Power System Technology
ISSN:1000-3673

Received: 06-05-2024 *Revised: 15-06-2024* *Accepted: 28-07-2024*

The Relationship between Lean Construction and Sustainable Construction: The Positive Effects of Lean Methodology on Sustainability in Construction

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Abstract

Sustainable construction (SC) focuses on using sustainable development methods in any activity related to the construction industry. However, lean construction (LC) is a newly proposed philosophical thinking to create innovative changes in the construction industry. Lean process emphasizes improving the performance of the construction process and minimizing waste to enhance sustainable construction regarding health and safety improvement and energy consumption [1]. LC and SC approaches are increasingly being used in developed countries. Nevertheless, the application of LC and SC in developing countries such as Iran has faced many challenges and has yet to reach the implementation stage due to the lack of information and sufficient knowledge of these approaches in construction projects. Despite the passage of about two decades since the emergence of these approaches, limited research has been conducted in Iran in this field. The application of LC and SC has been stopped at the stage of presenting the initial definitions, and the positive effects of relationships between the approaches have not been evaluated in past studies. Therefore, this study aimed to accurately introduce LC and SC and determine their prerequisites, capabilities, and relationships for broader synergy between these two strategies. The main parameters of lean construction were classified based on the implementation results of Structural Equation Modeling (SEM) and Interpretive Structural Modeling (ISM). In addition, the functional level of each factor was prioritized using interpretive structural modeling of relationships between lean construction factors.

1. Introduction

Recently, businesses have been under increasing pressure to improve their performance based on different effects of sustainable development dimensions, including economic, social, and environmental. Therefore, organizations active in various industries, especially project-oriented organizations, decided to implement new executive and operational solutions. The in-

Power System Technology
ISSN:1000-3673
Received: 06-05-2024 Revised: 15-06-2024 Accepted: 28-07-2024

depth study of different strategies in sustainable development shows that studying the relationship between lean process and sustainability is a tangible way to find out how to integrate these two approaches and benefit from their common productivity [2]. Like other various industries, the construction industry is increasingly moving towards adopting new strategies such as lean thinking and sustainability to enhance its efficiency goals, and both philosophies have concerns about using efficient resources [3]. Lean thinking includes waste elimination, value increase, cost reduction, and product and process quality improvement. Accordingly, sustainability involves various environmental, social, and economic elements in the construction industry. The simultaneous implementation of lean construction (LC) and sustainable construction (SC) strategies is practical in a strategic approach to improve the efficiency of the construction industry for reducing losses, which leads to positive results in the productivity of economic, social, and environmental dimensions in sustainability. Although each LC and SC can provide significant benefits in the productivity of projects, organizations still face many challenges for their successful integration [4]. Therefore, an interactive system of the interaction of the positive methods of lean process on various dimensions of sustainable construction can significantly affect the productivity of projects regarding their integration.

Murtaq et al. (2020) evaluated sustainable and flexible construction in the current situation and assessed future challenges. The authors gathered a collection of articles about the progress and improvement potential in the construction sector regarding stability and flexibility against changing conditions [5]. Abbasian et al. (2022) investigated the integration of lean construction, sustainable development, and building information modeling using scientometric concepts based on 95 internationally valid articles, primarily focused on the pairwise integration of these concepts. Based on this study, integrating the three mentioned concepts can significantly affect waste and consumables management performance compared to other areas [6]. Farrokhizadeh and Shokouhi (2020) examined safety and environment in the construction industry (2013-2020) and the goals, tools, indicators, and the interaction of these concepts in HSE. In this study, developing literature and helping policymakers and project implementers was a way to identify research indicators by providing an integrated model [7].

2. Method

This study aimed to evaluate the relationship between lean construction (LC) and sustainable construction (SC) and the positive effects of lean construction methods on sustainability in the construction industry. The main variables affecting lean construction and sustainable construction in Iran were re-localized after extracting the principal components by examining the current situation of the construction industry in Iran and consulting with activists. A close-ended questionnaire was prepared to investigate the factors, governing relationships, and parameters affecting lean construction and sustainable construction in Iran and sent to construction industry experts. The data were accurately evaluated after data collection for quantifying qualitative data using Structural Equation Modeling (SEM). The collected data were analyzed again using Interpretive Structural Modeling (ISM) to assess the relationships

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ISSN:1000-3673
Received: 06-05-2024 Revised: 15-06-2024 Accepted: 28-07-2024

between the main components of lean construction and sustainable construction. A comprehensive interactive model was presented regarding the positive effects of lean methods in achieving various dimensions of sustainable construction in the construction industry of Iran by summarizing the model results.

