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A Phase-Based Roadmap for Proliferating BIM within the Construction Sector Using DEMATEL Technique: Perspectives from Egyptian Practitioners

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Abstract: Building Information Modelling (BIM) has not been sufficiently proliferated in the developing construction communities. This is owing to the lack of incorporating the key success factors (KSFs) of BIM implementation in a phase-based roadmap to support implementing BIM in practice on a step-by-step approach. With this in mind, this work aims at (1) defining the KSFs for implementing BIM within the developing economies' socio-economic environment, (2) investigating the interrelationships among the KSFs, and (3) establishing the KSFs in a phased approach to devise a roadmap for their implementation on a step-by-step basis. First, 18 KSFs for implementing BIM have been specified by systematically investigating the pertinent literature and interviewing six well-qualified practitioners in BIM from Egypt, as a developing country. Second, from ten Egyptian BIM experts, data on the influences of the KSFs on each other have been gathered, employing a matrix format-based questionnaire. Third, the experts' evaluations have been processed, utilizing the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique. Proficiently, DEMATEL through its causal diagram portrayed the cause-and-effect relations map of the KSFs. Besides, it divided the KSFs into four clusters, each of which signifies a phase in the BIM implementation journey along with its corresponding priority as well as the priorities of the KSFs that it encompasses. The causal diagram indicated that phase one related KSFs of the BIM implementation journey: research and development investments, senior management support, and firm's fiscal support contribute to the whole success of the developed BIM implementation roadmap. This study equips construction practitioners in the developing economies with a four-phased roadmap for applying the KSFs of BIM implementation journey in practice on a step-by-step basis. This contribution helps in better prioritizing their decisions and optimizing the allocation of their resources when applying BIM in their business. Hence, at a fast pace, BIM can be proliferated in those countries.

Keywords: key success factors (KSFs); Building Information Modelling (BIM); construction; roadmap; decision-making trial and evaluation laboratory (DEMATEL)

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1. Introduction and Theoretical Background

Over the past few decades, Building Information Modeling (BIM) has been emerging in the construction industry as a chief technological shift for professionally supporting the management of this vital sector's projects [1]. This is attributed to its intelligent physical dimensions, which have been created to process and visualize the inputs and outputs of the project information within a single inclusive model [2,3]. This includes the representation of the drawings and designs in a three-dimensional model (third-dimension), scheduling (fourth-dimension), costs (fifth-dimension), sustainability (sixth-dimension), facility management (seventh-dimension), and safety (eighth-dimension) [2,4]. Across the world, several serious initiatives, especially from the developed construction markets have been focused on embedding BIM in their projects. In the United States, the projects of Walt Disney Concert Hall, Washington National Park, and the Museum of Pop Culture at Seattle Center have been accomplished utilizing BIM technology [5]. Additionally, various projects in France, Germany, Finland, Australia, Norway, Sweden, and Singapore have been realized by employing this technology [6]. In the same vein, other initiatives have been launched from some developing countries, which are characterized by the robustness of their construction markets globally. These encompass the projects of World Expo Pavilion and the World Expo Cultural Center in Shanghai-China [5] and the projects of Aquarium Hilton Garden Inn, Savannah State University, and the Mansion on Peachtree in Georgia [7].

In view of these initiatives, numerous success stories have been written to document BIM value in these projects. This is not only ascribed to the smooth progress and the successful achievement of the projects [5,6], but further, the tangible savings realized from implementing BIM in relation to the projects stakeholders' permanent challenges, i.e., time and cost. Instances of these savings are what have been noticed in the project of Aquarium Hilton Garden Inn in Atlanta-Georgia, where the cost and schedule savings are $200,000 and 1143 hours, respectively, compared to BIM implementation cost of $90,000 [7]. Relying upon these tangible successes, the policymakers in many construction markets worldwide have ascertained that BIM is their future tendency [8]. Backing this approach, the academics started to work in leaps and bounds in several research trends to incorporate BIM in the construction sector. Among these trends are defining the key success factors (KSFs) for implementing BIM and structuring them in a phased approach to provide a roadmap for their implementation on a step-by-step basis. According to Ma et al. [3], this is a highly needed investigation because BIM is a modern technology, and its implementation requires considerable investments in staff, technology, and training [9]. Further, the impacts of implementing BIM can extend to make changes and updates in the existing codes, legislations, and regulations of the construction markets [10]. Definitely, such requirements will collide with the financial agenda of the policymakers, whether they belong to the public or the private construction sector. However, identifying the KSFs of BIM implementation, specifically in a stepwise-based structure allows the policymakers to systemically and progressively allocate their managerial and financial resources to fulfill their KSFs [1,11].

Appreciating the aforementioned significance, the scholarly-based knowledge has been enriched with the literature of Table A1 (see Appendix A). The criteria used for considering these studies in the existing research will be illustrated later in the "Defining the KSFs of BIM Implementation" section. By taking a deep insight at these works in terms of the publication year, target country, scope, and analyzing tools, the next facts can be concluded. Concerning the publication year and the target country, the studies continue to rise year to year, especially from 2018 to 2020, whether in the developing or the developed economies. This implies that with time, the consciousness of the academics and construction practitioners concerning the significance of exploring the KSFs of BIM implementation has been increased, and more investigations will emerge in the future. On the other hand, regarding these literature scopes, the 44 studies of Table A1 can be classified into (a) 16 studies (marked with *) focused their scopes entirely on exploring the KSFs building on the expertise of their countries' experts, (b) 18 researches (labeled with **) allocated an objective for the KSFs among their scopes and investigated them according to their surveyed experts' practical knowledge, (c) 4 studies (marked with ***) examined the KSFs in a theoretical framework relying upon the analyses of prior literature, and (d) 6 researches (labeled with ****) set the KSFs among their goals; however, their investigations have been based on the subjective perspectives of their authors, not on the surveying of the experts' knowledge. Indeed, reviewing the scopes related to the literature on the KSFs of BIM implementation informs that this area is at the early phase since its publications number (i.e., 44) is too small compared to those of the other construction management's themes.

Focusing on the analyzing tools of the studies of Table A1, it can be extracted that the academics' contributions have been built on (a) the conventional tools of the Relative Importance Index (RII) (e.g., [12]), the proportion of choices by the respondents (e.g., [13]), and the Mean Score (MS) (e.g., [14]) for deriving the KSFs ranking, (b) utilizing a previously suggested cutoff point (e.g., [15]) or a normalized benchmarked value (e.g., [3]) to distinguish between the SFs and the KSFs, (c) the Exploratory Factor Analysis (EFA) (e.g., [16]) and the Principal Competent Analysis (PCA) (e.g., [17]) for defining the fundamental dimensions of the KSFs, and (d) the Interpretive Structural Modelling (ISM) (i.e., [18]), Structural Equation Modelling (SEM) (i.e., [17]), and DEMATEL (i.e., [19]) for grasping the interrelationships, either among the KSFs or their underlying dimensions. Worth mentioning is that despite the diversity in the utilized techniques for analyzing the KSFs, the nontraditional analytical techniques of EFA, PCA, ISM, SEM, and DEMATEL are with considerable limited utilization among the academics. Correspondingly, the conventional procedure of MS with a suggested cutoff point or a normalized benchmarked value is the mainstream methodology for investigating the KSFs. The broad utilization of this traditional approach stems from its simplicity, which helps the academics to quickly define the KSFs for implementing BIM in their construction markets. However, this approach has a severe drawback on realizing a comprehensive understanding of the KSFs in terms of their underlying dimensions and their interrelationships, which are the core of investigating the KSFs of BIM implementation on a step-by-step basis [18].

In light of this background, it can be mentioned that the literature associated with the KSFs for implementing BIM has three limitations. First, the majority of the archival works of Table A1 have been focused on exploring the KSFs of BIM on a non-stage basis. This is owing to the academics' major dependency on using MS with a suggested cutoff point or a normalized benchmarked value for identifying the KSFs, which finally leads them to consider approximately half of the studied factors as KSFs [1]. This, in turn, means that if the firms want to apply BIM in their activities, they have to implement all the KSFs concurrently. More critically, these firms' senior managers have to provide considerable investments simultaneously to activate the functions of the suggested KSFs for implementing BIM in their works. Indeed, this in view of the senior management of the firms, particularly those who are characterized by constrained resources is not realistic for the application at all [1,11]. Unfortunately, this may make the firms' senior management decide to not think about applying BIM in their business. Second, other literature, i.e., Ma et al. [18] and Qin et al. [19], whose analyses have been built on analytical techniques that can identify the KSFs on a step-by-step basis including the ISM and DEMATEL, respectively, were directed to study specific categories of the SFs. Accordingly, their frameworks are not representative of all the impacting KSFs for comprehensively drawing up their construction markets' BIM implementation roadmap. Third, although nearly all the researches of Table A1 are in the developing countries' socio-economic context, their devoted efforts failed to sufficiently proliferate BIM in those countries [19].

Having touched on the gaps in the literature of the KSFs of BIM implementation, this study contributes to addressing them by (1) exploring the KSFs for implementing BIM in the developing nations, (2) investigating the interrelationships among the KSFs to portray their causal relations map, and (3) establishing the KSFs in a phased approach to devise a roadmap for their implementation on a step-by-step basis. The knowledge gained from these objectives will actively contribute to the widening of the deployment of BIM in the developing construction markets and embedding its mature use among their organizations. This is because the KSFs of BIM in this paper will be presented in a stepwise-based structure. This is the desired approach for implementing BIM in practice [3]. For realizing this contribution, an initial list of the KSFs has been extracted from the literature of Table A1; and then, through interviews, the KSFs have been validated within the context of Egypt, as a developing country. In the same context, the KSFs have been subjected to a questionnaire-based survey for collecting the data of this study. In this research, additionally, DEMATEL has been employed as the major analyzing tool. Selecting DEMATEL is owing to the ability of its causal diagram to specify and draw the interrelations among the research factors. In addition, this diagram can divide the research field factors into four consecutive groups, each of which corresponds to the field that it represents, its corresponding priority, as well as the priorities of the factors that it comprises [5,20].

2. Research Methodology

Focusing on achieving the aforementioned objectives, this research's methodology has consisted of three pivots. First, a profound content analysis of the literature on the KSFs for implementing BIM, along with interviews with highly experienced Egyptian BIM specialists, has been conducted to generate a comprehensive and valid list of the KSFs. Second, a matrix format-based questionnaire according to the procedures of DEMATEL has been designed and sent to the experts of BIM in Egypt for appraising the influence of each KSF on the other KSFs. Third, the evaluations of BIM experts have been processed relying upon the analysis of DEMATEL to reveal the interrelations among the KSFs and structure the KSFs in a phased approach to support implementing BIM in practice on a step-by-step basis. Figure 1 illustrates a flowchart for showing the sequences of these three pivots to attain the goals of the current paper. Further, the details of the methodology and the utilized research methods in these three pivots are presented under the following three subheadings.

