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Framework for the Implementation of Lean Construction Strategies using ISM technique: A case of Saudi Construction Industry

Abstract

Purpose: The purpose of this study is to develop a framework for implementing lean construction, and consequently to improve performance levels in the construction industry taking Saudi Arabia as the context. There is currently no framework for implementing lean construction srateges particularly in the KSA construction industry. Existing lean construction frameworks are focused on other countries and are less applicable in the KSA due to differences in socio-cultural and operational contexts.

Design/methodology/approach: This study employs the interpretive structural modelling (ISM) technique for data collection and analysis. Firstly, following a survey of 282 construction professionals, 12 critical success factors (CSFs) for implementing lean construction were identified by Sarhan, Olanipekun and Xia (2016). Secondly, 16 of these professionals who have 15 years or more experience were exclusively selected to examine the contextual relationship among the 12 CSFs. A row and column questionnaire was used for a pairwise comparison of the CSFs. A matrix of cross-impact multiplications was applied to a classification analysis (MICMAC) analysis of the questionnaire data to develop an ISM model that can serve as framework for implementing lean construction. Thirdly, the framework was subjected to further validation by interviewing 16 experts in order to check for conceptual inconsistencies and for the applicability of the framework in the context of the KSA construction industry.

Findings: The findings reveal that the CSFs are divided into four clusters: autonomous, linkage, dependent, and driving clusters. Additionally, the findings reveal seven hierarchies of interrelationships among the CSFs. The order of practical application of the CSFs descends from the seventh hierarchy to the first hierarchy.

Originality/value: The new framework is a significant advancement over existing lean construction frameworks as it employs the ISM technique to specify the hierarchical relationships among the different factors that contribute to the successful implementation of lean construction. The primary value of this study is the development of a new framework that reflects the socio-cultural and operational contexts in the KSA construction industry and can guide the successful implementation of lean construction. Therefore, construction industry operators such as contractors, consultants, government departments and professionals can rely on the framework to implement lean construction more effectively and successfully.

Keywords: Critical Success Factors (CSFs), Framework, Kingdom of Saudi Arabia, Interpretive structural modelling, Lean Construction

Paper type: Research paper

1. Introduction

The construction industry is an important sector globally as it creates the built environment for a country through the production of a wide range of buildings, and civil and heavy engineering infrastructure (Jiang and Wong, 2016). This infrastructure serves to enhance the health, economic, social and cultural aspects of humanity (Xiong *et al.*, 2016). In addition, the construction industry provides job opportunities and a livelihood for both professional practitioners, and skilled and unskilled labourers (Lu et al., 2015). The Kingdom of Saudi Arabia (KSA) has the largest construction industry in the Middle East with an approximate annual expenditure of more than USD 120 billion dollars (Alrashed *et al.*, 2014), providing about 15% of the total employment in the country (Dhahran International Exhibition Company, 2015).

In KSA, many construction projects perform poorly both in terms of cost and time (Assaf and Al-Hejji, 2006). For instance, the Haramian Railway project experienced a delay of about one year, thereby increasing the cost of completion to $14 billion, from an initial estimated completion cost of $11.1 billion (McElroy, 2014). In addition, the quality performance of construction projects is also poor with many projects collapsing before reaching the end of their design life span (AMEInfor, 2014). The poor performance of construction projects is also attributable to the struggles of many construction organisations to efficiently manage the construction process, minimise waste, increase productivity and control delay (AlSehaimi, 2011). As a result, the KSA construction industry is generally not effective in delivering the best value for clients (Ali and Wen, 2011).

In the broader construction industry, lean construction is employed as a continuous process of improving construction projects through the elimination or reduction of wastes while aiming to meet or even exceed client requirements. (Chandrasekar and Kumar, 2014; Diekmann *et al.*, 2004). Additionally, the application of lean construction in the construction industry contributes to eliminating non-value adding activities in the construction process, while increasing value adding activities (Love and Li, 1998). Therefore, the application of lean construction practices enable construction projects to be carried out in a more healthy and sustainable manner, thereby leading to increased construction productivity to both meet the needs of clients (Marhani *et al.*, 2012) and to improve profitability for constructors (Ogunbiyi *et al.*, 2011). In order to improve the performance of construction projects and organisations, especially in terms of construction processes, lean construction strategies have been introduced to the KSA construction industry (Al-Sudairi 2007; AlSehaimi *et al.*, 2009).

However, despite the importance and demonstrated effectiveness of lean construction for improving performance in the construction industry, there is currently no framework for implementing lean construction in the KSA construction industry. Existing lean construction frameworks focus on the construction industry in other countries, and due to differences in socio-cultural and operational contexts, they are inapplicable in the KSA construction industry [give reference of your previous papers]. The KSA is a Middle-eastern society where practices in the construction industry are quite different from those in the Western construction industry [reference]. An example is Al-Aomar's (2012) Lean–Six Sigma framework which identifies lean construction activities and incorporates a Six Sigma rating system to evaluate the cost, quality and scheduling implications of those practices in the United Arab Emirates (UAE). Another one is Banawi's (2013) framework which incorporates lean, Green, and Six Sigma for the purpose of reducing wastes during the delivery of construction projects. A consequence of the inapplicability of the existing frameworks to the KSA construction industry context is the low level of implementation of lean construction in the KSA construction industry to date (AlSehaimi *et al.*, 2009; Sarhan *et al.,* 2017).

To promote the implementation of lean construction, and consequently improve performance levels, there is a need for an applicable framework that reflects the socio-cultural and operational contexts. The framework will serve as a guideline to identify relevant lean construction practices and specify step-by-step procedures to implement lean construction (Lehman and Reiser, 2000; Banawi, 2013; Johansen and Walter, 2007; Al-Aomar, 2012; Banawi and Bilec, 2014). Therefore, the aim of this study is to develop a framework for implementing lean construction in the KSA construction industry. To achieve this aim, the technique of interpretive structural modelling (ISM) was adopted to analyse the interrelationships among the factors that constitute the proposed framework (Attri *et al.*, 2013). In contrast to existing lean construction frameworks, the proposed framework specifies the hierarchies of different factors that contribute to the successful implementation of lean construction.

The study builds on an existing study by Sarhan, Xia and Olanipekun (2016) which identified 12 critical success factors (CSFs) for implementing lean construction in the KSA construction industry. The major contribution of the paper is the development of a new framework that reflects the socio-cultural and operational contexts in the KSA construction industry and can guide the successful implementation of lean construction. Therefore, construction industry operators such as contractors, consultants, government departments and industry professionals in this country can rely on the framework to implement lean construction more effectively and successfully. The second contribution is that the new framework is an improvement over existing lean construction frameworks as it employs the ISM technique to specify the hierarchical relationships among the different factors that contribute to the successful implementation of lean construction in the KSA construction industry.