3. Classifying the main parameters of LC and SC

Lean construction or lean thinking in the construction industry should be deeply identified to extract lean construction's fundamental factors. Previous studies have shown that the following five classes can affect lean construction (Figure 1):

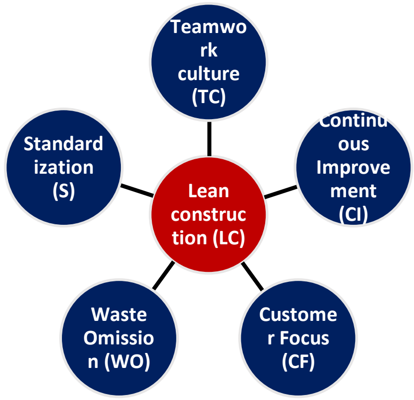

Figure 1. The main elements of lean construction

Previous studies on sustainability in the construction industry have revealed that sustainable construction has been studied based on economic, social, and environmental points of view.

The main stakeholders and actors of a project in the construction industry projects include supplier, developer-contractor, and customer, and the main elements of sustainable construction are accordingly evaluated. Table 1 presents economic, social, and environmental points of view based on their influence and factors of lean construction.

Table 1. The main elements of sustainable construction based on lean construction components

Elements of sustainable construction			
Economic	Supplier	Extraction & Processing	Economic values are expressed through the efficient use of resources and a practical development process based on the systemic understanding of value, customer needs, and consumption process.
		Logistics & Distribution	
	Developer	Design & Planning	
		Delivering & Build	
	Customer	Co-creation	
		Operation	
Social	Supplier	Extraction & Processing	Social aspects are more challenging to quantify than economic and environmental concerns. Social values in lean construction include the protection of human well-being throughout the
		Logistics & Distribution	
	Developer	Design & Planning	
		Delivering & Build	

Received: 06-05-2024 *Revised: 15-06-2024* *Accepted: 28-07-2024*

	Customer	Co-creation	life cycle of projects, apart from human and community development, fair labor methods, human health, and equal opportunities.
		Operation	
Environmental	Supplier	Extraction & Processing	Environmental values involve a consistent combination of different values, such as waste and pollution reduction, efficient energy consumption and use of natural resources, green production, and logistics.
		Logistics & Distribution	
	Developer	Design & Planning	
		Delivering & Build	
	Customer	Co-creation	
		Operation	

3.1. Main research variables

The main parameters of the lean process included teamwork culture (TC), continuous improvement (CI), customer focus (CF), waste omission (WO), and standardization (S). Figure 2 illustrates each of the main parameters of lean construction in each part.

Figure 1. Main parameters and components of lean construction

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ISSN:1000-3673
Received: 06-05-2024 *Revised: 15-06-2024* *Accepted: 28-07-2024*

This study included 16 lean construction variables and three sustainable construction variables to evaluate their relationship (Table 2).

Table 2. The main components of lean construction and sustainable construction (research variables)

No.	Classification	Main components of lean construction and sustainable construction	Code
1	Teamwork culture (TC)	Partnership Individuals (PI)	F1
2		Organization Commitment (OC)	F2
3		Training (TR)	F3
4	Continuous improvement (CI)	Design Standardization (DS)	F4
5		Response to defects (RD)	F5
6		Error Amendment (EA)	F6
7		Organizational Learning (OL)	F7
8	Customer focus (CF)	Flexible Resources (FR)	F8
9		Value Optimization (VO)	F9
10	Waste omission (WO)	Supply Chain Management (SCM)	F10
11		Optimizing the Production System (OPS)	F11
12		Reducing the cycle time (RCT)	F12
13		Work Content Optimization (WCO)	F13
14	Standardization (S)	Visual Management (VM)	F14
15		Project Workplace (PW)	F15
16		Defined Processes (DP)	F16
17	Sustainable Construction (SC)	Economic	F17
18		Social	F18
19		Environmental	F19

3.2. Questionnaire evaluation

The required data were collected via a questionnaire and experts' opinions in Iran's construction industry. The questionnaire was set to obtain data based on the results from the previous section and the extraction of the main effective parameters in lean construction and sustainable construction (Table 2).

3.3. Sampling adequacy

The Kaiser-Meyer-Olkin (KMO) test is used to measure the adequacy of sampling, and its coefficient was calculated by coding the relationships and implementing the calculation algorithm in MATLAB software (KMO=0.7039). Since the KMO of the research sampling was more than 0.6, sampling was sufficient.

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Received: 06-05-2024 *Revised: 15-06-2024* *Accepted: 28-07-2024*

4. Statistical results

This study evaluated the level of education, history of activity in the construction industry, history of activity in new topics (lean construction and sustainable construction), and the respondents' type of activity.

4.1. Evaluating the level of education of the population

The questionnaire was distributed among experts with education levels, including bachelor's, master's, and PhD. Figure 3 shows the results of the evaluation of the collected questionnaires.

