.5. MICMAC Analysis

The Matrice d'Impacts Croises Multiplication Appliques à un Classement (MICMAC) is used to analyse and classify a list of variables. This study uses matrix multiplication to evaluate each critical barrier's relative importance and influence in adopting LC in the Portuguese construction industry. The technique ranks the barriers based on the extent of their dependence on other variables and their ability to effect change. Dependency power refers to the number of variables affecting a particular barrier while driving power refers to the number of variables that a particular barrier affects. This approach provides a comprehensive understanding of the factors influencing the adoption of LC in the Portuguese construction industry by taking interdependencies between variables into account.

Those ranks divide the critical barriers into four groups: autonomous, dependent, linkage, and independent [26,27]. The autonomous group includes barriers with weak dependency and weak driver power. The dependent group includes barriers with high dependency and a low driving force. The linkage group includes barriers with high dependency and a high driving force. Finally, the independent group includes barriers with low dependency but a high driving force [15].

4. Results

To calculate Spearman's correlation coefficient, a ranking was created where the barriers were listed according to the evaluation of each group. The results are displayed in Table 4. As stated, results between 0.4 and 0.7 are considered moderate correlations, and anything above 0.7 is a strong correlation. Analysing the results, the clients and contractors have a weak connection; however, the coefficient is close to 0.4. The other combinations between groups have moderate correlations. The consultant's group is the one with the higher correlation with the global results, which can be explained by the fact that 58% of the respondents were consultants.

Table 4. Spearman's Correlation Coefficient.

Group	Client	Consultant	Contractor	Global
Client	1			
Consultant	0.692	1		
Contractor	0.393	0.659	1	
Global	0.714	0.957	0.805	1

The results obtained from the survey are displayed in Table 5. These results were considered valid by applying several tests, including the calculation of the Cronbach Alpha and by conducting a Levene test, an ANOVA test and, when necessary, a Welch test.

Table 5. Survey results.

Code	Barrier	Mean			
		Client	Consultant	Contractor	Global
B16	Lack of adequate Lean awareness and understanding	4.417	4.316	4.167	4.283
B10	Inadequate delivery performance and material delivery delays	4.250	4.053	4.367	4.172
B15	Lack of support and commitment from top management	4.250	4.105	4.133	4.131
B23	Excessive bureaucracy and inflexible licensing and approvals	4.000	4.088	4.233	4.121
B4	Lack of communication and transparency between stakeholders	4.083	4.035	4.267	4.111
B20	Absence of long-term planning	4.500	4.018	4.067	4.091
B3	Lack of organizational communication	4.167	3.930	4.333	4.081
B11	Lack of prefabrication and the limited usage of off-site construction techniques	4.083	3.912	4.367	4.071
B17	Management's resistance to change	4.250	4.105	3.767	4.020
B5	Unsuitable organizational structure	4.083	3.930	4.100	4.000
B14	Lack of identification and control of waste in the project and in the company	4.167	3.912	3.967	3.96
B21	Lack of performance measurement systems	3.833	3.930	4.000	3.939
B6	Employees' aversion to change and fear of new procedures	4.250	3.860	3.933	3.929
B18	Lack of planning for quality	4.250	3.842	3.900	3.909
B1	Not recognizing the financial advantage	3.917	3.789	4.067	3.889
B13	Lack of green initiatives that reduce waste	3.917	3.719	4.00	3.828
B25	Fragmentation and subcontracting	3.750	3.842	3.700	3.788
B22	Lack of knowledge of new technologies (BIM)	3.500	3.825	3.800	3.778
B2	Implementation cost	3.500	3.719	3.967	3.768
B9	Lack of lean consultants and trainers	3.583	3.719	3.900	3.758
B19	Lack of understanding of customer needs	4.333	3.754	3.500	3.747
B26	Lack of "design-build" procurement models	3.750	3.614	3.767	3.677
B12	Lack of long-term relationships with suppliers	3.667	3.614	3.767	3.667
B7	High turnover of the workforce	3.583	3.579	3.800	3.646
B8	Low-skilled workforce with a lack of education	3.833	3.474	3.867	3.636
B24	Lack of government support	3.083	3.649	3.800	3.626
B27	Cultural differences in Western countries	3.750	3.246	3.367	3.343

As stated before, the ANOVA method was used to study the differences between the respondent groups. To successfully use ANOVA, it is necessary to meet certain conditions. First, the sample must be collected independently, meaning that the inclusion or exclusion of other members should not influence each sample member. Second, the population from which the sample is drawn must have a normal distribution. A Levene test was performed to ensure that the third condition, homogeneity of variance, was met. The null hypothesis for this test is that the data's variance, or spread, is equal among all the groups of respondents. The alternative hypothesis is that the variance is not equal among all groups. The p-value, a statistical significance measure, is used to determine whether to accept or reject the null hypothesis. If the p-value is below 0.05, it is considered statistically significant, and the null hypothesis is rejected.

In this case, the Levene test showed that out of the list of barriers considered, the barriers of management's resistance to change (B17), the lack of understanding of customer needs (B19), and the lack of "design-build" procurement models (B26) had p-values below 0.05. This indicates that the variance for these barriers was not equal to that of the other barriers. Therefore, the homogeneity of variance was not met for this particular barrier. The authors performed the Levene test for the other barriers. When the Levene test had a p-value below 0.05, a Welch test was conducted instead of the ANOVA.

