# Interpretive Structural Model (ISM) and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) Analysis of Lean Barriers in Iraqi Construction Projects

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## ABSTRACT

**Iraqi construction projects are consistently affected by the schedule overruns, cost increases, and frequent quality and safety concerns. Empirical studies link these shortcomings to organizational and technical barriers that hinder the adoption of lean construction. This study identifies, ranks, and structurally analyzes these barriers to the implementation of lean construction practices in Iraq. A field questionnaire of 47 respondents rated 32 barriers drawn from the literature; the barriers with a mean score above 3.4 on a five-point Likert scale were retained for analysis. Interpretive Structural Modeling (ISM) combined with Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) mapped eleven key barriers into a hierarchy of influence and dependence. The lack of government support for technological advancement stands out as the only driving barrier, with a high influence and low dependence, activating six influential linkage barriers: reliance on traditional management methods, limited technical training, inadequate technology adaptation, absence of performance benchmarks, low practitioner awareness, and insufficient information on lean practices. These barriers, in turn, lead to four dependent barriers: traditional design practices, slow hierarchical decision making, delayed material deliveries, and inefficient use of high-quality materials. The study proposes that stakeholders: (1) lobby government agencies for policies and incentives that encourage the lean practices; (2) enhance the technical skill training and the uptake of digital tools; (3) plan improvement initiatives in line with the ISM and MICMAC hierarchy by addressing the driving and linkage barriers. Implementing these steps can accelerate the adoption of lean construction practices and help reduce the overruns while improving the quality and safety of Iraqi construction projects.**

***Keywords-barriers to lean construction; Interpretive Structural Modeling (ISM); the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC); driving barrier; linkage barriers; dependent barriers***

## I. INTRODUCTION

Lean construction is a strategy to improve the performance and productivity [1]. It is an approach that provides a means to achieve more with less human effort, less equipment, and less space [2]. It was introduced as a construction management concept that seeks to reduce the construction waste while addressing the changing construction needs [3, 4]. The aim of the lean approach is to achieve a higher level of industrial productivity through the effective use of resources, with the possibility of reaching the maximum value of production [5]. Lean construction includes five principles: accurately defining the concept of value, defining the value flow, uninterrupted value flow, allowing the customer to pull value, and seeking perfection [6, 7]. Lean construction provides effective techniques to improve the management of the construction operation flow with the minimum waste generation [5]. Lean system is specially designed to increase the productivity of the construction sector by eliminating the activities and procedures responsible for generating waste [8, 9]. Lean construction overcomes many problems, including time delays, cost overruns, safety concerns, and poor quality [10]. The former uses new techniques and tools to maximize the production value for customers and to bring changes in the organizational culture by achieving perfection in the process of product delivery, identification, and disposal of waste, while it contributes to finding a green sustainable environment [11]. In general, the application of the lean construction concept is still slow and limited, because there are some barriers that prevent its successful implementation [12]. Despite its many benefits, the effective implementation of lean construction is very low and rare in developing countries [3, 8, 11].

The low level of awareness among professionals has been identified as the main barrier for implementing lean construction methods in the industry [5]. The production team at the Catholic University of Chile researched the implementation of lean building techniques, developed strategies and tools, and discussed the barriers that impede the implementation of lean building techniques in more than 100 building projects over five years [13]. Authors in [14] classified these barriers in Uganda according to the ease of overcoming them and showed that the easiest barriers to address are the material and resource management, the lack of buildable designs, and participatory management of the workforce. In addition, the lack of organizational support culture for teamwork, lack of pre-fabrication, and lack of skilled and knowledgeable workers are low-strength barriers that are difficult to overcome. Authors in [15] studied the effects of applying lean construction and identified the barriers related to this application.

Authors in [16] assessed the main barriers in South Nigeria upon project delivery and found that the most important of them in lean construction adaption were: lack of technology and knowledge, leadership and management, culture and complexity, participation and relationship, and financial and communication barriers. Authors in [17] showed that the biggest challenge in UK's construction industry is the resistance to the change behavior and methods. Authors in [18] showed that the lack of conviction to adopt the lean system, the lack of guarantee of the supply chain, the tendency to adopt traditional management methods, and the lack of support for senior management are among the most important barriers to the implementation of the lean system in India. Authors in [19] demonstrated that the most important barriers to implementing the lean system in Morocco are the lack of awareness about the lean construction, unskilled human resources, and insufficient finances. Authors in [20] addressed the most important barriers to the lean construction, namely the procedures of senior management and the unwillingness to implement lean construction in companies, as they believe it is expensive and requires special expertise. Authors in [21] showed that the most important barriers in Bangladesh are the lack of awareness, skill, mismanagement, traditional culture, attitude of workers, insufficient resources and techniques, and lack of modern technologies.

Authors in [22] showed that the absence of support from senior management, low awareness of the lean construction concept, and lack of transparency are the most important barriers to implementing the lean system in Jordan. Authors in [23] revealed that the Iraqi construction industry needs lean construction and indicated that the most important barriers are the lack of experience, skills, awareness, and knowledge of the lean construction principles. Authors in [24] indicated that the three most important barriers to the implementation of lean construction in the Kurdistan region of Iraq are the lack of training, low level of vocational education and unskilled workers, and limited use of off-site construction techniques. Authors in [25] studied the advantages and challenges of applying the lean construction methods in the public sector from a biometric perspective. Authors in [26] presented a systematic method of identifying the barriers, enabling factors, and effects on the application of the lean system, along with a model that establishes the relationships between the enabling factors and the barriers. It was found that the most important barriers are the lack of awareness, resistance to change, and lack of support and commitment from the senior management.

