

Article

Identification of Critical Success Factors (CSFs) of BIM Software Selection: A Combined Approach of FCM and Fuzzy DEMATEL

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Abstract: The architecture, engineering, and construction (AEC) industry has seen a significant rise in the adoption of Building Information Modeling (BIM) in the last few years. BIM software have launched with numerous robust capabilities and features to satisfy the ever-demanding needs of the AEC industry. Various factors are associated with the selection of BIM software depending on a company's requirements and constraints. BIM software selection is a daunting process as most AEC industries are unaware of the factors to consider when making this important decision. This study focuses on identifying the critical success factors (CSFs) and their interrelationship for efficient BIM software selection. For this research, a questionnaire was developed and disseminated in two stages in India, the United States of America (U.S.A.), Germany, and the United Kingdom (U.K.). In the first stage, a total of twenty-six identified CSFs were analyzed with the factor comparison method (FCM) to identify the top fifteen CSFs. Subsequently, the identified top fifteen CSFs were further assessed by implementing Fuzzy DEMATEL to categorize them into cause-and-effect groups based on respective influence strength, depicted with a causal diagram. Out of fifteen CSFs, five and ten factors were grouped into the cause group and effect group for BIM software selection, respectively. The most important factors were identified as software functionality, BIM adoption strategies and processes, interoperability, staff competencies, BIM standards and regional regulations. The outcome of this research can help BIM user companies improve their BIM software selection framework and decision-making process during purchasing software.

Keywords: BIM; software selection; decision-making process; critical success factors; Fuzzy DEMATEL; FCM; AEC



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1. Introduction

In the digital age, Building Information Modelling (BIM) has been a 'game-changing' technology for the AEC industry [1,2]. It has significantly boosted team coordination, construction productivity, project performance and project profits [3,4]. Consequently, BIM adoption has significantly increased with remarkable enthusiasm in various construction domains, such as clash detection, construction planning, progress monitoring, facility management, maintenance, safety management, and energy management [3]. Due to the accrued benefits of BIM adoption, BIM implementation is predicted to become common practice in the construction industry.

Despite the many advantages, BIM adoption remains low in many countries; however, many governments have emphasized BIM implementation as part of their strategy to improve the value and productivity of the AEC industry [1,5]. This also suggests that

the market for BIM software will continue to expand for the foreseeable future. Since the inception of BIM, many BIM software have been introduced with ever-improving capabilities [6,7]. At present, a wide range of BIM software packages is being utilized throughout the project life cycle, such as Autodesk Revit, Navisworks, ArchiCAD, Synchro, Solibri, Vico office, Tekla structure, and Bentley open roads. With so many options, selecting the right BIM software has become critical for the success of an AEC business because it can significantly minimize the costs, time and risks associated with their projects [8]. This decision will impact the potential benefit of BIM implementation, the time for software setup, training, and the realized return on investment (ROI). Therefore, right BIM software selection is a vital decision-making problem for management and directly influences the businesses and projects' desired outcomes. Typically, this decision-making process for BIM software selection is time-consuming, complex and ambiguous due to the availability of a large number of BIM software with associated features [9]. It is usually even more difficult for infant BIM user organizations due to their lack of experience with technology. For them, additional effort, understanding, and special knowledge are required to identify and prioritize the important factors to consider. Misreckoning these factors may result in the wrong BIM software being selected, negatively impacting efficiency, project profits and project duration [10]. Therefore, it is important to improve the BIM selection process by identifying and prioritizing critical success factors (CSFs).

In the field of information systems, Rockard [11] introduced the concept of CSFs to identify key areas where 'things must go right' for developing the business. Several research studies have been carried out on CSFs in various research domains. Fosu [9] studied the criteria based decision-making process for Mechanical, Electrical and Plumbing (MEP) BIM software selection in the United States of America (U.S.A.). Evans et al. [12] investigated CSFs for adopting BIM and lean practices in the construction industry. Tsai et al. [13] carried out a study to develop CSFs for the assessment of BIM technology adoption. Khemlani [14] researched various criteria related to BIM software maturity in the AEC field. Liberatore and Johnson [15] carried out a research study to identify factors influencing the selection of project software. Kannan and Vinay [16] applied the AHP method to prioritize criteria for the selection of CAD/CAM software packages. Yazgan et al. (2009) implemented an analytical network process (ANP)-based artificial neural network on developing a model for ERP software selection [17]. Ayag and Özdemir [18] studied fuzzy ANP for the development of an intelligent approach to select ERP software. Furthermore, many other research endeavours have been made for the identification of CSFs for ERP software selection and BIM adoption [19–22]. However, no research endeavour was found in the literature to identify the critical success factors and their interrelationship (cause-effect) for BIM software selection. To address this research gap, this research article aims to implement a combined approach of FCM and Fuzzy DEMATEL for the identification of critical success factors and provide a visual representation of their interrelationship with a cause-effect diagram to assist the decision-making process of BIM software selection.

This research article is organized as follows. The second section and third section brief the research methodology and results of the study, respectively. Subsequently, the discussion section presents a discussion of key findings and managerial implications of the study. The last section reports a conclusion consisting of the limitations of the study and future study.

2. Research Methodology

For this study, the research methodology is classified into three steps: (1) identification of factors for BIM software selection through literature review; (2) data collection through questionnaire survey; and (3) data analysis with a combined approach of the Factor Comparison Method (FCM) and Fuzzy DEMATEL method. Figure 1 shows the research process for this study.

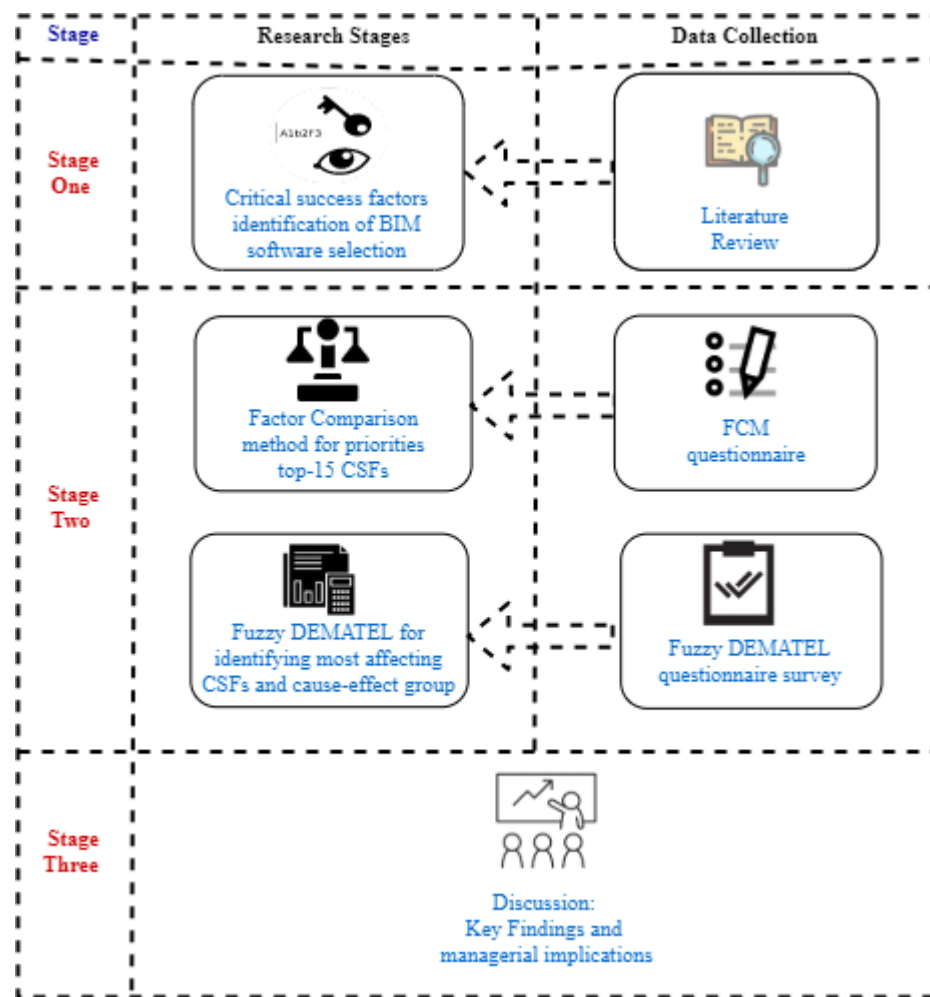


Figure 1. Research process.