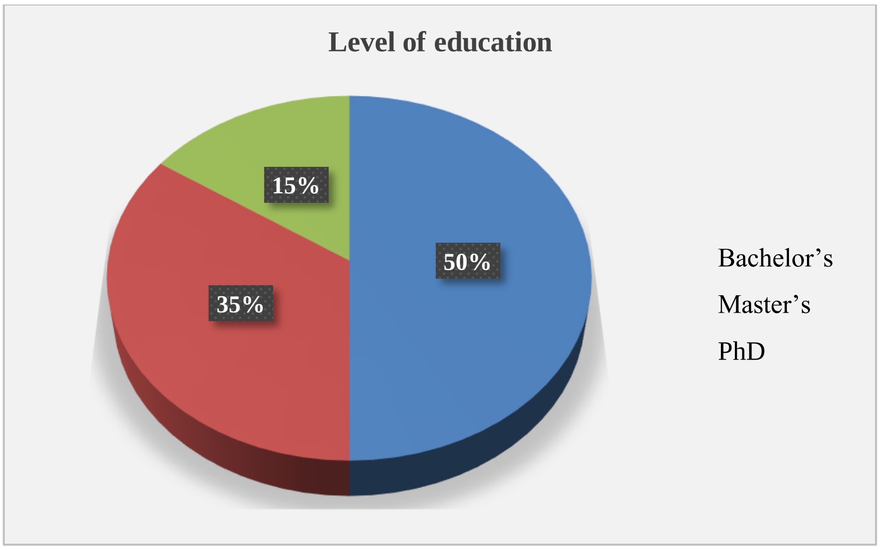

Figure 3. Data on respondents' level of education

Figure 4 demonstrates the results of evaluating the questionnaire data.

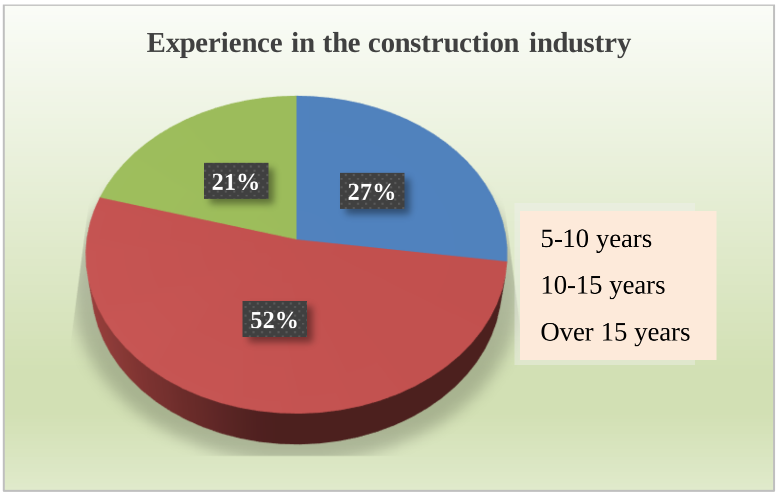

Figure 4. Data on respondents' experience in the construction industry

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ISSN:1000-3673
Received: 06-05-2024 Revised: 15-06-2024 Accepted: 28-07-2024

Figure 5 shows the data regarding the history of familiarity and activity in LC and SC.

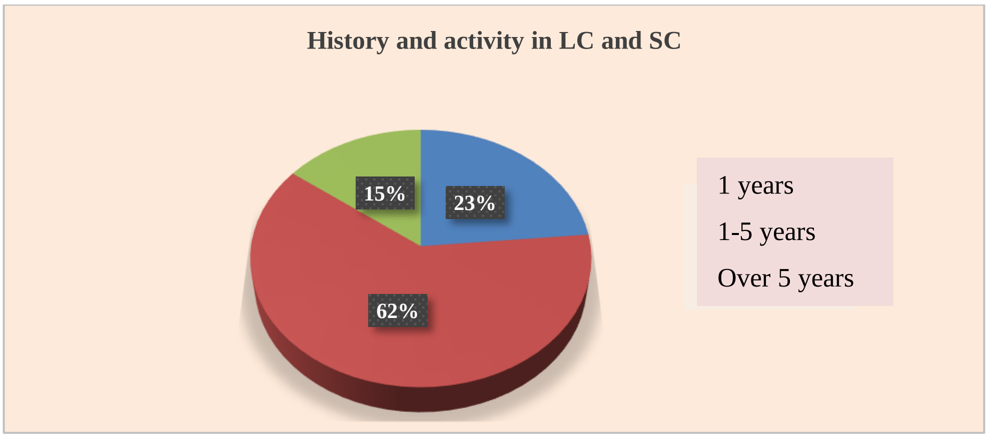

Figure 5. Data on respondents’ history and activity in LC and SC

Figure 6 provides information about the respondents’ position.

