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Identification and Prioritization of Critical Success Factors for Off-Site Construction Using ISM and MICMAC Analysis

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Abstract: Many studies have been conducted to define the critical success factors (CSFs) for off-site construction (OSC) activation, but there has been a lack of identification of the relationship with the identified CSFs. However, it is necessary to clearly identify the hierarchy and relationships with the success factors in order to develop specific strategies for OSC activation. This work presents a study that was conducted to identify the CSFs for OSCs and establish the relationships of the identified CSFs for OSC. First, 20 CSFs for OSCs were identified through prior study reviews related to CSFs for OSC. Next, the interpretive structural modeling (ISM), which has advantages in developing an understanding of complex relationships, was leveraged in order to analyze the relationships between 20 CSFs for OSC to derive a hierarchical model consisting of seven levels. The CSFs for OSC were classified into four groups using MICMAC analysis, which is useful for classifying factors by the strength of the relationship with factors based on driving power and dependence power. This proposed model can be used as a basis for developing management measures for OSC project success.

Keywords: off-site construction (OSC); critical success factors; interpretive structural modeling (ISM); matrix of cross-impact multiplication applied to classification (MICMAC) analysis

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1. Introduction

Traditionally, a construction system is based on field labor, by which most of the raw materials and production materials are transported to the building site and are used for construction with the assistance of necessary equipment. These systems are less and less productive due to factors that deteriorate the industrial environment such as increasing project and site complexities [1], insufficiently skilled labor at frontline and supervisory levels, the poor safety of construction workers [2], and cost escalation and time overrun considerations [3]. To overcome the limitations of such existing construction systems, research on off-site construction (OSC) is accelerating.

OSC refers to the planning, design, fabrication, and assembly of building elements at a given location, different from the finally installed location, to implement the rapid and efficient construction of permanent structures [4]. It is a general concept that encompasses other similar concepts such as off-site prefabrication, off-site manufacturing, modern methods of construction, prefabricated construction, and industrial building [5]. OSC was introduced in the 1900s after World Wars I and II as an alternative to large-scale housing restoration projects and have been developed since the 2000s through new technologies and improvements in construction methods. The OSC market is estimated to represent approximately USD 9 billion in the U.K. (as of 2019), USD 39.6 billion in the U.S. (as of 2019), and USD 41.4 billion in China (as of 2018) [6]. OSC is being actively applied to various construction projects such as schools, hospitals, factories, hotels, offices, and residential housing.

However, the construction industry continues to strive for higher levels of OSC activation [7]. To address this issue, a number of studies have been conducted to identify the critical success factors (CSFs) for OSC activation. These studies have proposed CSFs for the OSC project, including basic information needed to establish a plan for the successful activation of the OSC project.

However, the relationship among the identified CSFs has yet to be established. Each CSF should be identified individually, given that CSFs are inter-related, because a clear identification of hierarchies and interrelationships among success factors can lead to more concrete proposals for the success of OSC projects. In this study, the following objectives were set in this regard: to identify the critical success factors for OSC, to establish the relationship among the identified CSFs and propose a structural model of CSFs for OSC performance, and to discuss the managerial implications of this study (based on the proposed structural model).

To achieve these objectives, the interpretive structural modeling (ISM) and matrix of cross-impact multiplication were applied to classification (MICMAC) analysis methodologies in this study. The ISM is a well-established methodology for identifying the relationships among specific items that define a problem or an issue [8]. Meanwhile, the MICMAC analysis is used to classify and validate the factors obtained from ISM to obtain results and draw conclusions [9]. Thus, the ISM is a methodology used to represent the hierarchical relationships among factors, and the MICMAC analysis is a methodology used to classify and derive implications based on the strength of the relationships derived from the ISM process. Therefore, in this work, the ISM methodology will be applied to present a structural model of OSC success factors and classify them according to the strength of the relationship through MICMAC analysis.

The remainder of this paper is organized as follows. Section 2 presents the objectives and significance of this study, along with a comparison between existing research related to the concept, development trends, and critical success factors of OSC. In Section 3, our research methods were clarified by conducting a review of the ISM and MICMAC methodologies. Section 4 identifies the major OSC success factors used in existing research and various examinations related to these factors. Section 5 establishes an ISM model of OSC success factors using the ISM and classifies CSFs for OSC into four groups using MICMAC analysis. Finally, Section 6 presents the significance and expected effects of our findings as well as the limitations of our study and future research trends.

2. Literature Review

With the introduction and development of OSC globally, many researchers have begun to recognize the need to identify and consider critical success factors for the successful implementation of new construction methods. Over the past decades, various studies have been conducted by various researchers abroad on the key success factors of OSC projects.

Choi (2014) [10] presented 21 key success factors for modularization and identified correlations with project performance. He identified the relationships among cost, process, construction, and start-up performance of modularity, and his representative success factors included early design freeze, the participation of key participants in the entire project, and the recognition of the early completion of the project. O'Connor et al. (2014) [11] identified key success factors needed to create an optimal environment for wider and more effective uses of modularity in the engineering, procurement, and construction (EPC) industries. They identified 21 critical success factors and divided them into project processes and participating entities. The top five CSFs implied that participants should pay attention to module envelope limitations, the organizational alignment of project drivers, adequate planning resources and processes by the owner, the timely freezing of scoping and design, and the recognition of possible early completion from modularization.

Li and Li et al. (2018) [12] identified 23 critical success factors in China's prefabricated housing production through literature reviews, in-depth interviews, and pilot studies with experts, and they ranked them in terms of their relative importance through a survey of five experts. As such, 23 success factors were presented separately into five clusters by conducting a factor analysis. These five clusters are as follows: information, communication, and collaboration; technology and method; experience and knowledge; external environment; and the competence of the project manager.

Wuni and Shen (2019) [13] reviewed 55 research studies conducted from 1993 to 2019 on the success factors of modular architecture, and they presented a total of 35 key success factors, with frequency analyses of six key success factors (e.g., design standardization, effective supply chain management, cooperation and effective communication among participants, and accurate design).

Azhar (2013) [14] conducted a study identifying important factors and constraints that can help select modular architectural methods. Through interviews, literature reviews, and surveys with industry experts, he presented 12 important decision factors and 6 key constraints. Blismas and Wakefield (2009) [15] conducted workshops, interviews, case studies, and surveys to identify drivers and constraints in the Australian construction industry.

Lau (2011) [16] conducted a case study of six companies in Hong Kong, China, and Singapore with experience in modular product design, presenting seven key success factors. Pan et al. (2007) [17] identified OSC activation factors through interviews with UK home builders. In addition, Ismail et al. (2012) [18] identified control factors through a literature review, investigating factor-specific importance, and Wuni and Shen (2020) [3] conducted research to derive success factors for 25 modular architectures, evaluating factor-specific weights through surveys and statistical analysis.

Several studies [3,10–18] identified the factors related to OSC success in a variety of ways, such as to provide the underlying information needed to establish strategies for the successful implementation of OSC projects. However, the relationship and hierarchy of interactions between the identified factors are yet to be determined. In response, this study aims to establish the interrelationship among OSC success factors identified in the existing research literature and to propose a structural model for success factors. Furthermore, it discusses the managerial implications based on the proposed structural model.