This paper is structured as follows. Firstly, a review of existing lean construction frameworks is carried out to identify gaps in the knowledge. Secondly, the research methodology is presented. This section contains a description of the ISM technique and how it is applied in this study. Thirdly, a discussion of findings is presented, followed by the conclusion.

2. Review of existing lean construction frameworks

Lean construction frameworks, often known as lean construction models, provide guidelines for the application of lean construction strategies, that enable proactive control of the performance of construction projects (Swefie 2013; Al-Aomar, 2012). The use of a framework to implement lean construction helps to achieve significant project success, especially in terms of cost, time and quality performance (Al-Aomar, 2012).

In the literature, there are a number of lean construction frameworks covered. For instance, Paez et al. (2005) developed a socio-technological framework, which harmonises both lean manufacturing and lean construction practices (as they share similar technical and human elements in their operation), therefore, providing the basis for adopting lean manufacturing principles into a construction context. Green and May (2005) observed that lean construction is a concept which has multiple meanings and interpretations in different contexts. This often undermines how lean construction is interpreted and conceptualized among competing actors in the construction industry, especially the managerial and non-managerial actors (Green and May, 2005). Consequently, after interviewing 25 construction sector policy-makers in the UK construction industry, these authors, determined three dominant concepts that characterized the meaning of lean construction. The first one is waste elimination, which depicts lean construction as a process of ensuring resource efficiency. The second one views lean construction as a partnering concept for bringing together project actors and achieving collaboration in the construction industry. The third combines the elements of the previous two, and emphasizes that lean construction can help in bringing about changes in the way projects are delivered, using a range of approaches from conventional models to more innovative, technologically driven and collaborative models.

A conceptual framework developed by Johansen and Walter (2007) identifies eight specific areas where the lean concept can be applied in the construction industry, based on results from a survey of management-level professionals and operators in 61 top construction companies in Germany. These areas are design, procurement, supply, installation, management, planning/control, collaboration and change management (Johansen and Walter, 2007). As the framework did not reveal how lean construction could be implemented in different types of construction projects, the adoption of lean construction has remained limited in the German construction industry.

Al-Aomar (2012) developed an ambitious framework which identifies lean construction activities incorporating a Six Sigma rating to evaluate the cost, quality and schedule implication of those practices. The framework also proposed a look-ahead period of planning before execution of these practices, whereby performance could be measured and necessary corrections made. The framework demonstrated how lean construction can be implemented in reality, using a case study of 28 different sized construction companies in Abu Dhabi. Although this is a very unique contribution, the framework focuses only on construction-waste elimination. Other sources of construction inefficiencies such as delays and errors are not included in the framework, thus allowing for further investigation.

While Al-Aomar's (2012) framework can be regarded as a Lean-Six Sigma framework, Banawi (2013) proposed a Lean-Green-Six Sigma framework. Lean focuses on waste reduction, Green assesses environmental impacts while Six Sigma is introduced to improve productivity. The framework comprises of three steps: define and measure, analyse and improve, and control. In a case study on an institutional facility in Pittsburgh, USA, implementation of the framework contributed to reducing waste in the construction process. Similar to Al-Aomar's (2012) framework, this framework is mainly concerned with waste elimination, despite incorporating Green and Six Sigma concepts for reducing environmental impact and enhancing productivity levels, respectively.

Other recently developed frameworks focus on the implementation of lean construction. This indicates that implementation of lean construction is a continuing challenge in the construction industry. For instance, Gao and Low (2014) proposed a 'Toyota-way' model, comprising 14 principles within four layers, as an alternative framework for implementing lean construction. The layers, each of which can be a separate model, include: philosophy, process, people and partners, and problem-solving. While many frameworks for lean construction have a strong technical focus, this framework encompasses both technical and human aspects, thereby providing alternative approaches to lean construction implementation.

Jang et al. (2014) observed that many lean tools and techniques are not directly applicable in for implementing lean construction in the construction industry, due mainly to the non-participation of the supposed users (or practitioners) in that industry. As a result of this, an action research-based framework for incorporating the input of industry practitioners into the academic research on tools and techniques for implementing lean construction was proposed. The aim of insisting on the participation of industry practitioners, is to ensure that lean construction frameworks developed through research are properly applied by practitioners in the industry. The study also validated the proposed framework by implementing it in a light-rail transit construction in South Korea and demonstrating its effectiveness in terms of enhancing productivity (Jang *et al.,* 2014).

The current literature review reveals the knowledge and use of different lean construction frameworks in the construction industry. Their significance ranges from revealing how to adapt lean manufacturing to the construction context, how to increase the adoption of lean construction and promote its effective use, integrating other concepts to complement the effectiveness of lean construction, and most importantly, providing an indication of how to implement lean construction practices. However, none of the previous frameworks are focused on the KSA construction industry, in particular. In addition, none of them specify the CSFs that assist in the implementation of lean construction in the construction industry, nor do they examine whether any relationships exist between the CSFs that effectively promote this implementation. Therefore, this study builds on an existing study that identifies the CSFs for implementing lean construction in the KSA construction industry (Sarhan, Olanipekun, *et al.,* 2016), but furthermore, it proposes an ISM approach to specify the interrelationships among the CSFs in order to develop a framework for the implementation of lean construction in the KSA construction industry.

3. Research methodology

As mentioned previously, this study builds on an earlier study by Sarhan, Olanipekun, *et al.* (2016), but the aim of this study is to develop a framework for the implementation of lean construction in the KSA construction industry using Interpretive Structural Modelling (ISM).

3.1 Interpretive structural modelling (ISM) process

According to Warfield (1994), the ISM technique enables an understanding of the relationships among many elements associated with a system by developing a structured model of these relationships. This helps to impose order on, and direction to, the relationships among elements in a system, such that their influence can be analysed (Mandal and Deshmukh, 1994; Sharma *et al.,* 1995; Singh *et al.,* 2003; Sarhan, Hu *et al.,* 2016). According to Kumar et al. (2013), the various steps involved in ISM are as follows:

Step 1: Identify the factors relevant to the system under investigation. In this project, this involves a survey of 282 construction professionals in the KSA construction industry to identify 12 CSFs.

Step 2: Establish contextual relationships among the factors identified in Step 1 based on expert opinion.

Step 3: Formulate a structural self-interaction matrix (SSIM) of the factors to reveal pairwise relationships.

Step 4: Develop a reachability matrix based on the SSIM to calculate the numerical mutual influence, and check the matrix for transitivity. The transitivity of the contextual relationship is a basic assumption in ISM, which states that if element A is related to B, and B is related to C, then A is also related to C.

Step 5: Partition the reachability matrix into different levels.

Step 6: Remove the transitivity links, and draw a directed graph (diagraph), based on the relationships given in the reachability matrix.

Step 7: Convert the digraph into an ISM-based model by replacing element nodes with the statements.