2.1. Factors Identification through Literature Review

BIM software selection is associated with various factors depending on the relevant requirements and constraints of the organization. Single BIM software cannot be applied universally as each software comes with unique strengths and weaknesses [23]. A rigorous effort was made to identify factors influencing the decision-making process for BIM software selection from the literature. Table 1 shows the 26 factors that were identified and subsequently categorised under four parameters, i.e., cost, management, technical, and vendors related.

1. **Cost:** Every organization needs to purchase the required BIM software considering the overall cost. There are many direct and indirect costs associated with the BIM software, which plays a key role in decision making, i.e., cost of license upgrades, cost of hardware upgrades, an initial investment in the software purchase and cost of implementation and training. This needs to be balanced by stakeholders who are economically benefited by the utilization of BIM in terms of enhanced productivity (improved cost, quality, and time).
2. **Management:** The usage of BIM software affects several organizational aspects, such as organizational workflows, job descriptions, credential requirements, project delivery methods, contractual agreements, skills, and general knowledge requirements. Therefore, many important factors should be considered, such as BIM adoption policies, staff competencies, awareness of BIM, flexibility, and willingness to change the workflow & business model, co-operation and support from other stakeholders, supportive contractual framework, and training of the employees.

3. Technical: With the swift progress of technology, BIM software have to be supplemented with desired technical attributes to address relevant issues for enhanced project performance in AEC. The technical aspects are important such as software functionality, interoperability, user-friendliness, BIM standards and regulations, data security and privacy protocols, potential capabilities of application integration/extension, accessibility of BIM software, capacity to handle large data, BIM objects/library, level of data management and compatibility with existing hardware.
4. Vendor: Vendor characteristics can impact the BIM software selection process. The BIM software vendor acts as a key player in the BIM software demand and supply chain. New updated/upgraded version releases of software at regular time intervals play a vital role in improving usability. Factors such as software popularity and reputation, technical service support, R&D capabilities, documentation, and training support have considerable influence in the decision-making process.

Table 1. Factor identification from the literature.

Parameters	Factors	Description	References
Cost	Annual cost of upgrades (AN)	Cost associated with every license upgrade of the BIM software annually, including applicable taxes	[8,24–26]
	Cost of required hardware upgrades (CO)	Cost incurred in the hardware/system up-gradation according to the system requirements of the latest available BIM software	[8,24–26]
	Initial cost of software (IN)	Cost expenses for the initial setup and purchase of the suitable BIM software	[8,24–26]
	Implementation cost (IM)	Cost expenditures consisting of BIM adoption and execution, i.e., cost of software and hardware per resource, cost of experts/technicians, cost of operations, etc.	[8,24–26]
Management	BIM adoption strategies and process (BI)	Policies and strategies defined by the top management of the stakeholders for BIM adoption.	[26–32]
	Staff competencies (ST)	Technical competencies and respective experience of the human resources/employees involved in the project.	[27–32]
	BIM software awareness (BT)	Impact and awareness of the various BIM software in the respective country/state.	[26–28,33,34]
	Flexibility to change the workflow and business model (FL)	Willingness of the stakeholders to adopt the changes in the workflow and business model to incorporate BIM.	[27,28,30,31,35]
	Co-operation from other industry partners (CI)	Inter-collaboration of the industry partners/stakeholders supporting the BIM adoption.	[25,27,36]
	Contractual framework (CN)	Terms and conditions of the contract favouring the BIM implementation in the project.	[25,27,28,34]
	Training of employers (TR)	Frequency of the training provided to the employers to keeping them updated about the recent technology trends in the industry.	[8,24,26,27,32,35]

Table 1. Cont.

Parameters	Factors	Description	References
Technical	Software functionality (SO)	Functionality of the software in terms of design, engineering, analysis, management, etc.	[8,25,28,34,35,37–39]
	Interoperability (IT)	Options of interoperability of the files with other BIM software.	[8,25,29,31,34,37–39]
	User-friendliness (UF)	User interface/graphic interface easiness of the BIM software to utilize in the various types of projects.	[8,24–26,35]
	BIM standard, codes, rules, and regulations (BS)	Presence/enforcement of specific BIM standard codes, rules, and regulations by the government authorities in the country/state.	[26,29,30,33,37–39]
	Data security and privacy protocols (DT)	Level of security and privacy of the project data managed in the BIM software.	[34,35,37,40]
	Application integration/extension (API) capabilities (AP)	Availability/possibility of various extensions or plugins for the BIM software.	[28,37,41]
	Accessibility of BIM software (AC)	Ease of availability/accessibility of the BIM software in the region.	[28,33–35,37]
	Large data handling capacity (LA)	Capability of the BIM software to manage/process large size files.	[28,29,34,37]
	BIM objects/library (BL)	Availability of the BIM objects for various BIM software.	[8,25,37]
	Sophistication of data management (SD)	Ease of the data/information exchange process for BIM projects.	[8,25,29,34,37]
Vendors	Compatibility with existing hardware (CH)	System requirements/compatibility of the BIM software with the existing hardware of the systems used by stakeholders.	[28,31,37,39]
	Popularity (PO)	Popularity and reputation of the vendor company across the globe for their BIM software utilization.	[8,25,29,39]
	Technical service support (TS)	Quality of post-sales service and level of customer satisfaction.	[8,25,39]
	Innovation & research development capabilities (ID)	R&D capacity of the vendor company in terms of funding as well as resources.	[8,25,39]
	Documentation & training support (DO)	Provision of supportive documentation and training to the customers on the newly launched BIM software and latest techniques.	[8,25,39]

2.2. Data Collection

A questionnaire survey is an efficient way to capture all project stakeholders' insights and empower these insights to be analyzed and compared [42]. In this study, the questionnaire survey was carried out in two stages, and responses were gathered from India, the U.S.A., Germany, and the United Kingdom. For both questionnaire stages, a five-point scale was utilized because it improves the response rate and quality while minimizing the frustration level of respondents [43]. In the first stage, a structured questionnaire was designed based on the literature review. A questionnaire consisted of two parts; In the first part, respondents' details were included, such as name, company size, job position,

and years of experience. In the second part, the questionnaire included the main four parameters categorized into 26 sub-factors for BIM software selection. The first questionnaire with closed-ended questions was designed to acquire the importance score (0 to 4) of various CSFs against each of the CSFs of BIM software selection. The distribution of the questionnaire was done electronically (google form) and physically to the respondents located in the U.S.A., Germany, the United Kingdom, and India. Initially, the questionnaire was sent to the targeted top-level respondents to identify the most important 15 CSFs using the factor comparison method (FCM), which was further used to determine cause and effect groups by the Fuzzy DEMATEL method. Top-level and high experienced field experts were selected from BIM consultancies, AEC design firms, and project management consultancies. The sample size of the first questionnaire stage was targeted to senior personnel to acquire more useful data. Moreover, the sample size was sufficient to no new themes to turn up. In Table 2, the respondents' details are illustrated for FCM analysis.

Table 2. Respondents' details for FCM.

Characteristics	Classification	Total Numbers
Company size	Large (>200 employees)	9
	Medium (100 to 200 employees)	4
	Small (<100 employees)	2
Position	CEO/Managing director	10
	CTO/Technical head/Manager	5
Years of experience	>15 years	11
	5 to 10 years	4

In the second stage, the questionnaire was carried out to identify the most important CSFs and to reveal their cause-effect relationship by using the Fuzzy DEMATEL technique. A questionnaire was divided into two sections; The first section was consisting of respondents' information such as name, job position, company type and years of experience; whereas, the second section was consisting of questions. A total of 60 structured questionnaires were distributed physically as well as electronically (google form). The respondents were requested to rate the top fifteen CSFs according to a five-point Likert scale (1 = Very low influence, 5 = Very high influence). A total of 48 out of 60 questionnaires were returned, depicting an ~80% response rate. Table 3 represents the respondents' details of the second stage questionnaire. Respondents were targeted from the top and mid-level officials from government, BIM consultancies, design consultancies, contractors, and project management consultancies.

Table 3. Respondents' details for Fuzzy DEMATEL analysis.

Characteristics	Classification	Total Numbers
Company type	Government organization	5
	BIM consultancy and design consultancy	20
	Contractor company	11
	Project management consultancy	12
Position	Top-level	37
	Mid-level	11
Years of experience	<5 years	11
	5 top 10 years	24
	>10 years	13

2.3. Data Analysis Techniques

2.3.1. Factor Comparison Method (FCM)

The factor comparison method, a Multi-Criteria Decision Making (MCDM) method, was used as a funnel process to prioritize the CSFs of BIM software selection for further analysis with the Fuzzy DEMATEL method. The factored matrix was created, where each factor was compared with other factors by pairwise comparison to calculate their relative weights [44]. As shown in Table 4, a five-point scale was used to provide a priority score based on the arithmetic mean of collected responses from the questionnaire survey stage 1. A priority score was assigned to a more influential parameter over another parameter based on relative importance for each factor. Subsequently, a summation of all the factors was computed to provide the ranking based on the total score.