3. Methodology

As discussed in Chapter 2, many studies have defined CSFs for OSC, but only a few studies have identified the relationships with the identified CSFs. However, it is necessary to clearly identify the hierarchy and relationships with CSFs in order to develop strategies for specific OSC activation. This study was aimed at identifying the CSFs for OSCs and establishing the relationships with identified CSFs for OSCs.

The ISM used in this study is a methodology specialized in representing hierarchical relationships with factors, measuring the driving power and dependence power, and even considering the transitivity of influences among factors. Furthermore, the ISM has schematic hierarchical relationships with factors, thus making them easy to grasp at a glance. On the other hand, the MICMAC analysis is a methodology for classifying factors into four groups and deriving implications using the driving power and dependance power calculated during the ISM process.

Thus, applying ISM methods would help implement a hierarchical structural model that identifies the complex relationships of CSFs with OSCs, and MICMAC analysis would help classify factors into four groups and derive group-specific implications. The concepts and analysis procedures for ISM and MICMAC analysis are given below.

3.1. Interpretive Structural Modeling (ISM)

The ISM was first proposed by Warfield (1974) [19] and is based on the principle of pairwise comparison. Its basic idea is to use the hands-on experience and knowledge of experts to break down complicated systems into multiple subsystems and build a multilevel structural model [20]. The method is interpretive in that the group's judgment decides whether and how elements are related. An overall structure is determined for a complex set of elements on the basis of their relationships, and the overall structure and specific relationships are portrayed in a digraph model [21], resulting in the structural modeling denomination of this modeling technique.

The ISM generally involves the following steps [22–24]:

- Step 1: Identify the variables relevant to the current issue or problem.
- Step 2: Establish a contextual relationship among the variables from the elements identified in Step 1.
- Step 3: Develop a structural self-interaction matrix (SSIM) for variables that identify pairwise relationships among the elements of the system.
- Step 4: Develop a reachability matrix from the SSIM and check the matrix for the transitivity of the contextual relationship. The transitivity is a basic assumption made in ISM. It dictates that if X is related to Y and Y is related to Z, then X is necessarily related to Z.
- Step 5: Partition the reachability matrix obtained in Step 4 into different levels.
- Step 6: Develop a directed graph based on the contextual relationships found in the reachability matrix and remove the transitive links from the digraph.
- Step 7: Convert the digraph developed in Step 6 into an ISM model by replacing the variable nodes with relationship statements
- Step 8: Review the ISM model developed in Step 7 to identify conceptual inconsistencies and make necessary modifications.

3.2. Matrix of Cross-Impact Multiplication Applied to Classification (MICMAC) Analysis

MICMAC refers to "Matrice d'Impacts Croisés Multiplication Appliquée a un Classement," which implies cross-impact matrix multiplication applied to classification [25]. One of the main objectives of this analysis is to investigate and classify the factors of interest in terms of driving power and dependence, wherein all the variables are classified into four clusters with the following characteristics [9,26].

- Cluster I contains "autonomous factors" that have neither high driving power nor high dependence. These factors are relatively disconnected from the system and have weak or no dependence on other factors.
- Cluster II contains "dependent factors" that have low driving power and high dependence. These factors are primarily dependent on other factors.
- Cluster III contains "linkage factors" that have high driving power and high dependence. These factors are unstable and influence other factors.
- Cluster IV contains "independent factors" that have high driving power and low dependence. As strong key factors, these factors have little influence from other factors and have to be paid maximum attention.

4. Identification of Critical Success Factors for Off-Site Construction

The Critical Success Factors (CSFs) are specific elements that help achieve the strategic goals of the project. They have a significant impact on the success and failure of the project. Establishing strategies to clearly identify and manage CSFs is essential for successful implementation. In this study, existing literature reviews related to OSC success factors were conducted to identify the CSFs for OSC.

For obtaining the existing literature on OSC success factors, this study defined OSC as a method for planning, fabricating, and assembling building elements at a location different than the construction site, such as a factory, and then transporting them to the site for installation as the final object. The OSC encompasses other similar concepts, including prefabricated, industrialized, modular, and panelized construction. In addition, this study defined CSFs, such as constraint factors, project management and control factors, influence factors, failure factors, barriers and enabling factors, and recommendation concepts, as having a significant effect on the success and failure of the project.

By focusing on these OSC and key success factors related keywords, this study collected 104 existing works of literature related to the CSFs for OSC and collected the CSFs for OSC mentioned in the existing literature collected. The collected CSFs were identified by merging different representations but having the same meaning, dividing between concepts with contrasting meanings, and counting the numbers mentioned in the existing literature. The 20 most frequently appearing factors are shown in Table 1 and identified as follows:

(1). F1: Availability and active involvement of key project team members from the earliest stages of the project OSC projects are divided into design, factory production, transport, and site construction stages, and the information generated at each stage requires integrated management considering continuity. Therefore, the coordination between various steps is essential for the systematic and integrative management of the vast amount of information arising from the project. Considering that the benefits of OSC are realized when modularity is planned earlier in the design development process [3,27], it is essential for key participants such as designers, fabricators, suppliers, and contractors to participate in the process [28,29].

(2). F2: Effective communication and information-sharing among participants The OSC project separates between on-site and off-site operations, with various organizations participating in detailed processes such as design, manufacturing, transportation, and assembly. Therefore, the efficient and successful operation of the OSC project dictates the efficient communication of information between on-site and off-site operations [30] as well as the coordination of opinions between various organizations and participants [31]. In particular, it is important to establish effective communication and information sharing channels among all participants throughout the entire project, as OSC projects consider factors such as the manufacturing and transportation of parts, field assembly, and construction from an early stage [10,18,32].

(3). F3: Extensive project planning, scheduling, and control Project management is a success factor for OSC project management as well as all construction projects. Among the various project management capabilities, "project schedule management" has been identified as a particularly important factor. Extensive activity planning and scheduling in advance are important to ensure project performance, coordination, improved scope control, and smooth project sequences [31]. Avoiding owner delays and transport delays were proposed as measures to ensure the proper scheduling of OSC projects [7,10,11,33].

(4). F4: Effective use of information and communication technology (e.g., BIM) Many researchers have suggested that information and communication technologies such as building information modeling (BIM) and radio frequency identification (RFID) should be utilized to support efficient communication and information sharing [3,34,35]. The use of these information and communication technologies not only supports communication and information sharing among participants but also enables real-time progress monitoring [36], which facilitates the process management and supply chain management of projects [37].

(5). F5: Availability of skilled labor The successful implementation of the OSC project requires skilled personnel and appropriate skills in the manufacturing and production of OSC parts and field construction [38]. Since the introduction of OSC to address the lack of functional personnel and the degradation of functional levels in the construction industry, securing and utilizing people with higher skill levels in comparison with existing field-oriented construction methods has been highlighted as an essential factor for the success of OSC [37,39]. In response, researchers such as Kamar et al. (2010) [35] and Thanoon et al. (2003) [40] emphasized that proper training such as the on-site installation training of OSC components should secure sufficient functional personnel to improve the skill level of labor.