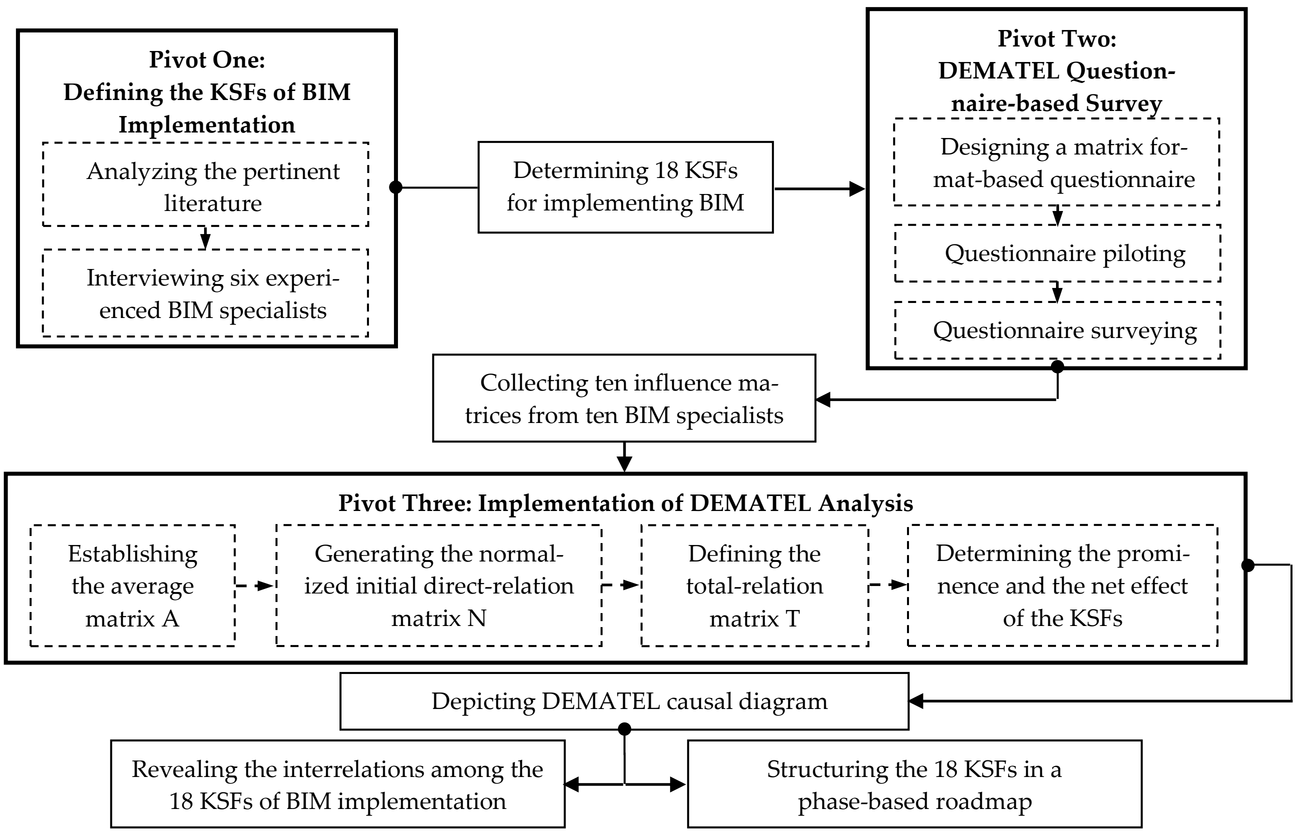

Figure 1. Pivots of the research methodology.

2.1. Defining the KSFs of BIM Implementation

In this paper, a systematic plan of six steps has been drawn up to define the KSFs of BIM implementation. This plan is a mixture of the prior academics' expertise, and its two central pivots are (a) content analysis of the associated literature to compose an initial list of the KSFs and (b) discussing the initial list with subject matter practitioners (SMPs) to validate the appropriateness and comprehensiveness of its KSFs [9,16]. The steps of the pivots of this plan are as follows:

2.1.1. Step 1: Setting a Definition of the KSFs of BIM Implementation

This initial step is crucial, and its implication on the accuracy of identifying the KSFs is important. This stems from the fact that some of the KSFs of BIM implementation-related works have the title "critical or key success factors for implementing or adopting BIM"; however, a number of their KSFs are BIM implementation returns and benefits. In other words, they consider the KSFs as motivation factors that attract the construction stakeholders' attention toward BIM (e.g., [21,22]). Emphatically, as the conceptualization of the KSFs of BIM implementation is inaccurate, its based-derived factors are imprecise in providing the policymakers with the necessary activities of their BIM implementation roadmap. For avoiding such result, this research's KSFs of BIM implementations are "drivers/enablers whose existence results in success, and their absence causes failure regarding adopting and implementing BIM in the construction community" [14].

2.1.2. Step 2: Specifying the Utilized Keywords to Search the Databases

Relying upon the aforementioned definition of the KSFs, the keywords that can lead to searching the databases for collecting the required literature have been extracted. These keywords are combined of two or more of the following terms: "critical success factors", "key success factors", "factors affecting", "factors influencing", "enablers", "drivers", "Building Information Modelling", "BIM", "adoption", "implementation", "adopting", "implementing", "enhancing", "improving", "enhancement", "improvement", "strategies", "strategic", "roadmap", "ways", "successful", "performance", "construction industry", "construction projects", "architecture, engineering, and construction", and "AEC". Additionally, the key descriptors of "barriers", "challenges", and "risk factors" have been deemed during searching the databases. It is crucial to consider the literature interrelated with the hindering factors of embracing a growing approach, as this literature may be interested in some cases in devising their controlling strategies. Hence, this study's preliminary list of the KSFs can be enriched with more effectual factors. Likewise, Ozorhon and Karahan [16] reviewed the studies of BIM implementation barriers to define their KSFs in Turkey.

2.1.3. Step 3: Identifying the Databases

According to the associated literature suggestions, e.g., Seyis [9] and Abbasnejad et al. [23], the databases that will be searched have been located. This encompasses the research engines of (a) Google and Google Scholar and (b) the engineering, construction, and management journals of Emerald, ASCE, Taylor and Francis, and Elsevier. A list of these academic journals is mentioned in Abbasnejad et al. [23]. Further, since the ResearchGate is among the authoritative platforms for the academia to present and exchange their scientific contributions effortlessly, its database will be relied on in the search as well.

2.1.4. Step 4: Allocating the Screening Criteria of the Publications

In this step, three criteria have been allocated for examining each publication's eligibility to provide the research with its KSFs initial list. They are (a) reading the publication, particularly its abstract, objectives, and conclusion, (b) investigating the publication methodology if the elements of the previous criterion indicate their compatibility with this research scope, and (c) precisely scrutinizing the KSFs of the publication to guarantee their matching with the definition of Amuda-Yusuf [14]. In fact, most of these criteria are always among the tools of BIM researchers (e.g., [2]) to screen a publication and signify its conformity with their studies' aims. However, employing the methodology as a tool to reflect the publications' appropriateness for a specific field is believed to be out of the screening criteria of the earlier related studies. The focus on utilizing this criterion is due to the approach of some of the analysts of the KSFs (e.g., [19]) for mentioning the identification basis or the descriptions of the KSFs in their methodologies instead of listing the explanation of each

KSF in their developed list. Hence, considering this criterion during the screening of the publications is of crucial implication on supplying this study with its KSFs.

2.1.5. Step 5: Surveying the Databases

By utilizing the keywords of step 2 in the research engines of step 3 within the consideration of the screening criteria of step 4, the databases of the research engines have been surveyed. Surveying the databases is kept limited to the last two decades following the propositions of Seyis [9] and Abbasnejad et al. [23]. Approximately after three months of searching the databases and filtering several publications, it has been ascertained that the 44 researches of Table A1 (see Appendix A) are the most adequate studies, either for outlining the theoretical background of the research or introducing its KSFs. As a result, the content of the 44 studies of Table A1 has been analyzed and 18 KSFs have been extracted to supply the research with its initial list of the KSFs. Table 1 shows each KSF along with its corresponding description and sources from the 44 studies of Table A1.

Table 1. BIM implementation key success factors.

Code	Key Success Factor	Explanation	Supporting Literature
K_{SF1}	Firm's fiscal support	Construction firm's willingness to assign adequate financing for implementing BIM, including startup and continuous investments	[3,11,13,15,18,24–29]
K_{SF2}	Adequate and suitable ICT infrastructure	Provision of efficient information and communication technology infrastructure within the firm implementing BIM	[3,10,13,15,16,27,29–31]
K_{SF3}	Professional BIM staff	Existence of/hiring professional staff with sufficient knowledge of BIM implementation	[1,11–13,15,16,27,31–36]
K_{SF4}	BIM training courses	Equipping the junior and senior BIM cross-field specialists with the necessary BIM training courses	[1,3,10,11,13,14,16–18,23–28,30–33,35–49]
K_{SF5}	Senior management support	The firm's senior management approach supportive for adopting BIM policy and facilitating its implementation	[1,11,14–16,18,19,23–26,30,41,43,48]
K_{SF6}	Staff willingness for learning	Willingness and interest of the firm's/industry's staff for acquiring and learning BIM knowledge	[14,18,27]
K_{SF7}	BIM awareness level	Sufficient awareness of the industry's stakeholders with the benefits of BIM and its application areas	[8,12,14,16,18,24–26,29–32,34,42,47,50]
K_{SF8}	Supporting the culture of changing and updating	The culture's of the industry stakeholders supportive of the change and the implementation of the up-to-date technology	[12–14,16–18,24,25,27,34,37,38,47,48]
K_{SF9}	Consulting and technical support	Existence of consulting firms with BIM experience as well as BIM software vendors in the local construction market	[1,3,11,14,16,23,25,26,33,44]
K_{SF10}	BIM software functionality	Functionality of BIM software, including efficiency and simplicity in the application and interoperability and compatibility of exchanging data	[1,3,8,13–15,18,19,26,30,33,37,39,44,48]
K_{SF11}	Maintenance and upgrading plan	Setting an executive plan for periodically maintaining and upgrading BIM software and hardware	[27,44]
K_{SF12}	Governmental support	Government-led initiatives and supportive strategies for backing BIM implementation within the construction sector	[1,3,8,10,12–14,16,19,24–27,30,34–36,40,41,43,46–48,51–53]
K_{SF13}	Research and development investments	Interesting of the government and industry stakeholder on allocating investments for BIM research and development (e.g., development of engineering software and hardware industry)	[10,36,42,44–46,50]

Table 1. *Cont.*

Code	Key Success Factor	Explanation	Supporting Literature
K_{SF14}	Industry-academia cooperation	Existence of communication platforms among the academics and industry practitioners for sharing knowledge and expertise	[16,24,25,44]
K_{SF15}	Standardization	Availability of appropriate guidelines and legislation (e.g., codes, standards, BEP forms) for standardizing the working procedures of BIM within the construction industry	[3,8,10,11,13,14,16,18,19,26–28,31,32,35–37,39–41,45,46,50,52]
K_{SF16}	Encouraging and incentivizing culture	Encouraging and incentivizing the employees who are experts or willing to implement BIM in practice	[11,18,23,47]
K_{SF17}	BIM education	Integrating BIM approach in the courses of engineering faculties	[8,13,24,25,29,31,42,44,47,52,53]
K_{SF18}	Collaboration and communication environment	Existence of a cooperative project environment and effective communication conduits among project parties	[3,11,13,16,18,26,28,30,37,40,41,43]

Notes: ICT: Information and communication technology infrastructure. BEP: BIM execution plan.

2.1.6. Step 6: Validating the Initial List of the KSFs

This step has been focused on discussing the KSFs initial list with SMPs on BIM to examine its validity within the Egyptian construction market's context. Relying upon the criteria of Seyis [9], the qualifications for considering the participants as BIM experts have been pinpointed. This, in turn, confirms that this step's extracted results have been built on a scholarly-based approach, not on a subjective-based suggestion. In accordance with Seyis [9], the criteria for deeming the participant as a BIM expert in terms of the expertise level are: (a) having at least 5 years of expertise in the construction sector and (b) having at least 2 years of expertise in BIM-based projects. As for the educational background, the criteria contain: (a) owning a bachelor's degree (B.Sc.) in the disciplinary of construction (e.g., civil engineering) and (b) holding a master's degree in construction projects information technology. It is worth mentioning that these criteria have been presented by Seyis [9] to describe the entrant as a BIM expert if he/she has at least one criterion from every group separately. Building on the aforesaid criteria, 2 BIM experts from the first author's personal network and 4 from his colleagues' recommendations have been reached for reviewing the KSFs initial list. All the experts have then been phoned to check their willingness for participating in the study and to determine how they want to be interviewed. As a result, 3 of the experts asked to be personally interviewed, while the 3 others chose the telephonic interview after receiving the list of the KSFs on their online social accounts of Whatsapp. At the time and position designated by each expert, each practitioner has been discussed to verify the inclusiveness and aptness of the KSFs with respect to the characteristics of Egypt's construction market. Further, they have been asked to mention or remove any significant or unrelated KSF to the KSFs list.