Table 4. Pairwise comparison scale for FCM.

Score	Difference of Importance between Two CSFs
0	No difference
1	Minor difference
2	Average difference
3	Major difference
4	High difference

2.3.2. Fuzzy DEMATEL Method

Decision making is a complex process and relies on various factors in a fuzzy environment [45]. The Fuzzy DEMATEL method demonstrated a unique capability of showing corresponding influence (indirect and direct) among various factors. This can further be expanded to show a visual representation of the cause-effect relationships [46]. Furthermore, the Fuzzy DEMATEL method can convert the qualitative response into quantitative measures to assess the weight of each criterion; providing a rank while considering mutual factors' interactions. Other MCDM methods fail to represent such valuable insights for decision-makers. Therefore, this article proposes the Fuzzy DEMATEL method to rank CSFs and analyze their inter-relationships for improving the decision-making process of the BIM software selection process. Fuzzy DEMATEL is a hybrid approach of the DEMATEL method and Fuzzy theory, as described below.

DEMATEL Method

Decision-Making Trial and Evaluation Laboratory (DEMATEL) was originated by the Geneva research centre of the Battelle Memorial Institute [47]. Initially, DEMATEL was explored for integrated solutions to antagonistic and fragmented societies of the world [47]. It became popular in various domains because of its superior ability to gather knowledge, examine linkages among success factors and portray this structure with a cause-effect relationship diagram [46]. It depicts interrelationship and the influence of the strength of factors by structural modelling [46]. It allows researchers to identify the most important factors that influence other factors. This study employs DEMATEL to categorize the most important factors into cause and effect groups with their interrelationship for the selection process of BIM software. DEMATEL methods can be summarized with the following steps [47].

1. Pairwise comparisons are determined into five levels by quantifying the linguistic assessments of expert's response evaluation, where "No influence", "Low influence", "Medium influence", "High influence", and "Very High Influence" are denoted by 1, 2, 3, 4, and 5, respectively.
2. The direct relation matrix T is developed. As illustrated in Equation (1), T is an $n \times n$ matrix generated by a pairwise relationship in reference to influence and the direction between success factors.

$$T = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} & \begin{bmatrix} 0 & t_{12} & \cdots & t_{1n} \\ t_{21} & 0 & \cdots & t_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ t_{n1} & t_{n2} & \cdots & 0 \end{bmatrix} \end{matrix} \quad (1)$$

3. The normalized direct-relation matrix can be generated using Equation (2), where $Y = [y_{ij}]_{n \times n}$ and $0 \leq y_{ij} \leq 1$. Moreover, u can be derived using Equation (3). All principal diagonal members in matrix Y are set to zero.

$$Y = u \times T \quad (2)$$

$$u = \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^n t_{ij}}, \quad i = 1, 2, \dots, n. \quad (3)$$

4. The total relation matrix is generated on the basis of a normalized direct-relation matrix by using Equation (4), where I is $n \times n$ identity matrix. The member w_{ij} denotes the indirect influence effect that factor i have on factor j , so matrix W can show the total relationship between each pair of system factors.

$$W = Y(I - Y)^{-1} \quad (4)$$

5. In this step, w_{ij} ($i, j = 1, 2, \dots, n$) is considered to be the members of the total matrix W . Subsequently, a summation of rows and columns is carried out from the total relation matrix. Hence, rows and columns are represented as B_i and Q_j , respectively.

$$W = w_{ij}, \quad i, j = 1, 2, \dots, n.$$

$$B = \left[\sum_{j=1}^n w_{ij} \right]_{n \times 1} \quad (5)$$

$$Q = \left[\sum_{j=1}^n w_{ij} \right]_{1 \times n} \quad (6)$$

6. In the last step, the cause-effect relationship graph is developed by mapping the ordered pairwise dataset of $(B + Q, B - Q)$, where the horizontal axis is generated by summation of B_k and Q_k , and the vertical axis is obtained by subtracting Q_k from B_k . The horizontal axis "Prominence" represents the significance of the factor, and the vertical axis depicts "Relation". Here, the positive value of $(B_k - Q_k)$ brings factors into the cause group, whereas the negative value of $(B_k - Q_k)$ turns into the effect group. Thus, the complex relationship between factors can be visualized with a casual cause-effect relationship graph.

Fuzzy Theory

Fuzzy theory helps to tackle the vagueness of human thoughts, perceptions and decision making [48]. Experts tend to express their qualitative evaluation in lingual terms rather than exact numbers based on their knowledge, experience, and perception during the decision-making problem of a complicated system [42]. These lingual terms are vague to analyze further. So, fuzzy set theory can be utilized to compute ambiguous concepts linked with subjective human judgement [49,50]. A fuzzy linguistic scale can be applied to convert ambiguous evaluation/judgements into fuzzy triangular numbers C , denoted by a triplet (d, e, f) , where $d \leq e \leq f$. A fuzzy triangular Membership function $\mu_{\hat{\lambda}}$ is shown in Figure 2 and Equation (7). Here, fuzzy numbers denote the fuzzy set on a real line R , and

their membership function is $\mu_x(y) : \mathbb{R} \rightarrow [0, 1]$, where $\mu_x(y)$ is a convex fuzzy subset and continuous piecewise.

$$\mu_{\bar{A}}(y) = \begin{cases} 0, & y < d \\ y - d/e - d, & d \leq y \leq e \\ f - y/f - e, & e \leq y \leq f \\ 0, & y > f \end{cases} \quad (7)$$

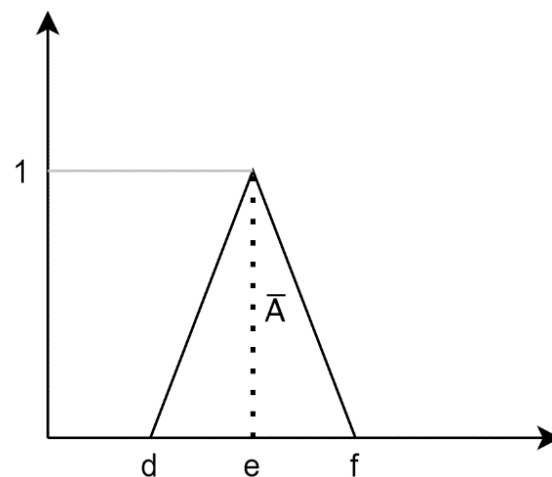


Figure 2. The presentation of fuzzy triangular membership functions.

Fuzzy numbers are not fit for matrix calculations. Therefore, a defuzzification algorithm can be used for fuzzy aggregation. The Converting Fuzzy data into Crisp Scores (CFCS) method can be utilized to obtain a crisp value of the total-relation matrix [51]. The left and right-side calculations are carried out by fuzzy minimum and maximum based on the fuzzy number range. Finally, the total crisp value is computed as per the membership function. The steps of the CFCS method are as follows:

1. Normalization of the fuzzy numbers is carried out with the following Equations (8)–(11).

$$d_{ij}^n = \frac{(d_{ij}^k - d_{ij}^k)}{\Delta_{\min}^{\max}} \quad (8)$$

$$e_{ij}^n = \frac{(e_{ij}^k - \min d_{ij}^k)}{\Delta_{\min}^{\max}} \quad (9)$$

$$f_{ij}^n = \frac{(f_{ij}^k - \min d_{ij}^k)}{\Delta_{\min}^{\max}} \quad (10)$$

$$\Delta_{\min}^{\max} = f_{ij}^k - d_{ij}^k \quad (11)$$

2. Normalized crisp values are computed for the left side and right side, using Equations (12) and (13).

$$d_{ij}^s = \frac{e_{ij}^n}{(1 + e_{ij}^n - d_{ij}^n)} \quad (12)$$

$$f_{ij}^s = \frac{f_{ij}^n}{(1 + f_{ij}^n - d_{ij}^n)} \quad (13)$$

3. Total normalized crisp values are computed with the following Equation (14).

$$y_{ij} = \frac{[d_{ij}^s(1 - d_{ij}^s) + f_{ij}^s \times f_{ij}^s]}{[1 - d_{ij}^s + f_{ij}^s]} \quad (14)$$

4. In this step, crisp values are calculated by utilizing the following Equation (15).

$$T_{ij}^n = \text{mind}_{ij}^n + y_{ij}^n \times \Delta_{\min}^{\max} \quad (15)$$

5. In the last step, the integration of crisp values is computed by using Equation (16).

$$T_{ij} = 1/h \left(T_{ij}^1 + T_{ij}^2 + T_{ij}^3 + \dots + T_{ij}^h \right) \quad (16)$$

3. Data Analysis and Result

3.1. Result of FCM

The resultant FCM matrix is shown in Table 5. All twenty-six CSFs were ranked to prioritize the top fifteen CSFs for further calculations by Fuzzy DEMATEL.