Table 6 shows the mean of each barrier and the results from the ANOVA and Welch tests. Using the global mean, the barriers with a higher mean were critical barriers and were therefore used in the ISM and MICMAC study. Since there is not a big difference between the means of each barrier, in order to define the critical barriers, the top fifteen barriers with a higher mean were considered critical barriers as Ma et al. [24], Olorunniwo and Li [28], and Wu at al. [29] state that to properly conduct an ISM study the maximum number of variables should be fifteen. The critical barriers are B1, B3, B4, B5, B6, B10, B11, B14, B15, B16, B17, B18, B20, B21, and B23.

Table 6. Mean results and ANOVA and Welch test results.

Code	Barrier	Mean				Anova	Welch
		Client	Consultant	Contractor	Global		
B16	Lack of adequate Lean awareness and understanding	4.417	4.316	4.167	4.283	0.608	----
B10	Inadequate delivery performance and material delivery delays	4.250	4.053	4.367	4.172	0.225	----
B15	Lack of support and commitment from top management	4.250	4.105	4.133	4.131	0.879	----
B23	Excessive bureaucracy and inflexible licensing and approvals	4.000	4.088	4.233	4.121	0.630	----
B4	Lack of communication and transparency between stakeholders	4.083	4.035	4.267	4.111	0.397	----
B20	Absence of long-term planning	4.500	4.018	4.067	4.091	0.160	----
B3	Lack of organizational communication	4.167	3.930	4.333	4.081	0.070	----
B11	Lack of prefabrication and the limited usage of off-site construction techniques	4.083	3.912	4.367	4.071	0.053	----
B17	Management's resistance to change	4.250	4.105	3.767	4.020	----	0.127
B5	Unsuitable organizational structure	4.083	3.930	4.100	4.000	0.564	----
B14	Lack of identification and control of waste in the project and in the company	4.167	3.912	3.967	3.960	0.633	----
B21	Lack of performance measurement systems	3.833	3.930	4.000	3.939	0.805	----
B6	Employees' aversion to change and fear of new procedures	4.250	3.860	3.933	3.929	0.446	----
B18	Lack of planning for quality	4.250	3.842	3.900	3.909	0.274	----
B1	Not recognizing the financial advantage	3.917	3.789	4.067	3.889	0.388	----
B13	Lack of green initiatives that reduce waste	3.917	3.719	4.000	3.828	0.338	----
B25	Fragmentation and subcontracting	3.750	3.842	3.700	3.788	0.784	----
B22	Lack of knowledge of new technologies (BIM)	3.500	3.825	3.800	3.778	0.43	----
B2	Implementation cost	3.500	3.719	3.967	3.768	0.273	----
B9	Lack of Lean consultants and trainers	3.583	3.719	3.900	3.758	0.568	----
B19	Lack of understanding of customer needs	4.333	3.754	3.500	3.747	----	0.002
B26	Lack of "design-build" procurement models	3.750	3.614	3.767	3.677	----	0.687
B12	Lack of long-term relationships with suppliers	3.667	3.614	3.767	3.667	0.754	----
B7	High turnover of the workforce	3.583	3.579	3.800	3.646	0.621	----
B8	Low-skilled workforce with a lack of education	3.833	3.474	3.867	3.636	0.214	----
B24	Lack of government support	3.083	3.649	3.800	3.626	0.179	----
B27	Cultural differences in Western countries	3.750	3.246	3.367	3.343	0.284	----

Using the global mean, the barriers with a higher mean were critical barriers and were therefore used in the ISM and MICMAC study. Since there was not a big difference between the means of each barrier, in order to define the critical barriers, the top fifteen barriers with a higher mean were considered critical barriers. Ma et al. [24], Olorunniwo and Li [28], and Wu at al. [29] state that to properly conduct an ISM study, the maximum number of variables is 15. The critical barriers are as follows: not recognizing financial advantage (CB1), lack of organizational communication (CB2), lack of communication and transparency between stakeholders (CB3), unsuitable organizational structure (CB4), employees' aversion to change and fear of new procedures (CB5), inadequate delivery performance and material delivery delays (CB6), lack of prefabrication and the limited usage of off-site construction techniques (CB7), lack of identification and control of waste in the project and in the company (CB8), lack of support and commitment from top management (CB9), lack of adequate lean awareness and understanding (CB10), management's resistance to change (CB11), lack of planning for quality (CB12), absence of long-term planning (CB13), lack of performance measurement systems (CB14), and excessive bureaucracy and inflexible licensing and approvals (CB15).

The relations between barriers were defined during a meeting with two industry specialists, creating the SSIM (Table 7) and, following stage III of the methodology, the IRM (Table 8), FRM (Table 9), and the Level partitioning (Table 10).

Table 7. Structural self-interaction matrix (SSIM).

CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		O	O	A	O	O	V	V	A	A	O	O	O	V	O
2			X	X	V	O	O	V	A	V	V	O	O	O	O
3				O	O	V	V	O	A	V	O	V	V	O	O
4					V	O	O	O	A	O	X	O	O	V	O
5						O	V	O	A	V	X	O	O	O	O
6							V	A	O	O	O	V	O	A	A
7								O	A	A	A	O	O	A	A
8									O	A	O	V	O	A	O
9										V	V	O	O	O	O
10											X	V	V	V	O
11												V	O	O	O
12													A	A	A
13														O	O
14															O
15															

Table 8. Initial reachability matrix (IRM).

CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	0	0	0	0	0	1	1	0	0	0	0	0	1	0
2	0	1	1	1	1	0	0	1	0	1	1	0	0	0	0
3	0	1	1	0	0	1	1	0	0	1	0	1	1	0	0
4	1	1	0	1	1	0	0	0	0	0	1	0	0	1	0
5	0	0	0	0	1	0	1	0	0	1	1	0	0	0	0
6	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0
7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
8	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0
9	1	1	1	1	1	0	1	0	1	1	1	0	0	0	0
10	1	0	0	0	0	0	1	1	0	1	1	1	1	1	0
11	0	0	0	1	1	0	1	0	0	1	1	1	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
14	0	0	0	0	0	1	1	1	0	0	0	1	0	1	0
15	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1

Table 9. Final reachability matrix (FRM).

CB	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	0	0	0	0	1 *	1	1	0	0	0	1 *	0	1	0
2	1 *	1	1	1	1	1 *	1 *	1	0	1	1	1 *	1 *	1 *	0
3	1 *	1	1	1 *	1 *	1	1	1 *	0	1	1 *	1	1	1 *	0
4	1	1	1 *	1	1	1 *	1 *	1 *	0	1 *	1	1 *	1 *	1	0
5	1 *	1 *	1 *	1 *	1	1 *	1	1 *	0	1	1	1 *	1 *	1 *	0
6	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0
7	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
8	0	0	0	0	0	1	1 *	1	0	0	0	1	0	0	0
9	1	1	1	1	1	1 *	1	1 *	1	1	1	1 *	1 *	1 *	0
10	1	1 *	1 *	1 *	1 *	1 *	1	1	0	1	1	1	1	1	0
11	1 *	1 *	1 *	1	1	1 *	1	1 *	0	1	1	1	1 *	1 *	0
12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
14	0	0	0	0	0	1	1	1	0	0	0	1	0	1	0
15	0	0	0	0	0	1	1	0	0	0	0	1	0	0	1

Note: * Represents transitive relations.

Table 10. Level partitioning results.

Barriers	Reachability Set	Antecedent Set	Intersection Set	Level
CB7	CB7	CB1, CB2, CB3, CB4, CB5, CB6, CB7, CB8, CB9, CB10, CB11, CB14, CB15	CB7	**I**
CB12	CB12	CB1, CB2, CB3, CB4, CB5, CB6, CB8, CB9, CB10, CB11, CB12, CB13, CB14, CB15	CB12	**I**
CB6	CB6	CB1, CB2, CB3, CB4, CB5, CB6, CB8, CB9, CB10, CB11, CB14, CB15	CB6	**II**
CB13	CB13	CB2, CB3, CB4, CB5, CB9, CB10, CB11, CB13	CB13	**II**
CB8	CB8	CB1, CB2, CB3, CB4, CB5, CB8, CB9, CB10, CB11, CB14	CB8	**III**
CB15	CB15	CB15	CB15	**III**
CB14	CB14	CB1, CB2, CB3, CB4, CB5, CB9, CB10, CB11, CB14	CB14	**IV**
CB1	CB1	CB1, CB2, CB3, CB4, CB5, CB9, CB10, CB11	CB1	**V**
CB2	CB2, CB3, CB4, CB5, CB10, CB11	CB2, CB3, CB4, CB5, CB9, CB10, CB11	CB2, CB3, CB4, CB5, CB10, CB11	**VI**
CB3	CB2, CB3, CB4, CB5, CB10, CB11	CB2, CB3, CB4, CB5, CB9, CB10, CB11	CB2, CB3, CB4, CB5, CB10, CB11	**VI**
CB4	CB2, CB3, CB4, CB5, CB10, CB11	CB2, CB3, CB4, CB5, CB9, CB10, CB11	CB2, CB3, CB4, CB5, CB10, CB11	**VI**
CB5	CB2, CB3, CB4, CB5, CB10, CB11	CB2, CB3, CB4, CB5, CB9, CB10, CB11	CB2, CB3, CB4, CB5, CB10, CB11	**VI**
CB10	CB2, CB3, CB4, CB5, CB10, CB11	CB2, CB3, CB4, CB5, CB9, CB10, CB11	CB2, CB3, CB4, CB5, CB10, CB11	**VI**
CB11	CB2, CB3, CB4, CB5, CB10, CB11	CB2, CB3, CB4, CB5, CB9, CB10, CB11	CB2, CB3, CB4, CB5, CB10, CB11	**VI**
CB9	CB9	CB9	CB9	**VII**

With the IRM defined, an ISM Model with seven levels was established by following the steps described in the methodology (Figure 2). Using the dependence and driving power of the barriers defined in the FRM, the MICMAC analysis split the critical barriers into the clusters explained in the methodology (Figure 3).

