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Prioritizing BIM Capabilities of an Organization: An Interpretive Structural Modeling Analysis

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Abstract

The Indian Architectural Engineering and Construction sector is grappling with the adoption of BIM as is evident from a relatively low level of adoption. While there have been sufficient number of successful (and unsuccessful) project level implementations of BIM in India, the maturity level of the overall industry and its constituents remains relatively low. One of the challenges faced, especially at the organizational level, is an understanding and development of the organization's BIM capabilities. These capabilities need attention in terms of their effectiveness and hierarchy of implementation in order to overcome the challenges of adoption and increasing maturity levels in BIM usage. The inability to identify crucial BIM capabilities is one of the primary barriers to ineffective BIM implementation and slow adoption in India. The aim of this study is to investigate the dynamics of different BIM capabilities and to understand how these capabilities can be represented as a set of interrelated elements by adopting Interpretive Structure Modeling (ISM) technique Accordingly, a clear understanding regarding the nature of each BIM capability is developed that will help the organizations to plan the strategic implementation of BIM on any project and gain systematic, logical and productive results. Through the three-phased study, it was concluded that BIM capabilities namely visualization, energy and environment analysis, structural analysis, MEP system modelling, constructability analysis, and BIM for as-built were found to be the independent BIM capabilities having strong driving power but weak dependence power. Facilities management is a dependent BIM capability with weak driving power but strong dependence power. This study provides a roadmap to BIM implementers by highlighting the driving and dependence power of each BIM capability which is deemed useful for enhanced delivery of construction projects. Significant theoretical and practical implications are envisioned for both researchers and project managers through the findings of this study.

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1. Introduction and Background

As compared to the rest of the industries, AEC sector is experiencing decline in terms of productivity [1] during a last few years with most of the projects facing the challenge of cost overrun, time delays and poor quality [2–5]. Several reasons have been documented as the crucial causes of this decline. Amongst these causes, some of the most prevalent ones include poor exchange of project information, lack of communication, adversarial relationships, low productivity rates, high rates of inefficiency and rework, frequent disputes and lack of innovation [3,6]. Past research [7–11] suggests that implementation of Building Information modeling (BIM) on projects is a successful solution to overcome these challenges. Despite being adopted globally, BIM capabilities need attention in terms of their effectiveness and hierarchy of implementation in order to overcome the challenges of overall construction project cost overrun and time delays. In comparison to the other countries, a relatively low BIM adoption level of 22% has been reported [12] with design coordination; clash detection; and quantity measurement as the three top uses of BIM in India. Although several attempts have been made [13–15] to evaluate the value and usage of BIM throughout the life cycle of a project, but the decision regarding development of a BIM capability within an organization is usually made on the basis of market pressure or a manager's intuition leading to tremendous cost burdens on the AEC firms [16]. Authors envisage that the inability to identify crucial BIM capabilities and lack of knowledge regarding the advantages/disadvantages of implementing them in a project, are the primary reasons for ineffective BIM implementation and slow BIM adoption in India [17]. This belief led to the need for an explicit research that can help BIM users in India to understand BIM process, develop organizational capabilities and explore the maximum potential of BIM to meaningful results and efficient outcomes. This was done by identifying and interconnecting various capabilities of BIM, placing them in order of rank and categorizing them as independent, dependent, autonomous and linkage capabilities.

2. Literature Review

The extent of BIM adoption by the construction industry is defined with its perceived benefits [9,18–24]. As a result of the study conducted in 2007, it was highlighted by the project team members in the US and Europe AEC industries, that the existing BIM software is too complex to be used [25,26]. It is stated by Miettinen and Paavola [10] that BIM needs to be analyzed as a multidimensional, historically evolving and a complex phenomenon. Unavailability of process implementation guidelines and lack of practical knowledge have been reported as the highlighted challenges to BIM adoption in India as faced by the AEC industry [12]. It is concluded that BIM adoption can be accelerated with the help of a well-defined approach where organizations will require a thorough understanding of BIM and its relevant functions so that appropriate capabilities can be developed within the organization [17]. The relative importance of BIM capabilities as developed by the organization with respect to driving power and dependence relationship will help them to plan strategic adoption and implementation of BIM for Indian construction industry in order to yield efficient results. Hence, requiring examination and in order to identify, prioritize and understand the dynamics of BIM capabilities, this study embraces a qualitative approach of ISM technique along with MICMAC analysis that helps to develop hierarchy of defined organizational BIM capabilities , imposes order and direction to these capabilities.