3.2. Result of Fuzzy DEMATEL

Based on the result from FCM analysis, most of the fifteen top-ranked factors were selected for Fuzzy DEMATEL analysis to develop a cause-effect diagram for BIM software selection. Fuzzy DEMATEL was equipped to analyze the collected responses of experts with the following major nine steps:

Step 1: The fuzzy-based linguistic scale was designed based on a five-level Likert scale and shown with positive triangular fuzzy numbers (d, e, f) for the evaluation of the responses, as shown in Table 6.

Table 6. Fuzzy-based linguistic scale.

Influence Score	Linguistic Terms	L	M	U
1	No influence	0	0.1	0.3
2	Very low influence	0.2	0.3	0.5
3	Low influence	0.3	0.5	0.7
4	High influence	0.5	0.7	0.9
5	Very high influence	0.7	0.9	1

Step 2: The direct relation matrix was calculated as illustrated in Table 7. Here, the arithmetic mean of all experts' responses was computed to develop the direct relation matrix using Equation (1).

Table 7. Direct relation matrix.

	SO	BI	IT	IN	ST	PO	BT	UF	BS	TS	FL	ID	DT	AP	CI
SO	-	2	2	4	3	3	3	4	3	4	4	3	1	3	2
BI	2	-	5	3	3	3	3	4	4	3	5	4	2	3	3
IT	4	3	-	5	3	3	4	3	5	4	4	5	1	2	5
IN	3	3	4	-	4	4	4	5	4	4	5	5	2	1	4
ST	3	4	4	3	-	5	4	3	3	5	5	3	4	4	2
PO	2	2	3	4	4	-	4	3	1	3	4	4	2	3	2
BT	2	3	3	4	3	3	-	4	4	3	4	3	3	1	3
UF	3	4	4	5	4	3	5	-	5	4	5	5	2	2	3
BS	4	4	4	4	3	3	5	4	-	3	4	4	2	1	2
TS	2	3	3	3	2	2	4	4	4	-	4	5	5	4	4
FL	4	4	4	4	5	3	5	5	4	3	-	5	4	3	4
ID	4	4	4	4	3	3	5	5	5	4	4	-	3	2	3
DT	3	3	3	5	4	4	4	3	3	5	5	4	-	4	4
AP	4	3	3	4	5	5	3	4	3	5	5	3	4	-	2
CI	4	4	5	3	4	2	3	3	3	3	4	4	2	2	-

Step 3: The fuzzy direct-relation matrix was generated by converting the direct relation matrix into fuzzy numbers, using the fuzzy-based linguistic scale as shown in Table 8.

Table 8. Fuzzy direct relation matrix.

	SO	BI	IT	IN	ST	PO	BT	UF	BS	TS	FL	ID	DT	AP	CI
SO	(0.00, 0.00, 0.00)	(0.50, 0.70, 0.90)	(0.50, 0.70, 0.90)	(0.70, 0.90, 1.00)	(0.20, 0.30, 0.50)	(0.70, 0.90, 1.00)	(0.70, 0.90, 1.00)	(0.70, 0.90, 1.00)	(0.20, 0.30, 0.50)	(0.70, 0.90, 1.00)	(0.70, 0.90, 1.00)	(0.70, 0.90, 1.00)	(0.50, 0.70, 0.90)	(0.50, 0.70, 0.90)	(0.70, 0.90, 1.00)
BI	(0.30, 0.50, 0.70)	(0.00, 0.00, 0.00)	(0.50, 0.70, 0.90)	(0.50, 0.70, 0.90)	(0.50, 0.70, 0.90)	(0.50, 0.70, 0.90)	(0.70, 0.90, 1.00)	(0.70, 1.00, 1.00)	(0.30, 0.50, 0.70)	(0.50, 0.70, 0.90)	(0.50, 0.70, 0.90)	(0.70, 1.00, 1.00)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.50, 0.70, 0.90)
IT	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.00, 0.00, 0.00)	(0.30, 0.50, 0.70)	(0.50, 0.70, 0.90)	(0.30, 0.50, 0.70)	(0.50, 0.70, 0.90)	(0.50, 0.70, 0.90)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.50, 0.70, 0.90)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.50, 0.70, 0.90)
IN	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.00, 0.00, 0.00)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.50, 0.70, 0.90)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.50, 0.70, 0.90)

Table 8. Cont.

	SO	BI	IT	IN	ST	PO	BT	UF	BS	TS	FL	ID	DT	AP	CI
ST	(0.50, 0.70, 0.90)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.50, 0.70, 0.90)	(0.00, 0.00, 0.00)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.00, 0.10, 0.30)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)
PO	(0.50, 0.70, 0.90)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.00, 0.00, 0.00)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.00, 0.10, 0.30)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)
BT	(0.70, 0.90, 1.00)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.00, 0.10, 0.30)	(0.30, 0.50, 0.70)	(0.00, 0.00, 0.00)	(0.10, 0.10, 0.30)	(0.10, 0.10, 0.30)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)
UF	(0.90, 1.00, 1.00)	(0.10, 0.30, 0.30)	(0.10, 0.30, 0.30)	(0.10, 0.30, 0.30)	(0.70, 0.90, 0.90)	(0.50, 0.70, 0.70)	(0.30, 0.50, 0.50)	(0.00, 0.00, 0.00)	(0.10, 0.30, 0.30)	(0.10, 0.30, 0.30)	(0.30, 0.50, 0.50)	(0.10, 0.30, 0.30)	(0.10, 0.30, 0.30)	(0.10, 0.30, 0.30)	(0.10, 0.30, 0.30)
BS	(0.00, 0.10, 0.30)	(0.70, 0.90, 1.00)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.00, 0.10, 0.30)	(0.00, 0.10, 0.30)	(0.00, 0.10, 0.30)	(0.90, 0.90, 0.90)	(0.30, 0.30, 0.30)	(0.70, 0.70, 0.70)	(0.30, 0.30, 0.30)	(0.90, 0.90, 0.90)
TS	(0.10, 0.30, 0.30)	(0.30, 0.50, 0.50)	(0.10, 0.30, 0.30)	(0.50, 0.70, 0.70)	(0.30, 0.50, 0.50)	(0.70, 0.90, 0.90)	(0.50, 0.70, 0.70)	(0.30, 0.50, 0.50)	(0.30, 0.50, 0.50)	(0.00, 0.00, 0.00)	(0.30, 0.50, 0.50)	(0.30, 0.50, 0.50)	(0.10, 0.30, 0.30)	(0.10, 0.30, 0.30)	(0.10, 0.30, 0.30)
FL	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.00, 0.10, 0.30)	(0.20, 0.30, 0.50)	(0.00, 0.10, 0.30)	(0.50, 0.70, 0.90)	(0.20, 0.30, 0.50)	(0.00, 0.00, 0.00)	(0.00, 0.10, 0.30)	(0.00, 0.10, 0.30)	(0.50, 0.70, 0.90)	(0.20, 0.30, 0.50)
ID	(0.50, 0.70, 0.90)	(0.20, 0.30, 0.50)	(0.70, 0.90, 1.00)	(0.30, 0.50, 0.70)	(0.00, 0.10, 0.30)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.00, 0.10, 0.30)	(0.00, 0.10, 0.30)	(0.00, 0.10, 0.30)	(0.00, 0.00, 0.00)	(0.50, 0.70, 0.90)	(0.00, 0.30, 0.30)	(0.00, 0.30, 0.30)
DT	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.00, 0.10, 0.30)	(0.30, 0.50, 0.70)	(0.00, 0.10, 0.30)	(0.20, 0.30, 0.50)	(0.00, 0.10, 0.30)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.00, 0.00, 0.00)	(0.00, 0.10, 0.30)	(0.20, 0.30, 0.50)
AP	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.30, 0.50, 0.70)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.00, 0.10, 0.30)	(0.00, 0.10, 0.30)	(0.20, 0.30, 0.50)	(0.00, 0.10, 0.30)	(0.20, 0.30, 0.50)	(0.00, 0.00, 0.00)	(0.00, 0.10, 0.30)
CI	(0.20, 0.30, 0.50)	(0.70, 0.90, 1.00)	(0.20, 0.30, 0.50)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.00, 0.10, 0.30)	(0.20, 0.30, 0.50)	(0.00, 0.10, 0.30)	(0.50, 0.70, 0.90)	(0.20, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.00, 0.10, 0.30)	(0.00, 0.10, 0.30)	(0.20, 0.30, 0.50)	(0.00, 0.00, 0.00)

Step 4: As illustrated in Table 9, the fuzzy direct-relation matrix was normalized, using Equations (2) and (3).