Authors in [27] focused on identifying the most significant constraints the construction sector faces when attempting to integrate Building Information Modeling (BIM) with lean construction in Iraq. These include the lack of government regulations, the absence of industry standards for BIM, insufficient funding, lack of government involvement, and the sector's resistance to the changing traditional operating methods. Authors in [28] used ISM while studying the barriers to implementing lean construction in India. Authors in [29] studied the barriers to lean manufacturing using the ISM-Impact Matrix Multiplication Applied to Classification (ISM-MICMAC) and found that the lack of knowledge about lean manufacturing, lack of top management support and commitment, and weak leadership are the main barriers. Most previous studies focused on identifying and evaluating the lean construction barriers were limited to finding the relative importance or a weighted average and did not assess the interrelationships between the barriers or identify the influential and dependent barriers.

This research aims to identify the barriers to the lean construction, in addition to studying the interrelationships between the barriers using ISM while constructing a multi-level structural model that illustrates the arrangement and influence of these barriers on each other. The barriers are then classified based on their strength and dependency using MICMAC.

## II. RESEARCH METHODOLOGY

Figure 1 presents the research methodology, identifying and structurally analyzing the key barriers hindering the implementation of the lean construction in Iraq. The methodology integrates both qualitative and quantitative methods, thereby ensuring rigor and contextual relevance. This study analyzes the barriers to the lean construction implementation, drawing on observations from construction industry professionals with practical experience in the Iraqi context.

The research process commenced with a systematic review of the existing literature to develop a comprehensive list of the potential barriers. Subsequently, a field questionnaire was conducted using a purposive sampling technique to engage experts with direct exposure to lean construction practices. The collected data were filtered, followed by the application of ISM to determine the hierarchical relationships among the barriers. Finally, the MICMAC method was used to categorize the barriers based on their driving and dependence power, offering insights into their strategic implications.

### *A. Theoretical Literature Review*

Table I presents a summary of the barriers, organized by the countries in which the respective studies were conducted. This classification enables a contextual understanding of how the challenges of implementing lean construction practices vary across different geographical and developmental settings.

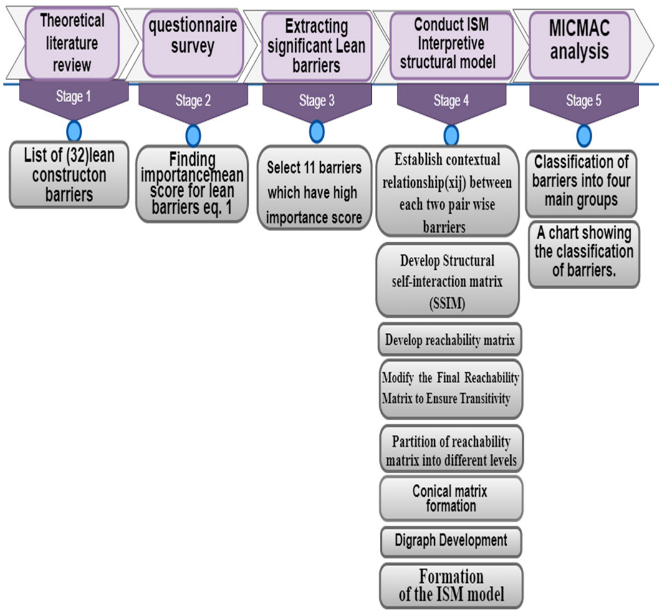


Fig. 1. The research methodology.

TABLE I. BARRIERS TO LEAN CONSTRUCTION

| Ref. | Barriers | Country | Ref. | Barriers | Country |
|---|---|---|---|---|---|
| [13] | ✓ | Chile | [4] | ✓ | Nigeria (Port Harcourt ) |
| [14] | ✓ | Uganda | [20] | ✓ | General |
| [18] | ✓ | India | [34] | ✓ | South Africa |
| [17] | ✓ | UK | [35] | ✓ | Malaysia (Klay Valley) |
| [15] | ✓ | Sri Lanka | [21] | ✓ | Bangladesh |
| [30] | ✓ | UK | [22] | ✓ | Jordan |
| [5] | ✓ | Nigeria | [16] | ✓ | Nigeria (South Nigeria). |
| [31] | ✓ | Nigeria | [27] | ✓ | Iraq |
| [19] | ✓ | Morocco | [24] | ✓ | Iraq ( Kurdistan) |
| [32] | ✓ | Kingdom of Saudi Arabia | [25] | ✓ | Systematic review |
| [33] | ✓ | General review | [36] | ✓ | Literature review |

## B. Field Questionnaire

A field questionnaire was conducted to assess the mean importance score of the lean barriers [37-39]:

$$ms = \frac{\sum sf}{\sum f} \quad (1)$$

where $MS$ represents the mean score, $s$ represents the weight of the respondents' answers according to the five-point Likert scale (1 is very low, 2 is low, 3 is medium, 4 is high, and 5 is very high), and $f$ represents the number of respondents' answers for each weight.

A total of 60 questionnaires were distributed … ($n$ = 47). A purposive sampling strategy was used, targeting experienced professionals. Although the sample size is modest, this aligns with the ISM best practices in similar studies [40]. Purposive sampling prioritizes the information-rich respondents selected according to purpose [41].