Step 8: Review the model to check for conceptual inconsistencies and make any necessary alterations. In this study, interviews were conducted with experts who have a sound understanding of lean construction and the operations of the KSA construction industry, in order to validate the ISM model developed in step 7.

4. Analysis of Results: Development of the ISM framework

Step 1: Identify the CSFs: As mentioned previously, the first step in the ISM process was achieved in a study by Sarhan *et al.,* (2016). Following a questionnaire survey of 282 construction professionals, the study identified the 12 CSFs for successful implementation of lean construction in the KSA construction industry. Of the 282 respondents, 51 per cent have more than 10 years of professional working experience, while the other 49 per cent have 1–10 years experience. Additionally, 80 per cent of the respondents have either a bachelor degree or a diploma, while 20 percent of have postgraduate degree qualifications in the construction field. From an organisation perspective, 39 per cent of the respondents work in project management organisations, 23 per cent in general contracting organisations, 10 per cent in architectural firms, 9 per cent in speciality contracting firms, 5 per cent in client, academic and government organisations, 3 per cent in subcontracting firms and one per cent in supplier organisations. The 12 CSFs are presented in Table 1.

Table 1: Critical success factors for the implementation of lean construction

No.	Critical success factors
1	Top management commitment to and leadership of lean construction
2	Providing education and training for lean construction in the construction industry (e.g. Staff, contractors, designers etc.)
3	Adopting alternative procurement methods in project delivery (e.g. Design-Build, early contractor involvement etc.)
4	Adopting new construction technologies/methods (e.g. BIM)
5	Applying appropriate lean construction tools / techniques (e.g. Last Planner System, 5S, Value Stream Mapping etc.)
6	Implementing organisational change (culture, strategy, vision and performance evaluation system)
7	Promoting a culture of teamwork during construction projects

8	Adoption of continuous improvement
9	Clear definition of client's requirements
10	Applying the lean methodology at an early stage of the building project delivery (e.g. Planning, design stage etc.)
11	Coordinating and promoting efforts at a national level (e.g. establishment of a National Lean Construction Institute)
12	Establishing long-term relationships within the supply chain

Step 2: Examine contextual relationships among the factors identified in Step 1: From the 12 CSFs obtained in step 1, the contextual relationships among the CSFs were identified. Of the 282 construction professionals surveyed, 16 of them, each with 15 years or more working experience, were selected to examine the contextual relationships among the 12 CSFs. With the level of experience they have, the selected professionals can each provide their educated opinion regarding the factors that are more related to each other than to other factors. Hence, they were asked to complete a pairwise-comparison of the 12 CSFs via a row and column questionnaire. In the questionnaire, the 12 CSFs in Table 1 are listed in the rows and columns. However, the CSFs are labelled as shown in Table 2 to enable the pairwise comparison. Specifically, the experts were instructed to compare the column statement to the row statement for each cell on the questionnaire and to select an appropriate symbol from the symbol-set (V, A, X, O), according to their perception of direct relationships between the two CSFs in question. In essence, the questionnaire has been designed in order to query the existence of a relationship between any two CSFs, and also determine the associated direction of that relationship. Below is a description of each symbol as stated on the questionnaire.

V – CSF i will help achieve CSF j; but not in the opposite direction
A - CSF j will help to achieve CSF i; but the reverse will not occur
X – CSF i and j will help to achieve each other
O – CSF i and j have no relationship with each other

(Note: the values for 'i' and 'j' are from CSF 1, 2,….12)

Steps 3: Formulate the structural self-interaction matrix (SSIM): According to R. Kumar *et al.* (2013), SSIM is a technique for finding the contextual relationships among identified factors using expert opinions. On the basis of the pairwise comparison by the experts using the V, A, X, O symbol-set, the SSIM was formulated to reveal the pairwise relationships of the CSFs in Table 2. Note, the entries in the SSIM were based on the maximum responses obtained for the pair of CSFs.

Table 2 Structural self-interaction matrix (SSIM)

CSF j → / CSF i ↓	12	11	10	9	8	7	6	5	4	3	2	1

1	Top management commitment and leadership	V	V	V	O	V	V	V	V	V	V	V	
2	Education and training	V	A	V	V	V	V	V	V	V	V		
3	Adopting alternative procurement methods	V	A	X	X	V	O	A	A	A			
4	Adopting new construction technology/methods	V	A	V	A	X	V	A	X				
5	Applying appropriate lean construction tools	V	A	X	A	X	V	A					
6	Implementing organisational change	V	A	V	V	V	X						
7	Promoting a culture of teamwork	O	A	A	O	X							
8	Adoption of continuous improvement	V	A	A	O								
9	Clear definition of client's requirements	O	O	A									
10	Early application of lean methodology	V	A										
11	Coordination and promotion at a national level	V											
12	Long-term relationships within the supply chain												

Step 4: Develop a reachability matrix based on the SSIM to calculate the numerical mutual influence, and check the matrix for transitivity: As shown in Table 3, the initial reachability matrix is derived from the SSIM by substituting the V, A, X and O symbols with binary digits of either "1" or "0" based on the following rules (see N. Kumar *et al.,* 2013).

- If the (i, j) entry in the SSIM is V, then the (i, j) entry in the initial reachability matrix becomes 1 and the (j, i) entry becomes 0; for V(1,12) in SSIM, '1' has been recorded in cell (1,12) and '0' in cell (12,1)
- If the (i, j) entry in the SSIM is A, then the (i, j) entry in the initial reachability matrix becomes 0 and the (j, i) entry becomes 1; for A (2,11) in SSIM, '0' has been recorded in cell (2,11) and '1' in cell (11,2)
- If the (i, j) entry in the SSIM is X, then both the (i, j) and (j, i) entries of the initial reachability matrix becomes 1; for X (5,10) in SSIM, '1' has been recorded in cell (5,10) and '1' in cell (10,5) and,
- If the (i, j) entry in the SSIM is O, then both the (i, j) and (j, i) entries of the initial reachability matrix becomes 0; for O (7,12) in SSIM, '0' has been recorded in cell (7,12) and '0' in cell (12, 7).

CSF j →Initial reachability matrix		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
CSF i ↓													
1	Top management commitment and leadership	1	1	1	1	1	1	1	1	0	1	1	1
2	Education and training	0	1	1	1	1	1	1	1	1	1	0	1
3	Adopting alternative procurement methods	0	0	1	0	0	0	0	1	1	1	0	1
4	Adopting new construction technology/methods	0	0	1	1	1	0	1	1	0	1	0	1
5	Applying appropriate lean construction tools	0	0	1	1	1	0	1	1	0	1	0	1
6	Implementing organisational change	0	0	1	1	1	1	1	1	1	1	0	1

7	Promoting a culture of teamwork	0	0	0	0	0	1	1	1	0	0	0	0
8	Adoption of continuous improvement	0	0	0	1	1	0	1	1	0	0	0	1
9	Clear definition of client's requirements	0	0	1	1	1	0	0	0	1	0	0	0
10	Early application of lean methodology	0	0	1	0	1	0	1	1	1	1	0	1
11	Coordination and promotion at a national level	0	1	1	1	1	1	1	1	0	1	1	1
12	Long-term relationships within the supply chain	0	0	0	0	0	0	0	0	0	0	0	1

Table 3: Initial reachability matrix

The final reachability matrix is obtained by incorporating transitivity. The transitivity of the contextual relationship is a basic assumption of the ISM technique, which states that if element A is related to B, and B is related to C, then A is also related to C (Kumar, Luthra and Haleem, 2013). In Table 4, '*' indicates the presence of transitivity. For instance, CSF1 is related to CSF 1, 2, 3, 4, 5, 6, 7, 8 and CSF 9 is added as a transitive element to CSF 10.