Table 9. Normalized fuzzy direct relation matrix.

	SO	BI	IT	IN	ST	PO	BT	UF	BS	TS	FL	ID	DT	AP	CI
SO	(0.00, 0.00, 0.00)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.06, 0.07, 0.08)	(0.02, 0.02, 0.04)	(0.06, 0.07, 0.08)	(0.06, 0.07, 0.08)	(0.06, 0.07, 0.08)	(0.02, 0.02, 0.04)	(0.06, 0.07, 0.08)	(0.06, 0.07, 0.08)	(0.06, 0.07, 0.08)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.06, 0.07, 0.08)
BI	(0.02, 0.04, 0.06)	(0.00, 0.00, 0.00)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.06, 0.07, 0.08)	(0.06, 0.07, 0.08)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.06, 0.07, 0.08)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)
IT	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.00, 0.00, 0.00)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)
IN	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.00, 0.00, 0.00)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.06, 0.07, 0.08)	(0.04, 0.06, 0.07)	(0.06, 0.07, 0.08)
ST	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.00, 0.00, 0.00)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.00, 0.01, 0.02)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)
PO	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.00, 0.00, 0.00)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.00, 0.01, 0.02)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)
BT	(0.06, 0.07, 0.08)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.01, 0.02, 0.04)	(0.04, 0.06, 0.07)	(0.00, 0.00, 0.00)	(0.01, 0.02, 0.04)	(0.01, 0.02, 0.04)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)
UF	(0.06, 0.07, 0.08)	(0.00, 0.01, 0.02)	(0.00, 0.01, 0.02)	(0.01, 0.01, 0.02)	(0.06, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)	(0.00, 0.00, 0.00)	(0.01, 0.01, 0.02)	(0.01, 0.01, 0.02)	(0.02, 0.02, 0.04)	(0.01, 0.01, 0.02)	(0.01, 0.01, 0.02)	(0.01, 0.01, 0.02)	(0.01, 0.01, 0.02)

Table 9. Cont.

	SO	BI	IT	IN	ST	PO	BT	UF	BS	TS	FL	ID	DT	AP	CI
BS	(0.00, 0.01, 0.02)	(0.06, 0.07, 0.08)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.00, 0.01, 0.02)	(0.00, 0.00, 0.00)	(0.00, 0.01, 0.02)	(0.04, 0.06, 0.07)	(0.00, 0.01, 0.02)	(0.02, 0.04, 0.06)	(0.00, 0.01, 0.02)	(0.04, 0.06, 0.07)
TS	(0.00, 0.01, 0.02)	(0.02, 0.02, 0.04)	(0.00, 0.01, 0.02)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.04)	(0.00, 0.00, 0.00)	(0.02, 0.02, 0.04)	(0.02, 0.02, 0.04)	(0.00, 0.01, 0.02)	(0.00, 0.01, 0.02)	(0.00, 0.01, 0.02)
FL	(0.02, 0.04, 0.04)	(0.04, 0.06, 0.06)	(0.02, 0.04, 0.04)	(0.04, 0.06, 0.06)	(0.02, 0.04, 0.04)	(0.01, 0.02, 0.02)	(0.02, 0.04, 0.04)	(0.01, 0.02, 0.02)	(0.06, 0.06, 0.07)	(0.04, 0.06, 0.06)	(0.00, 0.00, 0.00)	(0.00, 0.01, 0.02)	(0.00, 0.01, 0.02)	(0.04, 0.06, 0.07)	(0.00, 0.01, 0.02)
ID	(0.06, 0.07, 0.07)	(0.02, 0.04, 0.08)	(0.07, 0.08, 0.08)	(0.04, 0.06, 0.06)	(0.01, 0.02, 0.02)	(0.04, 0.06, 0.06)	(0.02, 0.04, 0.04)	(0.04, 0.06, 0.06)	(0.01, 0.02, 0.02)	(0.01, 0.02, 0.02)	(0.01, 0.02, 0.02)	(0.00, 0.00, 0.00)	(0.06, 0.07, 0.07)	(0.01, 0.02, 0.02)	(0.01, 0.02, 0.02)
DT	(0.02, 0.04, 0.04)	(0.02, 0.04, 0.04)	(0.00, 0.01, 0.02)	(0.02, 0.04, 0.06)	(0.00, 0.01, 0.02)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.04)	(0.02, 0.04, 0.04)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.00, 0.01, 0.02)	(0.00, 0.01, 0.02)	(0.00, 0.01, 0.02)
AP	(0.04, 0.06, 0.06)	(0.04, 0.06, 0.06)	(0.04, 0.06, 0.06)	(0.04, 0.06, 0.06)	(0.02, 0.04, 0.04)	(0.02, 0.04, 0.04)	(0.02, 0.04, 0.04)	(0.04, 0.06, 0.06)	(0.01, 0.02, 0.02)	(0.01, 0.02, 0.02)	(0.02, 0.04, 0.04)	(0.01, 0.02, 0.02)	(0.02, 0.04, 0.04)	(0.00, 0.00, 0.00)	(0.01, 0.02, 0.02)
CI	(0.02, 0.04, 0.04)	(0.06, 0.07, 0.08)	(0.02, 0.04, 0.04)	(0.02, 0.04, 0.04)	(0.02, 0.04, 0.06)	(0.00, 0.02, 0.02)	(0.02, 0.04, 0.04)	(0.00, 0.02, 0.02)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.04)	(0.02, 0.04, 0.06)	(0.00, 0.01, 0.02)	(0.00, 0.01, 0.02)	(0.02, 0.04, 0.04)	(0.00, 0.00, 0.00)

Step 5: The fuzzy total-relation matrix was calculated using Equation (4), as shown in Table 10.

Table 10. Fuzzy total-relation matrix.