(6). F6: Design standardization and the more effective use of the concept of repetition One of the greatest constraints that reduces the industrial competitiveness of OSC projects is the high value of its direct costs [41]. Several researchers have pointed to low-level design standardization as one of the main reasons for the high direct cost of OSC projects [42,43]. The design standardization of OSC projects can improve the efficiency of module production by facilitating the repeated use of limited configuration modules. This is because the standardization of modules enables mass manufacturing, the specialization of labor, and the automation of production processes using the same materials, equipment, and processes [13]. However, while there is concern that the use of limited modules may undermine the diversity of project designs, standardized modules have the advantage of being able to create different types of differentiated projects that fit the nature of the project [44].

(7). F7: Alignment of module architecture and long-term collaboration among fabricators, suppliers, designers, subcontractors, and contractors. OSC projects are generally divided into design, manufacturing, transport, and assembly processes, but the harmony between processes is highly emphasized [31,45,46]. In this regard, the participation of key participants among project precursors is important. In OSC projects, designers, engineers, OSC part makers (suppliers), and constructors participate in collaboration with each other, enabling more efficient OSC project management. The participation of OSC part makers and builders in the design phase can also prevent the risks associated with actual module production and field installation [16,37,39,47] as well as unnecessary design implementation changes [48].

(8). F8: Effective coordination of supply chain segments As existing construction industries use non-standardized and manpower-oriented production methods, the effects of supply chain management are difficult to determine. However, OSC is expected to maximize the effectiveness of supply chain management, as it can standardize production modules and secure automated production technologies. The OSC project's supply chain includes a variety of sectors, such as design, engineering, manufacturing, transportation, storage, and field assembly, that have interdependent relationships. Therefore, it is important to proactively prevent risks through the appropriate coordination between various sectors [41]. However, this requires a strategy to support communication between relevant stakeholders, including potential risks in the initial stage, in regard to appropriate information sharing and consultation between various sectors [49].

(9). F9: Robust drawings and specifications Design changes should be prevented to reduce the direct costs of OSC projects. While this is an important success factor not only in OSC projects but also in general architectural projects, design changes in OSC projects that affect air and construction costs are even more important. Therefore, many scholars, including Gibb and Isack (2001) [50], Choi (2014) [10], Li and Li et al. (2018) [12], and Wuni and Shen (2019) [13], have noted that design development and early design freeze are important. This requires accurate design at the design stage, considering that OSC projects have shorter lead times than typical projects [2].

(10). F10: Continuous improvement and learning Regarding other construction projects, the performance of OSC projects should be defined and measured to achieve strategic objectives and successful results [7,10,11,33]. This is because the project performance can be continuously improved through performance analysis and by adopting best practices and benchmarking them [41,51]. Choi (2014) [10] and Wong et al. (2018) [52] stated that performance management systems should be applied to measure and manage performance systematically.

(11). F11: Effective coordination of on-site and off-site trade The OSC project is divided into factory work to manufacture components and field work to construct factory-manufactured components, but the harmony between the two work types is highly emphasized [31,46]. OSC projects require close coordination between on-site and off-site operations, as they run in parallel [53]. This can prevent problems such as production delays and rework [12].

(12). F12: Adequate relevant experience and knowledge of the manufacturer The manufacturing phase of the OSC project is widely recognized as the greatest point of difference with the traditional field production method [37,54], and the experience and knowledge of OSC part makers are also cited as critical success factors. The knowledge and experience of OSC part makers are important considerations in developing production plans to achieve on-time delivery [55] and preventing physical damage in the loading and unloading of finished OSC parts [56] through the intervention of a well-informed and experienced manufacturer [12].

(13). F13: Suitable procurement strategy and contracting The effective integration between manufacturers and suppliers in the decision-making process and cooperation between project participants are important factors for efficient procurement strategies and the appropriate contracting of OSC projects [17]. Ismail et al. (2012) [18] proposed partnering and strategic alliances by developing complementary objectives among project participants. Meanwhile, Rentschler et al. (2016) [49] stated that a procurement strategy should be established to select a small number of OSC component manufacturers, if the management objective of the OSC project is to reduce the construction period. They also pointed out that the success of the OSC project depends largely on the capabilities of the OSC part manufacturer, and Wuni & Shen (2019) [13] stated that proper consideration should be given to past project performance, manufacturing capability, and the scope of work when selecting OSC part manufacturers.

(14). F14: Adequate relevant experience and knowledge of the contractor The experience and knowledge of the contractor performing field installation and assembly work also affect the success or failure of the project. This requires appropriate management. O'Connor et al. (2014) [11] stated that contractors should have sufficient experience in modular approaches and that owners should add modular experience to the criteria for selecting contractors from pre-FEED through detailed design and give significant weight to the decision of selecting contractors. Kamar et al. (2009) [39] and Pan et al. (2008) [37] noted that an understanding of the complexities of transportation, logistics, and interfaces is necessary to integrate and manage complex OSC construction processes.

(15). F15: Maturity of manufacturing technology and facilities The maturity of the technology and equipment applied for each detailed process is also essential for OSC success. In particular, the maturity of the manufacturing technology and facilities of components is critical to the success or failure of the OSC project [11]. Unlike the traditional construction method, where actual construction takes place on site, actual OSC projects are executed in manufacturing facilities. Li and Li et al. (2018) [12] stated that the mechanization and automation of manufacturing technologies would increase the productivity of an OSC project.

(16). F16: Maturity of the transportation method of prefabricated components The maturity of OSC component transport technology has also been identified as an important success factor. Transportation technologies include technologies and equipment that support the movement and transportation between and within factories and sites. The project budget must be considered through a proper advance review of the availability of transportation technologies and equipment [7,11,33].

(17). F17: Adequate relevant experience and knowledge of the designers and engineers Li et al. (2018) [12] emphasized that the most important factors in OSC projects are the experience and knowledge of designers. The experience and knowledge of designers have a significant impact on the success and failure of the project from start to end [57], as accurate design prevents design fluctuations, which in turn affects time and cost savings [58].

(18). F18: Maturity of on-site assembly technology and equipment The maturity of field assembly technologies and equipment has a significant impact on OSC success. The efficient use of on-site assembly equipment is effective in reducing construction costs and shortening construction periods [10,41]. In addition, the use of high-level field assembly techniques to prevent quality problems is critical because quality problems occur more frequently in construction sites than in manufacturing plants [12].

(19). F19: Intensive early research on modularization Lee and Kim (2017) [59] suggested "inappropriate selection of the modular system," "module size not reflecting the road and access conditions to the site," "module size not reflecting legal regulations for transportation," and "inconsistent factory fabrication rate per a modular unit" as cost-increasing factors of the OSC project, and they stated that early research on modularization was important. In addition, Choi and O'Connor (2014) [7] stated that owners should be willing to invest in early research studies on modularization to achieve full benefits.

(20). F20: Persistent policies and incentives To ensure the activation of OSCs, securing new technologies and differentiated project management technologies is also important. Further, creating an external environment for projects such as government policies and related infrastructure is crucial. One of the key success factors in this regard is the government's "continuing policies and incentives." In this regard, Li & Li et al. (2018) [12] pointed out that, at the time of introducing new technologies into the market, relevant contractors resorted to existing mature technologies in lieu of new ones deprived of any incentives. As a result, they emphasized that policies should be devised to encourage the use of new technologies at the government level. Therefore, devising policies related to the activation of the OSC is essential, especially considering that OSCs not only have minimal performance in the construction industry but are also faced with great reluctance from private businesses.