Table 2 summarizes the experts' background information and their responses for the KSFs validity. As this table presents, both the quality and quantity have been realized in the experts' profiles to consider their responses. Considering the quality, the experts' expertise and knowledge are fully matched with the criteria of Seyis [9]. As for quantity, because no KSF has been noticed to be added or removed by the entrants (see the last column in Table 2), especially from the responses of the last experts (i.e., Experts E and F), the implication is the saturation of the data, and accordingly, the experts' number sufficiency [35]. These outcomes, in turn, lead to approving the KSFs in their current form for realizing the first objective of this research, i.e., defining the KSFs of BIM implementation within Egypt. More importantly, the experts' satisfaction and their consensus for the appropriateness and comprehensiveness of the KSFs in their presented form indicate that the procedures that they have been based upon are effective to be a reliable reference in future studies to locate their KSFs.

Table 2. Background of the entrants in validating the list of the KSFs.

Expert	Working Organization	Position	Education Background	Years of Expertise		Comment on the Initial List of the KSFs
				Construction Field	BIM Field	
A	Higher education institute for engineering + private consulting and engineering services firm	Associate professor + BIM coordinator	Ph.D. in structural engineering	22	6	The list of the KSFs is valid
B	University + private consulting and engineering services firm	Demonstrator + BIM specialist	B.Sc. in architectural engineering	3	3	The list of the KSFs is valid
C	Private contracting firm	Senior BIM engineer/modeler	B.Sc. in architectural engineering	5	3	The list of the KSFs is valid
D	Private design and engineering services office	Junior BIM engineer/modeler	B.Sc. in mechanical engineering	2	2	The list of the KSFs is valid
E	Private consulting and engineering services firm	Senior BIM engineer/modeler	B.Sc. in civil engineering	7	4	The list of the KSFs is valid
F	Private consulting and engineering services firm	BIM coordinator	B.Sc. in civil engineering	3	3	The list of the KSFs is valid

2.2. DEMATEL Questionnaire-Based Survey

Generally speaking, the way through which DEMATEL works regarding the data collection methodology is inserting the research factors of the issue under analysis in a matrix, called the influence matrix. Then, the expert is required to fill out this matrix's cells by identifying the degree to which he/she considers each factor of the matrix affects each of the others, utilizing a specific numerical rating system [20]. Along the same lines, the pre-validated list of the KSFs (see Table 1) has undergone a matrix format-based questionnaire to assemble data from Egypt's BIM experts on the influences of the KSFs on each other. The questionnaire has three parts. In part one, the entrant has been asked about his/her educational and expertise information. Yet, part two has been focused on providing the participant with the names and explanations of the KSFs. As for the third part, through an 18×18 matrix of the identified KSFs, the respondent has been requested to appraise the influences of the KSFs on each other. This is on the basis of employing a five-level numerical rating system, encompassing 0 = no-influence, 1 = low-influence, 2 = medium-influence, 3 = high-influence, and 4 = extreme-influence [5,20], for denoting the influence degree of a KSF from a row on a KSF from a column. This rating system, additionally, has been clarified with an illustrative example for aiding the participant to apply it in evaluating the influence level of a KSF on another one.

For piloting the questionnaire or starting the survey, the non-probabilistic purposive sampling strategy has been utilized. Employing this sampling technique is not based on the authors' subjective selection, but it is mandatory given three facts. First, BIM adoption rates in the developing construction markets are limited [16,19,54], and lacking of expertise in this area is among the critical barriers of this challenge [55]. In such case, it is become too difficult to get an official record of BIM experts from a reputable organization to recognize their whole number along with their contacting addresses in order to randomly engage them in the survey. Second, as this study's results are essentially tied to the assessments of the influences of the specified KSFs on each other, they should be evaluated proficiently. Therefore, Olawumi and Chan [26] emphasized utilizing the purposive sampling strategy to ensure that the reached expert has the expertise and knowledge required for proficiently answering the subject matter questions. Third, in this research, the participant will exert sizeable efforts to fill out the cells of the questionnaire's appraisal matrix (i.e., 306 cells = 18 × 18 minus 18 diagonal cells, representing the influence of each KSF on itself). Accordingly, the entrant's willingness to offer such endeavors is a main reason to call him/her for taking a part in the survey to raise the data richness [56]. Certainly, whenever there is a specific criterion (such as willingness) upon which the participant is invited for surveying, it is systematically advisable to base his/her selection on the purposive sampling strategy [26,56].

Against this backdrop and the criteria allocated by Seyis [9] for nominating the entrant as a BIM expert (see section: Defining the KSFs of BIM Implementation), the study has been geared toward the step of engaging the Egyptian experts in piloting and surveying its DEMATEL-based questionnaire. This step represented a critical obstacle to the authors. The reasons are quite understandable because of the lack of an official record from a reputable organization in Egypt that includes the contacting addresses of BIM practitioners and the limitation in finding engineers with convenient experiences in the domains of BIM [57]. Facing this challenge, the first author has depended on his personal network and online social account of Facebook for finding BIM-related experts. Besides, he asked his engineering colleagues to help him by suggesting well-qualified practitioners in BIM along with their contact accounts for getting in touch with them. The academics in BIM-associated literature, e.g., Arshad [2] and Stride et al. [35], relied upon their personal networks as well as online social platforms for targeting the participants of their surveying. This, in turn, supports this study's methodology in identifying its entrants from the first author's personal network and online social accounts. With the assistance of the first author's personal network, the study reached the first participant, who is an assistant professor in the structural engineering discipline, possessing 22 years of expertise in the construction industry, encompassing 6 years in BIM. On 4 May 2021, the expert has been handed the questionnaire of the study in his office to check its authenticity in terms of the structure, language and grammatical errors, and instructions' clearness. This is after phoning him for ascertaining that he has the willingness for being interviewed and to determine the interview time and location. At a fast pace, specifically on 8 May 2021, the expert completed his questionnaire copy and re-handed it back without any comments on its authenticity.

Contrary to the fast pace in which the questionnaire of the study has been piloted and validated, at a relatively slow pace, between 11 May and 15 July 2021, its surveying process has been conducted. In this regard, the first author has utilized his personal network, online social networks of Facebook and Whatsapp, and email, whether for reaching the experts of BIM and inviting them to the survey or receiving their responses. Meanwhile, the first author's colleagues assisted him by sending the questionnaire to their friends who are BIM practitioners. Although all the contacted experts showed their willingness for participating in the survey, only 9 of them submitted their questionnaire copies. At first glance, the authors, in view of the responding experts' number (i.e., 10: 1 from questionnaire piloting + 9 from the surveying), thought that this adds a major limitation for achieving their research objectives. However, an in-depth analysis of DEMATEL system-based construction management literature negated this belief completely. More importantly, it highlighted that the realized BIM experts' number and the data provided by them ensure a reliable basis and a high-reliability value for carrying out the analysis of DEMATEL. This is because of the fact confirmed by Costa et al. [20] that DEMATEL technique functions well with small samples. For instance, Hiete et al. [58] and Costa et al. [20] utilized DEMATEL based on the participation of 3 and 8 experts, respectively. Further, without any statistical examination, Cong et al. [59] interpreted that their survey data have high reliability because they targeted their evaluation team relying upon the purposive sampling strategy, which enabled them to select experts with extensive understating and comprehensive knowledge of their subject matter's questions. In the same context, Costa et al. [20] regarded the richness of their survey data is owing to the commitment of their responding experts for involving in their research.

On the basis of the aforementioned information, this study refers to the aptness of its surveying finding with respect to the sample size and data reliability. This is because, first, the number of participants in DEMATEL questionnaire-based survey is 10, exceeding the maximum norms of both Hiete et al. [58] with 3 entrants and Costa et al. [20] with 8 entrants.

Second, all the experts have been purposively surveyed according to the criteria set by Seyis [9] for recruiting the entrant as a BIM expert. Accordingly, their bio-data meet the criteria of Seyis [9] in order to be deemed as well-qualified practitioners in BIM. Third, due to the full willingness of the responding experts for involving in the survey, the richness of their data is situated [56]. Combining these points, the conclusion is that the data offered by the experts of BIM are enough and reliable for conducting DEMATEL analysis. This can be asserted by investigating Table 3. Based on this Table 3, 6 of the experts are civil engineers, 3 are architectural engineers, and 1 is a mechanical engineer. Their years of expertise in the construction and BIM fields range from 2 to 22 years and from 2 to 6 years, respectively. Two of the BIM experts work as junior BIM engineers/modelers, 3 work as senior engineers/modelers, 1 works as a BIM specialist, 3 work as BIM coordinators, and 1 works as a technical sales specialist in BIM. Besides, they represent different organizations, comprising consulting offices, contracting firms, and academia. Further, although all the experts are Egyptian, it is pertinent to mention that experts C and H have international expertise in BIM by working on overseas BIM-based projects in Saudi Arabia and the United Arab Emirates. The bio-data of the experts reaffirm that they are well-qualified practitioners in BIM. Consequently, their background can be relied upon for presenting credible findings to BIM management literature.

Table 3. Background of the entrants in DEMATEL questionnaire-based survey.

Expert	Working Organization	Position	Education Background	Years of Expertise	
				Construction Field	BIM Field
A	Higher education institute for engineering + private consulting and engineering services firm	Associate professor + BIM coordinator	Ph.D. in structural engineering	22	6
B	Private consulting and engineering services firm	BIM coordinator	B.Sc. in civil engineering	4	3
C	Engineering software design firm	Technical sales specialist in BIM	B.Sc. in civil engineering	6	6
D	University + private consulting and engineering services firm	Demonstrator + BIM specialist	B.Sc. in architectural engineering	3	3
E	Private designing and manufacturing steel structure firm	Senior BIM engineer/modeler	B.Sc. in civil engineering	4	4
F	Private consulting and engineering services firm	Junior BIM engineer/modeler	B.Sc. in civil engineering	2	2
G	Higher education institute for engineering + private design and engineering services office	Demonstrator + junior BIM engineer/modeler	B.Sc. in architectural engineering	2	2
H	Private contracting firm	Senior BIM engineer/modeler	B.Sc. in civil engineering	8	4
I	Private consulting and engineering services firm	BIM coordinator	B.Sc. in mechanical engineering	9	7
J	Private contracting firm	Senior BIM engineer/modeler	B.Sc. in architectural engineering	5	3

2.3. Implementation of DEMATEL Analysis

DEMATEL approach, according to the construction management-related literature, has countless contributions as a successful instrument in supporting the academics with a holistic analysis concerning the research factors of their multicriteria issues [20]. This wide popularity of DEMATEL among the academics stems from the methodology that it works through for viewing the essential features of their research problems' factors. This methodology comprises the matrix tool for converting the experts' evaluations into quantitative findings and the graph theory for portraying them in a well-organized pattern, called DEMATEL causal diagram [5,19]. The outcomes of this causal diagram involve:

(a) identifying the strength associated with the relevance and influence of each research factor toward the debated issue, (b) specifying the cause-effect associations among the research factors and presenting them in a cause-and-effect map, and (c) dividing the research field factors into consecutive clusters, each with its corresponding priority in respect to the field that they represent [5,20]. Emphatically, in view of this information, the academics can afford the policymakers in the construction markets with a stepwise-based smart structural model that can better prioritize their decisions to manage their encountered multicriteria decision-making problems. Hence, DEMATEL modeling better suits the issue under analysis, as its causal diagram can elucidate the interrelationships among the KSFs and introduce the KSFs in a successive groups-based plan, each of which has its priority regarding the process of BIM implementation.