## C. Extracting the Significant Barriers

A total of 32 barriers were initially identified through a comprehensive review of prior international and regional studies addressing the challenges in lean construction. To ensure their contextual relevance to the Iraqi construction sector, a two-stage contextualization approach was adopted. In the first stage, a structured questionnaire was administered to local industry professionals ($n = 47$), allowing participants to evaluate the significance of each barrier using a five-point Likert scale. In the second stage, the barriers with mean importance scores above 3.4 were selected. Five senior Iraqi construction experts conducted a critical review to validate the local applicability of the identified barriers.

This rigorous filtering process led to the selection of 11 core barriers that accurately reflect the prevailing conditions and implementation challenges specific to Iraq. To ensure contextual alignment, recent Iraq-focused studies were referred. These included [42], which explored the lean construction barriers within conflict-affected environments; [23], which assessed the feasibility of lean adoption in Iraqi infrastructure projects; and [24], which examined the specific challenges of implementing lean management practices in the Kurdistan region. Collectively, these sources confirmed the relevance and robustness of the final set of barriers selected for the ISM–MICMAC analysis.

## D. ISM Analysis

The ISM method represents the hierarchical relationships between the factors, measuring the momentum and dependence, and also taking into account the cross-influence of the factors [43, 44]. Furthermore, the ISM features schematic hierarchical relationships with factors, based on the principle of pairwise comparison. Its basic idea is to use the experience and practical knowledge of experts to divide complex systems into multiple subsystems and construct a multi-level structural model. The method is interpretive, as group judgment determines whether and how the elements are related.

The ISM method encompasses organizing a variety of directly and indirectly related elements into a comprehensive, systematic model [44]. The resulting model depicts the structure of a complex problem in a carefully considered pattern, suggested by both images and text [45, 46]. There may be multiple aspects related to a problem in each complex situation under discussion, and the situation is more accurately described by the direct and indirect relationships between the elements rather than by any one aspect considered individually [45]. Therefore, ISM works to build an understanding of these relationships through collective knowledge.

The ISM methodology includes the following steps [29, 45-48].

- Step 1: Identify the variables relevant to the current problem.
- Step 2: Identify the contextual relationship between the variables identified in Step 1.

- Step 3: Develop a Structural Self-Interaction Matrix (SSIM) of the variables that defines the pairwise relationships between the system elements. The four symbols ($V$, $A$, $X$, $O$) are converted to binary values (1 or 0) according to standard ISM methodology rules, as:

  •If the ($i$, $j$) entry in SSIM is V, then ($i$, j) = 1 and ($j$, $i$) = 0

  •If the ($i$, $j$) entry is A, then ($i$, $j$) = 0 and ($j$, $i$) = 1

  •If the ($i$, $j$) entry is X, then ($i$, $j$) = 1 and ($j$, $i$) = 1

  •If the ($i$, $j$) entry is O, then ($i$, $j$) = 0 and ($j$, $i$) = 0

- Step 4: Develop a reachability matrix from the SSIM and verify the matrix for contextual relationship transcendence. [39, 40]. Transitivity is a fundamental assumption in ISM that states that if $X$ is related to $Y$ and $Y$ is related to $Z$, then $X$ is necessarily related to $Z$. The symbols $V$, $A$, $X$, and $O$ are converted to 1 and 0 according to specific rules to create the initial reachability matrix. The final reachability matrix is then developed using the concept of transitivity.
- Step 5: Divide the reachability matrix obtained in Step 4 into different levels. The levels are separated using access, precedence, and intersection sets derived from the final reachability matrix.
- Step 6: Develop a directed graph based on the contextual relationships present in the reachability matrix and remove the transitive links from the graph.
- Step 7: Convert the directed graph developed in Step 6 to an ISM model by replacing variable nodes with relationship statements.
- Step 8: Review the ISM model developed in Step 7 to identify the conceptual inconsistencies and make necessary adjustments.

### *E. MICMAC Analysis*

MICMAC aims to examine and classify factors of interest in terms of their driving force and dependence. All variables were classified into four groups based on their driving force (their ability to influence other factors) and dependence (the extent to which a factor is influenced by other factors) calculated during the ISM process [30, 44, 49]:

- Group 1: Autonomous factors: These factors have a relatively low driving force and dependence and are relatively isolated from the system.
- Group 2: Dependent factors: These factors have a low driving force and high dependence. They are primarily dependent on other factors.
- Group 3: Linkage factors: These factors have a high driving force and dependence. They are unstable and and are influenced by other factors [50].
- Group 4: Independent factors: These factors have a high driving force and low dependence. These are considered strong key factors that have a significant impact on the system, with a minimal influence from other factors. The values of momentum and dependence calculated from the final access matrix in the ISM are used to classify the factors into these four groups in the MICMAC analysis [30, 49]. Therefore, the latter relies heavily on the results of the ISM process to classify the factors and draw conclusions based on the strength of the derived relationships. In short, the two methodologies work together. ISM identifies and organizes the relationships between the barriers, while MICMAC analyzes these relationships and classifies the barriers based on their mutual influence, providing a comprehensive understanding of the barriers to the lean construction implementation.

## III. RESULTS AND DISCUSSION

### *A. Literature Review Findings*

The literature review resulted in a list of the most important barriers to lean construction, comprising 32 barriers. Then, a 47-questionnaire survey and validation were conducted with five Iraqi construction professionals to reflect the local context. This process ensured that the 11 final barriers are Iraq-specific and are aligned with the domestic conditions.

