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Challenges for implementing smart construction in Korean construction industry using MICMAC-ISM approach

Junhak Lee[1], Jinwoo Won[2], Seung H. Han[3*]

[1] Department *of Civil and Environmental Engineering, Yonsei University, South Korea, kongs2000@yonsei.ac.kr*
[2] Department *of Civil and Environmental Engineering, Yonsei University, South Korea, wonjw@yonsei.ac.kr*
[3] Department *of Civil and Environmental Engineering, Yonsei University, South Korea, shh6018@yonsei.ac.kr*

Abstract:
Despite various government and institutional movements to promote implementation of smart construction, the utilization of smart technologies in the construction industry is still low compared to other industries. To take a systemic look at the impediments in the implementation of smart construction, this study identifies and analyzes the challenging factors of smart construction within the Korean construction industry. Through content analysis of relevant literature, including official documents, research reports, databases, 19 challenging factors have been identified. The intricate relationships among these challenging factors have been examined based on a hierarchy structure established by using the Interpretive Structural Modeling (ISM) approach. Furthermore, factors are classified into four distinct clusters by using the MICMAC analysis: driving factors, dependent factors, autonomous factors, and linkage factors. This classification delineates the interrelationships among the challenging factors and identifies the key factors that drive the system, which is different from that in traditional studies where the relative importance is generally given between factors. The findings will provide crucial information for policy designers and top-level authorities, indicating which challenging factors to prioritize limited resources and efforts. It will aid in formulating effective policies, standards, and regulations to foster the implementation of smart construction in the Korean construction industry.

Key words: smart construction, challenges, ISM, MICMAC

1. INTRODUCTION

In the era of the Fourth Industrial Revolution, core technologies such as big data, cloud, Internet of Things (IoT), and artificial intelligence (AI) are rapidly integrating with existing industries, thereby extensively affecting both the economy and society at large. Many types of industries are experiencing the opportunity to explode their performance through technologies that include digitalization and automation [1]. For example, the manufacturing industry is rapidly realizing dramatic cost reductions and high added value through systematization by embedding software and communication systems in traditional manufacturing elements, and the machinery industry (automobile, shipbuilding, robotics) is promoting product innovation and process innovation through the development of smart robots and autonomous vehicles by utilizing mobile, cloud, and IoT.

In response to these ongoing movements, the construction industry is increasingly embracing smart construction technologies, including Building Information Modeling (BIM), drone usage, digital twin technology, modular construction methods and more. These innovations aim to address the industry's longstanding challenges related to productivity and safety. Despite various government and institutional movements to promote implementation of smart construction across the world, architecture, engineering, and construction (AEC) industry has been among the slowest to digitize and innovate [2]. In Korea, the ratio of domestic construction companies' use of technology for the 4th industrial revolution (7.5%) was lower than that of other industries, scoring only about 57% compared to the average of all industries (13.2%) [3].

There are various factors hindering the implementation of smart construction and previous studies and reports have extensively investigated these hindrances. Oesterreich and Teuteberg [1] identified the construction industry's general reluctance to embrace new technologies and new systems as a key barrier to smart construction. Hwang [4] attributed the difficulty in integrating smart construction technologies to the fragmentation of the value chain within the construction industry, emphasizing the need to streamline this complex value chain. Additionally, Ministry of Land, Infrastructure and Transport of Korea [5] emphasized that the activation of smart construction faces hurdles due to the absence of environment in place to educate technology users on smart construction technology, coupled with insufficient conditions for developing and spreading smart construction technology.

However, existing studies have not examined the intricate relationships among the challenging factors within the specific context of the Korean construction industry. The challenging factors are not isolated, but rather form complex intricate relationships (directly or indirectly) in impeding successful implementation of smart construction. The presence of direct or indirect relationships among factors complicates the system's structure, making it difficult to deal with a system in which the structure is not clearly defined [6]. Moreover, with limited resources, it is crucial to prioritize efforts and expenditures on addressing challenging factors that are most effective in fixing the system. Therefore, it becomes imperative to undertake a thorough examination of the factors hindering the implementation of smart construction within the context of construction industry and deep exploration into the intricate relationships among these factors.