Hereafter are the steps of constructing the causal diagram of the 18 KSFs of BIM implementation, utilizing DEMATEL system as has been informed by Chien et al. [5], Costa et al. [20], and Cong et al. [59] along with the literature therein:

2.3.1. Step 1: Establishing the Average Matrix A

On the basis of DEMATEL questionnaire-based survey, 10 influence matrices have been extracted from the questionnaires of the 10 BIM professionals. Undoubtedly, in each kth expert's influence matrix ($D^k = [d^k{}_{ij}]_{n\times n}$), the given score ($d^k{}_{ij}$) exemplifies the own perspective of the professional k regarding his/her judgment on the strength of the influence of KSF i of ith row on KSF j of jth column. Hence, to gather all the experts' evaluations together for further analysis, the average matrix ($A = [a_{ij}]_{n\times n}$) should be established by averaging the professionals' scores for the influence of KSF i of ith row on KSF j of jth column. Equation (1) summarizes the process of deriving the average matrix (A) from a number of influence matrices of H experts. Further, the outcome of its application for aggregating the influence matrices of the 10 participants in DEMATEL questionnaire-based survey has been illustrated in Table A2 of Appendix A.

$$\left[a_{ij}\right]_{n\times n} = \frac{1}{H} \times \sum_{k=1}^{H} \left[d^k{}_{ij}\right]_{n\times n} \tag{1}$$

2.3.2. Step 2: Generating the Normalized Initial Direct-Relation Matrix N

The normalized initial direct-relation matrix ($N = [n_{ij}]_{n\times n}$), according to Equation (2), is the output of dividing the average matrix ($A = [a_{ij}]_{n\times n}$) by the notation (S). This notation in DEMATEL method is named the normalization factor, and its value can be defined following Equation (3). In accordance with Equation (3), to identify the normalization factor (S), the summation of the values of each row $\left(\sum_{j=1}^{n} a_{ij}\right)$ and that of each column $\left(\sum_{i=1}^{n} a_{ij}\right)$ in the average matrix (A) has to be calculated, and the largest summation is denoted as the normalization factor. Building on this explanation, the normalization factor (S) from the average matrix (A) of Table A2 is the total of the existing scores in its eighth column and equals 50.80. Additionally, its usage as a denominator for each number of the cells of the average matrix (A) of Table A2 provides the (N) matrix, as Table A3 of Appendix A shows.

$$\left[n_{ij}\right]_{n\times n} = \frac{\left[a_{ij}\right]_{n\times n}}{S} \tag{2}$$

$$S = \max\left(\max_{1\le i\le n} \sum_{j=1}^{n} a_{ij}, \max_{1\le j\le n} \sum_{i=1}^{n} a_{ij}\right), i,\ j = 1,\ 2,\ 3,\ \ldots\ldots.,\ n \tag{3}$$

2.3.3. Step 3: Defining the Total-Relation Matrix T

Developing the total-relation matrix ($T = [t_{ij}]_{n\times n}$) is the core step in DEMATEL system. This arises from the value (t_{ij}) that each cell (i, j) included in this matrix. Based upon the characteristics of the ($T = [t_{ij}]_{n\times n}$) matrix, the value (t_{ij}) of a cell (i, j) signifies that there is a cause-effect relationship between factor i of the ith row and factor j of the jth column. Further, in this causal relation, the influencing factor is i, and the affected one is j. Significantly, this finding indicates that underlining the cause-effect associations among the KSFs of BIM implementation and their visualization on the causal diagram of DEMATEL are associated with developing their total-relation matrix. To this end, the total-relation matrix ($T = [t_{ij}]_{n\times n}$) can mathematically be specified from Equation (4) as a function of the normalized initial direct-relation matrix ($N = [n_{ij}]_{n\times n}$) and the identity matrix ($I = [i_{ij}]_{n\times n}$). Table A4 of Appendix A shows the (T) matrix of the KSFs of BIM implementation based on employing the (N) matrix of Table A3 in Equation (4).

$$T = N \times (I - N)^{-1} \tag{4}$$

2.3.4. Step 4: Determining the Prominence and the Net Effect of the KSFs

In DEMATEL method, the prominence (P_i) is defined as the index of clarifying the significance of variable i to the whole system, whilst the net effect (NE_i) is denoted as the indicator of elucidating the net impact that the variable i exerts on the system. Besides, these indices represent together the coordinate of locating the variable i on the causal diagram of DEMATEL, in which the P_i is the x-coordinate, while the NE_i is the y-coordinate. To compute the indices of the P_i and the NE_i of ith factor, its vectors R_i and C_j should be firstly determined. Equations (5) and (6) explain that the vectors R_i and C_j of ith factor are the summation of the values of its ith row and that of its jth column in the total-relation matrix (T), respectively. Thereafter, by adding the vector R_i to the vector C_j, as Equation (7) illustrates, the P_i in a positive value is obtainable. In contrast, by subtracting the vector C_j from the vector R_i (see Equation (8)), the NE_i can be drawn in a positive or a negative value. According to the positive sign of the P_i, the implication is that the higher the score of the P_i is, the more significant the degree of variable i in the entire system is. As for the sign of the NE_i, the positive categorizes the variable i as a net cause variable, whereas the negative classifies it as a net effect of the other variables in the system.

$$R_i = \sum_{j=1}^{n} t_{ij},\ i = j = 1,\ 2,\ 3,\ \ldots\ldots.,\ n \tag{5}$$

$$C_j = \sum_{i=1}^{n} t_{ij},\ i = j = 1,\ 2,\ 3,\ \ldots\ldots.,\ n \tag{6}$$

$$P_i = \left(R_i + C_j\right),\ i = j = 1,\ 2,\ 3,\ \ldots\ldots.,\ n \tag{7}$$

$$NE_i = \left(R_i - C_j\right),\ i = j = 1,\ 2,\ 3,\ \ldots\ldots.,\ n \tag{8}$$

3. Results and Analysis

This section includes the next two subsections:

(1) Section 3.1. "Depicting the Causal Diagram of the KSFs of BIM Implementation": this subsection shows how the causal diagram of the KSFs of BIM implementation has been depicted relying upon the outputs of the prior steps of DEMATEL analysis.
(2) Section 3.2. "Analyzing the Causal Diagram of the KSFs of BIM Implementation": this subsection illustrates the results of the causal diagram of the KSFs of BIM implementation.

3.1. Depicting the Causal Diagram of the KSFs of BIM Implementation

The causal diagram of DEMATEL is a scatter graph with two major axes. While the horizontal axis is represented by the prominence index (P_i), the vertical one is illustrated, using the indicator of the net effect (NE_i). Hence, to lay ith factor on this diagram, its indices of the P_i and the NE_i should be called upon. Undoubtedly, the P_i of ith factor will be employed to indicate its x-coordinate on the horizontal axis of the prominence. Yet, its NE_i will be utilized to signify its y-coordinate on the vertical axis of the net effect. Table 4 presents the 18 KSFs of BIM implementation, their vectors R_i and C_j, as well as their indices of the P_i and the NE_i, utilizing the Equations from (5) to (8). Furthermore, based on these values of the P_i and the NE_i of the KSFs of BIM implementation, their DEMATEL causal diagram has been drawn in Figure 2.

Table 4. Prominence and net effect of the KSFs of BIM implementation.

K_{SF}	R_i	C_j	P_i	NE_i
K_{SF1}	9.558	8.946	18.504	0.612
K_{SF2}	8.357	8.745	17.102	−0.388
K_{SF3}	9.167	9.555	18.722	−0.387
K_{SF4}	9.355	9.508	18.863	−0.154
K_{SF5}	9.712	9.447	19.159	0.265
K_{SF6}	8.616	9.341	17.957	−0.725
K_{SF7}	9.008	10	19.008	−0.992
K_{SF8}	9.193	10.14	19.333	−0.952
K_{SF9}	9.362	8.926	18.288	0.436
K_{SF10}	9.433	9.839	19.272	−0.406
K_{SF11}	9.097	9.232	18.329	−0.135
K_{SF12}	8.725	8.16	16.885	0.565
K_{SF13}	9.729	9.463	19.192	0.265
K_{SF14}	9.255	9.036	18.291	0.219
K_{SF15}	8.074	7.362	15.436	0.712
K_{SF16}	9.329	8.639	17.968	0.689
K_{SF17}	9.698	9.778	19.476	−0.08
K_{SF18}	9.384	8.929	18.313	0.456

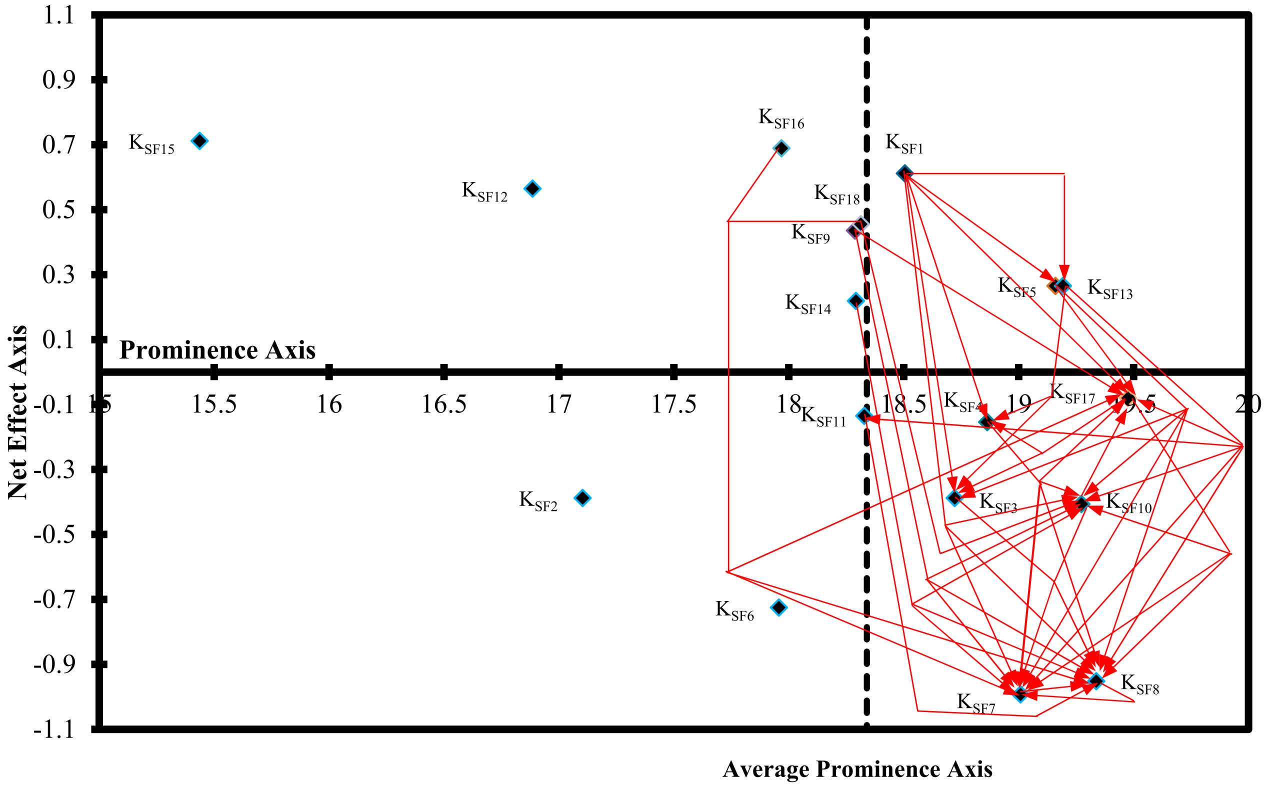

Figure 2. DEMATEL causal diagram of the KSFs of BIM implementation.

By taking a deep insight at the causal diagram of Figure 2, it can be found that there is another vertical axis in a dotted line under the name of average of the prominence. Following the procedures of DEMATEL, the location of this axis on the causal diagram of the KSFs of BIM implementation is the average of the P_i values of the 18 KSFs, which equals 18.339. On the basis of this axis, specifically, its point of intersection with the horizontal axis of prominence, the causal diagram of the KSFs of BIM implementation can be divided into four quadrants. The implication of these quadrants is that they divide the KSFs into four consecutive groups, each having a significance-based priority during the process of implementing BIM. This implication, in turn, affords this study with its pivotal contribution, i.e., establishing the KSFs in a phased approach to devise a roadmap for their implementation on a step-by-step basis. In this roadmap (see Figure 2), the sequence of its phases concerning implementing BIM starts from the upper right-hand quarter, then to the upper left-hand quarter, followed by the lower left-hand quarter, and ends at the lower right-hand quarter. As for the priorities of the KSFs of each phase, they have been defined through their locations on the range that their set occupies on the horizontal axis of the prominence, employing the rule of Costa et al. [20] that the further to the right, the KSF is denoted as more prominent or relevant. For more clarification, phase one of the BIM implementation journey involves K_{SF13}, K_{SF5}, and K_{SF1}; and K_{SF13} with P_i = 19.192 is closer to the right of the horizontal axis of the prominence than K_{SF5} (P_i = 19.159) and K_{SF1} (P_i = 18.504). As such, their priorities regarding the process of BIM implementation are ordered as follows K_{SF13}, K_{SF5}, and K_{SF1}. Along the same lines, the KSFs of each phase have been prioritized. Table 5 summarizes the 4 phases of the BIM implementation roadmap along with their locations on the causal diagram of DEMATEL and the priorities of the KSFs of each phase.