### *B. Results of Questionnaire Survey*

A field questionnaire was conducted to assess the relative importance of the barriers in lean construction implementation. A total of 60 questionnaires were distributed and 47 valid forms were received for analysis. Analyzing the questionnaire with the SPSS program, a five-point scale was used to evaluate the barriers, in addition to the item of demographic information, as follows:

#### *1) Demographic Information*

Table II presents the demographic information of the respondents:

- Specialization: The highest percentage is 85% for civil engineering, followed by 6.4% for water resources, while chemical and mechanical engineering each account for the lowest percentage at 4.3%.
- Academic Qualification: The highest rate is 83% for the bachelor's degrees, with most respondents working as site engineers and construction operators, while doctorate and master's degrees account for 12.7% and 4.35%, respectively.
- Occupation: 27.65% are academics and the same percentage corresponds to engineers working in various ministries, 12.8% engineers in non-governmental organizations, and 31.9% engineers working in private sector companies.
- Years of experience: Among the respondents, 80.9% had between 1 and 10 years of experience, followed by 10.6% with more than 20 years of experience and 8.5% with 11-20 years of experience.
- Type of implemented projects: Among the respondents, 25.5% had previously worked on building projects, 21.3% on structural projects, and 17% on reconstruction and road projects.

- Governorate: 63% of the respondents are from Salah al-Din Governorate, and the rest are distributed in small proportions over seven Iraqi governorates between northern and central Iraq.

TABLE II. THE DEMOGRAPHIC INFORMATION OF THE RESPONDENTS

| Variable | | Number | Percentage |
|---|---|---|---|
| Specialization | Mechanical engineering | 2 | 4.300 |
| | Civil engineering | 40 | 85.00 |
| | Chemical engineering | 2 | 4.300 |
| | Water resources | 3 | 6.400 |
| Qualification | Bachelor | 39 | 83.00 |
| | Master | 2 | 4.300 |
| | Ph.D. | 6 | 12.70 |
| Occupation | Academic | 13 | 27.65 |
| | Multiple government ministries | 13 | 27.65 |
| | International non-governmental organization | 6 | 12.80 |
| | Private company | 15 | 31.90 |
| Years of experience | 1-10 | 38 | 80.90 |
| | 11-20 | 4 | 8.500 |
| | > 20 | 5 | 10.60 |
| Type of implemented projects | Reconstruction | 8 | 17 .05 |
| | Building | 12 | 25.50 |
| | Service | 5 | 10.60 |
| | Structural | 10 | 21.30 |
| | Housing units | 4 | 8.500 |
| | Road projects | 8 | 17.05 |
| The governorate | Baghdad | 6 | 12.8 |
| | Babylon | 1 | 2.1 |
| | Salahalddin | 30 | 63.8 |
| | Diyala | 2 | 4.3 |
| | Sulaymaniyah | 1 | 2.1 |
| | Kirkuk | 3 | 6.4 |
| | Anbar | 1 | 2.1 |
| | Nineveh | 3 | 6.4 |

### *2) Stability and Reliability of the Questionnaire*

The reliability of the questionnaire was calculated using the Cronbach's alpha. In this study, the Cronbach's alpha value was 0.916, which is considered excellent according to [4, 51-53].

### *3) Mean Importance Score for Lean Barriers*

Table III shows the Mean importance score for the barriers to the lean construction in Iraq, where most of the barriers range in importance between high and medium. The most important barriers are: lack of government support for technological progress, lack of awareness and understanding of lean construction, lack of technological adaptations, and the lowest barriers are: difficulty working in a group (teamwork), poor communication between the construction team, and the fragmented nature of work in lean construction.

## *C. Extracting Significant Lean Barriers*

To conduct the ISM analysis, it is necessary to choose the most important barriers to the lean construction. In this study, 11 barriers to lean construction in Iraq were selected, which have a high importance mean score.

The ISM analysis was conducted using Smart ISM [54].

- Establish contextual relationship between each pair of barriers: The interactive relationships between each pair of barriers were studied in the context of lean construction within the Iraqi construction projects.
- Develop SSIM: Table IV shows the SSIM—scores aggregated from expert input to determine the pairwise relationships, where a directional relationship between the barriers B1 and B3 (V) indicates that the barrier B1 significantly influences the barrier B3, as agreed by the expert panel.
- Develop reachability matrix: Table V presents the initial reachability matrix, which clarifies its role in deriving the final structure; the symbols were replaced by 0 and 1. Table VI displays the final reachability matrix, which ensures the transitivity property and describes the levels and partitions, with indirect (non-explicit) relationships indicated by *1. The final reachability matrix is then used to conduct the MICMAC analysis, with the rows representing the strength of influence and the columns representing the strength of dependence.
- Division of reachability matrix into different levels: Table VII illustrates the division of the final reachability matrix into levels based on the access set (all barriers that directly or indirectly affect the selected barrier, extracted from the row for that barrier in the final reachability matrix) and the precedent set (all barriers that directly or indirectly affect the selected barrier, extracted from the column for that barrier in the final reachability matrix).