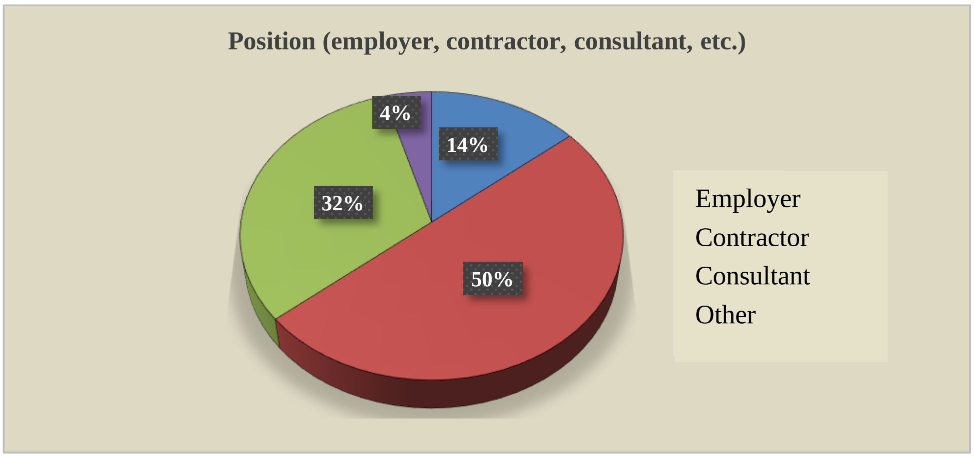

Figure 6. Data on respondents’ position

5. Data analysis using SEM

Smart PLS software was used to evaluate the data based on SEM in PLS software, and the value of 0.5 was presented as a criterion for data suitability for factor analysis to check the correlation of variables. Thus, values more than 0.5 indicate a proper correlation among variables. Table 3 presents that the multiple correlation coefficient for all the research parameters was more than 0.5 (between 0.7 and 0.9), indicating the suitability of the correlation of the research variables for implementing factor analysis.

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Table 3. Multiple correlations of the research variables for the total data

Research variables	)R^2(
F1: PI	0.829
F2: OC	0.791
F3: TR	0.778
F4: DS	0.764
F5: RD	0.801
F6: EA	0.776
F7: OL	0.782
F8: FR	0.741
F9: VO	0.829
F10: SCM	0.791
F11: OPS	0.757
F12: RCT	0.755
F13: WCO	0.785
F14: VM	0.759
F15: PW	0.788
F16: DP	0.778
F17: Economic aspects	0.754
F18: Social aspects	0.771
F19: Environmental aspects	0.779

Table 4 represents the statistical description of research variables based on the six classifications and the appropriateness of the correlation of research variables to perform factor analysis.

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Table 4. Statistical specifications of research variables

No.	Variables	Quantity of data	Min	Max	Mean	SD	Variance
1	Teamwork culture (TC)	136	1	6	3.4925	0.7125	0.4187
2	Continuous improvement (CI)	136	2	5	3.5330	0.5697	0.3112
3	Customer focus (CF)	136	2	5	3.6125	0.6287	0.5312
4	Waste omission (WO)	136	2	5	3.7525	0.7065	0.6814
5	Standardization (S)	136	2	5	3.5212	0.7925	0.6712
6	Sustainable Construction (SC)	136	2	4	3.4258	0.7147	0.5127

5.1. Research hypothesis in structural equation modeling

The structural model of the research was created in PLS software based on the research data and hypotheses. The parameters were classified as lean construction and sustainable construction. Figure 7 displays the structural model of the studied parameters and the initial relationships established between the parameters.