Table 5. Characteristics of the four phases of BIM implementation roadmap.

Phase No.	Location of the Phase on the Causal Diagram	KSF of the Phase	Prominence Index (P_i)	Priority of the KSF in its Phase
Phase one	The upper right-hand quarter of the causal diagram	K_{SF13}	19.192	1st
		K_{SF5}	19.159	2nd
		K_{SF1}	18.504	3rd
Phase Two	The upper left-hand quarter of the causal diagram	K_{SF18}	18.313	1st
		K_{SF14}	18.291	2nd
		K_{SF9}	18.288	3rd
		K_{SF16}	17.968	4th
		K_{SF12}	16.885	5th
		K_{SF15}	15.436	6th
Phase Three	The lower left-hand quarter of the causal diagram	K_{SF11}	18.329	1st
		K_{SF6}	17.957	2nd
		K_{SF2}	17.102	3rd
Phase Four	The lower right-hand quarter of the causal diagram	K_{SF17}	19.476	1st
		K_{SF8}	19.333	2nd
		K_{SF10}	19.272	3rd
		K_{SF7}	19.008	4th
		K_{SF4}	18.863	5th
		K_{SF3}	18.722	6th

To realize a deeper analysis of the 18 KSFs of BIM implementation, the causal diagram of Figure 2 utilizes the lines with arrows for visualizing their cause-effect associations.

The visualization of the cause-effect relationships among the 18 KSFs has been achieved, using the total-relation matrix (T) of Table A4. Nevertheless, the (T) matrix provides several relations among the KSFs. Accordingly, considering all the relations on the causal diagram of Figure 2 will certainly make its readability to elicit the necessary information too complicated process. Therefore, it is very crucial to employ a reasonable threshold value that can exclude the unimportant effects in the (T) matrix and consider those of the important impacts. In this regard, Cong et al. [59] advocated computing the threshold value on the basis of the total of the average and standard deviation of the values (t_{ij}) of the (T) matrix. Relying upon this rule, the threshold value of screening the insignificant relations in the (T) matrix of Table A4 is 0.556. Based on this finding, all the values (t_{ij}) that are equal to or greater than 0.556 have been listed in bold in the (T) matrix of Table A4. More significantly, they have been considered to represent the significant cause-effect associations among the KSFs of BIM implementation, as the arrows of the cause-and-effect map of Figure 2 explain. Thence, in view of this map, the cause-effect relationship between any two KSFs can be informed, considering the fact that the KSF, which has a location at the tail of the arrow influences the KSF whose location is at the arrowhead.

3.2. Analyzing the Causal Diagram of the KSFs of BIM Implementation

The causal diagram of DEMATEL (see Figure 2) introduces several findings that can be investigated from different angles concerning the KSFs of the BIM implementation journey. The horizontal axis represents the P_i of each KSF to specify its significance regarding the whole process of implementing BIM. According to this axis, the P_i values range from +15.436 to +19.476. Further, along this axis from the far right to the far left, the KSFs can be graded in terms of their importance from the most to the least: K_{SF17}, K_{SF8}, K_{SF10}, K_{SF13}, K_{SF5}, K_{SF7}, K_{SF4}, K_{SF3}, K_{SF1}, K_{SF11}, K_{SF18}, K_{SF14}, K_{SF9}, K_{SF16}, K_{SF6}, K_{SF2}, K_{SF12}, and K_{SF15}. On the vertical axis, on the other hand, each KSF is provided with the net effect that it exerts on the overall process of implementing BIM. Depending on this axis, the NE_i scores of the KSFs vary from −0.992 to +0.712. Following this range from NE_i = +0.712 to NE_i = −0.992, the sorting of the KSFs in descending order of their NE_i values are K_{SF15}, K_{SF16}, K_{SF1}, K_{SF12}, K_{SF18}, K_{SF9}, K_{SF5}, K_{SF13}, K_{SF14}, K_{SF17}, K_{SF11}, K_{SF4}, K_{SF3}, K_{SF2}, K_{SF10}, K_{SF6}, K_{SF8}, and K_{SF7}. More importantly, in terms of whether the sign related to the NE_i of the KSF is positive or negative, the KSF can be termed as a net cause or a net effect of the other KSFs for implementing BIM. Accurately, this classification can be described relying upon the intersection of the horizontal and vertical axes of the prominence and net effect. As Figure 2 explains, above the horizontal axis of the prominence are 50% of the KSFs. All of them, including K_{SF15}, K_{SF16}, K_{SF1}, K_{SF12}, K_{SF18}, K_{SF9}, K_{SF5}, K_{SF13}, and K_{SF14} represent the KSFs of the cause set since their signs of the NE_i are positive. Yet, below the horizontal axis of the prominence are the other 50% of the KSFs, encompassing K_{SF17}, K_{SF11}, K_{SF4}, K_{SF3}, K_{SF2}, K_{SF10}, K_{SF6}, K_{SF8}, and K_{SF7} with negative signs regarding their NE_i. Accordingly, they are the KSFs of the effect collection.

By categorizing the KSFs into net causes and net effects KSFs, a considerable implication can be introduced to the policymakers in the construction community to deeply grasp the process of managing the KSFs of BIM implementation. This implication is that realizing success in the BIM implementation journey is associated with achieving the 9 KSFs of the cause set. Numerically, these KSFs exemplify 50% of the whole KSFs of the BIM implementation process. However, in accordance with the methodology of DEMATEL, the KSFs of the effect collection are strongly impacted by them, especially those which have important cause-effect relations with the KSFs of the cause group. Hence, the KSFs of the cause collection can be perceived as the underlying KSFs behind the success of the BIM implementation journey. Practically, this implication directs a crucial message to the construction practitioners: if they seek to efficiently manage their process of implementing BIM, their concentration should be laid on the KSFs of the cause collection. For supporting this result with the significant cause-effect relationships, either among the KSFs of the same category or between the KSFs of the cause group and those of the effect set, the lines with arrows of the cause-and-effect map of Figure 2 can be followed. In this map, the total number of important relationships after deeming the threshold value of 0.556 for excluding the insignificant relations in the (T) matrix of Table A4 is 54. Additionally, all the 18 KSFs for implementing BIM have connections with each other, except K_{SF2}, K_{SF6}, K_{SF12}, and K_{SF15}. Moreover, in light of the number of the causal relationships that each KSF has (see the last column in Table A4), the KSFs can be prioritized in descending order of significance: K_{SF1}, K_{SF13}, K_{SF5}, K_{SF17}, K_{SF4}, K_{SF9}, K_{SF18}, K_{SF10}, K_{SF14}, K_{SF16}, K_{SF3}, K_{SF7}, K_{SF8}, and K_{SF11}.

A deeper analysis of this ranking reports that the most significant KSFs that have crucial causal relationships with the other KSFs belong to the cause collection, comprising K_{SF1}, K_{SF13}, and K_{SF5}. As the last column of Table A4 illustrates, from the 54 highlighted important causal relations, they have 23 ones. Yet the other 4 KSFs of the cause set and those related to the effect cluster have from these 54 causal relationships 14 and 17 relations, respectively. More notably, the arrows of the cause-and-effect map of Figure 2 underline that 7 out of the 9 KSFs of the effect group, including K_{SF3}, K_{SF4}, K_{SF7}, K_{SF8}, K_{SF10}, K_{SF11}, and K_{SF17}, have been influenced by K_{SF1}, K_{SF13}, and K_{SF5}. Yet the other 4 KSFs of the cause collection, i.e., K_{SF9}, K_{SF14}, K_{SF16}, and K_{SF18}, have impacted only 4 out of the 9 KSFs of the effect set, encompassing K_{SF7}, K_{SF8}, K_{SF10}, and K_{SF17}. Emphatically, all the causal relationships of the KSFs of the effect group are between its KSFs and each other; consequently, no KSF from the cause collection has been influenced by one of them. Significantly, this analysis brings a profound view of the KSFs, including specifying the most crucial KSFs in terms of their gross relation with the other KSFs. Additionally, it adds to the construction practitioners' knowledge the fact that in view of devoting their efforts for realizing the KSFs of the cause cluster, especially K_{SF1}, K_{SF13}, and K_{SF5}, 7 out of the 9 KSFs of the effect group can be successfully fulfilled.

4. Discussion and Recommendations

This section discusses the 4 phases of the BIM implementation roadmap and their associated KSFs, as presented in Figure 2 and supported by Table 5. Besides, it includes recommendations to improve the performance and the outcomes of these phases.

4.1. Phase One of BIM Implementation Roadmap

The upper right-hand quarter of Figure 2 comprises phase one of the BIM implementation journey. Its components are three net causes KSFs and their priorities for implementing BIM are: research and development investments (K_{SF13}) (P_i = 19.192), senior management support (K_{SF5}) (P_i = 19.159), and firm's fiscal support (K_{SF1}) (P_i = 18.504). Clearly, this phase's content reflects that the BIM implementation journey can be successfully launched if the policymakers' visions in the government and the construction sector are supportive to apply BIM in their business. Further, their practical boost to this vision by providing the necessary funds for meeting BIM implementation running costs and BIM-related research and development is more important. Undoubtedly, the top management's satisfaction with BIM benefits, either for professionally managing their projects or optimizing their investment returns is the major motivation to direct their managerial efforts and financial resources toward embedding BIM in their works. Emphatically, this will have an important consequence on achieving the other KSFs of the BIM implementation roadmap, particularly those which depend on the fiscal appropriations availability. This includes at the organizations level: hiring professional staff, up skilling the employees through training, conducting symposiums and workshops to enhance the BIM awareness level of the personnel of the shop floor, and periodically maintaining and upgrading BIM software and hardware. As for the government level, this encompasses: backing the software and hardware industry and providing the necessary tools of the software and hardware for integrating BIM in the engineering colleges.

Indeed, the aforementioned KSFs are K_{SF3}, K_{SF4}, K_{SF7}, K_{SF8}, K_{SF10}, K_{SF11}, and K_{SF17}, which have significant cause-effect relations with the KSFs of phase one of the BIM implementation roadmap. This, in turn, sheds a novel light on the BIM implementation process.

This process is a dynamic process based on the government and construction organizations' fiscal support, where providing the financial investments for realizing the KSFs of its first phase paves the way for the KSFs of its next phases for being achieved. To this end, the government and construction practitioners are advised to keep in mind that prior to embarking on their BIM implementation journey, they should have the willingness to set aside sufficient funding for being invested in this process [1]. More significantly, they should not be in hurry to receive the returns of their investments, as implementing BIM is an extended journey lasting for many years [16,21]. To widen the implication scope of the finding extracted from this phase, i.e., financial support value for implementing BIM, a comparison has been undertaken with studies from three developing economies, comprising China [3], Turkey [16], and Nigeria [14]. According to Ma et al. [3] and Amuda-Yusuf [14] in China and Nigeria, respectively, this KSF has a significant consequence on implementing BIM. Conversely, in Turkey, it has been found to have a moderate effect on applying BIM [16]. The similarity between the result of the current research and the outputs of Ma et al. [3] and Amuda-Yusuf [14] signifies that the priorities of the KSFs of BIM implantation are not context based. However, the incompatibility with the outputs of Ozorhon and Karahan [16] indicates that they are context-based. Hence, the general implication is that the construction practitioners and academics can use the BIM implementation roadmap of other countries. Nevertheless, if they draw up their BIM roadmap considering the socio-economic environment of their construction community, they will have more accurate results. Umar [60] supports this advice that since the characteristics of the construction industry vary from country to country, the significance of the KSFs could be different as well.