The barriers whose reachability set is equal to the antecedent set are selected, as follows:

1. Level 1: The variable (10:B27) has the smallest reachability set, which is the barrier itself, and shares the same barrier 10 with the antecedent set. Thus, it represents the first level and is removed from the list.
2. Level 2: The variable (9:B22) represents the second level because it is the second point of intersection barrier between the reachability set and the antecedent set, and is also removed from the list.
3. Level 3: The variable (8:B10) is the third point of intersection barrier between the reachability set and the antecedent set and it is also removed from the list.
4. Level 4: The variable (4: B7) represents the intersection point barrier between the reachability set and the antecedent set. So, it represents the fourth level and is removed from the list.
5. Level 5: The variables (1: B1, 2: B3, 3:B6, 6:B12, 8:B17, 11:B28) are common barriers between the reachability set and the precedents in Level 5.
6. Level 6: The variable (7: B12) is the common barrier between the reachability set and the antecedent at this level.

- Conical matrix formation: The barriers (factors) are organized according to their hierarchical levels. This arrangement aims to clearly demonstrate the relationships between the barriers, which helps in developing an organized ISM model. Table VIII depicts the formation of a conical matrix, which includes:
- Reordering the barrier levels: Barriers are arranged from the highest level (least influential and most influenced) to the lowest level.
- Reordering the matrix according to hierarchical levels: The matrix is arranged according to the sequence of levels, resulting in a clear hierarchical structure and helping to identify the direct and indirect influences.

TABLE III. BARRIERS TO LEAN CONSTRUCTION IN IRAQ

| Code | Barriers | MS | Importance | Rank |
|---|---|---|---|---|
| B1 | Impact of traditional management methods | 3.51 | 7 | High |
| B2 | Considering a lean construction culture as an inappropriate organizational culture | 3.15 | 28 | Moderate |
| B3 | Lack of technical skills and training in lean construction style | 3.60 | 4 | High |
| B4 | Bad communication between the construction team | 3.00 | 31 | Moderate |
| B5 | The lack of a strong performance measurement system | 3.38 | 12 | Moderate |
| B6 | Lack of technological adaptations | 3.62 | 3 | High |
| B7 | Traditional design style | 3.51 | 8 | High |
| B8 | The long implementation period for lean construction in building operations | 3.34 | 15 | Moderate |
| B9 | Additional costs and inflation rates | 3.34 | 16 | Moderate |
| B10 | Slow decision-making processes due to the complex organizational hierarchy | 3.49 | 9 | High |
| B11 | Lack of clear job specifications from clients | 3.36 | 13 | Moderate |
| B12 | Lack of performance benchmarks | 3.53 | 6 | High |
| B13 | Lack of government support for technological advancement | 3.96 | 1 | High |
| B14 | Uncertainty (confidence) of the production process | 3.34 | 17 | Moderate |
| B15 | Use of non-standard components (not typical) | 3.21 | 24 | Moderate |
| B16 | Uncertainty (confidence) of the supply chain | 3.34 | 18 | Moderate |
| B17 | Lack of awareness and understanding of lean construction. | 3.87 | 2 | High |
| B18 | Few need to adopt the concept of lean construction | 3.15 | 29 | Moderate |
| B19 | Difficulty in understanding the lean construction concept | 3.28 | 22 | Moderate |
| B20 | Weak communication between clients, consultants, and contractors | 3.17 | 26 | Moderate |
| B21 | Considering waste is acceptable as an essential outcome of the ineffective use of quality standards | 3.26 | 23 | Moderate |
| B22 | Delay in the delivery of materials | 3.60 | 5 | High |
| B23 | Lack of an agreed methodology for the implementation of lean construction | 3.17 | 27 | Moderate |
| B24 | Lack of attention and commitment from top management | 3.34 | 19 | Moderate |
| B25 | Incomplete designs | 3.19 | 25 | Moderate |
| B26 | Lack of long-term commitment to change and innovation | 3.36 | 14 | Moderate |
| B27 | Ineffective use of high-quality materials | 3.40 | 10 | High |
| B28 | Lack of information (on lean construction) or assistance from other organizations | 3.40 | 11 | High |
| B29 | Having difficulty working in a group (group work) | 2.91 | 32 | Moderate |
| B30 | Lack of implementable lean-construction design schemes | 3.34 | 20 | Moderate |
| B31 | The fragmented nature of the industry (for work) in lean construction | 3.06 | 30 | Moderate |
| B32 | Lack of long-term relationships with suppliers | 3.32 | 21 | Moderate |
| **Mean** | | **3.36** | **Moderate** | |

TABLE IV. SSIM MATRIX

| | B1 | B3 | B6 | B7 | B10 | B12 | B13 | B17 | B22 | B27 | B28 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **B1** | | V | V | V | V | X | A | A | V | O | O |
| **B3** | | | A | V | V | A | A | V | V | V | A |
| **B6** | | | | V | V | V | A | A | V | V | V |
| **B7** | | | | | V | A | A | A | O | V | A |
| **B10** | | | | | | A | A | A | V | V | O |
| **B12** | | | | | | | A | V | V | V | V |
| **B13** | | | | | | | | V | V | V | V |
| **B17** | | | | | | | | | V | V | V |
| **B22** | | | | | | | | | | V | A |
| **B27** | | | | | | | | | | | A |
| **B28** | | | | | | | | | | | |

TABLE V. INITIAL REACHABILITY MATRIX

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Driving power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 7 |
| B3 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 6 |
| B6 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 8 |
| B7 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 3 |
| B10 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 3 |
| B12 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 9 |
| B13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| B17 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 8 |
| B22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| B27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| B28 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 5 |
| Dependence power | 4 | 6 | 4 | 8 | 8 | 4 | 1 | 4 | 9 | 10 | 5 | |