Table 1. Critical success factors for off-site construction.

No.	Critical Success Factors	Frequency	References
F1	Availability and active involvement of key project team members from the earliest stages of the project	29	[2,3,7,10,12,13,15,16,18,27–29,32,33,35,37,47,50,60–70]
F2	Effective communication and information sharing among participants	28	[3,10,12–14,16–18,30–35,37,39,43,61–64,66,68,70–74]
F3	Extensive project planning, scheduling, and control	26	[3,7,10–14,18,30,31,33–35,39,46,61,63,64,66,67,69,72,74–77]
F4	Effective use of information and communication technology (e.g., BIM)	23	[3,12–14,16,34–36,39,46,53,61,62,66,67,69,72,78–83]
F5	Availability of skilled labor	22	[3,12–15,31,32,35,37–41,51,61,62,67,70,71,76,84,85]
F6	Design standardization and more effective use on the concept of repetition	19	[3,11,13,14,16,32,35,38,42,43,50,51,61,63–66,76,86]
F7	Good working collaboration	18	[3,13,14,17,18,31,33,34,61–63,66,69,70,73,87–89]
F8	Effective coordination of the supply chain segments	16	[3,13,18,30,31,35,39,46,49,61,63,66,72,87,90,91]
F9	Robust drawings and specifications	16	[3,12–14,38,42,49,50,52,65,68,69,74,76,85,92]
F10	Continuous improvement and learning	15	[3,10,13,30,31,33,35,39,52,62,66,70,73,93]
F11	Effective coordination of on-site and off-site trades	15	[3,7,10–13,31,33,35,37,39,61,66,73,94]
F12	Adequate relevant experience and knowledge of manufacturer	14	[7,10,12–14,33,47,51,62,67,69,74,95,96]
F13	Suitable procurement strategy and contracting	14	[13,15,17,18,30,32,37,49,61,66,68–70,73]
F14	Adequate relevant experience and knowledge of the contractor	14	[7,10,11,13,32,33,39,47,51,61,62,68,69,74]
F15	The maturity of manufacture technology and facility	14	[7,10–14,33,41,45,51,54,63,67,76]
F16	The maturity of transportation method of prefabricated components	14	[7,10–14,33,41,45,51,54,63,67,76]
F17	Adequate relevant experience and knowledge of designer and engineer	11	[12–15,47,51,57,58,62,69,74]
F18	The maturity of on-site assembly technology and equipment	11	[3,7,10,11,13,14,33,41,51,63,76]
F19	Intensive early research on modularization	9	[7,10,11,13,31,33,59,68,76]
F20	Persistent policies and incentives	7	[12,15,32,47,95,97,98]

5. Prioritization of Critical Success Factors for Off-Site Construction

5.1. Structural Self-Interaction Matrix

In this study, contextual relationships between success factors were developed by understanding the nature of the relationships between these factors in consultation with eight industry and academic experts who have experience in carrying out OSC projects. A contextual relationship is defined as a relationship of the type "lead to" or "influence."

This indicates that any one factor affects the other. Based on the contextual relationship, the nature of this relationship between any two factors (i and j) is divided into four types:

- V: factor i leads to factor j
- A: factor j leads to factor i
- X: factor i and j influence each other
- O: no relation exists between factors i and j

Table 2 indicates the pairwise relationships between the 20 CSFs of the OSC. Some cases are given below. For example, the symbol V is entered (1, 3), as Factor F1 affects F18, and symbol A is entered in (1, 17), as Factor F4 affects Factor F1. Meanwhile, the symbol X is entered in (1, 19), as Factors F1 and F2 influence each other, while symbol O is entered in (1, 1), as there is no relation between Factor F1 and Factor F20.

Table 2. Structural self-interaction matrix (SSIM).

	F20	**F19**	**F18**	**F17**	**F16**	**F15**	**F14**	**F13**	**F12**	**F11**	**F10**	**F9**	**F8**	**F7**	**F6**	**F5**	**F4**	**F3**	**F2**
F1	O	O	V	O	V	V	O	V	O	V	V	V	V	X	V	O	A	V	X
F2	A	A	V	A	V	V	A	V	A	V	V	V	V	X	A	V	A	V	
F3	O	A	A	A	A	A	A	A	A	A	A	A	A	A	A	V	A		
F4	A	X	X	A	X	X	A	V	A	V	V	V	V	V	V	V			
F5	O	A	X	O	X	O	A	O	O	O	A	A	O	A	A				
F6	A	A	X	A	X	X	A	V	A	V	A	V	V	A					
F7	A	V	V	A	V	V	A	V	A	V	V	V	V						
F8	O	A	O	O	X	A	A	X	A	X	A	A							
F9	O	A	O	A	O	O	A	V	A	V	A								
F10	A	X	V	V	V	V	V	V	V	V									
F11	O	A	X	A	X	X	A	X	A										
F12	O	V	O	O	X	X	O	V											
F13	O	A	A	O	A	A	A												
F14	O	V	X	O	O	O													
F15	A	A	O	O	O														
F16	A	A	O	O															
F17	O	V	O																
F18	A	A																	
F19	A																		

5.2. Reachability Matrix

After SSIM, the initial reachability matrix was developed by taking the SSIM values as input (Table 3). The four symbols V, A, X, and O are converted to 1 and 0 according to the following rules:

(a) If entry (i, j) of SSIM is V, then entry (i, j) of the reachability matrix is 1 and entry (j, i) is 0.
(b) If the (i, j) entry of SSIM is A, then the (i, j) entry of the matrix is 0 and the (j, i) entry is 1.
(c) If the (i, j) entry of SSIM is X, then the (i, j) entry of the matrix is 1 and the (j, i) entry is 1.
(d) If the (i, j) entry of the SSIM is O, then the (i, j) entry of the matrix is 0, and so is the (j, i) entry.

In this study, a final reachability matrix was developed by applying the concept of transitivity to bridge the differences among expert results collected during the SSIM development. Transitivity represents the hidden interrelationships that exist between variables. For example, if A affects B and B affects C, then A is considered to affect C. This transitivity is shown in the final reachability matrix as 1 * (Table 4). Meanwhile, the final reachability matrix allows for the calculation of the driving power and the dependence of each variable. The driving power is the force of a variable that affects another variable and is calculated by summing all of the items in a row. Dependence is the degree to which the variable itself and the other variable are influenced, and it is calculated by summing all of the items in the column of Table 4.