	SO	BI	IT	IN	ST	PO	BT	UF	BS	TS	FL	ID	DT	AP	CI
SO	(0.02, 0.06, 0.16)	(0.06, 0.11, 0.22)	(0.06, 0.10, 0.21)	(0.07, 0.12, 0.23)	(0.03, 0.07, 0.17)	(0.07, 0.12, 0.22)	(0.07, 0.12, 0.22)	(0.07, 0.12, 0.22)	(0.03, 0.06, 0.16)	(0.07, 0.11, 0.20)	(0.07, 0.12, 0.22)	(0.07, 0.12, 0.21)	(0.05, 0.09, 0.20)	(0.05, 0.09, 0.19)	(0.07, 0.12, 0.21)
BI	(0.05, 0.09, 0.21)	(0.02, 0.05, 0.15)	(0.05, 0.10, 0.21)	(0.06, 0.10, 0.22)	(0.05, 0.09, 0.20)	(0.05, 0.10, 0.21)	(0.07, 0.12, 0.22)	(0.07, 0.11, 0.21)	(0.04, 0.08, 0.17)	(0.05, 0.09, 0.18)	(0.05, 0.10, 0.20)	(0.07, 0.11, 0.21)	(0.04, 0.08, 0.18)	(0.03, 0.07, 0.17)	(0.05, 0.10, 0.20)
IT	(0.04, 0.09, 0.19)	(0.04, 0.08, 0.19)	(0.01, 0.04, 0.12)	(0.04, 0.08, 0.19)	(0.05, 0.09, 0.18)	(0.04, 0.08, 0.20)	(0.05, 0.09, 0.20)	(0.05, 0.09, 0.19)	(0.03, 0.07, 0.16)	(0.03, 0.07, 0.16)	(0.04, 0.08, 0.18)	(0.05, 0.09, 0.19)	(0.03, 0.07, 0.17)	(0.03, 0.07, 0.16)	(0.05, 0.09, 0.19)
IN	(0.04, 0.08, 0.18)	(0.04, 0.08, 0.17)	(0.03, 0.07, 0.17)	(0.01, 0.04, 0.12)	(0.03, 0.06, 0.15)	(0.03, 0.06, 0.15)	(0.04, 0.07, 0.17)	(0.03, 0.06, 0.16)	(0.03, 0.06, 0.15)	(0.02, 0.05, 0.13)	(0.03, 0.06, 0.15)	(0.05, 0.09, 0.18)	(0.03, 0.06, 0.16)	(0.03, 0.06, 0.15)	(0.05, 0.09, 0.18)
ST	(0.05, 0.09, 0.18)	(0.03, 0.07, 0.17)	(0.03, 0.07, 0.16)	(0.05, 0.09, 0.18)	(0.01, 0.03, 0.10)	(0.03, 0.06, 0.14)	(0.04, 0.07, 0.16)	(0.03, 0.07, 0.16)	(0.02, 0.05, 0.13)	(0.02, 0.05, 0.13)	(0.01, 0.04, 0.13)	(0.03, 0.07, 0.16)	(0.02, 0.05, 0.13)	(0.02, 0.05, 0.13)	(0.03, 0.07, 0.16)
PO	(0.05, 0.09, 0.18)	(0.03, 0.07, 0.16)	(0.03, 0.07, 0.15)	(0.03, 0.07, 0.16)	(0.02, 0.05, 0.13)	(0.01, 0.03, 0.10)	(0.03, 0.06, 0.14)	(0.03, 0.07, 0.15)	(0.02, 0.05, 0.13)	(0.02, 0.05, 0.12)	(0.03, 0.07, 0.15)	(0.03, 0.07, 0.14)	(0.01, 0.04, 0.11)	(0.02, 0.05, 0.13)	(0.03, 0.07, 0.14)
BT	(0.06, 0.10, 0.17)	(0.03, 0.05, 0.14)	(0.02, 0.05, 0.13)	(0.03, 0.05, 0.14)	(0.01, 0.03, 0.11)	(0.03, 0.07, 0.14)	(0.01, 0.03, 0.09)	(0.01, 0.03, 0.11)	(0.01, 0.03, 0.10)	(0.02, 0.05, 0.12)	(0.03, 0.05, 0.13)	(0.03, 0.07, 0.14)	(0.03, 0.06, 0.14)	(0.02, 0.04, 0.12)	(0.02, 0.05, 0.13)
UF	(0.06, 0.09, 0.16)	(0.01, 0.03, 0.11)	(0.01, 0.03, 0.10)	(0.01, 0.03, 0.11)	(0.04, 0.07, 0.14)	(0.03, 0.06, 0.13)	(0.02, 0.05, 0.12)	(0.01, 0.03, 0.08)	(0.00, 0.02, 0.09)	(0.01, 0.03, 0.09)	(0.02, 0.04, 0.12)	(0.01, 0.03, 0.10)	(0.01, 0.03, 0.09)	(0.01, 0.03, 0.09)	(0.01, 0.03, 0.10)
BS	(0.01, 0.04, 0.13)	(0.06, 0.10, 0.18)	(0.03, 0.07, 0.15)	(0.03, 0.05, 0.14)	(0.03, 0.06, 0.14)	(0.02, 0.05, 0.13)	(0.03, 0.07, 0.15)	(0.01, 0.03, 0.12)	(0.01, 0.03, 0.09)	(0.01, 0.03, 0.11)	(0.05, 0.08, 0.16)	(0.01, 0.04, 0.12)	(0.03, 0.06, 0.14)	(0.01, 0.03, 0.11)	(0.05, 0.08, 0.16)
TS	(0.01, 0.03, 0.11)	(0.02, 0.05, 0.12)	(0.01, 0.03, 0.10)	(0.03, 0.06, 0.14)	(0.02, 0.04, 0.11)	(0.04, 0.07, 0.15)	(0.03, 0.06, 0.14)	(0.02, 0.04, 0.12)	(0.02, 0.04, 0.11)	(0.00, 0.02, 0.07)	(0.02, 0.04, 0.12)	(0.02, 0.04, 0.12)	(0.00, 0.02, 0.10)	(0.00, 0.02, 0.09)	(0.01, 0.03, 0.10)
FL	(0.02, 0.05, 0.13)	(0.03, 0.07, 0.15)	(0.02, 0.05, 0.13)	(0.03, 0.07, 0.15)	(0.02, 0.04, 0.12)	(0.01, 0.03, 0.11)	(0.02, 0.04, 0.13)	(0.01, 0.03, 0.11)	(0.04, 0.07, 0.15)	(0.02, 0.04, 0.11)	(0.01, 0.03, 0.09)	(0.01, 0.03, 0.11)	(0.01, 0.03, 0.10)	(0.04, 0.07, 0.14)	(0.02, 0.05, 0.13)
ID	(0.05, 0.09, 0.17)	(0.02, 0.05, 0.14)	(0.06, 0.09, 0.17)	(0.03, 0.07, 0.15)	(0.01, 0.03, 0.11)	(0.03, 0.07, 0.15)	(0.03, 0.05, 0.14)	(0.03, 0.07, 0.15)	(0.01, 0.03, 0.11)	(0.01, 0.03, 0.10)	(0.01, 0.04, 0.12)	(0.01, 0.03, 0.09)	(0.05, 0.08, 0.15)	(0.01, 0.03, 0.10)	(0.01, 0.04, 0.12)

Table 10. Cont.

	SO	BI	IT	IN	ST	PO	BT	UF	BS	TS	FL	ID	DT	AP	CI
DT	(0.02, 0.05, 0.13)	(0.02, 0.05, 0.12)	(0.01, 0.03, 0.10)	(0.03, 0.06, 0.14)	(0.01, 0.03, 0.10)	(0.02, 0.04, 0.12)	(0.01, 0.03, 0.11)	(0.02, 0.04, 0.12)	(0.02, 0.04, 0.11)	(0.02, 0.04, 0.11)	(0.03, 0.06, 0.13)	(0.03, 0.06, 0.13)	(0.00, 0.02, 0.07)	(0.00, 0.02, 0.09)	(0.02, 0.04, 0.12)
AP	(0.03, 0.07, 0.15)	(0.03, 0.06, 0.15)	(0.03, 0.06, 0.14)	(0.03, 0.07, 0.15)	(0.02, 0.05, 0.12)	(0.02, 0.05, 0.13)	(0.02, 0.05, 0.13)	(0.03, 0.06, 0.14)	(0.01, 0.03, 0.10)	(0.01, 0.03, 0.10)	(0.02, 0.05, 0.13)	(0.01, 0.03, 0.11)	(0.02, 0.04, 0.12)	(0.01, 0.02, 0.08)	(0.01, 0.03, 0.11)
CI	(0.02, 0.05, 0.14)	(0.06, 0.10, 0.17)	(0.02, 0.05, 0.13)	(0.03, 0.05, 0.14)	(0.03, 0.06, 0.14)	(0.01, 0.03, 0.11)	(0.03, 0.05, 0.13)	(0.01, 0.03, 0.11)	(0.05, 0.08, 0.15)	(0.02, 0.04, 0.12)	(0.03, 0.07, 0.14)	(0.01, 0.03, 0.11)	(0.01, 0.03, 0.11)	(0.02, 0.03, 0.12)	(0.01, 0.03, 0.09)

Step 6: The crisp total-relation matrix was generated by defuzzifying the fuzzy total-relation matrix into crisp values, using the CSFS method (Equations (8)–(14)), as shown in Table 11.

Table 11. Crisp total-relation matrix.