4.2. Phase Two of BIM Implementation Roadmap

Phase two of the BIM implementation roadmap contains, as the upper left-hand quarter of Figure 2 illustrates, the other six KSFs of the cause cluster. The sequence of these KSFs in order of priority for applying BIM is collaboration and communication environment (K_{SF18}) (P_i = 18.313), industry-academia cooperation (K_{SF14}) (P_i = 18.291), consulting and technical support (K_{SF9}) (P_i = 18.288), encouraging and incentivizing culture (K_{SF16}) (P_i = 17.968), governmental support (K_{SF12}) (P_i = 16.855), and standardization (K_{SF15}) (P_i = 15.436). In view of the first three KSFs in this phase (i.e., K_{SF18}, K_{SF14}, and K_{SF9}), the cooperation and communication of the project parties, either internally with each other or externally with the academics and BIM supply-chain parties are key agents for realizing BIM. According to Habib [40], constructing a project using BIM involves multiple parties, comprising BIM designers, contractors and subcontractors, and owners. Further, this technology is a completely digital system based on the availability of the e-communication conduits for sharing information [2]. Hence, the construction parties should work collaboratively and provide sufficient e-communication mechanisms for facilitating data-exchange of their project. The construction organizations, additionally, need to work collaboratively with external parties, including academics, BIM software vendors, and BIM consultants. This is because BIM diffusion in a lot of the enterprises of the construction markets is at its initial stages, particularly in small and medium companies. More seriously, the in-house expertise of these firms is not ready to deal with this new technology [16,23]. Thus, they are in an urgent necessitate to get consultancy support from others to reconstruct their ICT in order to be compatible with BIM requirements and to train their staff on the tools of this new technology. As such, their opportunity for success regarding implementing BIM could be optimized [1].

Encouraging and incentivizing culture (K_{SF16}) has the fourth rank in this phase. Actually, mastering BIM is a long and expensive journey lasting for more than a year. During this journey, the trainee exerts considerable efforts to understand its concepts and tools for applying them in the projects of his/her company. In such case, the senior management should bear the expenses of this journey and reward their staff for their endeavors to pass it successfully. Otherwise, the staff will not be encouraged to do their efforts for learning this technology. The fifth significant KSF in this phase is governmental support (K_{SF12}). In accordance with Phang et al. [1], the government is the major driving force for boosting BIM usage in its country. However, to date, the governments' attitudes in many developing countries unlike their counterparts in the developed ones are wait-and-see attitude. Unfortunately, this represents a critical barrier for proliferating BIM in those countries [55]. The governments of these countries, therefore, are advised to follow the initiatives that have been conducted by their counterparts in the developed countries. More details concerning these initiatives are listed in Wong et al. [51] and Zhou et al. [46]. Standardization (KSF_{15}) is the last KSF in this phase. According to Won et al. [11] and Amuda-Yusuf [14], standardizing BIM working procedures through developing guidelines, codes, and regulations is a vital enabler for accommodating BIM in the construction community. Qin et al. [19] explained this significance that standardizing BIM provides the construction companies with a formal and trustworthy guidance regarding its design and building processes. This, in turn, makes BIM new users more liable to go through fewer mistakes throughout BIM design and building processes [16]. Hence, more organizations will be encouraged to integrate BIM into their work. In this regard, the governmental agencies, particularly in the countries where BIM is quite new, have to work in leaps and bounds for standardizing BIM procedures in their construction markets. This is a mainstay for incentivizing the construction practitioners to utilize BIM [19,45].

4.3. Phase Three of BIM Implementation Roadmap

In phase three of the journey of implementing BIM (see the lower left-hand quarter of Figure 2), the maintenance and upgrading plan (K_{SF11}) (P_i = 18.329) has the first priority for implementing BIM, followed by staff willingness for learning (K_{SF6}) (P_i = 17.957) and adequate and suitable ICT infrastructure (K_{SF2}) (P_i = 17.102). These KSFs belong to the effect group. However, K_{SF11} is the only KSF that has significant interactions with the other KSFs, including its impact on K_{SF8} and the influence of K_{SF13} on it. Building on the first and third KSFs in this phase (i.e., K_{SF11} and K_{SF2}), the technology component in terms of purchasing the appropriate and up-to-date hardware and software is the essential infrastructure for implementing BIM in any organization [16]. This has been confirmed by Arshad et al. [2] and Abu Awwad et al. [30] that BIM is a completely digital system; therefore, its application needs to procure a compatible system of the hardware and software that can efficiently work together. Besides, the regular maintenance and upgrading of these tools to keep their efficiency for meeting the construction markets' requirements are significantly important. This finding again indicates the role of the firm's fiscal support regarding implementing BIM, as providing these tools is associated with prohibitive costs [53].

In light of the second significant KSF in this phase (i.e., K_{SF6}), the willingness of the firm's staff to learn BIM is no less important than the organization's fiscal support for applying BIM. This stems from the fact that even if the firms are willing to provide the financial component for starting their BIM implementation journey, their staff's unwillingness to learn the tools of this journey can impede its progress. In this respect, Chan et al. [27] and Ma et al. [18] clarified that the staff's unwillingness to learn BIM can be managed if their views about the advantages of utilizing BIM have been improved. This can be attained relying upon their top managers by organizing symposiums and workshops and inviting BIM supply-chain parties and academics to share their knowledge and previous expertise concerning BIM benefits. Additionally, incentivizing staff through bonuses can have a considerable role in raising their willingness to learn BIM. Building on the findings of this phase, the senior management can be provided with a significant message: launching their BIM implementation journey is associated with affording both the financial and human elements that are willing to do their efforts to learn BIM. If one of them is not available, the success of their journey cannot be guaranteed.

4.4. Phase Four of BIM Implementation Roadmap

Phase four has the lower right-hand quarter of Figure 2 and it includes 6 KSFs from the net effect cluster. Their priorities for implementing BIM are: BIM education (K_{SF17})

(P_i = 19.476), supporting the culture of changing and updating (K_{SF8}) (P_i = 19.333), BIM software functionality (K_{SF10}) (P_i = 19.272), BIM awareness level (K_{SF7}) (P_i = 19.008), BIM training courses (K_{SF4}) (P_i = 18.863), and professional BIM staff (K_{SF3}) (P_i = 18.722). Educating BIM in the engineering colleges is the most crucial KSF in this phase. All the other KSFs in this phase have been influenced by it. This is a logical finding owing to that educating BIM is the essential way to hone the graduates' skills with BIM knowledge. Emphatically, this knowledge will enable them to utilize and develop BIM-related software and hardware, illustrate BIM benefits to support the culture of changing toward using BIM, and offer the consultancy and training services for the construction firms. Thus, the governments, through their higher educational institutions, have to work on redesigning their engineering colleges' syllabuses to comprise BIM courses in their academic programs. This should be conducted in consultation with BIM supply-chain parties and construction organizations to benefit from their expertise during preparing these courses [53].

Supporting the culture of changing and updating (K_{SF8}) is the second significant KSF in this phase. This is a critical KSF because introducing any new technology like BIM in the construction community usually faces resistance from its organizations to implement it in their business [23]. Habib [40] regarded the firms' resistance to utilizing BIM is due to their lack of awareness concerning BIM features. Proficiently, the analysis of DEMATEL identifies the ideal solution to manage this issue when it links (K_{SF8}) with the fourth important KSF in this phase, i.e., BIM awareness level (K_{SF7}). As the arrows of the cause-and-effect map of Figure 2 explain, each of these KSFs has an impact on each other. Thence, it is noted that the higher the awareness level regarding BIM benefits is, the lower the resistance to its implementation becomes and the higher the spreading of BIM in the construction community is. This implication is consistence with the conclusion of Abu Awwad et al. [30] that implementing BIM becomes easier if the firms have past knowledge of BIM. In this context, the policymakers in the construction organizations are advised to absorb BIM benefits to take the appropriate decision regarding implementing BIM in their works.

Clearly, the technical component in terms of BIM software functionality (K_{SF10}) appears to be an important KSF in the BIM implementation journey, as it is ranked fourth in this phase. Indeed, applying BIM requires utilizing several programs with different data formats. Accordingly, the interoperability between BIM-related software programs is the fundamental technical element behind BIM implementation success. Moreover, the compatibility of BIM programs with the local construction industry's codes of practice is equally significant. Unfortunately, since BIM is rather new in many developing economies [16], these issues have not been addressed yet. Therefore, the governments in those countries, in association with their academics and domestic software developers, have to devote their endeavors to developing their local-oriented BIM software programs, which should be featured by the interoperability and compatibility with their national building codes. The fifth and sixth significant KSFs in this phase are BIM training courses (K_{SF4}) and professional BIM staff (K_{SF3}), respectively. Because BIM concepts and tools are new knowledge for the staff in many firms, their training for practicing this knowledge is imperative for supplying the construction markets with BIM practitioners. The analysis of DEMATEL supports also this outcome by indirectly linking K_{SF4} and K_{SF3} together through K_{SF17} (see the arrows of the cause-and-effect map of Figure 2). As the arrows of Figure 2 show, additionally, K_{SF4} is significantly influenced by K_{SF1} and K_{SF5}, which are the firm's fiscal support and senior management support, respectively. These relations together have a pivotal message for the senior management: enriching their organizational structure's capital with proficient personnel for practicing BIM in their business is associated with allocating sufficient funds for training their staff on BIM knowledge. According to Abbasnejad et al. [23] and Abu Awwad et al. [30], training is not only vital to hone their staff's skills with BIM knowledge, but it is also crucial for precipitating and ensuring the successful realization of BIM in their organizations.

5. Theoretical and Practical Implications

This paper has substantial theoretical and practical contributions for widening the deployment of BIM across the developing construction economies in particular and the global construction community generally. First, this study introduces a comprehensive scholarly framework for compiling the literature associated with studying the KSFs for implementing BIM. The outcomes of this step (see Tables 1 and A1) sum up the related literature attempts in terms of their scope and objectives, analyzing tools, and the KSFs of BIM implementation. This endeavor can be the bedrock for finalizing more future studies in this domain at a fast pace by reducing the scholars' time and efforts regarding specifying their KSFs from surveying the literature. Second, the research methodology's pivots, encompassing defining well-qualified practitioners in BIM, designing DEMATEL-based questionnaire, surveying the practitioners, and analyzing their evaluations using DEMATEL along with the aforementioned justifications, can be used worldwide. These elements have been drawn from global academic works; thus, they are valuable for performing comparable researches in other countries [3]. Third, in view of the terminology of Ma et al. [3] for the systematic process of BIM implementation in practice, i.e., a step-by-step effort, this research sheds a significant light on the pivotal point that can satisfy this process: modeling these process activities (i.e., KSFs) in a phased-based approach. More importantly, it locates the analytical technique that can meet this purpose, i.e., deeming DEMATEL system instead of the conventional ranking tools of the RII or MS, along with a suggested cutoff point or a normalized benchmarked value. This contributes to developing the academics thinking when they aim at structuring their KSFs of BIM implementation. Accordingly, the policymakers in the construction community will be encouraged to apply their findings, since they have been built on a step-by-step basis as they prefer.

Away from the aforementioned theoretical implications, this research offers the following practical contributions. First, this paper provides the top management of the contracting companies and the consultancy offices in Egypt with their practical roadmap for implementing BIM in their business. Indeed, such investigation is long overdue for filling the knowledge gap regarding elucidating the BIM implementation journey within the Egyptian construction market. Second, DEMATEL presents a novel terminology concerning the journey of implementing BIM: applying BIM is a dynamic process, where allocating the financial resources for realizing the KSFs of its first phase paves the way for the KSFs of its next phases to be achieved. More significantly, the government and construction organizations are partners with the same responsibilities for providing these resources. This implication has an imperative message to these parties: their cooperation is the bedrock for applying BIM in their country.