Table 3. Initial reachability matrix.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
F1	1	1	1	0	0	1	1	1	1	1	1	0	1	0	1	1	0	1	0	0
F2	1	1	1	0	1	0	1	1	1	1	1	0	1	0	1	1	0	1	0	0
F3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F4	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	1	1	0
F5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0
F6	0	1	1	0	1	1	0	1	1	0	1	0	1	0	1	1	0	1	0	0
F7	1	1	1	0	1	1	1	1	1	1	1	0	1	0	1	1	0	1	1	0
F8	0	0	1	0	0	0	0	1	0	0	1	0	1	0	0	1	0	0	0	0
F9	0	0	1	0	1	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0
F10	0	0	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0
F11	0	0	1	0	0	0	0	1	0	0	1	0	1	0	1	1	0	1	0	0
F12	0	1	1	1	0	1	1	1	1	0	1	1	1	0	1	1	0	0	1	0
F13	0	0	1	0	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0
F14	0	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	0
F15	0	0	1	1	0	1	0	1	0	0	1	1	1	0	1	0	0	0	0	0
F16	1	0	1	1	1	1	0	1	0	0	1	1	1	0	0	1	0	0	0	0
F17	0	1	1	1	0	1	1	0	1	0	1	0	0	0	0	0	1	0	1	0
F18	0	0	1	1	1	1	0	0	0	0	1	0	1	1	0	0	0	1	0	0
F19	0	1	1	1	1	1	0	1	1	1	1	0	1	0	1	1	0	1	1	0
F20	0	1	0	1	0	1	1	0	0	1	0	0	0	0	1	1	0	1	1	1

Table 4. Final reachability matrix.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20	Driving Power
F1	1	1	1	1 *	1 *	1	1	1	1	1	1	1 *	1	1 *	1	1	1 *	1	1 *	0	19
F2	1	1	1	1 *	1	1 *	1	1	1	1	1	1 *	1	1 *	1	1	1 *	1	1 *	0	19
F3	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1 *	0	1 *	0	0	4
F4	1	1	1	1	1	1	1	1	1	1	1	1 *	1	1 *	1	1	1 *	1	1	0	19
F5	1 *	0	1 *	1 *	1	1 *	0	1 *	0	0	1 *	1 *	1 *	1 *	0	1	0	1	0	0	12
F6	1 *	1	1	1 *	1	1	1 *	1	1	1 *	1	1 *	1	1 *	1	1	0	1	0	0	17
F7	1	1	1	1 *	1	1	1	1	1	1	1	1 *	1	1 *	1	1	1 *	1	1	0	19
F8	1 *	0	1	1 *	1 *	1 *	0	1	0	0	1	1 *	1	0	1 *	1	0	1 *	0	0	12
F9	0	0	1	0	1	0	0	1	1	0	1	0	1	0	1 *	1 *	0	1	0	0	9
F10	1 *	1 *	1	1 *	1	1	1 *	1	1	1	1	1	1	1	1	1	1	1	1	0	19
F11	1 *	0	1	1 *	1 *	1 *	0	1	0	0	1	1 *	1	1 *	1	1	0	1	0	0	13
F12	1 *	1	1	1	1 *	1	1	1	1	1 *	1	1	1	0	1	1	0	1 *	1	0	17
F13	0	0	1	0	1 *	0	0	1	0	0	1	0	1	0	1 *	1 *	0	1 *	0	0	8
F14	1 *	1	1	1	1	1	1	1	1	1 *	1	0	1	1	1 *	1 *	0	1	1	0	17
F15	1 *	1 *	1	1	1 *	1	1 *	1	1 *	1 *	1	1	1	0	1	1 *	0	1 *	1 *	0	17
F16	1	1 *	1	1	1	1	1 *	1	1 *	1 *	1	1	1	0	1 *	1	0	1 *	1 *	0	17
F17	1 *	1	1	1	1 *	1	1	1 *	1	1 *	1	0	1 *	0	1 *	1 *	1	1 *	1	0	17
F18	1 *	1 *	1	1	1	1	1 *	1 *	1 *	1 *	1	0	1	1	1 *	1 *	0	1	1 *	0	17
F19	1 *	1	1	1	1	1	1 *	1	1	1	1	1 *	1	1 *	1	1	1 *	1	1	0	19
F20	1 *	1	1 *	1	1 *	1	1	1 *	1 *	1	1 *	1 *	1 *	1 *	1	1	1 *	1	1	1	20
Dependence	17	14	20	17	20	17	14	19	15	14	19	14	19	12	18	20	8	20	13	1	

1 *: transitivity.

5.3. Level Partitions

The next step was to develop a level partition. Levels are separated using the reachability, antecedent, and intersection sets derived from the final reachability matrix. A reachability set consists of a given factor and the other factors that it can influence—that is, the reachability set consists of factors in rows with 1 in the final reachability matrix (Table 4). Meanwhile, the antecedent set consists of the corresponding factors and the other factors that may affect them. In the final reachability matrix, an antecedent set is composed of factors in columns with 1. An intersection set is a factor in which the reachability set and leading set intersect. Factors with similar reachability and crossings form the top level of the ISM model. A top-level factor is a factor that does not lead to other factors above its level. If the top-level variable is identified, it should be eliminated, and the same process should be repeated to find the next level of factor until all of the variables are leveled. The level partitions of this study are listed in Tables 5–11.

Table 5. Iteration 1.

	Reachability_Set	Antecedents_Set	Intersection_Set	Level
F1	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19	F1 F2 F4 F5 F6 F7 F8 F10 F11 F12 F14 F15 F16 F17 F18 F19 F20	F1 F2 F4 F5 F6 F7 F8 F10 F11 F12 F14 F15 F16 F17 F18 F19	0
F2	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19	F1 F2 F4 F6 F7 F10 F12 F14 F15 F16 F17 F18 F19 F20	F1 F2 F4 F6 F7 F10 F12 F14 F15 F16 F17 F18 F19	0
F3	F3 F5 F16 F18	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19 F20	F3 F5 F16 F18	1
F4	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19	F1 F2 F4 F5 F6 F7 F8 F10 F11 F12 F14 F15 F16 F17 F18 F19 F20	F1 F2 F4 F5 F6 F7 F8 F10 F11 F12 F14 F15 F16 F17 F18 F19	0
F5	F1 F3 F4 F5 F6 F8 F11 F12 F13 F14 F16 F18	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19 F20	F1 F3 F4 F5 F6 F8 F11 F12 F13 F14 F16 F18	1
F6	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F18	F1 F2 F4 F5 F6 F7 F8 F10 F11 F12 F14 F15 F16 F17 F18 F19 F20	F1 F2 F4 F5 F6 F7 F8 F10 F11 F12 F14 F15 F16 F18	0
F7	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19	F1 F2 F4 F6 F7 F10 F12 F14 F15 F16 F17 F18 F19 F20	F1 F2 F4 F6 F7 F10 F12 F14 F15 F16 F17 F18 F19	0
F8	F1 F3 F4 F5 F6 F8 F11 F12 F13 F15 F16 F18	F1 F2 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19 F20	F1 F4 F5 F6 F8 F11 F12 F13 F15 F16 F18	0
F9	F3 F5 F8 F9 F11 F13 F15 F16 F18	F1 F2 F4 F6 F7 F9 F10 F12 F14 F15 F16 F17 F18 F19 F20	F9 F15 F16 F18	0
F10	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19	F1 F2 F4 F6 F7 F10 F12 F14 F15 F16 F17 F18 F19 F20	F1 F2 F4 F6 F7 F10 F12 F14 F15 F16 F17 F18 F19	0