2. CHALLENGING FACTORS OF IMPLEMENTING SMART CONSTRUCTION

In this study, challenging factors of implementing smart construction in the Korean construction industry are identified. Content analysis is implemented to collect and analyze data from literature, official documents, research reports, databases, and other existing studies, especially in the field of construction research. Based on the frequency of occurrence and factor diversification, 19 challenging factors that are hindering the implementation of smart construction in Korean construction industry were collected and divided into six categories (see Table 1).

Table 1. Challenging factors of smart construction

Category	Code	Challenging Factors	References
Technology	T1	Low technical performance	[1] [4] [13] [15] [16] [17] [19]
	T2	Complex way of utilizing technology	[1] [18]
	T3	Low reliability on performance quality	[10] [13] [17]
	T4	Low technical compatibility	[1] [4] [13] [14] [15] [18] [21] [22]
Organization	O1	Organizational culture and perspective	[1] [4] [7] [12] [13]
	O2	Organization members	[1] [11] [12] [13]
Process	P1	Inconsistencies with current processes	[1] [4]
	P2	Lack of integrated management process	[5] [9] [10]
	P3	Lack of performance appraisal process	[9] [10]
Knowledge	K1	Lack of professional personnel	[1] [4] [5] [9] [11] [12] [19] [20]
	K2	Lack of owner's knowledge	[4] [8] [9]
	K3	Lack of technical training courses	[5] [9] [11]
Economic	E1	High cost of investment	[1] [4] [5] [9] [12] [17]

	E2	High cost of installation	[4] [5] [17] [18] [19]
	E3	High cost of maintenance	[4] [5]
Laws · Regulations	L1	Legal and regulatory barriers	[1] [4] [5] [7] [11] [12] [15] [20]
	L2	Lack of construction standards	[1] [4] [5] [7] [8] [9] [11] [12] [20]
	L3	Lack of system to certify performance	[1] [5] [8] [9]
	L4	Construction production system	[5] [7] [9]

3. METHODOLOGY

3.1. ISM & MICMAC

Interpretive Structural Modeling (ISM) is a method that decomposes a complex system into several levels, showing hierarchical relationship of the complicated multilevel system [23]. With ISM, the direct and indirect relationships among factors are well modeled to provide a systematic and clear depiction of the framework of a complex system [24]. ISM is especially powerful when there is a lack of prior research identifying meaningful relationships among the factors [25]. Given the lack of prior research identifying meaningful relationships among challenging factors of smart construction, ISM is an effective methodology for deriving intricate relationships among the challenging factors. However, ISM technique alone falls short in quantifying the extent to which individual factors influence this progression. To surmount this shortfall, the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) approach is employed to assess the driving and dependence power of factors previously analyzed via ISM [26]. Using the MICMAC approach, factors are classified into four distinct clusters: (1) driving factors with strong driving powers but weak dependence powers; (2) dependent factors with weak driving powers but strong dependence powers; (3) autonomous factors with both weak driving and dependence powers; and (4) linkage factors with both strong driving and dependence powers.