Mckinsey & Company, (2010) defines the term 'capability' as anything an organization does well that drives meaningful business results. The organizational capabilities have been defined as the collective skills, abilities and expertize of an organization [28]. Any technology adoption and implementation approach is actually as much about people and processes as it is about technology. Although several studies have identified various functions of BIM, however, there is a need for organizations to develop their own BIM capabilities. There is no study which has attempted to evaluate the relative importance of these capabilities except one international research in USA where the author has developed an algorithm based decision making tool that can aid new BIM users in understanding the advantages and disadvantages of developing and implementing BIM capabilities in a project [16] . Thus, in order to achieve the objective of this research, first the study attempts to explore various functions of BIM by conducting an in-depth literature review and then identifies and defines various BIM capabilities of an organization by conducting focus group with a diversified group experts from AEC industry. Finally, this research lists out thirty-three native BIM functions and fifteen organizational BIM capabilities which were screened after succeeding brainstorming sessions, suggestions, recommendations and interaction with seven industry experts: an architect, a civil engineer, a quantity surveyor, a sustainability specialist, a contractor, a structural engineer and a MEP consultant, which led to unanimous agreement and summarization of the following organizational BIM capabilities as sown in Table 1.

Table 1: BIM Capabilities

S.No.	BIM capabilities	References
1	Visualization	[29–31]
2	Design coordination	[23,32]
3	Prefabrication & Modularization	[8,14,33]
4	Construction sequencing & Scheduling	[34,35]
5	Energy & Environmental Analysis	[36–39]
6	Integrated Site Planning	[40,41]
7	Change Management	[42]
8	Structural Analysis	[43]
9	MEP System Modelling	[44]
10	Quantity Take-off	[24,45,46]
11	Facility Management	[47–49]
12	Constructability Analysis	[8,50]
13	Collaboration & Coordination	[51,52]
14	BIM for As-Built	[53,54]
15	BIM for Supply Chain Management	[55]

3. Using ISM to Model BIM Functions and Capabilities

ISM method has been used as it is interpretive and allegorical which can be applied to a system for solving the complexities and understanding the direct and indirect relationships amongst different organizational BIM capabilities. It is an accepted methodology for generating solutions of complex problems, for identifying and understanding the direct and indirect relationships among specific items to analyze the influence between the elements [56,57]. ISM is interpretive since judgment of group experts decides the appropriateness and connection of the identified variables. As this method helps to prepare an overall interactive structure of all the variables with levels of influence reported, thus it is described as structuring. Formation of digraphs for the entire structure with relations between variables graphically depicted describes this method as modeling [58]. The MICMAC is a systematic analysis which describes the system using a matrix and additionally categorizes variables based on their driving and dependence power [59]. In this research, MICMAC analysis has been applied to the various identified BIM capabilities of an organization for making the BIM implementation process more focussed and for prioritizing the BIM capabilities of an organization to achieve immediate high end benefits like faster construction, good quality, improved performance, cost saving and many others.

For this research, the semi-structured interviews and focus groups were conducted with seven industry experts along with an in-depth literature review. The various steps involved for carrying out the ISM analysis are as follows:

1. Step 1. From the native functions of BIM, different organizational capabilities of BIM were identified and listed as variables (shown in Table 1)
2. Step 2. A contextual relationship was established amongst these capabilities
3. Step 3. A structural self-interaction matrix (SSIM) was developed for BIM capabilities as shown in Table 2, which indicated pair-wise relationships among them. A contextual relationship of “leads to” type was chosen

for analysis, which meant that one variable leads to another variable. Following four symbols were used to denote the direction of relationship between the functionalities (i and j):

V: BIM capability i helps to achieve BIM capability j.
A: BIM capability j helps to achieve BIM capability i.
X: BIM capability i helps to achieve BIM capability j and BIM capability j helps to achieve BIM capability i.
O: BIM capabilities i and j have no relation between each other

Table 2: Structural Self Interaction Matrix for BIM capabilities

Variables	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	V	X	V	V	V	V	X	V	V	V	V	V	V	V	X
2	O	O	V	V	V	O	A	V	X	O	O	X	V	X	
3	V	O	X	X	O	V	A	A	O	O	O	X	X		
4	X	O	X	X	O	O	A	O	X	X	O	X			
5	O	O	O	O	V	O	X	O	O	O	X				
6	X	O	X	X	O	O	A	O	O	X					
7	X	O	V	X	V	X	O	A	X						
8	O	O	V	V	O	V	O	X							
9	V	V	V	V	V	V	X								
10	O	O	A	O	O	X									
11	A	A	A	O	X										
12	O	O	X	X											
13	X	A	X												
14	O	X													
15	X														