	SO	BI	IT	IN	ST	PO	BT	UF	BS	TS	FL	ID	DT	AP	CI
SO	0.07	0.12	0.11	0.13	0.08	0.13	0.13	0.13	0.08	0.12	0.13	0.13	0.10	0.10	0.12
BI	0.11	0.00	0.11	0.12	0.11	0.11	0.13	0.12	0.09	0.10	0.11	0.12	0.09	0.09	0.11
IT	0.10	0.09	0.00	0.10	0.10	0.09	0.11	0.10	0.08	0.08	0.09	0.10	0.08	0.08	0.10
IN	0.09	0.09	0.09	0.00	0.08	0.07	0.09	0.08	0.08	0.00	0.07	0.10	0.08	0.08	0.10
ST	0.10	0.09	0.08	0.10	0.00	0.00	0.09	0.08	0.00	0.00	0.00	0.08	0.00	0.00	0.08
PO	0.10	0.08	0.08	0.08	0.00	0.00	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.00	0.00
BT	0.11	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.08	0.07	0.00	0.00
UF	0.10	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BS	0.00	0.11	0.08	0.00	0.08	0.00	0.08	0.00	0.00	0.00	0.09	0.00	0.07	0.00	0.09
TS	0.00	0.00	0.00	0.07	0.00	0.08	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FL	0.00	0.08	0.00	0.08	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.08	0.00
ID	0.10	0.00	0.10	0.08	0.00	0.08	0.00	0.08	0.00	0.00	0.00	0.00	0.09	0.00	0.00
DT	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AP	0.08	0.08	0.07	0.08	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CI	0.00	0.11	0.00	0.00	0.07	0.00	0.00	0.00	0.08	0.00	0.08	0.00	0.00	0.00	0.00

Step 7: The crisp values of all factors were calculated using Equations (15) and (16). Subsequently, $B + Q$ and $B - Q$ were computed using Equations (5) and (6), where $B - Q$ depicts the net effects contributing to the entire system by a particular factor and $B + Q$ depicts the degree of the factor's importance in the system. The final result is tabulated as shown in Table 12.

Table 12. Crisp values of CSFs.

	Q	B	B + Q	B - Q
Software Functionality (SO)	1.227	1.675	2.901	0.448
BIM adoption strategies and process (BI)	1.188	1.557	2.744	0.369
Interoperability (IT)	1.079	1.352	2.431	0.273
Initial cost of software (IN)	1.197	1.196	2.393	-0.001
Staff competencies (ST)	0.989	1.107	2.096	0.119
Popularity (PO)	1.08	1.022	2.102	-0.059
BIM software awareness (BT)	1.14	0.922	2.062	-0.218
User friendliness (UF)	1.076	0.736	1.812	-0.34
BIM standard, codes, rules and regulations (BS)	0.893	1	1.893	0.107
Technical service support (TS)	0.873	0.768	1.641	-0.106
Flexibility to change the workflow and business model (FL)	1.079	0.881	1.96	-0.198
Innovation and research development capabilities (ID)	1.054	0.956	2.009	-0.098
Data security and privacy protocols (DT)	0.927	0.772	1.7	-0.155
Application integration/extension (API) capabilities (AP)	0.875	0.865	1.74	-0.011
Co-operation from other industry partners (CI)	1.055	0.925	1.979	-0.13

Step 8: Lastly, the cause-effect diagram was developed, as shown in Figure 3. The coordinate system helps to determine the position and inter-relationship of each factor with points in the coordinate system ($B + Q$, $B - Q$).

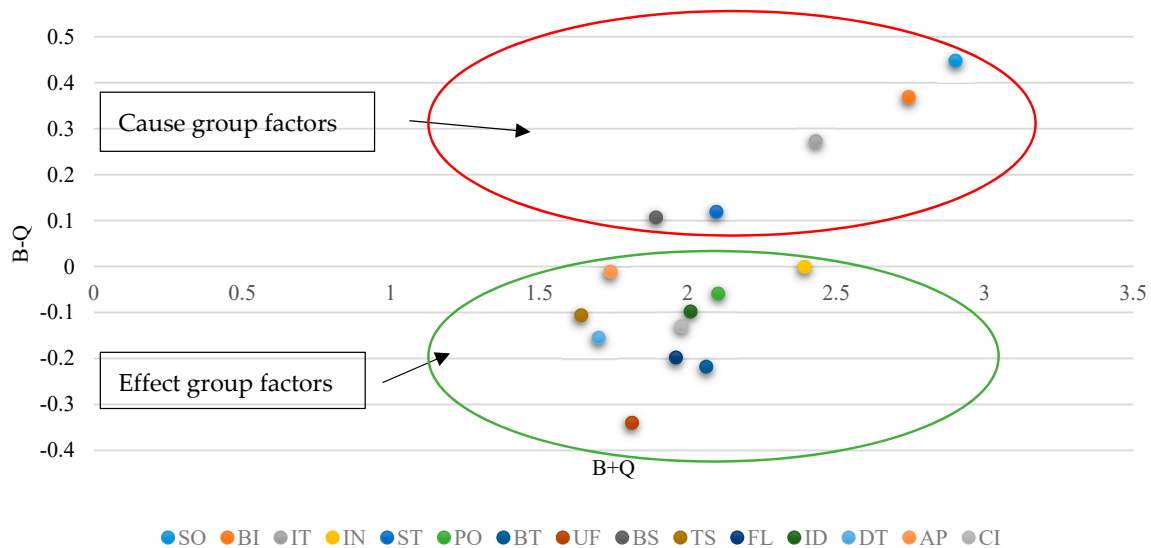


Figure 3. Cause-effect diagram.

3.3. Strategy Diagram

This research study identifies critical success factors for mapping the organization approach with a strategy map for cause and effects groups. As shown in Figure 4, the strategy map represents a causal relationship among critical factors of BIM software selection based on Table 12. In the strategy map, a total of fifteen factors is shown with circles, where the importance value of factors, $B + Q$, is represented with the line thickness of each circle. The thick line and thin line of the circle depicts $B + Q \geq 2.07$ and $B + Q < 2.07$, respectively. Furthermore, arrows are drawn from more influential factors to other factors to show the interrelationship between factors based on the influence of causes to effects. The arrow illustrates the influence based on the value of $B - Q$ in Table 12. The outgoing arrows from the node are drawn when $B - Q \geq 0.1$ and when $B - Q < 0.1$ is represented by incoming arrows. Hence, the direction of the arrow demonstrates the influence of the specified factor towards other factors, and its thickness shows the strength of the influence.

In the strategy map, cause factors are highlighted with a purple colour, and the effect factors are denoted by the white-coloured circle nodes. The thickness of the circle's boundary represents the significance of each selection factor. The selection factors with numerous interactive arrows in the strategy map imply that each selection factor shows a frequent interactive relation with the other selection factors.

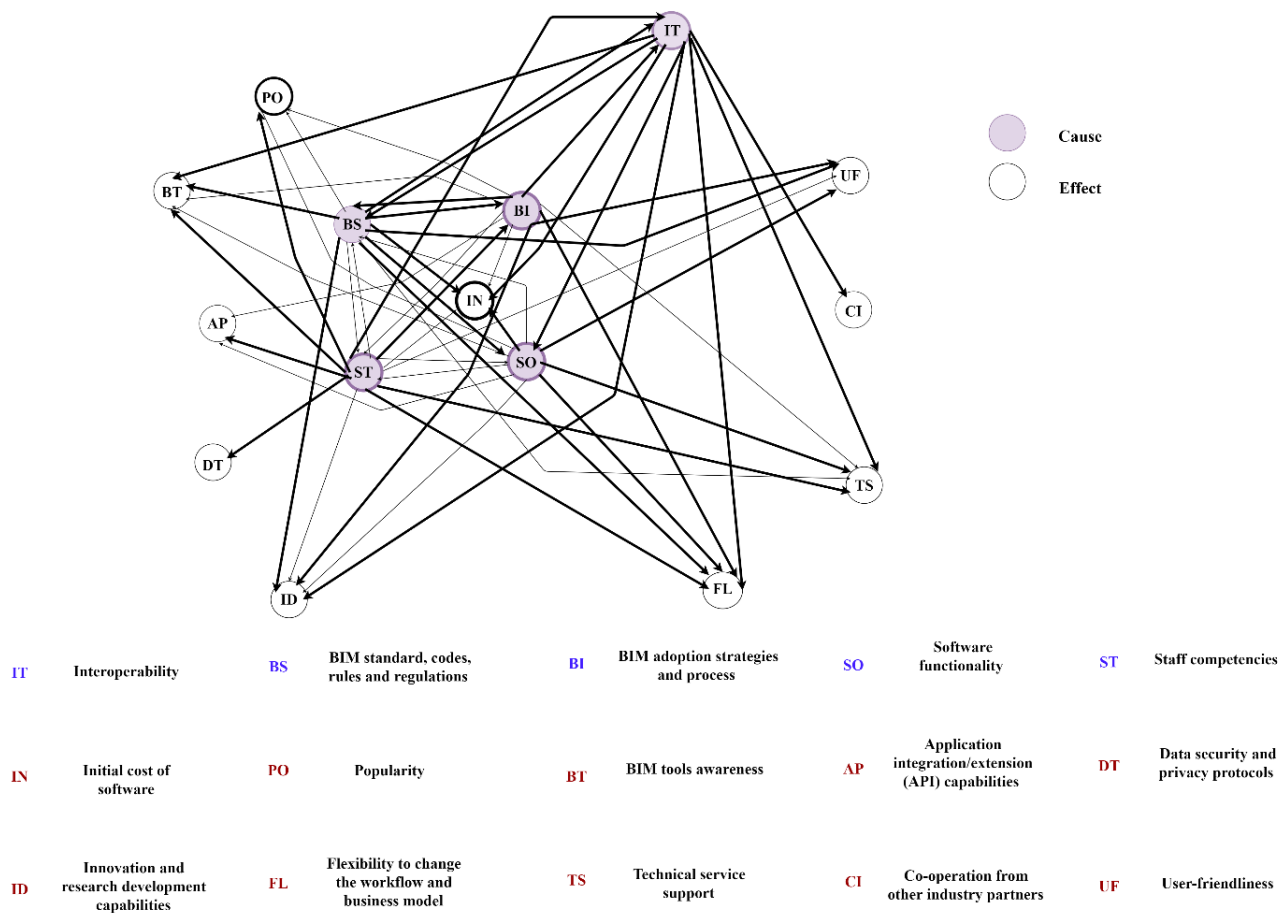


Figure 4. Strategy diagram for BIM software selection.