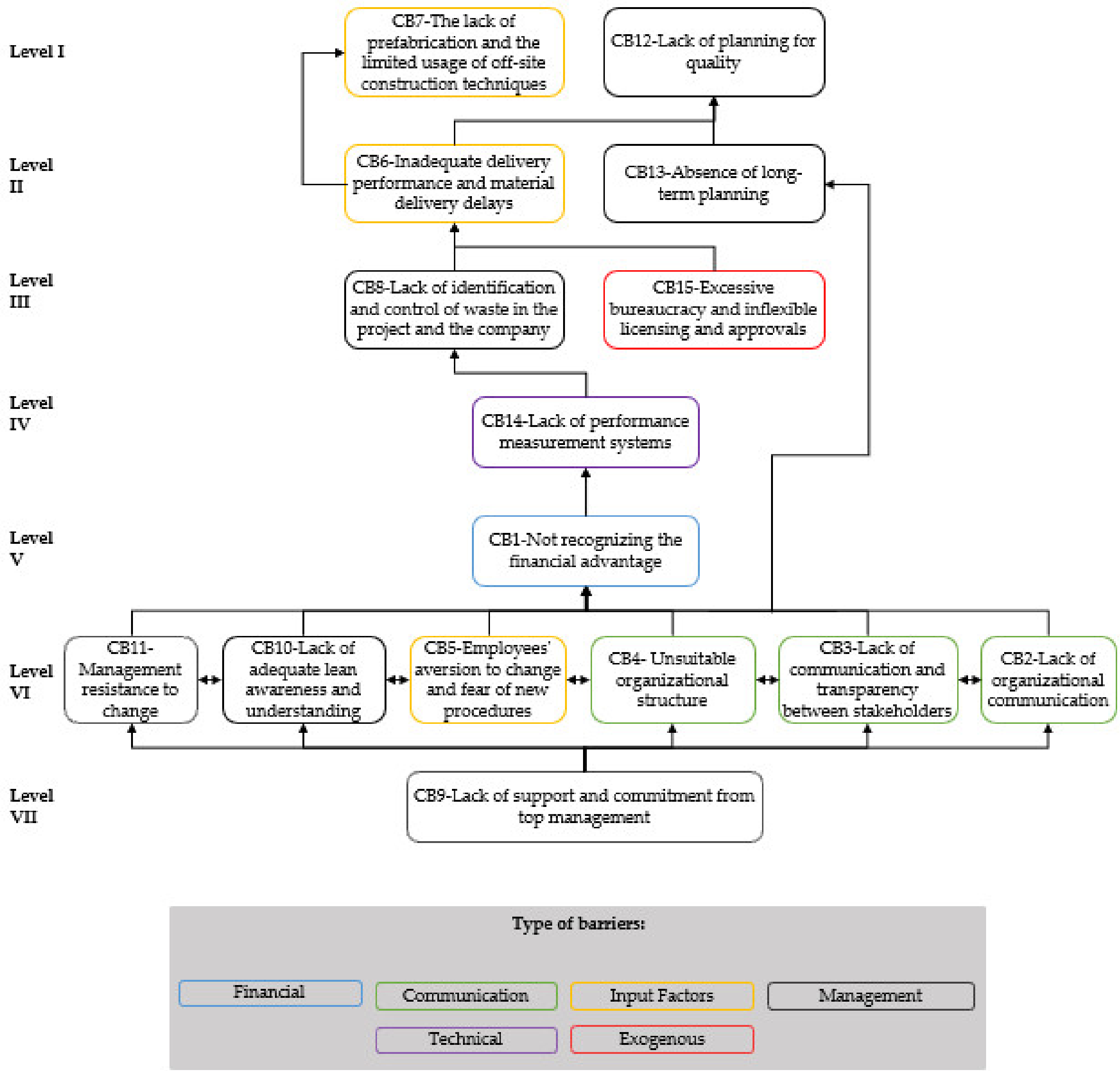

Figure 2. ISM Model.