4. Step 4. Once the SSIM was completed, it was converted into a binary matrix, called the initial reachability matrix by substituting V, A, X, O relationships with the binary value of 1 and 0 as per the case. The initial reachability matrix was then checked for transitivity, leading to the development of 'final reachability matrix'.
5. Step 5. The final reachability matrix obtained in Step 4 was partitioned into different levels as shown in Table 3. Further, the final reachability matrix was developed in its conical form, i.e. most zero (0) variables in the upper diagonal half of the matrix and most unitary (1) variables in the lower half.

Table 3: Level Partition and level determination for BIM capabilities

Variables	BIM capability	Reachability Set	Antecedent Set	Intersection Set	Level
1	Visualization	1 – 15	1,5,9,14	1,5,9,14	VI
2	Design coordination	2- 4, 6-8, 10 -13,15	1-10, 12, 13, 14, 15	2- 4, 6- 8, 10,12, 13,15	II
3	Prefabrication & Modularization	2- 4,6,7,10-13,15	1-9, 12, 13, 14, 15	2-4, 6,7, 10, 12, 13,15	II
4	Construction sequencing & Scheduling	2-4,6-8,10-13,15	1-10, 12, 13, 14, 15	2-4, 6- 8, 10, 12, 13, 15	II
5	Energy & Environmental Analysis	1-7, 9-15	1,5,9,14	1,5,9,14	V
6	Integrated Site Planning	2- 4,6,7,10-13,15	1-9,12-15	2-4,6,7,12,13,15	III
7	Change Management	2-4,6-8,10-13,15	1-10,12- 15	2-4, 6-8, 10, 12, 13, 15	II
8	Structural Analysis	2-4,6-8,10,11-13,15	1,2,4,7,8,9,14	2,4,7,8,9,14	IV
9	MEP System Modeling	1- 15	1,5,9,14	1,5,9,14	VI
10	Quantity TakeOff	2,4,7,10,11,12,13, 15	1-10,12-15	2,4,7,10,12,13, 15	II
11	Facility Management	11	1-15	11	I
12	Constructability Analysis	2-4,6,7,10-12,13,15	1-10,12-15	2-4, 6,7,10, 12, 13, 15	II
13	Collaboration & Coordination	2-4,6,7,10-13,15	1-10,12-15	2-4, 6, 7, 10, 12, 13, 15	II
14	BIM for As-Built	1-15	1,5,9,14	1,5,9,14	VI
15	BIM for Supply Chain Management	2-4, 6, 7, 10-13,15	1-10,12-15	2- 4, 6, 7, 10, 12, 13,15	II

6. Step 6. Based on the relationships given in the reachability matrix and the determined levels for each BIM capability, a digraph was drawn and the transitive links are removed.
7. Step 7. In the last step, the ISM model was developed as shown in Figure 1and was reviewed to remove any inconsistencies and necessary alterations were made.

Based on final reachability matrix, the final ISM-based model for BIM capabilities was obtained after removing the indirect links. Figure 1 shows the final ISM-based model for BIM capabilities. It was observed that ‘facility management’ (capability 11) was found to be at the top of the hierarchy reflecting the effectiveness of all the BIM capabilities. It is controlled by all the other BIM capabilities. The ‘visualization’ (capability 1), ‘MEP system modelling’ (capability 9) and ‘BIM for as-built’ (capability 14) which formed the base of the ISM hierarchy, were found to be interdependent. These BIM capabilities had the highest driving power which implied that these were the three key BIM capabilities which influenced the entire project. The next level capability was ‘energy and environmental analysis’ (capability 5) which was found to influence other BIM capabilities but was directly influenced by ‘visualisation’, ‘MEP system modelling’ and ‘BIM for as-built’. The ‘structural analysis’ (capability 8) was the next level BIM capability which was found to be influenced by the previously discussed capabilities of BIM but at the same time it directly affected ‘integrated site planning’. Forming the system core, ‘integrated site planning’ (capability 6) was identified as the major BIM capability requiring adoption on construction projects to yield effective results. It was found to directly influence a number of BIM capabilities and was controlled by other capabilities too. In addition to this, eight penultimate level BIM capabilities were found comprising of ‘design coordination’ (capability 2), ‘prefabrication & modularization’ (capability 3), ‘construction sequencing & scheduling’ (capability 4), ‘change management’ (capability 7), ‘quantity take-off’ (capability 10), ‘constructability analysis’ (capability 12), ‘collaboration/coordination’ (capability 13) & ‘BIM for supply chain management’ (capability 15).