Table 4: Final reachability matrix with driving power and dependence of CSFs

CSF j → / **CSF i ↓**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Driving power**
1	Top management commitment and leadership	1	1	1	1	1	1	1	1	1*	1	1	1	12
2	Education and training	0	1	1	1	1	1	1	1	1	1	0	1	10
3	Adopting alternative procurement methods	0	0	1	1*	1*	0	1*	1	1	1	0	1	8
4	Adopting new construction technology/methods	0	0	1	1	1	1*	1	1	1*	1	0	1	9
5	Applying appropriate lean construction tools	0	0	1	1	1	1*	1	1	1*	1	0	1	9
6	Implementing organisational change	0	0	1	1	1	1	1	1	1	1	0	1	9
7	Promoting a culture of teamwork	0	0	0	1*	1*	1	1	1	1*	1*	0	1*	8
8	Adoption of continuous improvement	0	0	1*	1	1	1*	1	1	0	0	0	1	7
9	Clear definition of client's requirements	0	0	1	1	1	0	1*	1*	1	1*	0	1*	8
10	Early application of lean methodology	0	0	1	1*	1	1*	1	1	1	1	0	1	9
11	Coordination and promotion at a national level	0	1	1	1	1	1	1	1	1*	1	1	1	11
12	Long-term relationships within the supply chain	0	0	0	0	0	0	0	0	0	0	0	1	1
Dependence		1	3	10	11	11	9	11	11	10	10	2	12	

Step 5: Partition the reachability matrix into different levels: According to Haleem *et al.* (2012), the segregation of the components of a structure into different levels makes it easier to understand the relationships in a hierarchy. The final reachability matrix is used for the partitioning of the CSFs into different levels, by determining the reachability set and the antecedent set (Kumar and Kumar, 2016). The reachability set (R) consists of the CSF itself and other CSFs, which it will support, whereas the antecedent set (C) consists of the CSF itself and other CSFs which will help in supporting it (Kumar,

Agrawal and Sharma, 2013). Consequently, the intersection of these sets (i.e. R∩C) is obtained for all of the 12 CSFs. As shown in Table 5, CSF 12 has the highest rank or hierarchy because its reachability (R), and intersection (R∩C) sets are the most similar, or the same (Yang, 2012). The CSF 12 is therefore selected in hierarchy level I. This process is repeated iteratively until the respective hierarchical levels for all the CSFs are identified. As shown in Table 6, the CSFs with the highest rank, or hierarchy, are the ones which have the same reachability (R) and intersection (R∩C), sets. As shown in Table 5, the 12 CSFs are partitioned into several levels ($L_1 – L_7$) demonstrated below.

$$L_1 = \{12\}; L_2 = \{4, 5, 7, 8\}; L_3 = \{3, 9, 10\}; L_4 = \{6\}; L_5 = \{2\}; L_6 = \{11\}; L_7 = \{1\}$$

Table 5 Iteration 1 of level partition

CSF	Reachability set	Antecedent set	Intersection set	Level
1	1,2,3,4,5,6,7,8,9,10,11,12	1	1	
2	2,3,4,5,6,7,8,9,10,12	1,2,11	2	
3	3,4,5,7,8,9,10,12	1,2,3,4,5,6,8,9,10,11	3,4,5,8,9,10	
4	3,4,5,6,7,8,9,10,12	1,2,3,4,5,6,7,8,9,10,11	3,4,5,6,7,8,9,10	
5	3,4,5,6,7,8,9,10,12	1,2,3,4,5,6,7,8,9,10,11	3,4,5,6,7,8,9,10	
6	3,4,5,6,7,8,9,10,12	1,2,4,5,6,7,8,10,11	4,5,6,7,8,10	
7	4,5,6,7,8,9,10,12	1,2,3,4,5,6,7,8,9,10,11	4,5,6,7,8,9,10	
8	3,4,5,6,7,8,12	1,2,3,4,5,6,7,8,9,10,11	3,4,5,6,7,8	
9	3,4,5,7,8,9,10,12	1,2,3,4,5,6,7,9,10,11	3,4,5,7,9,10	
10	3,4,5,6,7,8,9,10,12	1,2,3,4,5,6,7,9,10,11	3,4,5,6,7,9,10	
11	2,3,4,5,6,7,8,9,10,11,12	1,11	11	
12	12	1,2,3,4,5,6,7,8,9,10,11,12	12	I

Table 6 Level partitioning of criteria

No.	CSF	Level
1	Top management commitment and leadership	VII
2	Education and training	V
3	Adopting alternative procurement methods	III
4	Adopting new construction technology/methods	II
5	Applying appropriate lean construction tools	II
6	Implementing organisational change	IV
7	Promoting a culture of teamwork	II
8	Adoption of continuous improvement	II
9	Clear definition of customer requirements	III
10	Early application of lean methodology	III
11	Coordination and promotion at a national level	VI
12	Long-term relationships within the supply chain	I

Step 6: Remove the transitivity links and draw the directed graph (diagraph) based on the relationships given in the reachability matrix: The matrix of cross-impact multiplications applied to a classification analysis (MICMAC) is used to analyse the driving power and dependence power of the 12 CSFs. As shown in Table 4, the driving power of each CSF is the summation of the total number of factor interactions in the row (including itself), which it affects, while the dependence of each factor is the summation of the total number of factor interactions in the column (including itself), by which it is affected (Kumar and Kumar, 2016). Consequently, as shown in Figure 1, the driving power and dependence power summations of the CSFs are plotted into a diagraph of four clusters: autonomous, linkage, dependent and driving clusters (Mandal and Deshmukh, 1994).