3.2. Establishment of Adjacency Matrix & Reachability Matrix

Under the guiding principles of the Interpretive Structural Modeling (ISM) methodology, the process of translating qualitative descriptions of direct relationships among various factors into a quantifiable format is integral [27]. This translation is done by the creation of a binary matrix, known as the "Adjacency Matrix". In this matrix, the qualitative relationship between any two factors is represented numerically, either as '1' or '0'. Based on the finalized 19 challenging factors, three experts were asked to conduct the pairwise comparison through a structured survey to ascertain experts' opinions about the qualitative relationships among these challenging factors. All three experts have been engaged in research or industries related to smart construction for a long time and have sufficient expertise in both smart construction and construction industry. The three experts were asked to assess the contextual direct relationships between the challenging factors by following rules:

I. If indicator i has a direct influence on indicator j, then a_{ij} *is defined as 1; otherwise* a_{ij} *is 0*

II. If indicator j has a direct influence on indicator i, then a_{ji} *is defined as 1; otherwise* a_{ji} *is 0*

III. If indicator i has a direct influence on indicator j, and simultaneously indicator j has a direct influence on indicator I, then a_{ij} *and* a_{ji} *are both defined as 1*

In instances where divergent opinions emerged among experts regarding the relationship between two challenging factors, the approach adopted was guided by the principle of *"minority gives way to the majority"*. This principle operates as follows: When experts provide conflicting assessments about the presence or nature of a relationship between two factors, the majority opinion is considered decisive [28]. In other words, if two or more experts agree that indicator i has a direct influence on indicator j, then indicator i has a direct influence on indicator j.

Next step is the construction of the "Reachability Matrix", derived from the Adjacency matrix. Reachability Matrix(R) comprehensively illustrates both the direct and indirect relationships among the challenging factors, serving as a fundamental tool to visualize and understand the complexity of interactions that exist within the system of these challenging factors [29]. The concept of indirect relationship is elucidated thus: if measure 'i' has a direct influence on measure 'j', and measure 'j', in turn, has a direct influence on measure 'k', then it can be inferred that measure 'i' has an indirect influence on measure 'k'. This transitivity of relationships among the challenging factors is crucial for understanding the ripple effects within the system. In the context of the analysis where 'R' represents the Reachability Matrix and 'A' stands for the Adjacency Matrix, with 'I' being the identity (or unit) matrix, the concept of power iterations using transitivity is conducted for matrix convergence. The final Reachability Matrix will be obtained using the following equation:

$$A^m = (A + I)^m$$

$$R = A^m = A^{m+1} \ (m > 1)$$

Here, 'm' denotes the number of iterations carried out in this process and the power iterations are conducted until the matrix is converged. In this study, three power iterations were performed to obtain the final Reachability Matrix (see Table 2).

Table 2. The final Reachability Matrix(R) of 19 challenging factors

R	T1	T2	T3	T4	O1	O2	P1	P2	P3	K1	K2	K3	E1	E2	E3	L1	L2	L3	L4
T1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
T2	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
T3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T4	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
O1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
O2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
P1	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
P2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
P3	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
K1	0	0	1	0	0	1	0	1	1	1	0	0	0	0	0	0	0	1	0
K2	0	0	0	0	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0
K3	0	0	1	0	1	1	0	1	1	1	1	1	0	0	0	0	0	1	0
E1	1	1	1	1	1	1	0	1	0	0	0	0	1	1	1	0	0	0	0
E2	0	0	0	1	1	1	0	1	0	0	0	0	0	1	1	0	0	0	0
E3	0	0	0	1	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0
L1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1
L2	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0
L3	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
L4	0	0	1	1	1	1	0	1	1	1	1	1	0	0	0	0	0	1	1

4. Results

The analysis results are summarized in Fig. 1 and 2. Fig. 1 illustrates the intricate relationships among the challenging factors, and Fig. 2 demonstrates the distribution of the factors from the perspectives of driving-power and dependence-power. From these two figures, it can be observed that L1 (Legal and regulatory barriers), L2 (Lack of construction standards), L4 (Construction production system), E1 (High cost of investment) are the driving factors, positioned at the top levels in the hierarchy structure. Notably, L1 (Legal and regulatory barriers) exhibits the highest driving power but the lowest dependence power, indicating its significant influence on other challenging factors. Consequently, addressing this factor should be the highest priority to foster the implementation of smart construction.