TABLE VI. FINAL REACHABILITY MATRIX

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Driving power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1* | 1 | 1* | 1* | 10 |
| B3 | 1* | 1 | 1* | 1 | 1 | 1* | 0 | 1 | 1 | 1 | 1* | 10 |
| B6 | 1* | 1 | 1 | 1 | 1 | 1 | 0 | 1* | 1 | 1 | 1 | 10 |
| B7 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1* | 1 | 0 | 4 |
| B10 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 3 |
| B12 | 1 | 1 | 1* | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 10 |
| B13 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11 |
| B17 | 1 | 1* | 1 | 1 | 1 | 1* | 0 | 1 | 1 | 1 | 1 | 10 |
| B22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 2 |
| B27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| B28 | 1* | 1 | 1* | 1 | 1* | 1* | 0 | 1* | 1 | 1 | 1 | 10 |
| Dependence power | 7 | 7 | 7 | 8 | 9 | 7 | 1 | 7 | 10 | 11 | 7 | |

TABLE VII. DIVISION OF THE FINAL REACHABILITY MATRIX INTO LEVELS BASED ON ACCESS SET AND PRECEDENT SET

| Elements (Mi) | Reachability set R(Mi) | Antecedent set A (Ni) | Intersection set R(Mi)∩ A(Ni) | Level |
|---|---|---|---|---|
| 1 | 1,2,3,6,8,11 | 1,2,3,6,7,8,11 | 1,2,3,6,8,11 | 5 |
| 2 | 1,2,3,6,8,11 | 1,2,3,6,7,8,11 | 1,2,3,6,8,11 | 5 |
| 3 | 1,2,3,6,8,11 | 1,2,3,6,7,8,11 | 1,2,3,6,8,11 | 5 |
| 4 | 4 | 1,2,3,4,6,7,8,11 | 4 | 4 |
| 5 | 5 | 1,2,3,4,5,6,7,8,11 | 5 | 3 |
| 6 | 1,2,3,6,8,11 | 1,2,3,6,7,8,11 | 1,2,3,6,8,11 | 5 |
| 7 | 7 | 7 | 7 | 6 |
| 8 | 1,2,3,6,8,11 | 1,2,3,6,7,8,11 | 1,2,3,6,8,11 | 5 |
| 9 | 9 | 1,2,3,4,5,6,7,8,9,11 | 9 | 2 |
| 10 | 10 | 1,2,3,4,5,6,7,8,9,10,11 | 10 | 1 |
| 11 | 1,2,3,6,8,11 | 1,2,3,6,7,8,11 | 1,2,3,6,8,11 | 5 |

TABLE VIII. CONICAL MATRIX

| Variables | 10 | 9 | 5 | 4 | 1 | 2 | 3 | 6 | 8 | 11 | 7 | Driving power | Level |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 9 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| 5 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 |
| 4 | 1 | 1* | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 |
| 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1* | 0 | 10 | 5 |
| 2 | 1 | 1 | 1 | 1 | 1* | 1 | 1* | 1* | 1 | 1* | 0 | 10 | 5 |
| 3 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1* | 1 | 0 | 10 | 5 |
| 6 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 0 | 10 | 5 |
| 8 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1* | 1 | 1 | 0 | 10 | 5 |
| 11 | 1 | 1 | 1* | 1 | 1* | 1 | 1* | 1* | 1* | 1 | 0 | 10 | 5 |
| 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11 | 6 |
| Dependence power | 11 | 10 | 9 | 8 | 7 | 7 | 7 | 7 | 7 | 7 | 1 | | |
| Level | 1 | 2 | 3 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 6 | | |

- Digraph Development: The diagram constitutes a visual representation of the influence relationships between the barriers. The former consists of nodes denoting the barriers and arrows representing the causal relationship between the factors. The conical matrix is used as a reference. The lower-level barriers (the most influential) are placed at the bottom and the higher-level factors (the least influential) are placed at the top. The indirect links or relationships are removed, and the direct relationships are retained. Figure 2 exhibits the diagram of the barriers to the lean construction in Iraq, with the most influential variable being 7, as it affects the six variables 1, 2, 3, 6, 8, 9, and 10, while the six variables affect the variables with the least influence in order 4, 5, 9, and 10.
- Formation of the ISM model: Figure 3 presents the final ISM of the lean construction barriers in construction projects in Iraq. The model was drawn using a directed graph, where the nodes are replaced by barriers, with the arrows representing the causal relationship between the barriers.

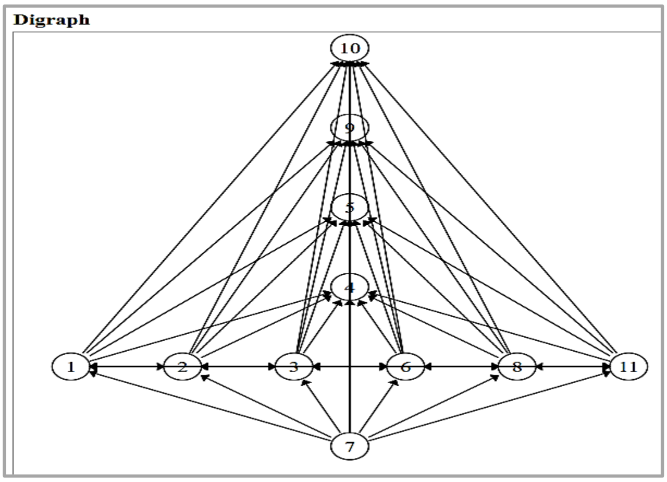


Fig. 2. Diagram of the barriers to lean construction in Iraq.