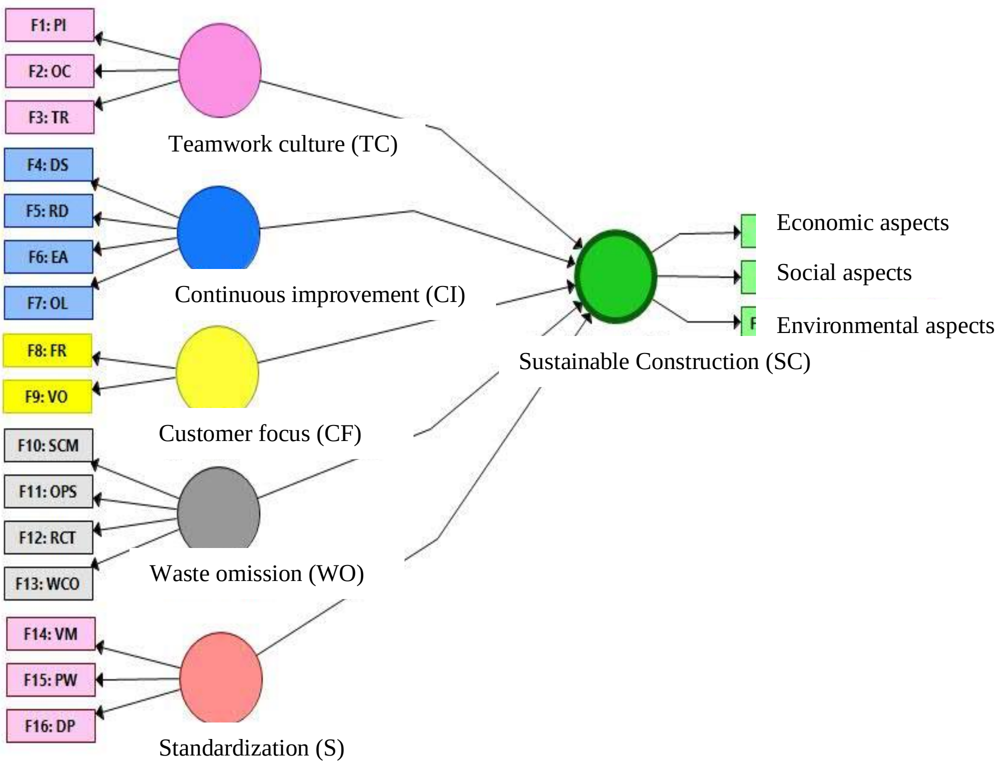

Figure 7. Structural model between the parameters of lean construction and sustainable construction

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According to the factor loading coefficient measure, if it is less than 0.5, the effect is inappropriate and should be removed from the structural model to prevent incorrect evaluation. Table 5 presents the values of the coefficients of factor loadings for each factor index of the structural model. All factor load coefficients of the structural model of the research have values greater than 0.5, which indicates the appropriate influence of the index on the description of the considered factor.

Table 5. Factor loading coefficients based on the structural model

Factor	Index	Factor loading coefficient
Teamwork culture (TC)	F1: PI	0.918
	F2: OC	0.92
	F3: TR	0.893
Continuous improvement (CI)	F4: DS	0.868
	F5: RD	0.9
	F6: EA	0.874
	F7: OL	0.87
Customer focus (CF)	F8: FR	0.907
	F9: VO	0.931
Waste omission (WO)	F10: SCM	0.877
	F11: OPS	0.852
	F12: RCT	0.856
	F13: WCO	0.875
Standardization (S)	F14: VM	0.865
	F15: PW	0.9
	F16: DP	0.901
Sustainable Construction (SC)	F17: Economic aspects	0.888
	F18: Social aspects	0.869
	F19: Environmental aspects	0.876

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5.2. Model reliability (Cronbach's alpha coefficients and composite reliability)

The model's fit was examined based on the data analysis algorithm in PLS after measuring the factor loading coefficients (Table 5), Cronbach's alpha, and composite reliability. Cronbach's alpha values and composite reliability greater than 0.7 indicate an acceptable measurement model fit. Table 7 shows the results of Cronbach's alpha coefficients, rho parameter (relative Cronbach's alpha), and composite reliability for variables based on the structural model.

Table 3. Structural model fit (Cronbach's alpha criterion and model composite reliability)

	Cronbach's Alpha	rho_A	Composite Reliability
Standardization (S)	0.867	0.869	0.919
Continuous improvement (CI)	0.901	0.901	0.931
Customer focus (CF)	0.817	0.828	0.916
Waste omission (WO)	0.888	0.889	0.922
Sustainable Construction (SC)	0.851	0.851	0.91
Teamwork culture (TC)	0.897	0.902	0.936

5.3. Convergence validity index

In the validity and convergence of the structural model, the average variance extracted (AVE) parameter is calculated for the latent variables based on the PLS algorithm, and the acceptable value is 0.5. The AVE values of the structural model more than 0.5 for the latent variables confirm the validity and convergence of the structural model. Table 4 presents the AVE values for the research variables.

Table 4. Convergence validity of the research structural model

	Average Variance Extracted (AVE)
Standardization (S)	0.79
Continuous improvement (CI)	0.771
Customer focus (CF)	0.845
Waste omission (WO)	0.748
Sustainable Construction (SC)	0.77
Teamwork culture (TC)	0.829

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ISSN:1000-3673
Received: 06-05-2024 *Revised: 15-06-2024* *Accepted: 28-07-2024*

6. Structural model's fit

At this stage, the fit of the structural model was implemented after evaluating the model and checking the reliability and convergence validity based on significant path coefficients and the R^2 criterion.

6.1. Evaluation of significant path coefficients

The structural model was analyzed using the BootStrap method, and the t parameter (t-test) was extracted for the access path between latent factors to evaluate the path coefficients. Figure 9 illustrates T-values for the communication paths between the variables of the structural model based on the BootStrap method. The t-values indicated the significance of the relationship between the latent variables (lean construction) and the final variable (sustainable construction) with a confidence level of 95%.