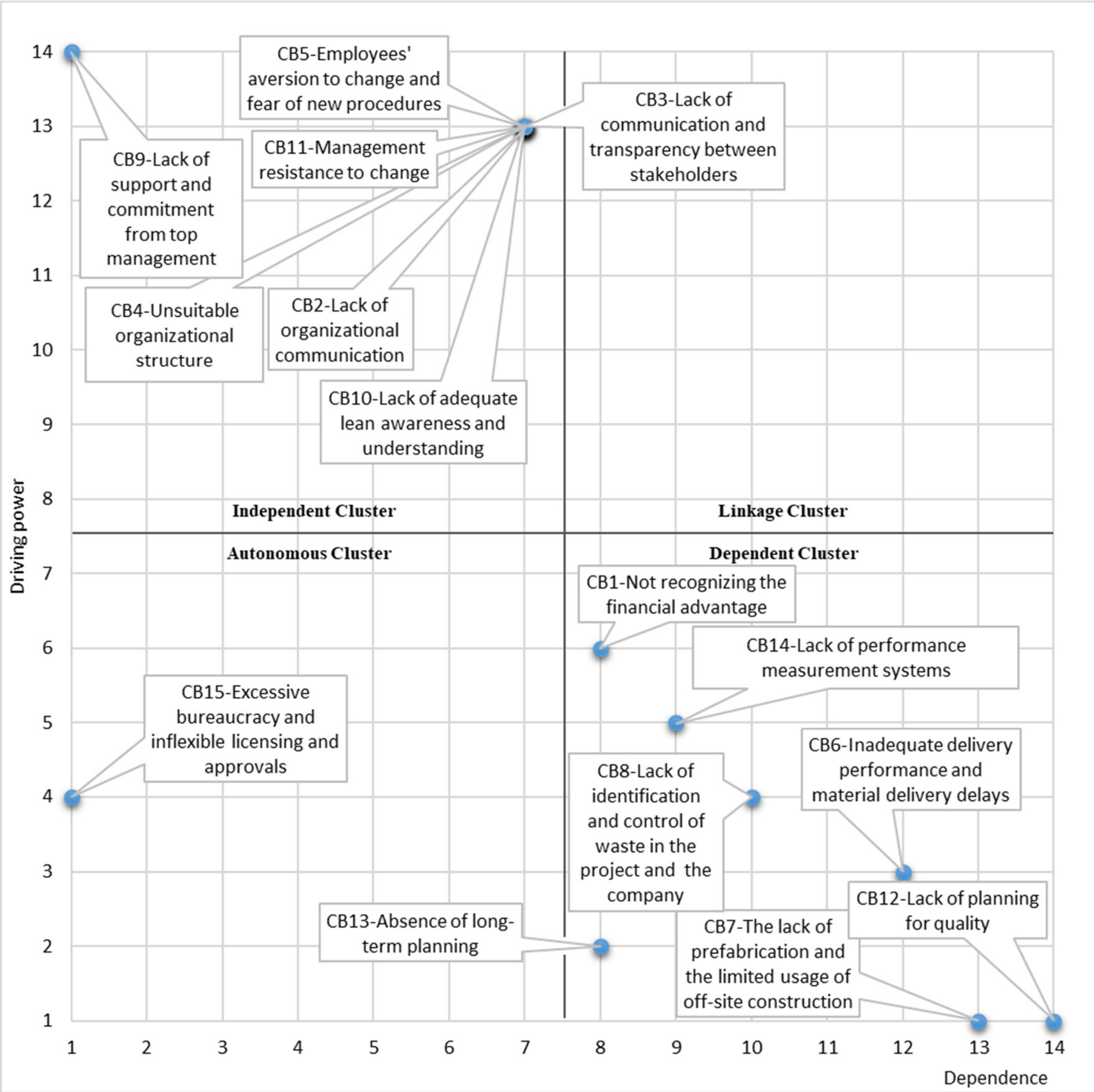

Figure 3. MICMAC Analysis.

5. Main Findings and Discussion

In this section, the results obtained from the survey were thoroughly analysed, starting with an internal consistency reliability analysis to validate the Likert scale used in the survey. With a Cronbach alpha of 0.8665, the scale was considered valid and the results from the different groups were studied using the Leven, ANOVA, and Welch tests, and the critical barriers were defined using the results.

With the results obtained, it is possible to compare the ranking of the barriers with the studies mentioned in the literature review. In the questionnaire answered by engineers and architects in the Portuguese construction industry, the barrier with the highest ranking was the lack of adequate Lean awareness and understanding (B16). This same barrier was ranked first in the study conducted by Sarhan and Fox [11] and second in the study conducted by Bayhan et al. [17]. Albalkhy's and Sweis's [18] study in Jordan also reached the same conclusion, stating that the lack of adequate Lean awareness and understanding was one of the most significant barriers. Cano et al.'s [14] extensive study of the Colombian construction industry also states that this barrier is critical. However, in the study by Shang and Peng [13], conducted in China, the barrier was ranked ninth out of twenty two. This ranking is lower than the results obtained in this study and the other studies considered in the literature review. One reason for this difference is the higher level of Lean application across all Chinese industries compared with the industries of the countries where the other studies were conducted.

For the Portuguese construction industry, inadequate delivery performance and material delivery delays (B10) was the second barrier with a higher result, a different result to the studies conducted in Jordan and China. In the Jordan survey conducted by Albalkhy and Sweis [18], this barrier was one of the barriers with a lower mean score. Regarding the three barriers related to input factors (materials), the inadequate delivery performance and the material delivery delays obtained the lowest scores, compared with this study, where these three barriers were also studied. For the Jordan construction industry, the lack of long-term relationships with suppliers was the barrier related to input factors (labour and materials) with the highest mean, whereas, in the Portuguese survey, this was one of the lowest means across all barriers.

As expected from the literature review, the barriers lack of support and commitment from top management (B15), management's resistance to change (B17), and the lack of communication and transparency between stakeholders (B4) are barriers with a high mean result and are critical barriers to the implementation of the Lean methodology in construction across the world and in Portugal.

The barrier of excessive bureaucracy and inflexible licensing and approvals (B23) also ranked higher than in the studies considered in the literature review. This could result from a higher bureaucracy in Portugal compared with the countries where this barrier was considered, such as China or Jordan.

The absence of long-term planning (B20) was another critical barrier in this survey. The results from the studies in the literature review provide different perspectives regarding this barrier. In the survey conducted in China, the lack of a long-term philosophy was the barrier with the highest mean. The results from the Jordan study are aligned with the ones from the Portuguese study, which consider this barrier as one of the top barriers but not one of the three highest means. In the questionnaire from Bayhan et al. [17], this barrier was ranked fourteenth with a mean value of 3.67, which is still in the top 15 but is significantly lower than the result from the Portuguese industry, where it is ranked sixth with a mean of 4091.

The lack of prefabrication and the limited usage of off-site construction techniques (B11) is ranked eighth in the Portuguese construction industry survey, a big contrast with the results from the China and Jordan surveys, where the same barrier obtained lower results. In the Chinese construction industry survey by Shang and Peng [13], the barrier was ranked 20th out of 22 barriers, with a mean value of just 3.22, whereas, in the Jordan survey, the mean was 3.55.

Regarding the unsuitable organizational structure, the survey from the Chinese construction industry showed a different result, with this barrier being only ranked 18th with a mean value of just 3.32. The study from Jordan achieved the same mean as the Chinese study, considering the unsuitable organizational structure one of the barriers with the lowest mean.

Employees' aversion to change and fear of new procedures (B6) was another critical barrier that had different results across the multiple studies. The barrier achieved a similar result in the study conducted by Bayhan et al. [17] and was also considered a critical barrier by Cano et al. [14]. However, Shang and Peng [13] and Albalkhy and Sweis [18] also studied the same barrier and it achieved much lower results, with the barrier ranking amongst the lower means.

Regarding the Levene, ANOVA, and Welch analyses, it is possible to state that the three different groups had the same opinion about the barriers' importance except for the lack of understanding of customer needs (B19), where the clients considered this to be more important than the consultants and the contractors. For the clients, this barrier was ranked third whereas, in the overall ranking, the barrier is ranked twenty-first due to the much lower mean from the consultants' and contractors' perspective.

The ISM model established seven different levels, with the lower levels demonstrating barriers that exist as a consequence of the barriers in the higher levels.