The first cluster, the autonomous cluster, comprises CSFs with weak driving power and weak dependence. In addition, autonomous cluster CSFs can be disconnected from the entire system, with little or no impact on other CSFs (S. Kumar *et al.,* 2013). In this study, there are no CSFs in the autonomous cluster. The second cluster is the dependent cluster, which comprises CSFs that have weak driving power, but strong dependence power. The one CSF under this cluster is the establishment of long-term relationships within the construction supply chain (12). Its strong dependence suggests that it requires other CSFs to be achieved (Haleem *et al.,* 2012). The third cluster is the linkage cluster, which comprises CSFs that have strong driving power and strong dependence. There are eight CSFs in this cluster: adopting continuous improvements, adopting alternative procurement methods in project delivery, clear definition of client requirements, promoting a teamwork culture during project construction, organisational change, applying the lean methodology at an early stage of building project delivery, adopting new construction technologies/methods, and applying appropriate lean construction tools/techniques. According to Kumar and Kumar (2016), and Haleem *et al.* (2012), CSFs in this cluster can be unstable as any action taken on any of these will affect other CSFs, and can cause feedback on the CSF itself. The last cluster is the driving cluster. It comprises CSFs that have strong driving power and weak dependence. The three CSFs in this cluster are: ensuring top management commitment and leadership for lean construction, coordinating and promoting efforts at a national level, and providing education and training for lean construction in the construction industry. Given their strong driving power, these CSFs are the fundamental key to the successful implementation of lean construction techniques (Attri *et al.,* 2013).

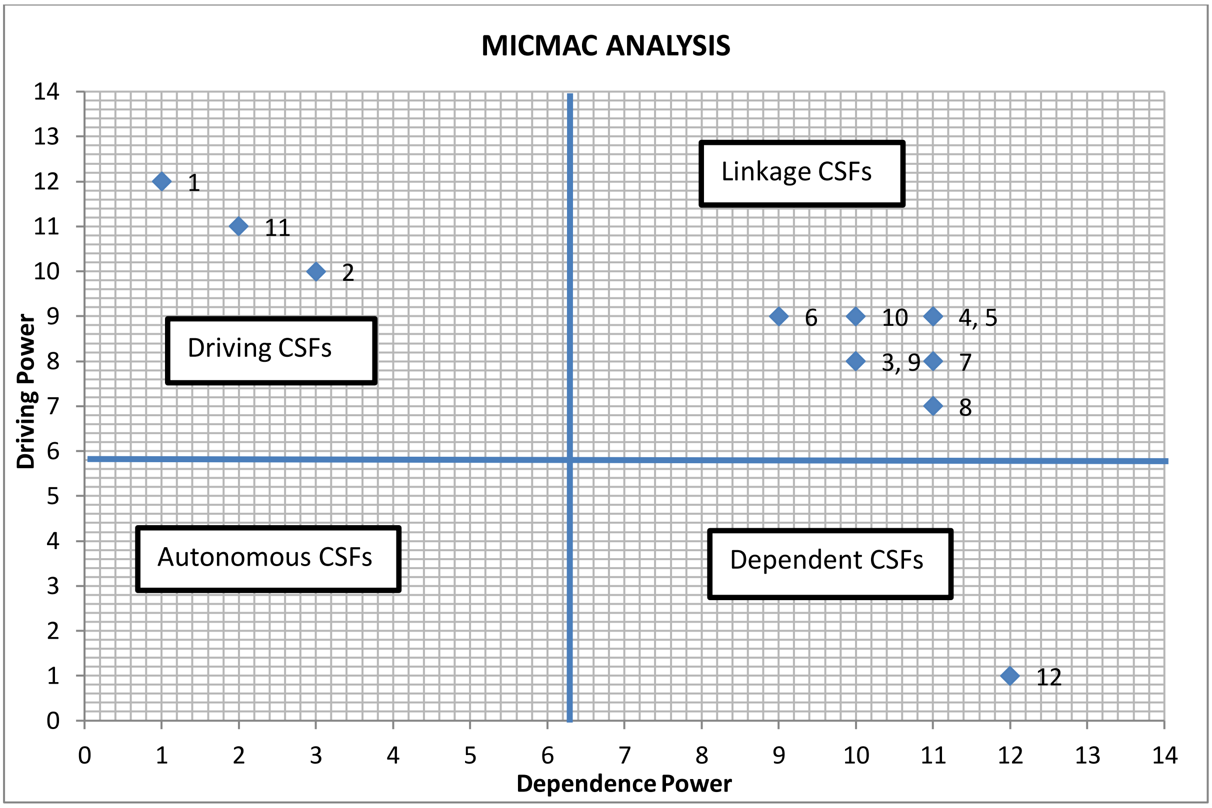

Figure 1 Driving power and dependence for CSFs for lean construction implementation

Step 7: Convert the digraph into an ISM-based model by replacing element nodes with the statements: The ISM model is generated from the final reachability matrix after removing the transitivity links and replacing the node numbers with statements (N. Kumar *et al.*, 2013). As shown in Figure 2, arrow directions indicate relationship(s) among the CSFs 'i' and 'j' (Haleem et al., 2012). It can be seen that 'top management commitment and leadership for lean construction (CSF1)' is very significant for the implementation of lean construction in the KSA construction industry, as it appears at the base of the hierarchy in the ISM model. In addition, 'establishing long-term relationships within the construction supply chain' is identified as the top-level CSF in the ISM model.