It can be also observed that T3 (Low reliability on performance quality), O1 (Organizational culture and perspective), O2 (Organization members), P2 (Lack of integrated management process) are the dependent factors, positioned at the low levels in the hierarchy structure. Remarkably, O2 (Organization members) and P2 (Lack of integrated management process) exhibit the highest dependence power but the lowest driving power. Therefore, these challenging factors can be considered as the dependent outcomes of driving factors, meaning that addressing driving factors will, in turn, address these dependent factors accordingly. Therefore, there is less need to devote limited resources to these dependent factors.

Other challenging factors excluding driving and dependent factors, T1 (Low technical performance), T2 (Complex way of utilizing technology), T4 (Low technical compatibility), K1 (Lack of professional personnel), P1 (Inconsistencies with current processes), P3 (Lack of performance appraisal process), K2 (Lack of owner's knowledge), K3 (Lack of technical training courses), E2 (High cost of installation), E3 (High cost of maintenance), L3 (Lack of system to certify performance), are observed to be autonomous factors, as no challenging factor is identified as a linkage factor in this study. Autonomous factors exhibit both weak driving and dependence power, indicating that these factors are relatively disconnected from the system they belong to. This means that these autonomous factors are less related to other factors and should be treated separately from the driving and dependent factors.

Figure 1. The hierarchy structure of the 19 challenging factors

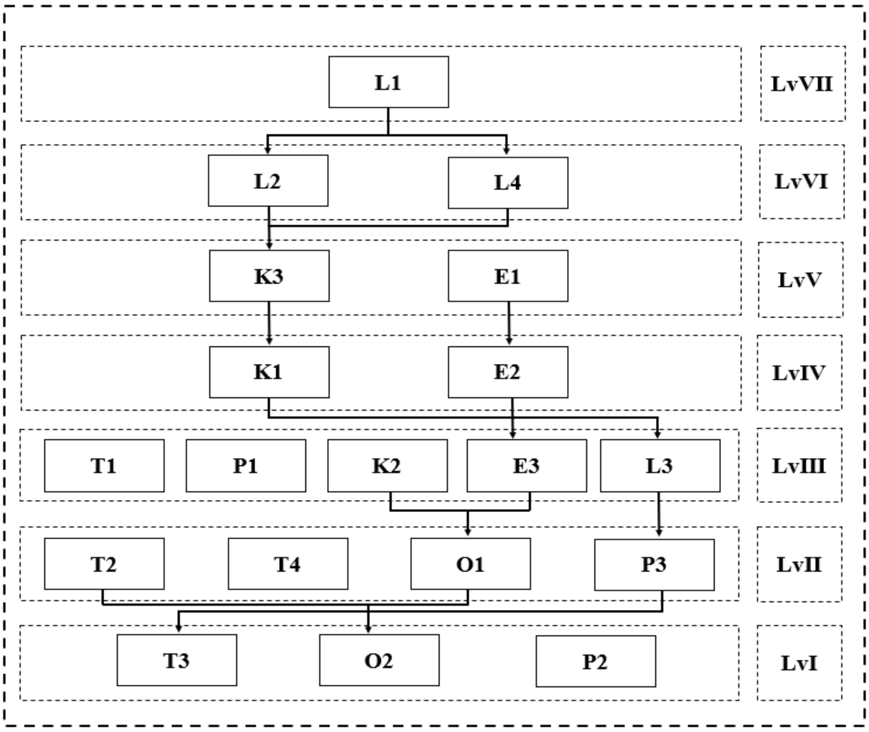
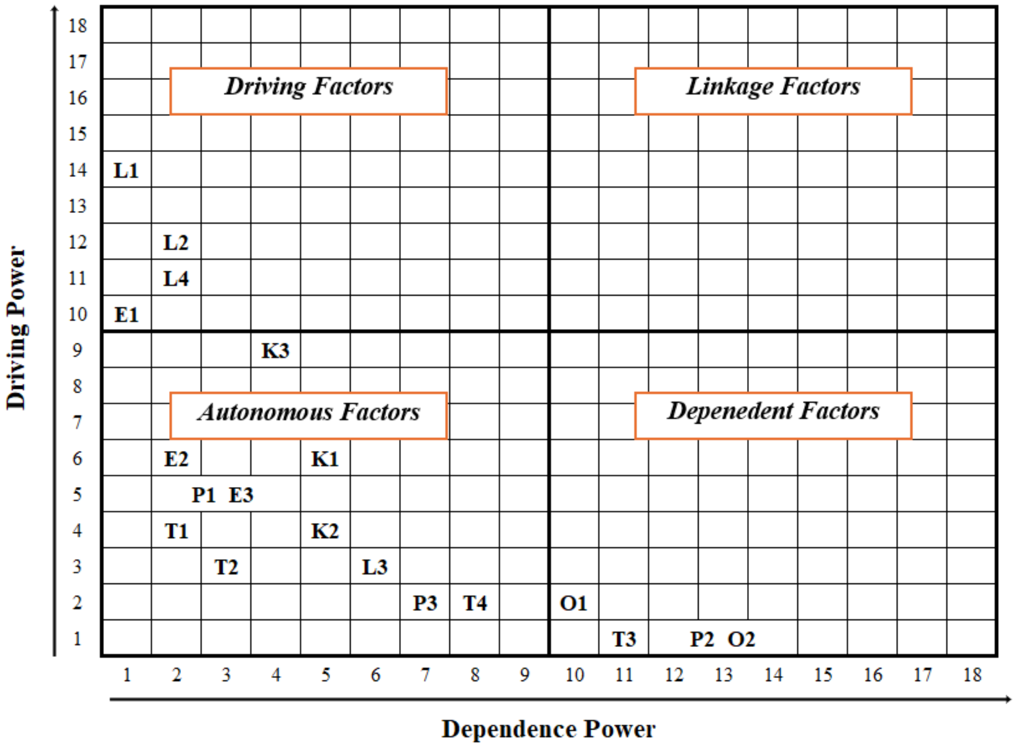