In Level VII is the lack of support and commitment from top management (CB9), and in Level VI are the following barriers: a lack of organizational communication (CB2), a lack of communication and transparency between stakeholders (CB3), unsuitable organizational structures (CB4), employees' aversion to change and fear of new procedures (CB5), a lack of adequate Lean awareness and understanding (CB10), and management's resistance to change (CB11). These barriers influence the lower levels, with top management's lack of support and commitment (CB9) being the most important barrier.

The fifth level of the model has just one barrier: not recognizing financial advantage (CB1). The fourth level also has only one barrier, the technical barrier of a lack of performance measurement systems (CB14).

Level III of the ISM model is composed of two barriers, one exogenous barrier, the excessive bureaucracy and inflexible licensing and approvals (CB15), and one barrier related to management, the lack of identification and control of waste in the project and in the company (CB8).

The second level has two barriers, one related to an input factor, inadequate delivery performance and material delivery delays (CB6), and one barrier related to management, the absence of long-term planning (CB13).

On the first level is a barrier related to management and a barrier related to an input factor. The barrier related to management is the lack of planning for quality (CB12) and the lack of prefabrication, and the limited usage of off-site construction techniques (CB7). These two barriers are the least important of the critical barriers and are the consequence of the barriers on the higher levels.

The MICMAC analysis classified the barriers into four clusters: autonomous, dependent, independent, and linkage.

The independent group consists of the following barriers: a lack of organizational communication (CB2), a lack of communication and transparency between stakeholders (CB3), unsuitable organizational structures (CB4), employees' aversion to change and fear of new procedures (CB5), a lack of support and commitment from top management (CB9) a lack of adequate Lean awareness and understanding (CB10), and management's resistance to change (CB11). Of these seven barriers, three are communication barriers, one is a barrier related to an input factor (labour), and the other three are barriers related to management. It is important to notice that of the original three communication barriers, all were considered critical, and all were considered independent barriers and root barriers. These seven barriers are the barriers with a higher driving power and a lower dependence power, meaning that these barriers significantly influence the other barriers and, therefore, are the root causes for the lack of LC in the Portuguese construction industry.

The autonomous group comprises a single barrier: excessive bureaucracy and inflexible licensing and approvals (CB15). This barrier has a driving power of 4 and a dependence power of 1, meaning it has few relations with the other barriers.

The linkage group has no barriers.

The dependent group is composed of all the other critical barriers: not recognizing financial advantage (CB1), inadequate delivery performance and material delivery delays (CB6), the lack of prefabrication and the limited use of off-site construction techniques (CB7), the lack of identification and control of waste in the project and in the company (CB8), the lack of planning for quality (CB12), the absence of long term planning (CB13), and the lack of performance measurement systems (CB14).

As mentioned in the literature review, Khaba and Bhar [15] conducted a study to develop an ISM model and a MICMAC analysis on the barriers to adopting LC. The results obtained in this research were different. The most significant difference is the resistance to change. In the study by Khaba and Bhar, the resistance to change is on the first level of the ISM model and is the barrier with the highest dependence power. In opposition, in this research, the employees' aversion to change and fear of new procedures (CB5) and management's resistance to change (CB11) are on the sixth level of the ISM model and are independent barriers with high driving power over the other barriers. This can be explained by the differences between the Portuguese construction sector in contrast to the construction sector in India. The lack of Lean awareness and understanding (CB10) also obtained a different result, being considered an independent barrier in this research and a linkage barrier in the study conducted by Khaba and Bhar. Not recognizing financial advantage (CB1) and the lack of planning for quality (CB12) were considered linkage barriers in the Khaba and Bhar study [15], whereas in this research, they were considered dependent barriers. The lack of performance measurement systems (CB14) obtained similar results, being classified as a dependent barrier in both studies. To tackle the critical barriers, a set of 14 mitigation measures was proposed (Table 11). The first 10 measures tackle the root barriers, on levels VII and VI. Mitigation measures 11 and 12 tackle two dependent barriers on levels V and IV. Finally, the exogenous barrier is tackled by mitigation measures 13 and 14.

Table 11. Mitigation Measures to Tackle the Barrier to adopt LC in Portugal.

Code	Rational	Mitigation Measure
MM1	Promote the use of Lean in public projects	Add new criteria to the proposal evaluation models that benefit companies that apply Lean
MM2	Improve communication	Create a communication unit
MM3		Develop a communication strategy
MM4	Force stakeholders to work together	Encourage early collaborations between project stakeholders
MM5	Analyse the efficiency of the company's organizational structure	Conduct audits on the company's organizational structure
MM6	Facilitate communication between managers and workers	Promote a safe and open space for communication between managers and workers
MM7	Promote new ideas to the employees	Create incentives from the management to the employees
MM8	Increase Lean awareness	Promote lectures and conferences about Lean
MM9	Persuade the managers to apply Lean	Government incentives
MM10	Study the advantages of Lean	Conduct studies on the benefits of LC
MM11	Study the financial advantages of Lean	Conduct financial–economic studies on the Lean methodology
MM12	Create more measurement systems	Develop evaluation mechanisms
MM13	Reduce bureaucracy and the inflexibility	Conduct a revision and simplification of audit technical norms
MM14		Incentives to increase the speed of the necessary approvals

6. Conclusions

This research aimed to identify the barriers to implementing LC in the Portuguese construction sector. In the literature review, twenty-seven different barriers were identified and categorized into six groups: financial barriers, communication barriers, barriers related to input factors (labor and materials), barriers related to management, technical barriers, and exogenous barriers. No previous work in Portugal on this matter was found in the literature. Most of the studies focused on developing countries. The barriers were a combination of the most important ones from different studies.