Table 5. *Cont.*

	Reachability_Set	Antecedents_Set	Intersection_Set	Level
F11	F1 F3 F4 F5 F6 F8 F11 F12 F13 F14 F15 F16 F18	F1 F2 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19 F20	F1 F4 F5 F6 F8 F11 F12 F13 F14 F15 F16 F18	0
F12	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F15 F16 F18 F19	F1 F2 F4 F5 F6 F7 F8 F10 F11 F12 F15 F16 F19 F20	F1 F2 F4 F5 F6 F7 F8 F10 F11 F12 F15 F16 F19	0
F13	F3 F5 F8 F11 F13 F15 F16 F18	F1 F2 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19 F20	F5 F8 F11 F13 F15 F16 F18	0
F14	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F13 F14 F15 F16 F18 F19	F1 F2 F4 F5 F6 F7 F10 F11 F14 F18 F19 F20	F1 F2 F4 F5 F6 F7 F10 F11 F14 F18 F19	0
F15	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F15 F16 F18 F19	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19 F20	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F15 F16 F18 F19	0
F16	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F15 F16 F18 F19	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19 F20	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F15 F16 F18 F19	1
F17	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F13 F15 F16 F17 F18 F19	F1 F2 F4 F7 F10 F17 F19 F20	F1 F2 F4 F7 F10 F17 F19	0
F18	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F13 F14 F15 F16 F18 F19	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19 F20	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F13 F14 F15 F16 F18 F19	1
F19	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19	F1 F2 F4 F7 F10 F12 F14 F15 F16 F17 F18 F19 F20	F1 F2 F4 F7 F10 F12 F14 F15 F16 F17 F18 F19	0
F20	F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F16 F17 F18 F19 F20	F20	F20	0

Table 6. Iteration 2.

	Reachability_Set	Antecedents_Set	Intersection_Set	Level
F1	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19	F1 F2 F4 F6 F7 F12 F14 F15 F17 F19 F20	F1 F2 F4 F6 F7 F12 F14 F15 F17 F19	0
F2	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19	F1 F2 F4 F6 F7 F10 F12 F14 F15 F17 F19 F20	F1 F2 F4 F6 F7 F10 F12 F14 F15 F17 F19	0
F4	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19	F1 F2 F4 F6 F7 F10 F11 F12 F14 F15 F17 F19 F20	F1 F2 F4 F6 F7 F10 F11 F12 F14 F15 F17 F19	0
F6	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F15	F1 F2 F4 F6 F7 F10 F11 F12 F14 F15 F17 F19 F20	F1 F2 F4 F6 F7 F10 F11 F12 F15	0
F7	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19	F1 F2 F4 F6 F7 F10 F12 F14 F15 F17 F19 F20	F1 F2 F4 F6 F7 F10 F12 F14 F15 F17 F19	0
F8	F8 F11 F13 F15	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19 F20	F8 F11 F13 F15	2
F9	F8 F9 F11 F13 F15	F1 F2 F4 F6 F7 F9 F10 F12 F14 F15 F17 F19 F20	F9 F15	0
F10	F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19	F1 F2 F4 F6 F7 F10 F12 F14 F15 F17 F19 F20	F2 F4 F6 F7 F10 F12 F14 F15 F17 F19	0
F11	F4 F6 F8 F11 F12 F13 F15	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19 F20	F4 F6 F8 F11 F12 F13 F15	2
F12	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F15 F19	F1 F2 F4 F6 F7 F10 F11 F12 F15 F19 F20	F1 F2 F4 F6 F7 F10 F11 F12 F15 F19	0
F13	F8 F11 F13 F15	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19 F20	F8 F11 F13 F15	2
F14	F1 F2 F4 F6 F7 F8 F9 F10 F11 F13 F14 F15 F19	F1 F2 F4 F7 F10 F14 F19 F20	F1 F2 F4 F7 F10 F14 F19	0
F15	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F15 F19	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19 F20	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F15 F19	2
F17	F1 F2 F4 F6 F7 F8 F9 F10 F11 F13 F15 F17 F19	F1 F2 F4 F7 F10 F17 F19 F20	F1 F2 F4 F7 F10 F17 F19	0
F19	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19	F1 F2 F4 F7 F10 F12 F14 F15 F17 F19 F20	F1 F2 F4 F7 F10 F12 F14 F15 F17 F19	0
F20	F1 F2 F4 F6 F7 F8 F9 F10 F11 F12 F13 F14 F15 F17 F19 F20	F20	F20	0

Table 7. Iteration 3.

	Reachability_Set	Antecedents_Set	Intersection_Set	Level
F1	F1 F2 F6 F7 F9 F10 F12 F14 F17 F19	F1 F2 F4 F6 F7 F12 F14 F17 F19 F20	F1 F2 F6 F7 F12 F14 F17 F19	0
F2	F1 F2 F6 F7 F9 F10 F12 F14 F17 F19	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19 F20	F1 F2 F6 F7 F10 F12 F14 F17 F19	0
F4	F1 F2 F4 F6 F7 F9 F10 F12 F14 F17 F19	F4 F7 F10 F12 F14 F17 F19 F20	F4 F7 F10 F12 F14 F17 F19	0
F6	F1 F2 F6 F7 F9 F10	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19 F20	F1 F2 F6 F7 F10	0
F7	F1 F2 F4 F6 F7 F9 F10 F12 F14 F17 F19	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19 F20	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19	0
F9	F9	F1 F2 F4 F6 F7 F9 F10 F12 F14 F17 F19 F20	F9	3
F10	F2 F4 F6 F7 F9 F10 F12 F14 F17 F19	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19 F20	F2 F4 F6 F7 F10 F12 F14 F17 F19	0
F12	F1 F2 F4 F6 F7 F9 F10 F12 F19	F1 F2 F4 F7 F10 F12 F19 F20	F1 F2 F4 F7 F10 F12 F19	0
F14	F1 F2 F4 F6 F7 F9 F10 F14 F19	F1 F2 F4 F7 F10 F14 F19 F20	F1 F2 F4 F7 F10 F14 F19	0
F17	F1 F2 F4 F6 F7 F9 F10 F17 F19	F1 F2 F4 F7 F10 F17 F19 F20	F1 F2 F4 F7 F10 F17 F19	0
F19	F1 F2 F4 F6 F7 F9 F10 F12 F14 F17 F19	F1 F2 F4 F7 F10 F12 F14 F17 F19 F20	F1 F2 F4 F7 F10 F12 F14 F17 F19	0
F20	F1 F2 F4 F6 F7 F9 F10 F12 F14 F17 F19 F20	F20	F20	0

Table 8. Iteration 4.