Figure 2. Results of MICMAC analysis



5. Discussion & Conclusion

It is evident that the usage of smart construction technologies is pivotal in addressing the prevailing challenges within the construction industry, notably the issues of low productivity and safety concerns. Despite various government and institutional movements to promote implementation of smart construction, utilization of smart construction in construction industry is still very low compared to the uptake of digital technologies in other industries. Through content analysis from relevant literature, including official documents, research reports, databases, this paper discovered 19 challenging factors that are hindering the implementation of smart construction within the context of the Korean construction industry. Subsequently, by utilizing the ISM method, 19 challenging factors were organized into a hierarchy structure. Furthermore, by applying MICMAC, 19 challenging factors were classified into four driving factors, four dependent factors, and eleven autonomous variables according to their driving and dependence powers. Previous studies primarily concentrated on enumerating challenging factors in implementation of smart construction and assessing their relative importance. However, this study offers a distinct perspective by delineating the interrelationships among the challenging factors, specifically illustrating their driving and dependence powers. This approach provides crucial information for policy designers and top-level authorities, indicating which challenging factors to prioritize limited resources and efforts. It will aid in formulating effective policies, standards, and regulations to foster the implementation of smart construction in the Korean construction industry. This study will also assist other countries aspiring to promote smart construction by proposing a framework to establish more effective policies and directions through the identification of intricate relationships among factors.

However, this study still has some limitations that should be handled. First, to prevent the increasing complexity of the MICMAC-ISM approach, some challenging perceived as less influential to the system were omitted in this study. Second, while this study analyzed the intricate relationships among the challenging factors and how they influence each other, further studies on the effective policy instruments harmonizing with these findings is necessary to foster the implementation of smart construction in the Korean construction industry. These limitations will be addressed in further studies.

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