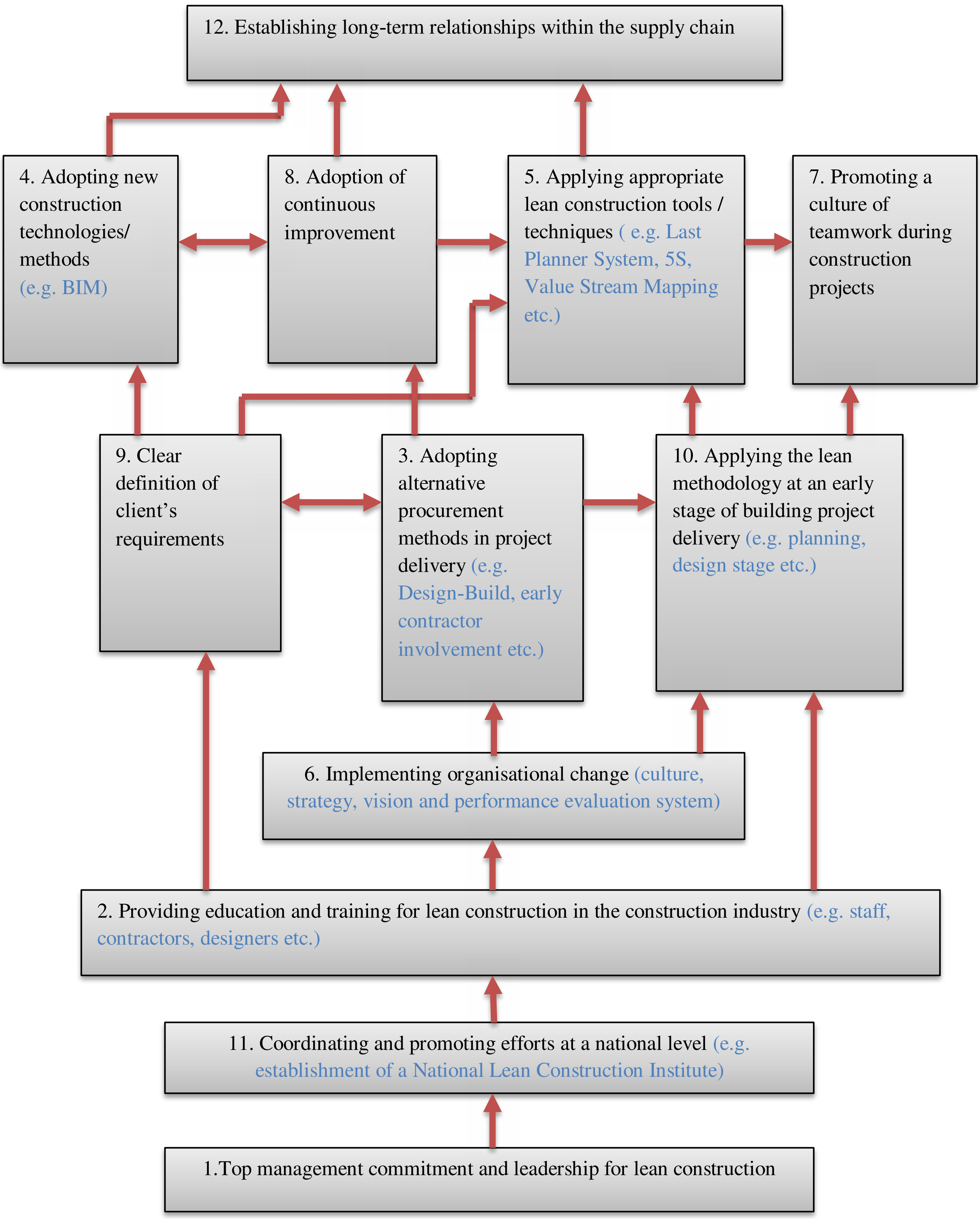

Figure 2: ISM-based model of lean construction implementation

Step 8: Review the model to check for conceptual inconsistencies and make the necessary alterations: This review process was carried out through validation using experts who have a sound understanding of both lean construction, and the operations of the KSA construction industry. Therefore, the experts were purposively selected. According to Xia (2010), validation is the last stage of a research study to verify whether the quality of a developed model is within an acceptable standard. The experts were asked to review the proposed ISM model in step 7, for conceptual inconsistencies and thereafter contribute improvements thought necessary. In addition, the experts were asked to verify the appropriateness and applicability of the model in the KSA construction industry context.

The validation of the ISM model by the experts was carried out using an interview methodology. This was preferred because it allows both the researcher and the interviewee to engage effectively in issues addressed in the interview, and in a greater degree of detail, with no doubt or ambiguity (Ahmed *et al.,* 2016; Bhattacherjee, 2012). Five interview questions were framed inductively from the developed ISM model. Each question was provided with a generic explanatory statement to indicate the findings, with examples in some instances, to provide context and help the experts fully understand the question. The questions were cast in an open–ended format to allow the experts to provide their own responses and views about the questions asked, without constraining them to a fixed set of possible answers (Ahmed *et al.,* 2016). The interview questions were carefully drafted into a one-page document with an introduction stating the aim of the validation study and outlining the potential benefits both to the experts and to the body of knowledge.

The researcher identified 10 experts from among those that participated in the survey in step 1 and eventually, five of these agreed to participate. The interview questions together with the developed ISM model in a separate document were sent to the experts one week before the actual interview, to allow them chance to study the model in detail and understand the questions before the interview. The experts were also instructed to communicate anything in the interview documents that they could not understand, well before the interview. The interview took place on the set date as agreed to by the experts. Given the limited number of questions and the clarity introduced with the explanatory statements added to each of the questions, the phone interviews with each expert lasted for an average of 20–30 minutes. In addition, each of the interview sessions was recorded digitally, with a total recorded time of 118 minutes for all interviews. During the interview sessions, whenever responses were ambiguous or unclear, the experts were asked further probing questions to clarify the meaning of their responses, especially with regard to analogies and examples. After the completion of each interview, the experts were thanked for their participation with a promise to provide them each a brief report of the final outcomes of the study.

The responses from the experts constitute qualitative data, which was analysed using content analysis in line with the method described in Elo and Kyngäs (2008). Firstly, the overall time of the interview of the experts was kept relatively short and the recording of each expert interview was transcribed manually into an Excel worksheet. Secondly, the responses to each of the interview questions by all the experts were manually merged to identify the themes and provide a means of description. The third step undertaken was the abstraction, i.e. the naming of the themes. Lastly, the themes are described by relating them to the implementation of lean construction in the KSA construction industry.

5. Validation results

The background information of the experts is contained in Table 7. These experts are both practitioners and practitioners with academic affiliations with an average of 15 years experience covering general construction practices and lean construction in the KSA construction industry.

Table 7: Background information of experts involved in the validation of the framework

Experts description	Years of experience	Designation	
		Industry and Academia	Industry
Expert 1	8	X	
Expert 2	10	X	
Expert 3	14		X
Expert 4	20		X
Expert 5	10	X	

Firstly, the experts were asked whether lean construction should be implemented in the KSA construction industry to enable collaboration among project participants, improving construction processes and overall industry performance. All the experts agreed that lean construction should be implemented for those purposes. Expert 5 expressed optimism that implementing lean construction can positively impact the KSA construction industry as a whole, while Expert 4 stated lean construction can help to improve the efficiency level in the industry. Expert 2 believed that the implementation of lean construction in the KSA construction industry would contribute to achieving the KSA 2030 vision of diversifying the economy and the development of service sectors through efficiency in project delivery and minimization of waste. In terms of how lean construction should be enforced, Expert 1 argued for a mandatory, rather than voluntary mode of enforcement. In this case, mandatory enforcement requires the participation of the government, which is the only entity empowered to make, and with the responsibility for enacting legislation and enforcing such in the KSA.

Secondly, the experts were asked whether the list of CSFs for successful implementation of lean construction in the KSA are comprehensive, and if not, whether there are other factors that should be included. All the experts agreed that the CSFs are very comprehensive. Meanwhile, Expert 4 suggested the addition of “integrated form of agreement” and “collaborative forms of project delivery”, which would support more effective lean construction. This suggestion is already incorporated in “adoption of alternative procurement systems such as DB” (CSF 3). In line with the intention of the expert, the factor enables early project involvement by participants, and collaboration in project delivery, in order to ensure successful lean construction implementation. Another factor which aligns with the intention of this expert is “promoting the culture of teamwork among participants involved in project delivery” (CSF 7). Expert 3 proposed that the CSF should be classified into different levels. Although the goal in this study is not to classify the CSF, the ISM model specifying the interrelationships among the CSF is divided into 7 levels of hierarchy. At the base of the hierarchy is ‘top management commitment and leadership for lean construction (CSF1)’, while “establishing long-term relationships within the construction supply chain’ is at the top of the hierarchy in the ISM model. Thirdly, the experts were asked whether the 7 levels of hierarchies identified in the ISM model are logical. All the experts agreed that the levels of hierarchy are very logical.