The most influential barrier is B13 (lack of government support for technological advancement), which affects the six barriers B1 (impact of traditional management methods), B3 (lack of technical skills and training in lean construction style), B6 (lack of technological adaptations), B12 (lack of performance benchmarks), B17 (lack of awareness and understanding of the lean construction), and B28 (lack of information on the lean construction ), which are at the same level of influence but have a lesser impact than B13. These barriers affect B7 (traditional design style), which in turn affects B10 (slow decision-making processes due to the complex organizational hierarchy), which affects B22 (delay in delivery of materials), which affects B27 (ineffective use of high-quality materials), which does not affect any of them.

## D. MICMAC Analysis

The final reachability matrix is used to conduct the MICMAC analysis. The rows represent the strength of influence and the columns the strength of dependence. The barriers in this analysis are displayed in a two-dimensional graph, where the x-axis denotes the strength of dependence and the y-axis the strength of influence, as portrayed in Figure 4, detailed implications of classified clusters.

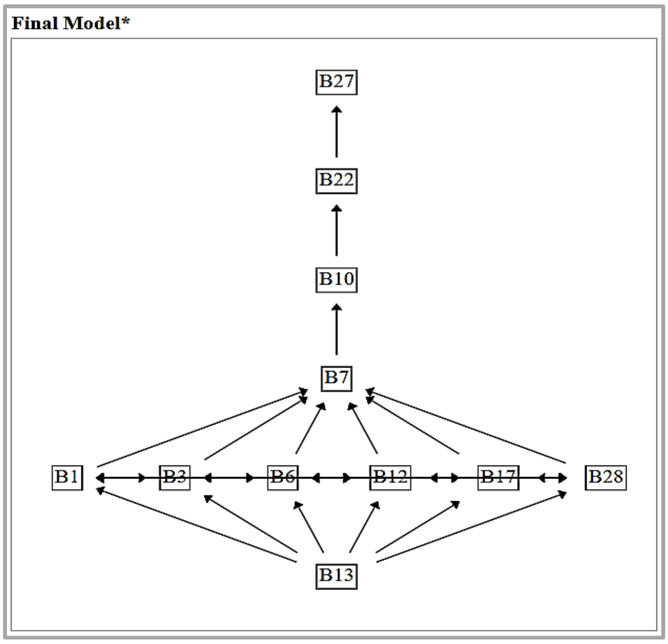


Fig. 3. The ISM model.

The barriers are divided into four groups according to the strength of dependence and the strength of influence of each barrier:

- Independent barriers: They have weak influence and weak dependence and do not significantly affect the system. There are no barriers in this group.
- Dependent barriers: They have a weak influence but depend on other barriers, represented by (4: B7, 5: B10, 9: B22, and 10: B27) in order of importance.
- Linkage barriers: They have a high influence and depend heavily on other barriers, making them unstable. These barriers are represented by (1: B1, 2: B2, 3: B6, 6: B12, 8: B17, and 11: B28).
- Driving barriers: They have a significant influence but depend little on others. These barriers are represented by (7:B13).

## E. Strategic Implications of MICMAC Classification

Based on the MICMAC analysis, the barrier “lack of government support for technological advancement” (B11) was positioned in the independent/driving quadrant, indicating a high level of influence over the system with minimal dependence on other factors. This barrier should be prioritized for intervention, as addressing it is likely to generate cascading improvements across the system. Strategic recommendations include introducing policy reforms, enhancing the public sector involvement in innovation, and establishing national frameworks to incentivize lean-related technologies [55].

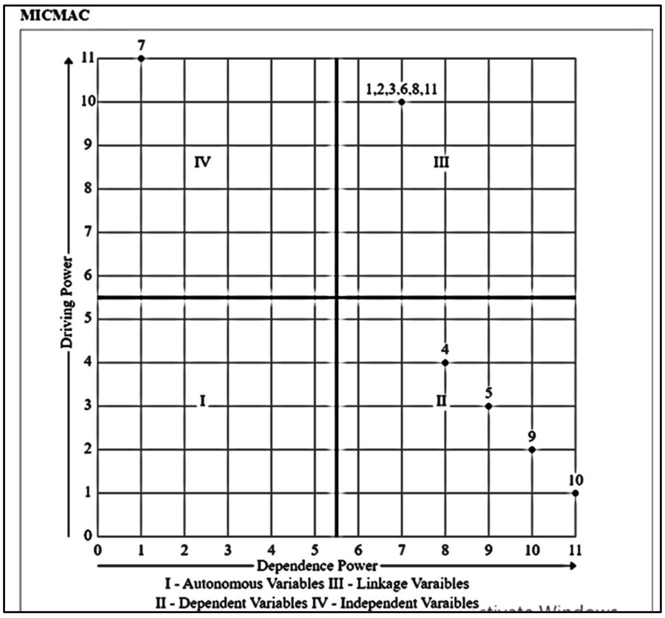


Fig. 4. MICMAC analysis

Six barriers were identified as linkage factors, characterized by both a high driving power and high dependence. These include traditional management methods, limited technical training, and insufficient adaptation of modern technologies. Such barriers are considered highly sensitive and unstable; therefore, the interventions targeting them must be sequenced carefully and implemented in coordination with the actions addressing the driving barrier. A simultaneous attention to these factors can prevent the systemic imbalance and feedback loops that may hinder progress [56].