	Reachability_Set	Antecedents_Set	Intersection_Set	Level
F1	F1 F2 F6 F7 F10 F12 F14 F17 F19	F1 F2 F4 F6 F7 F12 F14 F17 F19 F20	F1 F2 F6 F7 F12 F14 F17 F19	0
F2	F1 F2 F6 F7 F10 F12 F14 F17 F19	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19 F20	F1 F2 F6 F7 F10 F12 F14 F17 F19	4
F4	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19	F4 F7 F10 F12 F14 F17 F19 F20	F4 F7 F10 F12 F14 F17 F19	0
F6	F1 F2 F6 F7 F10	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19 F20	F1 F2 F6 F7 F10	4

Table 8. *Cont.*

	Reachability_Set	Antecedents_Set	Intersection_Set	Level
F7	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19 F20	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19	4
F10	F2 F4 F6 F7 F10 F12 F14 F17 F19	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19 F20	F2 F4 F6 F7 F10 F12 F14 F17 F19	4
F12	F1 F2 F4 F6 F7 F10 F12 F19	F1 F2 F4 F7 F10 F12 F19 F20	F1 F2 F4 F7 F10 F12 F19	0
F14	F1 F2 F4 F6 F7 F10 F14 F19	F1 F2 F4 F7 F10 F14 F19 F20	F1 F2 F4 F7 F10 F14 F19	0
F17	F1 F2 F4 F6 F7 F10 F17 F19	F1 F2 F4 F7 F10 F17 F19 F20	F1 F2 F4 F7 F10 F17 F19	0
F19	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19	F1 F2 F4 F7 F10 F12 F14 F17 F19 F20	F1 F2 F4 F7 F10 F12 F14 F17 F19	0
F20	F1 F2 F4 F6 F7 F10 F12 F14 F17 F19 F20	F20	F20	0

Table 9. Iteration 5.

	Reachability_Set	Antecedents_Set	Intersection_Set	Level
F1	F1	F1 F4 F12 F14 F17 F19 F20	F1	5
F4	F1 F4 F19	F4 F12 F14 F17 F19 F20	F4 F19	0
F12	F1 F4 F12 F19	F12	F12	0
F14	F1 F4 F14 F19	F14	F14	0
F17	F1 F4 F17 F19	F17	F17	0
F19	F1 F4 F19	F4 F12 F14 F17 F19 F20	F4 F19	0
F20	F1 F4 F19 F20	F20	F20	0

Table 10. Iteration 6.

	Reachability_Set	Antecedents_Set	Intersection_Set	Level
F4	F4 F19	F4 F12 F14 F17 F19 F20	F4 F19	6
F12	F4 F12 F19	F12	F12	0
F14	F4 F14 F19	F14	F14	0
F17	F4 F17 F19	F17	F17	0
F19	F4 F19	F4 F12 F14 F17 F19 F20	F4 F19	6
F20	F4 F19 F20	F20	F20	0

Table 11. Iteration 7.

	Reachability_Set	Antecedents_Set	Intersection_Set	Level
F12	F12	F12	F12	7
F14	F14	F14	F14	7
F17	F17	F17	F17	7
F20	F20	F20	F20	7

Table 5 extracts F3, F5, F16, and F18 with the same reachability set and intersection set at the top level. Next, F8, F11, F13, and F15 with the same reachability set and intersection set were identified as Level 2. F3, F5, F16, F18, and F18, were then identified as the highest levels in Table 6. The same process was repeated to identify F9 factors as Level 3 factors (see Table 7), and F2, F6, F7, and F10 factors as Level 4 factors (see Table 8). In addition, F1 factors were identified as Level 5 factors (see Table 9), and F4 and F19 factors were identified as Level 6 factors (see Table 10). Finally, F12, F14, F17, and F20 factors were identified as the lowest level factors (see Table 11).

5.4. ISM Model

The ISM model was developed based on the level partition results. Top-level factors were placed at the top and sequentially from top to bottom. An ISM model was developed by plotting the relationship between the factors in the form of a line drawn between the factors placed. The ISM model of the OSC success factors developed in this study is shown in Figure 1.

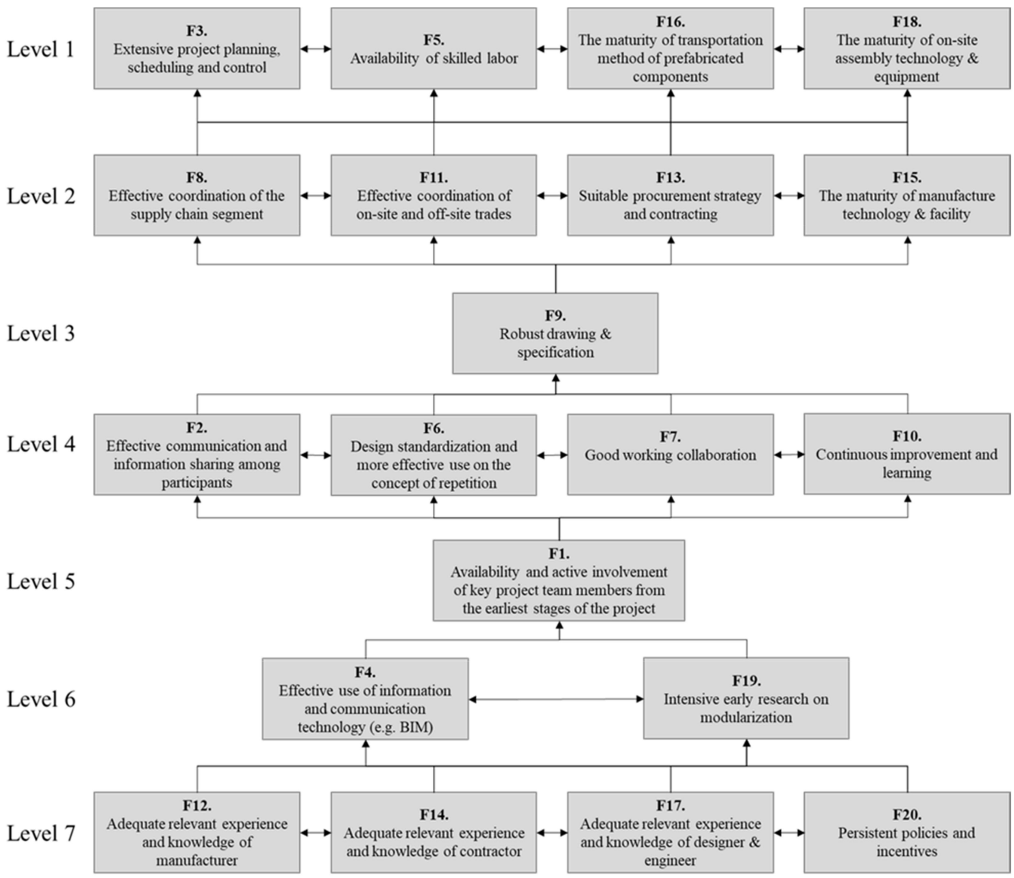

Figure 1. ISM model.

The following are placed at the top level of the model: F3 (extensive project planning, scheduling, and control), F5 (availability of skilled labor), F16 (maturity of transportation method of prefabricated components), and F18 (maturity of on-site assembly technology and equipment). The following are placed at the very bottom level of the model: F12 (adequate relevant experience and knowledge of manufacturer), F14 (adequate relevant experience and knowledge of the contractor), F17 (adequate relevant experience and knowledge of designers and engineers), and F20 (persistent policies and incentives). The factors placed at a lower level in the ISM model can be deduced to have more influence on OSC success than those placed at a higher level.

5.5. MICMAC Analysis

In the MICMAC analysis, the OSC success factors are clustered based on the dependence and driving power in the final reachability matrix (Table 4). Figure 2 shows the resulting four clusters (autonomous, dependent, linkage, and independent), with driving power under the x-axis and dependence under the y-axis.