To analyse the barriers, a survey was conducted with responses from 99 workers in the construction industry in Portugal. The results were considered valid and, from the 27 original barriers, 15 were considered critical. This list included the following barriers: a lack of adequate Lean awareness and understanding, inadequate delivery performance and material delivery delays, a lack of support and commitment from top management, excessive bureaucracy and inflexible licensing and approvals, a lack of communication and transparency between stakeholders, the absence of long-term planning, a lack of organizational communication, a lack of prefabrication and the limited usage of off-site construction techniques, management resistance to change, unsuitable organizational structure, a lack of identification and control of waste in the project and in the company, a lack of performance measurement systems, employees' aversion to change and fear of new procedures, a lack of planning for quality, and not recognizing financial advantage. These results were compared with the articles referred to in the literature review and the results were relatively similar given the fact that it is expected that different countries have different perspectives on the barriers and that most studies were from developing countries that have less in common with Portugal than more developed countries. Since knowing the critical barriers was not enough to successfully propose mitigation measures, another two methods were applied, the ISM approach and the MICMAC analysis, which help understand the relations between the different barriers and which barriers are the root cause of the lack of application of LC in Portugal.

The ISM model and the MICMAC analysis were studied in a meeting with two industry specialists. The results separated the barriers into different levels and clusters based on their importance. With the ISM model, the relations between the barriers were established. The FRM was used to determine the driving and dependence power of each barrier, with the lack of support and commitment from top management (CB9) being the barrier with the highest driving power and the lack of prefabrication and the limited usage of off-site construction techniques being the barrier with the highest dependence power. The barriers in the independent cluster are considered root causes for the lack of LC application in the Portuguese construction industry and, therefore, are considered the most significant barriers. These barriers are the lack of organizational communication (CB2), the lack of communication and transparency between stakeholders (CB3), unsuitable organizational structures (CB4), employees' aversion to change and fear of new procedures (CB5), the lack of support and commitment from top management (CB9), the lack of adequate Lean awareness and understanding (CB10), and management's resistance to change (CB11). Of these seven barriers, three are communication barriers, one is a barrier related to an input factor (labour), and the other three are barriers related to management. It is essential to notice that, of the original three communication barriers, all were considered critical, independent, and root barriers. It is also important to state that the independent barrier related to labour is based on the resistance to change, which has the same correspondence and importance as the management's resistance to change. This shows that the main barriers are mostly related to the industry's conservative attitude and lack of innovation, which leads to a fear of new ideas and a higher resistance to change.

An in-depth analysis of the ISM model and the MICMAC analysis was conducted to understand the interrelationships between the barriers to successfully propose mitigation measures. With the understanding from this analysis, fourteen mitigation measures were proposed, with ten tackling independent barriers, two tackling the autonomous barrier, and two tackling dependent barriers.

The objectives proposed in this research were accomplished with the barriers identified in the literature review and the critical barriers selected based on the survey's result. Using the ISM model and MICMAC analysis, it was possible to study the relations between those barriers to determine the root causes needed to propose mitigation measures successfully.

All the barriers studied in this research were previously mentioned in articles that studied the barriers to applying LC in other countries. This means that some barriers may not be identified since they only apply to the Portuguese case.

One of this study's limitations is that only 15 barriers were considered for the ISM model and MICMAC analysis. These barriers were selected based on the survey's results. However, since there was no significant difference in the importance given to each barrier, different results could have easily been obtained with a slightly different response group. From the 99 answers to the survey, only 12 were clients, whereas 57 were consultants, so the perspectives on the problem were not even for the different groups meaning the results could change with a more balanced response group. Another limitation of the survey was the fact that, from the 99 respondents, only 17 had prior experience with Lean methodology. This information is crucial as it indicates that most of the participants were not familiar with the principles and practices of LC, which may have affected their responses to the questions related to the implementation of LC in Portugal. This means the results from the ISM and MICMAC could have been different. There is a possibility that one of the root causes for the lack of LC in Portugal is one of the barriers that was not considered critical.

Regarding the survey, a larger and more balanced sample could be used in future work to achieve more reliable results.

In future works, a focus group with specialists in LC could validate the critical barriers and validate the relations between barriers, as this was a limitation in the research.

This research proposed a list of mitigation measures to tackle the critical barriers to adopting LC in Portugal. With the help of a focus group with industry experts, the measures could be validated, and new measures could be proposed with a proper plan to implement those measures.

Future studies about real application studies should be conducted to better understand the impact of each measure applicated and improve results. The conclusions from these studies should be shared with the construction industry sector.