Four barriers were classified as dependent factors, exhibiting a low driving power and high dependence. Barriers, such as inefficient material usage and delayed deliveries, are outcomes of the deficiencies in the upstream system. The direct intervention in these factors may not yield significant impact unless more influential driving and linkage barriers are first addressed.

No barriers were placed in the autonomous quadrant; however, continuous observation is proposed to ensure that no new isolated challenges emerge over time.

This structured prioritization is consistent with the implementation strategies reported in previous ISM–MICMAC studies [55, 57] and offers a practical roadmap for stakeholders to allocate resources efficiently, mitigate potential risks, and facilitate a phased implementation of the lean principles within the Iraqi construction sector.

## IV. CONCLUSION

This research analyzes the barriers to lean construction in Iraqi construction projects using Interpretive Structural Modeling (ISM) and Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) analysis. The study identifies the main barriers and evaluates their interconnections to develop a structured framework to overcome these challenges. The research categorizes 32 barriers based on their impact on the lean construction implementation. The most significant barriers include:

The lack of government support for technological advancements received a mean score of 3.96, complying with [12, 26], the lack of awareness and understanding of lean construction obtained 3.87, complying with [4, 5, 10, 22], the lack of technological adaptations achieved 3.62, complying with [9], the lack of technical skills, and training in lean construction style obtained 3.60, complying with [15, 22]. In addition, the delay in delivery of materials achieved 3.60, and the lack of performance benchmarks 3.53. The lean construction methods are partially applied in Iraq, but not under the name of lean construction, possibly because the companies may not know that the methods they use are lean construction methods. This demonstrates a lack of awareness and knowledge of the lean building methods.

The barriers identified may differ from those in developed countries that are technologically advanced and more inclined toward change; however, they are similar to those in other countries where there is a lack of sufficient awareness and understanding of the lean construction principles and techniques.

Based on the structural model, a MICMAC analysis classified the barriers into groups:

- The barriers at the lower level are the driving barriers, which must be addressed first as they affect the rest of the system. They are represented by the lack of government support for technological advancement.
- The barriers at the intermediate level are the linkage barriers because they are influenced by the primary factors and affect the higher factors, primarily represented. These barriers include the impact of traditional management methods, which regards the lean construction culture as an inappropriate organizational culture, lack of technological adaptations, lack of performance benchmarks, and lack of information (on lean construction) or assistance from other organizations).
- The barriers at the higher level are considered dependent barriers, which can only be resolved by addressing the factors that affect them. These barriers include the traditional design style, slow decision-making processes due to the complex organizational hierarchy, delay in delivery of materials, and ineffective use of high-quality materials.

Based on this analysis, the following recommendations are proposed:

### *A. General Recommendations*

- Government policy improvements by providing motivations for lean construction practices and implementation of regulations mandating lean construction methodologies.
- Educational and training programs by raising awareness among professionals through workshops and the integration of lean construction into the university curricula.

- Technological developments by:
- Encouraging the adoption of digital construction tools and providing financial support for the implementation of lean construction techniques.
- Improving supply chain management by building strategic partnerships with suppliers to reduce the material delays, and implementing lean procurement methods to enhance efficiency.

### *B. Practical Implications and Role-Based Recommendations*

To operationalize the ISM–MICMAC findings, the following stakeholder-specific strategies are proposed:

- Contractors and Project Managers: Introduce lean delivery systems, such as IPD and Just-in-Time coordination, to address the key driving barriers.
- Policymakers and Regulatory Bodies: Reform procurement regulations to support ther lean practices, inspired by successful regional frameworks.
- Design and Consulting Teams: Implement BIM-integrated lean design approaches to minimize waste from the early stages.
- Training Institutions: Deploy a phased training plan targeting driving, and then linkage and dependent barriers.

This study highlights the main barriers to lean construction in Iraq and presents a structured model that not only identifies these challenges, but also offers both general and role-specific recommendations. By adopting the proposed strategies, stakeholders across various levels can enhance the project efficiency and contribute to the successful implementation of the lean construction principles.

### *C. Limitations and Future Work*

One of the limitations of this study is its geographic focus solely on Salah al-Din Governorate. While this region provides valuable insights into the context of developing Iraqi construction projects, the results may not be fully generalizable to other regions with different conditions.

Future research should consider expanding the geographical scope to include multiple governorates across Iraq, particularly those with varying urbanization levels and construction practices. This would enhance the applicability and robustness of the findings and offer a better understanding of the lean implementation across diverse Iraqi contexts.

In line with the foundational ISM–MICMAC approaches, it is essential that future research moves beyond qualitative structural modeling and incorporates advanced quantitative validation techniques. Accordingly, the following directions are proposed:

- Employ Structural Equation Modeling (SEM) or Confirmatory Factor Analysis (CFA) to test and validate the proposed hierarchical structure, confirming the latent dimensions and interrelationships among the identified barriers.
- Utilize Exploratory Factor Analysis (EFA) to evaluate the underlying constructs and ensure the validity and reliability of the measurement scales used to assess the lean barriers.
- Expand the sample size and diversity by including participants from various regions across Iraq to enhance the generalizability and representativeness of the findings.

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