6. Limitations and Future Directions

Similar to any other study, this research is not without limitations. First, although this paper's considerable efforts in developing the list of the KSFs for implementing BIM and the methodological steps that have been followed in this respect, its usage in future studies, especially in the developed countries is associated with re-validating its KSFs with the targeted country's BIM experts. Second, while the participants' number has been discussed to be acceptable relying upon the justifications mentioned in the "Research Methodology" section, considering additional expertise and knowledge by surveying more BIM experts in the future can yield a more accurate roadmap for implementing BIM. Third, although DEMATEL showed its ability to reveal the interrelations among the KSFs and structure the KSFs in a phased approach, it is similar to the other cause-effect analytical methods, such as the ISM technique, which provides non-statistically validated results [45]. Thus, in future research directions, the results obtained from DEMATEL analysis should undergo the sensitivity analysis, as has been suggested and detailed by Cong et al. [59], for verifying their robustness. Finally, for handling the fuzziness of the evaluations of BIM experts regarding the influences of the KSFs on each other, this study can be further applied in the future by calling up Fuzzy-DEMATEL approach.

7. Conclusions

In response to the lack of proliferation of BIM technology in the developing economies, this paper affords a phase-based roadmap to support implementing BIM in practice on a step-by-step approach. To this need, this study identifies an inclusive list of 18 KSFs for implementing BIM by systematically investigating the pertinent literature and interviewing six well-qualified practitioners in BIM from Egypt, as a developing country. Subsequently, it subjects the KSFs to a matrix format-based questionnaire according to the procedures of DEMATEL for compiling data from Egypt's BIM experts on the influences of the KSFs on each other. Relying upon the analysis of DEMATEL, the 18 KSFs have been divided into four clusters, each of which signifies a phase in the BIM implementation journey along with its corresponding priority as well as the priorities of the KSFs that it encompasses. In this research, additionally, DEMATEL extends to pinpoint for the senior management, either in the government or construction organizations the three underlying net causes KSFs contributing to the whole success of the developed BIM implementation roadmap: research and development investments, senior management support, and firm's fiscal support. These main findings of the current research contribute to promoting the implementation of BIM in the developing construction markets by supplying their policymakers with a systematic roadmap of four phases for implementing BIM in their business on a step-by-step effort as they prefer. This roadmap, in turn, assists in better prioritizing the steps and optimizing the allocation of the resources of the policymakers during their BIM implementation journey. Hence, it is highly expected that this study will play a significant role in widening BIM deployment in the developing construction markets and embedding its mature use among their organizations.

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Appendix A

Table A1. Analyzing the literature of the KSFs of BIM implementation.

Study	Year	Country	Study Scope/Objectives	Key Analyzing Tools
[51] **	2011	Hong Kong	• Highlighting the government's role for boosting BIM implementation within the construction community. • Providing the departments of the government with the uses of BIM at different project's stages.	• Qualitative analysis
[32] **	2012	United Kingdom	• Providing answers for the questions of: (a) What are the construction organizations' present state of awareness and readiness toward BIM and its implementation? (b) Why the transition toward BIM is at a slow pace within the construction sector? (c) What are the strategies needed for developing a business model for entailing the usage of BIM?	• Number and proportion of choices by the respondents • Descriptive analysis

Table A1. *Cont.*

Study	Year	Country	Study Scope/Objectives	Key Analyzing Tools
[11] **	2013	International survey	• Answering the questions of: (a) What are the BIM adoption CSFs in a company? (b) What are the CSFs for choosing projects to employ BIM? (c) What are the CSFs for choosing BIM services? (d) What are the CSFs for choosing company-suitable BIM software applications?	• Mean score • Threshold value
[12] **	2014	Nigeria	• Specifying BIM adoption-related drivers and barriers within the construction community.	• RII
[8] **	2014	Hong Kong	• Drawing up a roadmap for the strategic implementation of BIM within the construction sector.	• Not specified
[37] ***	2014	Not specified	• Uncovering BIM implementation-associated CSFs. • Revealing the influences of the CSFs on each other.	• System analysis
[50] *	2015	Malaysia	• Discussing the pillars of Malaysia's BIM roadmap regarding the implementation of BIM within the construction community.	• Not specified
[24] **	2015	Libya	• Exploring BIM implementation-interrelated barriers and driving factors within the AEC industry.	• RII • MS • Pearson correlation
[38] *	2016	United States	• Investigating the present situation of BIM adoption within small-sized architectural firms. • Specifying the industry's existing attitudes and visions toward BIM. • Analyzing the small-sized architectural firms' culture-associated factors in relation to the successful adoption of BIM.	• MS • Pearson correlation
[39] ***	2016	Malaysia	• Suggesting the CSFs for implementing BIM within the construction community.	• Not specified
[40] **	2017	United Kingdom	• Developing a conceptual framework including the CSFs and contractual risk regarding the strategic management of the privately funded 2 projects implementing BIM.	• Content analysis • MS • Threshold value • Thematic analysis • Mind mapping
[33] **	2017	China	• Providing answers for the questions of: (a) What are the fields of BIM investment? (b) What are the benefits from BIM investment? (c) What are the ways for improving BIM returns? (d) What are the risk factors in implementing BIM?	• RII • Overall mean • Proportion of choices by the respondents
[16] *	2017	Turkey	• Locating BIM implementation-related CSFs. • Defining the fundamental dimensions of the CSFs.	• MS • EFA
[13] **	2018	Syria	• Suggesting a framework for enhancing BIM performance with respect to the AEC companies.	• Proportion of choices by the respondents
[14] *	2018	Nigeria	• Identifying BIM implementation-interrelated CSFs within the construction industry. • Grouping the CSFs into a set of clusters.	• MS • BIM benchmark index • EFA
[25] **	2018	Saudi Arabia	• Proposing a methodology for implementing BIM within the AEC industry.	• Pearson correlation • Weighted mean
[41] ***	2018	Not specified	• Investigating the academic literature regarding the CSFs for implementing BIM.	• Content analysis

Table A1. *Cont.*

Study	Year	Country	Study Scope/Objectives	Key Analyzing Tools
[26] *	2018	Surveying eight countries	• Specifying the CSFs regarding the compatible implementation of BIM and sustainability within the construction projects.	• MS • Kendall's concordance test • Inter-rater agreement • Spearman's rank correlation
[42] ****	2018	Syria	• Determining BIM implementation-associated obstacles with respect to the AEC industry. • Suggesting the needed requirements for implementing the technology of BIM.	• MS
[10] **	2019	Saudi Arabia	• Appraising the ability of the construction sector for adopting BIM. • Extracting the CSFs of BIM adoption within the construction community from the barriers facing BIM.	• Response ratio
[15] *	2019	Taiwan	• Developing a step-by-step approach for specifying BIM project goals, CSFs, and operational CSFs for accomplishing BIM-based projects successfully.	• MS • Cutoff point
[27] *	2019	Hong Kong	• Investigating BIM implementation-associated CSFs with respect to the AEC industry.	• MS • Kendall's coefficient of concordance • Spearman's rank correlation
[43] ****	2019	Singapore	• Determining the critical drivers for the change regarding BIM full implementation. • Suggesting strategies for boosting the positive impact of the specified drivers.	• MS • Threshold value • p-value
[28] **	2019	Singapore	• Identifying BIM implementation-interrelated critical hindering factors within the construction sector. • Clustering the hindering factors into a set of groups. • Defining the interrelationships among the groups of the hindering factors. • Recommending managerial strategies for controlling the critical hindering factors.	• MS • Normalization value • EFA • SEM
[18] *	2019	China	• Exploring the interactive relations between the technological and institutional factors impacting BIM adoption with respect to the AEC organizations.	• ISM • Matrix impacts cross-reference multiplication applied to a classification
[44] *	2019	Developing countries	• Providing practices for enhancing the processes and products of BIM. • Proposing a benchmarking model and evaluation template for measuring the implementation level of BIM practices in the developing economies.	• Moving basis heuristics
[17] *	2020	Malaysia	• Exploring BIM implementation-related CSFs among the AEC firms. • Grouping the CSFs into a set of clusters. • Specifying the interrelationships among the clusters of the CSFs.	• MS • Normalized mean value • PCA • SEM
[45] ****	2019	China	• Indentifying the barriers facing BIM usage in prefabricated construction. • Analysing the interrelationships among the barriers. • Proposing a framework to support the implementation of BIM in prefabricated construction.	• ISM • Matrix impacts cross-reference multiplication applied to a classification

Table A1. *Cont.*

Study	Year	Country	Study Scope/Objectives	Key Analyzing Tools
[46] **	2019	China	• Delineating BIM implementation-interrelated barriers within the construction sector. • Identifying strategies and suggesting recommendations for boosting the upgrading and implementation of BIM.	• MS • Comparative analysis
[23] ***	2020	Not specified	• Specifying the enabling factors of BIM adoption and implementation within the AEC firms.	• Priori coding
[52] ****	2020	Egypt	• Discussing three international BIM guidelines with the users of BIM for selecting the most suitable ones for developing the domestic BIM guidelines. • Proposing BIM work steps according to the project stages. • Suggesting a strategic roadmap for implementing BIM within the construction community.	• MS
[30] *	2020	United Kingdom	• Pinpointing the CSFs impacting implementing BIM level 2 within the small- and medium-sized firms.	• Content analysis • Level of importance
[29] **	2020	Nigeria	• Exploring BIM implementation related-challenges within the construction industry. • Identifying strategies for reducing the challenges and investigating their relationships.	• Content analysis • MS • Threshold value • Pearson correlation analysis
[47] ****	2020	Pakistan	• Defining the benefits of BIM within the AEC industry. • Investigating BIM implementation-related barriers and the interrelationships among them. • Recommending strategies and solutions for overcoming BIM implementation-interrelated barriers.	• Mean percentage • MS • ISM • Matrix impacts cross-reference multiplication applied to classification
[34] **	2020	Nigeria	• Investigating BIM adoption-associated barriers and drivers within the construction industry.	• RII • Rank agreement factor
[3] *	2020	China	• Specifying BIM implementation critical strategies within the AEC projects. • Grouping the strategies and investigating their latent factors.	• MS • Normalization value • PCA
[48] *	2020	Malaysia	• Exploring BIM adoption rate among the contractors. • Locating BIM adoption impacting factors according to the contractors' perspectives.	• RII
[53] ****	2020	Lagos State-Nigeria	• Identifying BIM implementation-related barriers within the construction industry. • Categorizing the barriers into a set of groups. • Revealing a roadmap for boosting BIM adoption.	• MS • Threshold value • Factor analysis
[1] *	2020	Surveying Asian and European countries	• Recognizing the maturity levels of BIM within the precast concrete companies. • Developing a model for specifying the CSFs of BIM adoption within the precast concrete companies.	• Learn to rank algorithm
[19] *	2020	China	• Investigating the causal relationships between the prominent factors of BIM adoption within the construction industry.	• Interval decision-making trial and evaluation laboratory • Simulation analysis
[35] **	2020	Australia	• Pinpointing the benefits and challenges of utilizing BIM in the facilities management according to the standpoints of the quantity surveyors. • Defining strategies for controlling the challenges.	• Open coding

Table A1. *Cont.*

Study	Year	Country	Study Scope/Objectives	Key Analyzing Tools
[49] **	2020	United Kingdom	• Defining the level of expertise of the small- and medium-sized firms in BIM tools. • Determining the level of knowledge of the small- and medium-sized firms with implementing the systems supporting BIM. • Exploring BIM adoption-related barriers and enablers within the small and medium firms.	• Proportion of choices by the respondents • RII • Spearman's rho
[36] *	2020	China	• Specifying the situation of BIM adoption among the construction enterprises. • Identifying the factors impacting BIM adoption. • Analyzing the impact of the specified factors on the efficiency of adopting BIM. • Enhancing BIM adoption efficiency among the construction enterprises.	• MS • EFA • SEM
[31] **	2021	Nigeria	• Assessing and grouping BIM implementation-associated barriers within the AEC firms. • Identifying the ways of enhancing BIM adoption within the AEC firms.	• MS • Factor analysis

Notes: * Means the whole focus of the study has been allocated to discuss the KSFs of BIM implementation and the KSFs have been evaluated in a practical manner.
** Means the KSFs of BIM implementation are among the study scope and the KSFs have been evaluated in a practical manner.
*** Means the whole scope of the study has been allocated to scrutinize the KSFs of BIM implementation and the KSFs have been appraised in a theoretical manner.
**** Means the KSFs of BIM implementation are among the study scope and the KSFs have been suggested based on the subjective perspectives or analyses of the authors, not on the surveying of the experts' knowledge.
CSFs: Critical success factors.
AEC: Architecture, engineering, and construction.