4. Discussion

Discussion of the result is briefed into two parts: (1) discussion on findings, (2) managerial implications.

4.1. Discussion On Key Findings

According to the cause-effect diagram, software functionality (SO), BIM adoption strategies and process (BI), interoperability (IT), staff competencies (ST), and BIM standard and regional regulations (BS) are bifurcated as cause group factors. In contrast, Initial software costing (IN), popularity and reputation (PO), BIM software awareness (BT), user-friendliness (UF), vendor service support (TS), flexibility to change the workflow and business model (FL), innovation and research development capabilities (ID), data security and privacy protocols (DT), integration/extension (API) capabilities (AP), and multi-stakeholder BIM collaboration (CI) are bifurcated as the effect group factors. As the cause group factors have an influence on the effect group factors, their degree of importance is greater and should be given more consideration. Hence, any change or modification in the cause group factors can have a significant impact on the effect group factors, as well.

The most critical selection factor is revealed as software functionality (SO) with the highest value of $(B + Q)$ 2.901 and $(B - Q)$ 0.448, which shows its prominent impact and influence, respectively. As interpreted from the strategy map, selection factor, software functionality (SO) has a significant influence on factors, vendor service support (TS), flexibility to change the workflow and business model (FL), user-friendliness (UF), and initial software costing (IN). On the other side, it has a low influence on factors such as innovation and research development capabilities (ID), integration/extension (API) capabilities (AP), staff competencies (ST), and awareness of BIM software (BT), popularity

and reputation (PO), and BIM standard and regional regulations (BS). This result suggests that BIM user companies should significantly emphasize functionalities and features of the software, considering the wide range of BIM applications in the AEC industry. Software functionality includes attributes such as design functions, analysis functions, modelling functions in reference to Level of Details (LOD) and BIM levels as its integral parts. The BIM adoption strategies and process (BI) received the second rank for BIM software selection with the value of $(B + Q)$ 2.744 and $(B - Q)$ 0.369. As per the strategy map, selection factor BIM adoption strategies and process (BI) has a prominent influence on factors of BIM standard and regional regulations (BS), interoperability (IT), flexibility to change the workflow and business model (FL), user-friendliness (UF), and innovation and research development capabilities (ID). BIM adoption strategy helps the organization to significantly modify the roles of project team members, the workflow of project execution, document management, coordination method, and deliverables [1,8]. Subsequently, the third position is obtained by interoperability (IT), having the value of $(B + Q)$ 2.431 and $(B - Q)$ and 1.079, respectively. As evident from the strategy map, the selection factor interoperability (IT) has a noticeable influence on factors such as multi-stakeholder BIM collaboration (CI), vendor service support (TS), flexibility to change the workflow & business model (FL), innovation & research development capabilities (ID), software functionality (SO), initial software costing (IN), BIM standard and regional regulations (BS), and BIM software awareness (BT). This is echoed by research findings that says a lack of interoperability is the key barrier for BIM adoption in AEC companies [52,53]. BIM software should be greatly determined by its capacity to create seamless interoperability among project stakeholders with various BIM software. The initial cost of BIM software (IN) is found as the fourth important factor of BIM software selection, receiving the value of $(B + Q)$ 2.393 and $(B - Q)$ -0.001 , respectively. The strategy map also confirms that although it is a significant factor, it has negligible influence on the other factors. The initial cost of BIM software is a quite important consideration factor for any naïve BIM user companies because they need to make a BIM implementation strategy based on the rate of return, enhancement of productivity rates through BIM, budget planning of the company, and time duration of software usage [54]. Staff competencies (ST) is identified as the fifth most important factor. The resulted values of $B + Q$ and $B - Q$ were identified as 2.096 and 0.119, respectively. The cost and time of BIM software training is the major aspect of BIM software selection [39,54]. The right selection of BIM software can significantly improve the rate of return on investment in staff training and software costs. Thus, the existing staff competencies should be considered significantly to achieve an efficient BIM software selection process.

4.2. Managerial Implications from Findings of Research Study

The findings of the study can lead to different managerial implications for BIM user organizations. This study helps BIM user organizations by revealing the most crucial CSFs for BIM software selection. This study identified 26 CSFs as important factors for BIM software selection, and it educates companies regarding the complexity associated with the decision making of the BIM software selection process. The resulting cause and effect diagram and strategy map can be applied to assess and choose BIM software. It also allows BIM user organizations to identify the existing contextual relationships between different CSFs. This study directs BIM user organizations to recognize the weaker and stronger performance areas of BIM software in reference to the identified CSFs. BIM user organizations can motivate BIM software vendors to improve their low-performance areas with recommendations. From the result of this study, BIM software vendors can also develop long-term strategic plans to increase their market reach. Thus, the strategy diagram guides BIM user organizations as well as BIM software vendors as to which CSFs require more attention to enhance the efficiency of BIM adoption in AEC industries.

5. Conclusions

This research study presented a novel approach for analyzing BIM software selection factors by using the FCM and Fuzzy DEMATEL methods. Initially, a total of twenty-six success factors were identified and categorized into major four groups, (1) technical, (2) cost, (3) management, and (4) vendor, through a systematic literature review. The factor comparison method was adopted as a funnel process to rank CSFs based on priority, and then the top fifteen CSFs were analyzed with the Fuzzy DEMATEL method to generate a cause-effect diagram for revealing interrelationship. The cause-effect diagram categorized five CSFs into the cause group and ten CSFs into the effect group. The result of this study depicted that decision-makers should give more consideration to software functionality, BIM adoption strategies and process, interoperability, staff competencies (skills, knowledge, experience), and BIM standard and regional regulations, as these cause factors have a large influence on the other factors from the effect group, i.e., software costing, popularity and reputation, familiarity and awareness of BIM software, user-friendliness, vendor service support, flexibility to change the workflow and business model, innovation and research development capabilities, data security and privacy protocols, application integration/extension (API) capabilities, and multi-stakeholder BIM collaboration. The research findings showed that software functionality has the greatest influence among all other factors and is perceived to be the source of influence. The software with the best “software functionality” consists of the functions of all the levels of details ranging from LOD 100–500 and possesses the compatibility to work in CDE (common data environment) for all the “levels” ranging from levels 1 to 3. The BIM software with the best software functionality might have better popularity and reputation, familiarity and awareness, user-friendliness, service support, innovation and research development capabilities, data security and privacy protocols, application integration/extension potential, multi-stakeholder BIM collaboration and competitive costing. Surprisingly, the initial cost factor was revealed as the fourth important factor, but it has a smaller influence value. Therefore, it can be interpreted that cost is an important factor, but it has less driving significance on the other factors of BIM software selection. This research study provided a checklist with the priority of factors that requires significant focus for BIM software selection. The resulted strategic map could be used as a visualization tool to select BIM software in line with the requirements of organizations. The result offers a logical base to deepen the understanding for selecting efficient and effective BIM software. The proposed approach/method may be proven to be more effective and efficient as compared to the conventional approaches because it reveals the interrelationships between the CSFs and the intensity of their effects on each other.

6. Limitation of Study

This research study relies on a knowledge-based approach, which is subjective to the knowledge and perception of respondents. It may be biased and arguable. The analysis of success factors with Fuzzy DEMATEL is not comprehensive, and response evaluation becomes practically challenging with the increase in the number of factors. It is suggested that future study be carried out to develop a knowledge-based software selection model to identify the optimal BIM software depending on the requirements and constraints of the company based on the identified success factors from this study.

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