1. Autonomous parameters: Factors in this cluster are relatively less important because of their small dependence and driving power. None of the factors identified in this study fall in this cluster, indicating that they all contribute significantly to the success of OSC.
2. Dependent parameters: F3 (extensive project planning, scheduling, and control), F9 (robust drawing and specification), and F13 (suitable procurement strategy and contracting) fall in this quadrant. The factors in this cluster are low in driving power but high in dependence. These factors are mainly dependent on other factors and can vary significantly.
3. Linkage parameters: Most factors fall within this quadrant. A total of 15 factors are included in this cluster: F1 (availability and active involvement of key project team members from the earliest stages of the project), F2 (effective communication and information sharing among participants), F4 (effective use of information and communication technology (e.g., BIM)), F5 (availability of skilled labor), F6 (design standardization and more effective use of the concept of repetition), F7 (good working collaboration), F8 (effective coordination of the supply chain segments), F10 (continuous improvement and learning), F11 (effective coordination of on-site and off-site trades), F12 (adequate relevant experience and knowledge of the manufacturer), F14 (adequate relevant experience and knowledge of the contractor), F15 (maturity of manufacturing technology and facility), F16 (maturity of the transportation method of prefabricated components), F18 (maturity of on-site assembly technology and equipment), and F19 (intensive early research on modularization). This cluster is characterized by high dependence and driving power. Factors in this category can be considered critical factors because they have a strong relationship with other factors.
4. Independent parameters: F17 (adequate relevant experience and knowledge of designer and engineer) and F20 (persistent policies and incentives) fall in this quadrant. These factors are high in driving power but low in dependence. Therefore, these are critical factors that require the most attention.

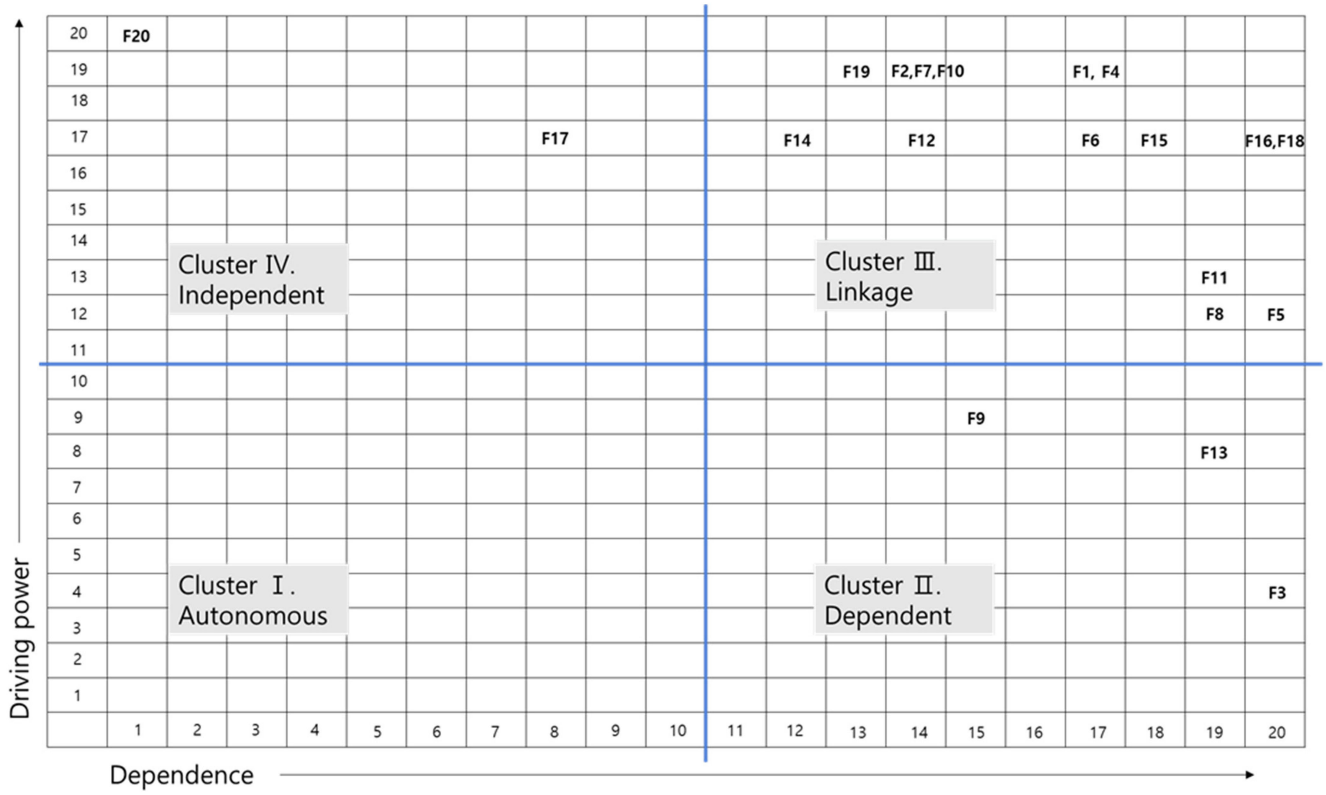

Figure 2. MICMAC analysis.

6. Conclusions

As labor productivity problems in the construction industry are emerging worldwide, the use of OSC is gaining attention as an alternative to overcome productivity limitations. As research on OSC is starting to accelerate, strategies that can effectively implement new construction methods become necessary. In this regard, a variety of studies have identified factors related to the success of OSC. However, research on the structuring of the relationship between factors based on the understanding of their nature remains limited. In this study, the OSC success factors presented in prior studies were identified, the relationship between the factors was defined using the ISM model and the MICMAC analysis, and a structural model reflecting the relationship between the factors was presented.

The comprehensive examination of the ISM model and MICMAC analysis results indicates that the most important success factors to be considered among the 20 success factors identified in this study are F17 (adequate relevant experience and knowledge of designers and engineers) and F20 (persistent policies and incentives). These factors constitute the lowest level of the ISM model and are included in Cluster 4 (independent parameters). In addition, F12 (adequate relevant experience and knowledge of the manufacturer) and F14 (adequate relevant experience and knowledge of the contractor) need to be given special consideration, as they constitute the lowest level of the ISM model and are included in Cluster 3 (linkage parameters). This implies that the appropriate selection of key project participants, designers, engineers (F17), manufacturers (F12), and contractors (F14) should be initially considered when establishing strategies for the success of OSC. This also implies that an institutional foundation (F20) should be established to encourage the use of OSC at the government's level, along with the appropriate selection of key project participants.

To establish high-quality and sustainable strategies for OSC success, understanding OSC success factors structurally and establishing an effective strategy to utilize them are important. Therefore, this study is significant in that it presents an ISM model that identifies the relationship between OSC success factors and distinguishes the factors based on the degree of influence between them, thereby improving the understanding of the OSC success factors.

A limitation of this study is that only 20 factors were considered to develop an understanding of the relationships between OSC success factors. More success factors need to be considered in future investigations. In addition, the relationship between the success factors was based, in this study, on the opinions of eight experts picked from the industrial and academic fields who have experience in OSC-related work and research. However, the opinions of these experts may change with time. Finally, this study is only applicable to the actual circumstances in South Korea. Additional research is required for applications in different countries.

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