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References

1. European Commission. *The European Construction Sector: A Global Partner*; European Commission: Brussels, Belgium, 2016.
2. Barbosa, F.; Woetzel, J.; Mischke, J.; Ribeirinho, M.J.; Sridhar, M.; Parsons, M.; Bertram, N.; Brown, S. *Re-Inventing Construction, In Brief*; Ruby Press: Oakland, CA, USA, 2017.
3. Pereira da Costa, E.; Leitão Afonso, C.; Pereira, F.; Inácio, P. *TE 84—Evolução Do Setor Da Construção Em Portugal, 2008 a 2018*; Gabinete de Estratégia e Estudos: Lisboa, Portugal, 2020.
4. National Statistics Office. *Estatísticas Da Construção e Habitação—2021*; National Statistics Office: Lisboa, Portugal, 2022.
5. Jørgensen, B. *Integrating Lean Design and Lean Construction: Processes and Methods*; Technical University of Denmark: Lyngby, Denmark, 2006.
6. Ohno, T. *Toyota Production System—Beyond Large-Scale Production*, 1st ed.; Productivity Press: New York, NY, USA, 1988; ISBN 9780429273018.
7. Koskela, L.J. *Application of the New Production Philosophy to Construction*; Technical Report, No. 72; CIFE—Center for Integrated Facility Engineering: Stanford, CA, USA, 1992.
8. Womack, J.P.; Jones, D.T. Lean Thinking—Banish Waste and Create Wealth in Your Corporation. *J. Oper. Res. Soc.* **1997**, *48*, 1144–1150. [CrossRef]
9. Dulaimi, M.F.; Tanamas, C. The Principles and Application of Lean Construction in Singapore. In Proceedings of the 9th Annual Conference of the International Group for Lean Construction, Singapore, 6–8 August 2001; p. 14.
10. Howell, G.A.; Ballard, G. Implementing Lean Construction: Understanding and Action. In Proceedings of the 6th Annual Conference of the International Group for Lean Construction, Guarujá, Brazil, 1–15 August 1998; p. 9.
11. Sarhan, S.; Fox, A. Barriers to Implementing Lean Construction in the UK Construction Industry. *Built Hum. Environ. Rev.* **2013**, *6*, 17.
12. Kumar, R.; Kumar, V. Barriers in Implementation of Lean Manufacturing System in Indian Industry: A Survey. *Int. J. Latest Trends Eng. Technol.* **2014**, *4*, 243–251.
13. Shang, G.; Pheng, L.S. Barriers to Lean Implementation in the Construction Industry in China. *J. Technol. Manag. China* **2014**, *9*, 155–173. [CrossRef]

14. Cano, S.; Delgado, J.; Botero, L.; Rubiano, O. Barriers and Success Factors in Lean Construction Implementation-Survey in Pilot Context. In Proceedings of the IGLC 23—23rd Annual Conference of the International Group for Lean Construction: Global Knowledge—Global Solutions, Perth, Australia, 29–31 July 2015; Volume 2015, pp. 631–641.
15. Khaba, S.; Bhar, C. Modeling the Key Barriers to Lean Construction Using Interpretive Structural Modeling. *J. Model. Manag.* **2017**, *12*, 652–670. [CrossRef]
16. Lodgaard, E.; Ingvaldsen, J.A.; Gamme, I.; Aschehoug, S. Barriers to Lean Implementation: Perceptions of Top Managers, Middle Managers and Workers. *Procedia CIRP* **2016**, *57*, 595–600. [CrossRef]
17. Bayhan, H.G.; Demirkesen, S.; Jayamanne, E. Enablers and Barriers of Lean Implementation in Construction Projects. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *471*, 022002. [CrossRef]
18. Albalkhy, W.; Sweis, R. Barriers to Adopting Lean Construction in the Construction Industry: A Literature Review. *Int. J. Lean Six Sigma* **2021**, *12*, 210–2362. [CrossRef]
19. Ribeiro, A.M.; Arantes, A.; Cruz, C.O. Barriers to the Adoption of Modular Construction in Portugal: An Interpretive Structural Modelling Approach. *Buildings* **2022**, *12*, 1509. [CrossRef]
20. Bland, J.M.; Altman, D.G. Statistics Notes: Cronbach's Alpha. *Br. J. Manag.* **1997**, *314*, 572. [CrossRef] [PubMed]
21. Forza, C. Survey Research in Operations Management: A Process-Based Perspective. *Int. J. Oper. Prod. Manag.* **2002**, *22*, 152–194. [CrossRef]
22. Akoglu, H. User's Guide to Correlation Coefficients. *Turkish J. Emerg. Med.* **2018**, *18*, 91–93. [CrossRef] [PubMed]
23. Piya, S.; Shamsuzzoha, A.; Khadem, M. An Approach for Analysing Supply Chain Complexity Drivers through Interpretive Structural Modelling. *Int. J. Logist. Res. Appl.* **2020**, *23*, 311–336. [CrossRef]
24. Ma, G.; Jia, J.; Ding, J.; Shang, S.; Jiang, S. Interpretive Structural Model Based Factor Analysis of BIM Adoption in Chinese Construction Organizations. *Sustainability* **2019**, *11*, 1982. [CrossRef]
25. Eswarlal, V.K.; Kumar Dey, P.; Shankar, R. Enhanced Renewable Energy Adoption for Sustainable Development in India: Interpretive Structural Modeling Approach. In Proceedings of the World Renewable Energy Congress—Sweden, Linköping, Sweden, 8–13 May 2011; Volume 57, pp. 351–358.
26. Kamble, S.S.; Gunasekaran, A.; Sharma, R. Analysis of the Driving and Dependence Power of Barriers to Adopt Industry 4.0 in Indian Manufacturing Industry. *Comput. Ind.* **2018**, *101*, 107–119. [CrossRef]
27. Sharma, H.D.; Gupta, A.D. Sushil The Objectives of Waste Management in India: A Futures Inquiry. *Technol. Forecast. Soc. Change* **1995**, *48*, 285–309. [CrossRef]
28. Olorunniwo, F.O.; Li, X. Information Sharing and Collaboration Practices in Reverse Logistics. *Supply Chain Manag. An Int. J.* **2010**, *15*, 454–462. [CrossRef]
29. Wu, W.S.; Ang, C.F.; Chang, J.C.; Château, P.A.; Chang, Y.C. Risk Assessment by Integrating Interpretive Structural Modeling and Bayesian Network, Case of Offshore Pipeline Project. *Reliab. Eng. Syst. Saf.* **2015**, *142*, 515–524. [CrossRef]