Fourthly, the experts were asked whether the framework could contribute to improving the performance of projects and organisations in the KSA construction industry. There were a range of responses from the experts. Both Expert 1 and 3 specifically agreed that the ISM model is implementable in the KSA construction industry, although Expert 1 emphasised the need to provide industry-wide education and training about lean construction, in order to ensure that all stakeholders have a fuller understanding of lean construction. Expert 4 pointed out that more guidance will be required to explain to operators in the construction industry, how they can implement the model. Accordingly, while the arrow directions are illustrative, careful explanation about the logical implementation of the framework is described in section 6. The comment from Expert 2 about model development was more generic, that outputs and expectations have to be defined and clarified throughout any model. For the current ISM model, it means that while the 12 CSFs in their respective levels of hierarchy and interrelationships are inputs to the implementation, the outputs or expected outcomes need to be specified. The outcome specified for this model is to improve performance of construction projects and organisations in the KSA construction industry. All the experts agreed with these, as being suitable outcomes of the model if implemented. For instance, Expert 5 stated that the model can contribute to improving the performance of construction projects and organisations if it is carefully implemented. Expert 4 agreed with Expert 5, and further stated that the framework will be useful for project clients, and decision and policy makers in the KSA construction industry.

Lastly, the experts were asked whether the research process described in section 3.1 and 6 was adequate for the development of the ISM model, and to provide any suggestions for future improvements. Experts 1, 3 and 5 specifically stated that the research process is already adequate and they did not suggest any additional improvements. However, as part of the research process, Expert 3 proposed the use of interviews and/or focus groups to further support the establishment of the relationships among the CSFs, while Expert 2 mentioned the need to validate the model using a qualitative case-study approach. This would require implementing the framework in real construction projects and organisations. The expert also suggested that based on the research results, further justification needs to be developed to clearly show that the model fulfils its initial objective, which is to improve the performance of projects and organisations in the KSA construction industry. Clearly, this is a sound suggestion, which requires more resources than were able to be provided in this study, but can be planned for future research.

6. Discussion of the ISM model

The driver-dependence diagram, or diagraph (Figure 1) provides some insights into the relative importance of the CSFs and their interdependencies, i.e., the links among the CSFs. On this basis, and in contrast to existing models such as Al-Aomar's (2012), and Banawi and Bilec's (2014), the current ISM model developed by this study reveals the interrelationships of the 12 CSFs in a hierarchical manner, and is developed for successful implementation of lean construction in the KSA construction industry. As shown in Figure 2, the ISM model is divided into seven hierarchies (VII-I).

Within the model, the hierarchy of each CSF is based on its ranking in the context of the respective driving and dependence powers (Kumar and Kumar, 2016). Thus, the top management commitment and leadership (VII) with a driving power of 12 and a dependence power of 1 is the most important CSF for the implementation of lean construction in the KSA construction industry. Many studies agree with the high importance of the top management commitment and leadership in construction organisations to inspire and motivate employees and lower-chain suppliers to embrace lean construction (Baviskar, 2015; Al-Najem *et al.,* 2012). Other highly important CSFs for the implementation of lean construction in the KSA construction industry are: coordinating and promoting efforts at a national level (VI) and providing education and training for lean construction in the construction industry (V) with driving powers of 11 and 10, and dependence powers of 2 and 3, respectively. It is therefore, important to give more consideration to these CSFs in the KSA construction industry. On the other hand, establishing long-term relationships within the construction supply chain (I) with a driving power of 1 and s dependence power of 1 is the least important CSF for the implementation of lean construction in the KSA construction industry. Hence, less importance should be given to this factor in the implementation of lean construction in the KSA construction industry.

Similarly, in line with Kumar and Kumar (2016), the directional arrows in the ISM model (Figure 2) indicate that any particular CSF is driven by another, or drives others. Hence, the top management commitment and leadership in the seventh hierarchy (VII) drives the coordinating and promoting efforts at a national level in the sixth hierarchy (VI). Normally, in the construction industry, there are many different organisations involved, such as contracting, consulting and supplying companies. These organisations have different responsibilities in the construction supply chain and are guided by different goals, values and ambitions. Given these differences, a holistic coordination of these organisations is very important to achieve joint goals. Therefore, in the KSA construction industry, there is a need for nation-wide coordination to align the different organisations to a singular holistic lean construction view. Those in top management positions in the various construction organisations in the KSA construction industry are in the best position to achieve this as they, collectively, are responsible for making the final decision to follow this path, and to provide the resources required for implementation. They also have the responsibility to lead their employees to follow and practice nationally aligned lean construction management and practices.

Consequently, coordination and promotion efforts at a national level also drives the education and training for lean construction in the construction industry in the fifth hierarchy (V). In order to attain the effective implementation of a nationally-aligned lean construction initiative, the participation of employees in construction organisations is important. They are responsible for daily operations of lean construction in different construction organisations, and for them to perform these roles effectively, education and training across the industry is required. Management in the construction organisations can achieve this by providing continuous and focused training to their employees. The regulatory and professional bodies in the KSA construction industry such as the Saudi Council of Engineers (SCE) are also responsible in this regard, for providing training to their professional members. With such training, the employees and professional members can increase their understanding of how lean construction is viewed from a national perspective, and how to effectively implement the concept (Al-Aomar, 2012).

By providing education and training for lean construction, the management in construction organisations, as well as the regulatory and professional bodies, are driving change towards lean construction principles (IV) by re-orientating the focus of employees in the construction industry. As part of organisational change for lean construction, which is in the fourth hierarchy (IV), top management in construction organisations often introduces lean construction principles as part of the organisational vision and mission for easy access, understanding and application by employees. According to Al-Najeem et al. (2012), it is possible to employ clear vision and strategy to build an effective lean culture in organisations.

It appears that organisational change leads to both the adoption of alternative procurement methods (III), and the application of lean methodology at an early stage of project delivery in the third (III) hierarchy. Mainly at the operational level of the organisation, effective organisational change in the long-term culminates in the adoption of alternative procurement systems such as design-build (DB), which encourages the early participation of project participants to work together for the successful implementation of lean construction. In addition, organisational change needs to focus on early-stage project delivery activities for the successful implementing lean construction. The latter is also driven by education and training for lean construction, in addition to a clear definition of clients' requirements

(III). For instance, in project owner and consulting organisations in the construction industry, education and training on how to properly define client requirements for the contracting side of project procurement can be crucial for the successful implementation of lean construction, while for contracting organisations, education and training can increase the capacity to evaluate and implement lean construction requirements of clients. Both a clear definition of clients' requirements and adoption of alternative procurement methods drive each other, due to their bi-directional relationship, while the latter drives the application of lean methodologies at an early stage of project delivery.