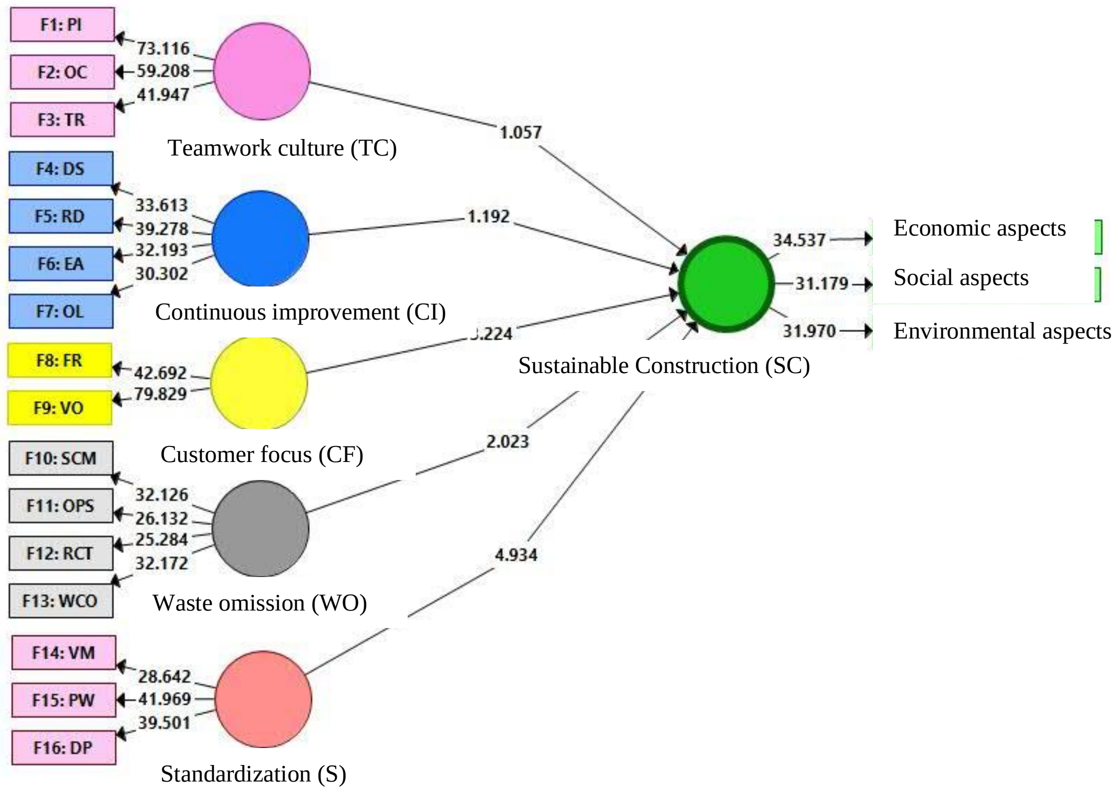

Figure 9. Structural model along with significant path coefficients

6.2. R^2 criterion

The R^2 coefficient related to dependent latent variables indicates the impact of an exogenous variable on an endogenous variable. According to the structural model of the study and the results of Figure 8, the R^2 coefficient for sustainable construction is equal to 0.845, which

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ISSN:1000-3673
Received: 06-05-2024 Revised: 15-06-2024 Accepted: 28-07-2024

indicates a strong impact and significant relationship between the latent variables and the component of sustainable construction.

7. Model's overall fit

The model's goodness of fit (GOF) index is calculated based on Equation 1 to evaluate the model's overall fit, determine the structural model's efficiency, and assess the relationships between endogenous and exogenous parameters.

$$(1) \qquad GOF = \sqrt{\underline{CR^2}}$$

Table 9 represents the values of c and R^2 parameters for the structural model.

Table 9. Values of c and R^2 parameters for the latent variables

	C	R2
Standardization (S)	0.781	0
Continuous improvement (CI)	0.833	0
Customer focus (CF)	0.781	0
Waste omission (WO)	0.831	0
Sustainable Construction (SC)	0.828	0
Teamwork culture (TC)	0.829	0.845
$\underline{C}$	0.8530	
GOF	0.8490	

8. Hypotheses testing

The hypotheses created between the latent variables of lean construction and sustainable construction were investigated based on SEM results. The positive and significant impact of all five endogenous variables of the structural model was evaluated on sustainable construction based on the research structural model, and the results showed the effect of all five factors on the construction parameters.