Table A2. Average matrix A.

K_{SF}	K_{SF1}	K_{SF2}	K_{SF3}	K_{SF4}	K_{SF5}	K_{SF6}	K_{SF7}	K_{SF8}	K_{SF9}	K_{SF10}	K_{SF11}	K_{SF12}	K_{SF13}	K_{SF14}	K_{SF15}	K_{SF16}	K_{SF17}	K_{SF18}
K_{SF1}	0	3.3	3	3.2	3.2	2.6	2.4	2.7	2.7	3.2	3	2.1	3.5	2.7	2	3	2.6	2.5
K_{SF2}	2.8	0	2.4	2	3.1	2.4	2.7	2.5	2.1	3	3.1	2.5	2.3	2.1	1.3	1.7	2.5	2.9
K_{SF3}	2.5	2.2	0	2.8	2.9	3.3	2.8	3	3.2	3	2.4	2.1	2.7	2.5	2.4	2.2	2.9	2.8
K_{SF4}	2.6	2.3	3.1	0	2.9	3.5	3.1	3.1	2.2	3.2	3	1.9	2.6	2.6	2.3	2.8	3.1	2.4
K_{SF5}	3.1	2.8	3.6	3.5	0	2.7	3.1	3.2	2.6	2.8	2.9	2.6	3.2	2.3	1.7	2.8	2.8	2.8
K_{SF6}	2.2	2.3	2.6	2.8	2.4	0	3.3	2.9	2.6	2.9	1.8	2.1	2	2.9	1.9	2.5	3.2	2.4
K_{SF7}	2.7	2.2	2.7	3.1	2.8	2.9	0	3.2	2.4	2.8	2.5	2.2	2.8	2.9	1.9	2.4	2.8	2.5
K_{SF8}	2.6	2.5	2.6	3.1	2.9	3	3.5	0	2.3	2.8	2.8	2.1	2.9	2.8	1.8	2.8	2.6	2.7
K_{SF9}	2.4	2.3	2.8	2.7	3	3	2.9	2.9	0	2.8	3.1	2.6	2.7	2.4	2.9	2.5	3.1	2.7
K_{SF10}	3	2.9	3	2.9	2.9	2.4	3.2	2.8	2.8	0	2.6	2.5	3.1	2.9	2.4	2.2	3.1	2.4
K_{SF11}	3	3.1	2.8	2.4	2.5	2.5	2.5	3.2	2.9	3.1	0	2.5	3.2	2.8	1.6	2.5	2.4	2.3
K_{SF12}	2.7	3	2.4	2.2	2.6	2.1	2.7	2.9	2.2	2.3	2.3	0	3.1	2.6	2.9	2.5	2.7	2.3
K_{SF13}	3.3	3.1	2.6	3.1	3.3	2.6	2.7	2.8	3	3	3.4	2.3	0	2.4	2.1	3.4	3	2.5
K_{SF14}	2.3	1.7	2.7	2.9	2.5	2.8	2.8	3.3	3	3	2.7	2.9	2.8	0	2.8	2.4	2.9	2.7
K_{SF15}	1.8	2.5	2.5	2.2	2	2.3	2.5	2.2	2.2	2.5	2	2.5	2.5	3	0	2.1	2.8	2.5
K_{SF16}	2.4	2.1	2.6	2.9	2.8	3.1	3.1	3.4	2.5	2.6	2.9	2.5	2.8	2.8	1.9	0	3.2	2.9
K_{SF17}	2.9	2.6	3.1	3	2.7	2.9	3.2	3.2	2.8	3.1	2.9	2.8	2.7	2.8	2.1	2.5	0	3.2
K_{SF18}	2.1	2.7	3.2	2.5	2.6	2.4	3.5	3.5	2.9	3.1	2.6	2.4	2.4	2.6	2.5	2.6	3.3	0

Table A3. Normalized initial direct-relation matrix N.

K_{SF}	K_{SF1}	K_{SF2}	K_{SF3}	K_{SF4}	K_{SF5}	K_{SF6}	K_{SF7}	K_{SF8}	K_{SF9}	K_{SF10}	K_{SF11}	K_{SF12}	K_{SF13}	K_{SF14}	K_{SF15}	K_{SF16}	K_{SF17}	K_{SF18}
K_{SF1}	0	0.065	0.059	0.063	0.063	0.051	0.047	0.053	0.053	0.063	0.059	0.041	0.069	0.053	0.039	0.059	0.051	0.049
K_{SF2}	0.055	0	0.047	0.039	0.061	0.047	0.053	0.049	0.041	0.059	0.061	0.049	0.045	0.041	0.026	0.033	0.049	0.057
K_{SF3}	0.049	0.043	0	0.055	0.057	0.065	0.055	0.059	0.063	0.059	0.047	0.041	0.053	0.049	0.047	0.043	0.057	0.055
K_{SF4}	0.051	0.045	0.061	0	0.057	0.069	0.061	0.061	0.043	0.063	0.059	0.037	0.051	0.051	0.045	0.055	0.061	0.047
K_{SF5}	0.061	0.055	0.071	0.069	0	0.053	0.061	0.063	0.051	0.055	0.057	0.051	0.063	0.045	0.033	0.055	0.055	0.055
K_{SF6}	0.043	0.045	0.051	0.055	0.047	0	0.065	0.057	0.051	0.057	0.035	0.041	0.039	0.057	0.037	0.049	0.063	0.047
K_{SF7}	0.053	0.043	0.053	0.061	0.055	0.057	0	0.063	0.047	0.055	0.049	0.043	0.055	0.057	0.037	0.047	0.055	0.049
K_{SF8}	0.051	0.049	0.051	0.061	0.057	0.059	0.069	0	0.045	0.055	0.055	0.041	0.057	0.055	0.035	0.055	0.051	0.053
K_{SF9}	0.047	0.045	0.055	0.053	0.059	0.059	0.057	0.057	0	0.055	0.061	0.051	0.053	0.047	0.057	0.049	0.061	0.053
K_{SF10}	0.059	0.057	0.059	0.057	0.057	0.047	0.063	0.055	0.055	0	0.051	0.049	0.061	0.057	0.047	0.043	0.061	0.047
K_{SF11}	0.059	0.061	0.055	0.047	0.049	0.049	0.049	0.063	0.057	0.061	0	0.049	0.063	0.055	0.031	0.049	0.047	0.045
K_{SF12}	0.053	0.059	0.047	0.043	0.051	0.041	0.053	0.057	0.043	0.045	0.045	0	0.061	0.051	0.057	0.049	0.053	0.045
K_{SF13}	0.065	0.061	0.051	0.061	0.065	0.051	0.053	0.055	0.059	0.059	0.067	0.045	0	0.047	0.041	0.067	0.059	0.049
K_{SF14}	0.045	0.033	0.053	0.057	0.049	0.055	0.055	0.065	0.059	0.059	0.053	0.057	0.055	0	0.055	0.047	0.057	0.053
K_{SF15}	0.035	0.049	0.049	0.043	0.039	0.045	0.049	0.043	0.043	0.049	0.039	0.049	0.049	0.059	0	0.041	0.055	0.049
K_{SF16}	0.047	0.041	0.051	0.057	0.055	0.061	0.061	0.067	0.049	0.051	0.057	0.049	0.055	0.055	0.037	0	0.063	0.057
K_{SF17}	0.057	0.051	0.061	0.059	0.053	0.057	0.063	0.063	0.055	0.061	0.057	0.055	0.053	0.055	0.041	0.049	0	0.063
K_{SF18}	0.041	0.053	0.063	0.049	0.051	0.047	0.069	0.069	0.057	0.061	0.051	0.047	0.047	0.051	0.049	0.051	0.065	0

Table A4. Total-relation matrix T.

K_{SF}	K_{SF1}	K_{SF2}	K_{SF3}	K_{SF4}	K_{SF5}	K_{SF6}	K_{SF7}	K_{SF8}	K_{SF9}	K_{SF10}	K_{SF11}	K_{SF12}	K_{SF13}	K_{SF14}	K_{SF15}	K_{SF16}	K_{SF17}	K_{SF18}	#
K_{SF1}	0.47	0.52	**0.558**	**0.559**	**0.556**	0.539	**0.57**	**0.583**	0.519	**0.576**	0.541	0.468	**0.562**	0.525	0.424	0.51	**0.562**	0.516	8
K_{SF2}	0.464	0.402	0.484	0.475	0.492	0.474	0.51	0.513	0.45	0.508	0.482	0.421	0.478	0.454	0.363	0.429	0.496	0.464	0
K_{SF3}	0.497	0.482	0.481	0.531	0.53	0.532	**0.556**	**0.567**	0.509	0.551	0.51	0.451	0.527	0.502	0.416	0.477	0.547	0.502	2
K_{SF4}	0.509	0.493	0.549	0.489	0.539	0.545	**0.572**	**0.579**	0.5	**0.565**	0.53	0.455	0.535	0.513	0.421	0.496	**0.56**	0.504	4
K_{SF5}	0.535	0.519	**0.576**	**0.572**	0.505	0.549	**0.591**	**0.601**	0.525	**0.577**	0.547	0.484	**0.564**	0.525	0.425	0.514	**0.574**	0.529	7
K_{SF6}	0.465	0.457	0.501	0.503	0.492	0.443	0.535	0.534	0.471	0.52	0.471	0.426	0.486	0.482	0.385	0.456	0.522	0.468	0
K_{SF7}	0.493	0.474	0.523	0.529	0.52	0.517	0.495	**0.561**	0.487	0.539	0.504	0.445	0.521	0.501	0.4	0.473	0.536	0.489	1
K_{SF8}	0.501	0.488	0.531	0.538	0.531	0.528	**0.57**	0.513	0.494	0.549	0.519	0.452	0.532	0.509	0.406	0.489	0.543	0.501	1
K_{SF9}	0.505	0.493	0.544	0.54	0.541	0.536	**0.568**	**0.576**	0.459	**0.558**	0.532	0.468	0.537	0.51	0.433	0.491	**0.56**	0.51	4
K_{SF10}	0.52	0.507	0.551	0.547	0.544	0.529	**0.577**	**0.578**	0.515	0.51	0.527	0.47	0.548	0.522	0.427	0.489	**0.564**	0.508	3
K_{SF11}	0.503	0.495	0.53	0.521	0.52	0.514	0.547	**0.566**	0.5	0.549	0.462	0.455	0.532	0.504	0.398	0.479	0.534	0.49	1
K_{SF12}	0.479	0.475	0.503	0.497	0.502	0.487	0.53	0.54	0.469	0.515	0.486	0.391	0.511	0.482	0.407	0.461	0.519	0.471	0
K_{SF13}	0.54	0.525	**0.56**	**0.566**	**0.566**	0.548	**0.585**	**0.595**	0.533	**0.582**	**0.557**	0.479	0.506	0.528	0.433	0.525	**0.578**	0.524	8
K_{SF14}	0.498	0.477	0.536	0.538	0.527	0.527	**0.561**	**0.577**	0.51	**0.556**	0.52	0.469	0.533	0.46	0.427	0.485	0.551	0.504	3
K_{SF15}	0.431	0.434	0.471	0.463	0.457	0.458	0.49	0.492	0.438	0.483	0.447	0.409	0.466	0.457	0.327	0.423	0.486	0.443	0
K_{SF16}	0.504	0.488	0.538	0.542	0.536	0.537	**0.57**	**0.583**	0.504	0.553	0.527	0.465	0.537	0.515	0.413	0.443	**0.56**	0.512	3
K_{SF17}	0.531	0.515	**0.567**	**0.562**	0.554	0.552	**0.592**	**0.6**	0.528	**0.582**	0.546	0.487	0.555	0.534	0.432	0.507	0.521	0.535	5
K_{SF18}	0.501	0.501	0.552	0.537	0.536	0.527	**0.58**	**0.588**	0.514	**0.565**	0.525	0.466	0.533	0.515	0.426	0.494	**0.565**	0.46	4
Total no. of the significant cause-effect relations																			54

Notes: Bold values signify that they are $\geq$ the threshold value of 0.556.

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