There are four CSFs in the second hierarchy (II). The first one is adopting new construction technologies/methods, and it is driven by a clear definition of clients' requirements. The second one is the adoption of continuous improvement such as *Kanban* during the project delivery, which has a bi-directional relationship with adoption of new construction technologies/methods and is driven by adopting alternative procurement methods. The third one is applying lean construction tools/techniques, and it is driven by three other CSFs including adoption of continuous improvements, a clear definition of clients' requirements, and applying lean methodology at an early stage of the project delivery. Notably, these three CSFs mainly focus on the adoption and implementation of lean tools, techniques and technologies. The technological involvement suggests that technology is very important to the implementation of lean construction. In practice, they are more relevant at the operational level during the project delivery and they must be carried out with high individual construction professional expertise and skills. The fourth CSF brings together the others in the second hierarchy, to work collaboratively and promote a culture of teamwork for the successful implementation of lean construction during project delivery. This CSF is driven directly by applying appropriate lean construction tools/techniques, and applying lean methodologies at an early stage of project delivery.

The CSF in the first hierarchy is establishing long-term relationships within the construction supply chain (I) and is directly driven by adopting new construction technologies/methods, adoption of continuous improvement and applying appropriate lean construction tools/techniques. Although this CSF has the least driving power and dependence power, it can be regarded as the enduring goal for lean construction in the KSA construction industry.

7. Conclusion

Lean construction strategies help to improve the performance of construction projects and organisations by identifying and eliminating/minimising waste. This research develops an ISM model specifying the interrelationships among the 12 CSFs for the implementation of lean construction in KSA construction industry in seven hierarchical levels (VII-I). The MICMAC analysis is used to analyse the driving power and dependence power of the 12 CSFs, and to divide them into autonomous, dependent, linkage, and driving clusters on the diagraph. The CSFs of top management commitment and leadership, coordinating and promoting efforts at a national level and providing education and training for lean construction in the construction industry have the highest driving powers and lowest dependence powers. They are also in the 7th, 6th and 5th hierarchies, respectively, in the ISM model. Therefore, they fall within the driving cluster on the diagraph as the most important CSFs for driving the implementation of lean construction in the KSA construction industry.

The majority of the CSFs have strong driving power and strong dependence power at the same time. In addition, they lie between the 4th and 2nd hierarchy in the ISM model. Therefore, they fall within the linkage cluster on the diagraph as very unstable CSFs, which when acted upon also affect other CSFs for the implementation of lean construction. These CSFs include: adopting continuous improvements, adopting alternative procurement methods in project delivery, clear definition of client requirements, promoting a teamwork culture during project construction, and organisational change, while others are: applying the lean methodology at an early stage of the building project delivery, adopting new construction technologies/methods, and applying appropriate lean construction tools/techniques.

The establishment of long-term relationships within the construction supply chain is the only CSF in the dependent cluster. With weak driving power and strong dependence power, and lying in the 1st hierarchy in the ISM model, this CSF is totally reliant on the other CSFs to be achieved for the implementation of lean construction. However, there are no CSFs in the autonomous cluster; indicating that all the 12 CSFs are required for lean implementation.

Finally, the expert opinion about the proposed model reveals that the seven hierarchical levels and the interrelationships specified in the ISM model are very logical and implementable. In conclusion, successful implementation of lean construction in the KSA construction industry should start with top management commitment and leadership in construction organisations and end with the establishment of long-term relationships among operators in the construction supply chain. Furthermore, the ISM model specifying the interrelationships among the 12 CSFs for the implementation of lean construction in seven hierarchical levels can be implemented to improve the performance of construction projects and organisations, and the overall performance of the construction industry.

The following insights about the ISM framework for implementing lean construction in the KSA construction industry contribute to the body of knowledge of lean construction. Firstly, those in top management positions in construction organisations have a role beyond their organisation towards ensuring successful implementation of lean construction. This study has shown that these top managers need to take responsibility for coordinating a holistic implementation of lean construction throughout the KSA construction industry. Secondly, the successful implementation of lean construction requires the synergy of efforts between the management authorities and employees in construction organisations. For instance, the management provides education and training to the employees who in turn provide effective lean construction operations on a daily basis. Thirdly, lean construction is both an organisational and a project-based process. Organisationally, lean construction is part of the ongoing changes to the construction industry processes, while at the project level, lean construction is employed as a technique for improving the project delivery process. Lastly, lean construction is technologically driven. The implementation of lean construction, especially at the project level requires the application of relevant technologies to ensure success.

Additionally, this study has a number of practical implications, especially with regard to how the CSFs will actually be implemented to improve the performance of construction projects and organisations. Firstly, operators, especially the management of construction organisations, should accord highest priority to the CSFs in the driving cluster. Secondly, the CSFs in the linkage cluster should be carefully thought-out and planned before implementation, due to their unstable interactions. For instance, organisational change is in the linkage cluster, which directly drives "adopting alternative procurement methods in project delivery" and "applying lean methodology at an early stage of the building project delivery", as shown in the ISM model. Therefore, in the process of making any organisational change to accommodate lean construction practice, the management in construction organisations should consider and ensure that such change is conducive to allowing both the selection of procurement methods, and the application of lean methodology at an early stage of projects. Thirdly, less effort should be expended on establishing long-term relationships within the construction supply chain, as this CSF is in the dependent cluster and, therefore, once other CSFs are in place, it will naturally lead to the formation of long-term relationships within the construction supply chain for ensuring successful implementation of lean strategies.

It is recommended that regulatory and professional bodies in the KSA construction industry should position themselves to coordinate and overview nationwide efforts to promote a holistic view of lean construction. These bodies should also be responsible for informing individual operators in the industry about the benefits of implementing lean construction into their projects and into the industry. Furthermore, operators within the industry should employ the current model to implement lean construction in their companies and during the delivery of their projects. Researchers in the built environment field can employ this model as a theoretical framework for further research into the successful implementation of lean construction strategies. Such further research should employ case study methodology whereby the ISM model can be applied in real projects. This will increase the understanding of the level of applicability of the model.

There are some limitations in this study. The model developed in the study was an ISM model with only 12 CSFs for implementing lean construction in the KSA. The number of CSFs was restricted to 12 in this case due to the inability of the ISM technique to accommodate too many variables. Hence, other variables which are less critical to successful implementation may have been omitted. Furthermore, the validation of the ISM model is based on the opinions of a small group of experts, which may be biased and not fully reflect the whole of industry practice.

In line with the suggestions of Expert 2, this framework needs to be used in a real life project in a future research study. Thus, the effectiveness of the framework to improve the performance of construction projects and organisations can be affirmed, and where necessary, further modifications can be made. The quantitative and qualitative data used for this study are limited to the KSA. In future, this study could also be replicated using data from other countries.

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