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9. Data analysis based on ISM

According to the results of structural equation modeling (section 6.4), the main components of lean construction with a significant relationship with sustainable construction were extracted into three main classifications and nine factors as follows:

Customer focus (CF)

Factor F8: Flexible Resources (FR)

Factor F9: Value Optimization (VO)

Waste omission (WO)

Factor F10: Supply Chain Management (SCM)

Factor F11: Optimization of the Production System (OPS)

Factor F12: Reducing the cycle time (RCT)

Factor F13: Work Content Optimization (WCO)

Standardization (S)

Agent F14: Visual Management (VM)

Factor F15: Project Workplace (PW)

Agent F16: Defined Processes (DP)

The opinions of experts and activists in Iran's construction industry can be observed in Figure 9 in the form of scores based on the application of the mentioned nine factors and their initial prioritization based on the research data (average score of each factor).

Table 10. Initial prioritization of the effective parameters of lean construction over sustainable construction

No.	Factor code	effective parameters of lean construction over sustainable construction	Average score of each factor
1	F8	Flexible Resources (FR)	3.68
2	F9	Value Optimization (VO)	3.46
3	F10	Supply Chain Management (SCM)	3.15
4	F11	Optimization of the Production System (OPS)	3.88
5	F12	Reducing Cycle Time (RCT)	3.75

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ISSN:1000-3673
Received: 06-05-2024 *Revised: 15-06-2024* *Accepted: 28-07-2024*

6	F13	Work Content Optimization (WCO)	3.21
7	F14	Visual Management (VM)	2.89
8	F15	Project Workplace (PW)	3.015
9	F16	Defined Processes (DP)	3.28

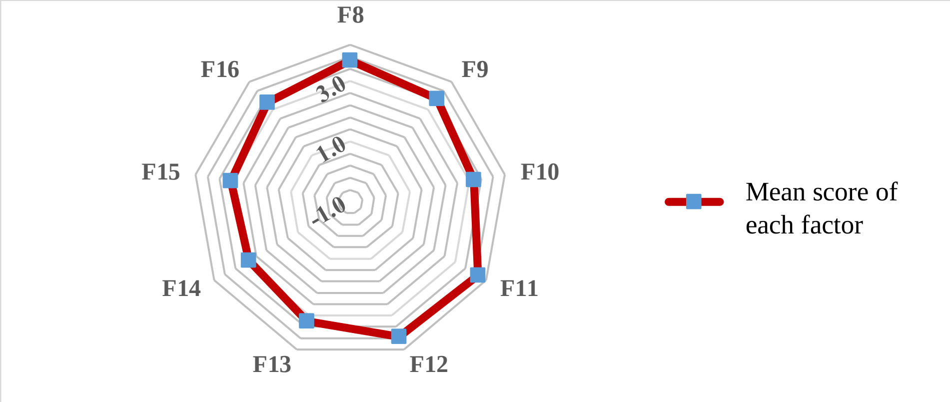

Figure 10. The effect of lean construction factors on sustainable construction

Various methods, such as Analytical Network Processing (ANP) and ISM, were used to analyze the interrelationships between different factors in a complex system. The changes and clustering of obstacles based on these two parameters are extracted as described in Figure 11 based on the values of the driving and dependence power parameters.

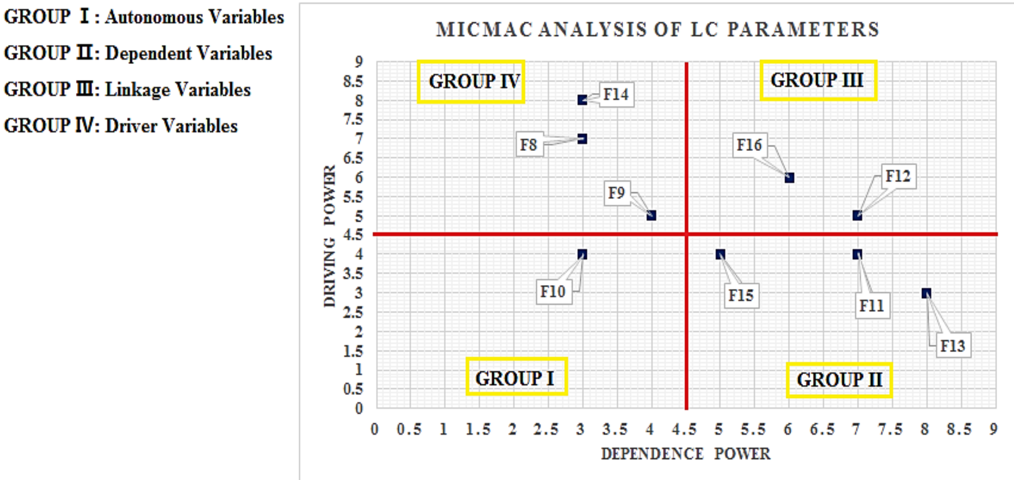

Figure 11. Results of MICMAC analysis (classification of lean construction factors)

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ISSN:1000-3673
Received: 06-05-2024 *Revised: 15-06-2024* *Accepted: 28-07-2024*

According to Figure 11 and the evaluation of the MICMAC analysis results based on the evaluation of driving and dependence power, the categories of lean construction factors are classified as follows:

1. **Group I: Autonomous variables**: they have weak driving power and dependence. Based on the analysis, the F10 factor is placed in this cluster.
2. **Group II: Dependent variables**: barriers in this category have strong dependence and weak driving power. According to the results, factors F11, F13, F15 are in this category.
3. **Group III: Linkage variables**: barriers in this group have strong dependence and driving power. Barriers F12 and F16 are in this category.
4. **Group IV: effective autonomous variables**: in this category, barriers have low dependence and strong driving power (F8, F9, F14).

10. The main barriers to lean construction and coping strategies to achieve sustainable construction

Each of the main factors of lean construction was prioritized based on ISM. In addition, the degree of dependence and driving power of each factor was evaluated by MICMAC analysis. In this part, the results of ISM were peer-reviewed to provide solutions to face and deal with the non-implementation of each factor. Solutions were presented based on determining the level of each lean construction factor and checking the degree of dependence and driving power (Table 12).

Table 12. Solutions provided to implement the main factors of lean construction to achieve sustainability

Executive steps	**Functional level of lean construction factors**	**Lean construction factors**		*** MICMAC Analysis**	**Solution**
		Factor classification	**Factor index**		
1	**Fifth**	Customer focus (CF)	Factor F8: Flexible Resources (FR)	**Cluste**	• **Users' needs and demands should be known and used to improve the**

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ISSN:1000-3673
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	level (V)	Standardization (S)	Agent F14: Visual Management (VM)	**r I V**	**quality of the project before starting the project design process.** • **Comprehensive supervision of the process of designing and implementing different parts of the project**
2	**Fourth level (IV)**	Customer focus (CF)	Factor F9: Value Optimization (VO)	**Cluster IV**	• **Enhancing the interaction of project elements with the consumer.** • **Providing a common definition of value between project elements** • **Improving project management control systems from the beginning to the end, such as contracting, agendas, meeting minutes, and securing financial issues.**
		Standardization (S)	Agent F16: Defined Processes (DP)	**Cluster III**	
3	**Third level (III)**	Waste omission (WO)	Factor F10: Supply Chain Management (SCM)	**Cluster I**	• **Using a cohesive team to provide materials in the minimum time and with sufficient accuracy.** • **Implementing monitoring systems in different parts of the project, communicating between the designer and the executive, and considering the primary needs of customers.**
		Standardization (S)	Factor F15: Project Workplace (PW)	**Cluster II**	
4	**Second level (II)**	Waste omission (WO)	Factor F11: Optimization of the Production System (OPS)	**Cluster II**	• **Applying new project management systems, such as building information modeling (BIM).** • **Peer review of project progress, need assessment, and objective reality in different time steps of the project**
			Factor F12: Reducing the cycle time (RCT)	**Cluster III**	

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5	**First level (I)**	Waste omission (WO)	Factor F13: Work Content Optimization (WCO)	**Cluster II**	**Determining the work cycle based on project needs** **Updating changes in the shortest possible time** **Using proficient experts in project management** **Utilizing expert consultants to implement and update BIM.** **Working with efficient and experienced experts in different parts of the project (qualified and trained contractors)**

11. Conclusion

This study aimed to evaluate the positive effects of lean construction on sustainability in construction, and the following results were achieved:

1. Structural equation modeling and the significance coefficient of the path (1.057) between the teamwork culture parameter and sustainable construction indicated no positive and significant effect at the confidence level of 95%.
2. The path coefficient for this parameter was 1.192, which was lower than 1.96 at the 95% confidence level. In other words, the continuous improvement parameter did not significantly affect the sustainable construction component.
3. The path coefficient between the parameter of customer focus and sustainable construction was 3.226, which indicated a significant relationship between this parameter and the component of sustainable construction, considering the criterion of 1.96 for the significance level of the t-statistic.
4. Structural equation modeling showed that the path coefficient between the waste omission parameter and sustainable construction was 2.023, more than the significance level (1.96). Waste omission in construction industry projects optimizes supply chain management and reduces the process cycle time, directly affecting lean construction's economic and environmental aspects. On the other hand, optimizing the production system and work content leads to a better adaptation of the executive process and the product (structure) to the social conditions and affects the environmental aspects of sustainable construction.
5. The path coefficient for this parameter was 4.934, which was higher than 1.96, considering the confidence level of 95%. Therefore, there was a significant relationship between standardization parameters and lean construction.
6. The analysis of lean construction and sustainable construction factors using the structural equation modeling (SEM) and interpretive structural modeling (ISM) future studies can be analyzed based on the factors and parameters stated in this study and the

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ISSN:1000-3673
Received: 06-05-2024 Revised: 15-06-2024 Accepted: 28-07-2024

new methods presented, such as artificial neural networks and machine learning, and the results can be compared with the results of this research.

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