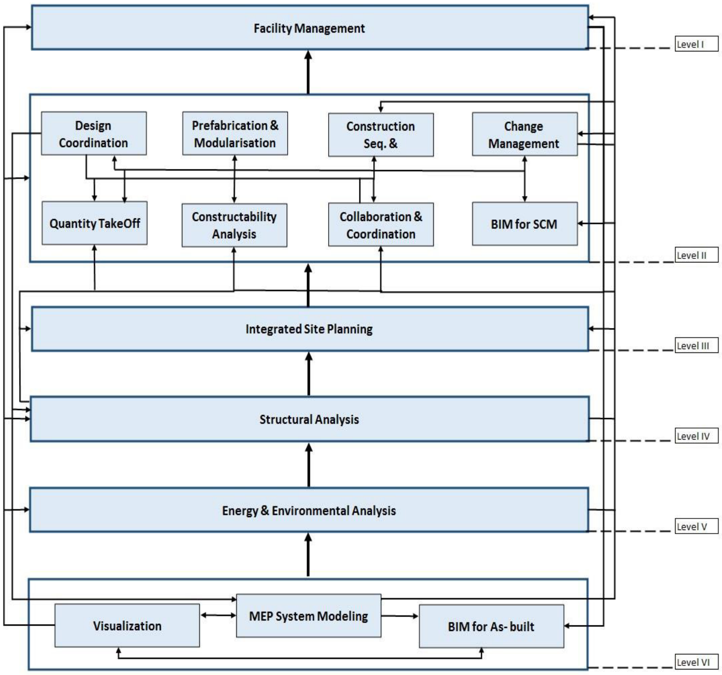

Figure 1: ISM Based model for BIM capabilities

4. MICMAC Analysis

After defining the levels to various BIM capabilities, the MICMAC analysis was used to analyze the driving and dependence power of these BIM capabilities [59] with valuable insights about their relative importance, nature and interdependencies. On the basis of the driving and dependence power, under the MICMAC analysis, each BIM capability was classified into four clusters as shown in Figure 2 , namely autonomous BIM capability, dependent BIM capability, linkage BIM capability, and independent BIM capability. The first cluster which is located in the south-west quadrant, consisted of the autonomous BIM capabilities that had weak driving power and weak dependence. These capabilities were reported to be relatively disconnected from the model. In the current research, no such capability was reported. The second cluster consisted of the dependent BIM capabilities that had weak driving power but strong dependence on other capabilities. ‘Facilities management’ (capability 11) that took the top position in ISM model came under this category. This category of BIM capability forces BIM users for greater consideration and deeper analysis as successful facility management is possible only if other capabilities are successfully implemented. Third cluster consisted of 8 linkage capabilities which showcased high driving as well as high dependence power. Many BIM capabilities including ‘design coordination’ (capability 2), ‘prefabrication & modularisation’ (capability 3), ‘construction scheduling and sequencing’ (capability 4), ‘integrated site planning’ (capability 6), ‘change management’ (capability 7), ‘quantity take-off’ (capability 10), ‘collaboration & coordination’ (capability 13), and ‘BIM for Supply chain management’ (capability 15) came under this category. These capabilities were reported to have an effect on other capabilities and also a feedback on themselves, hence they were considered as unstable. These capabilities were not only dependent on other capabilities but they were also found to drive the top-level BIM capabilities. These BIM capabilities are most important and require maximum attention of BIM implementers to achieve favourable results. For a desired result, BIM users need to implement these capabilities with scrupulous detail as these capabilities have the highest power to drive other BIM capabilities and are also equipped with strong dependence on other capabilities. The fourth cluster included of the independent BIM capabilities which were reported to have strong driving power but weak dependence power. These include ‘visualization’ (1), ‘energy & environment analysis’ (5), ‘structural analysis’ (8), ‘MEP system modelling’ (9), ‘constructability analysis’ (12), and ‘BIM for as-built’ (14). These BIM capabilities primarily lie at the bottom of ISM model and condition the entire system. These are considered with utmost importance since they can influence and help in achieving other capabilities to the maximum extent.

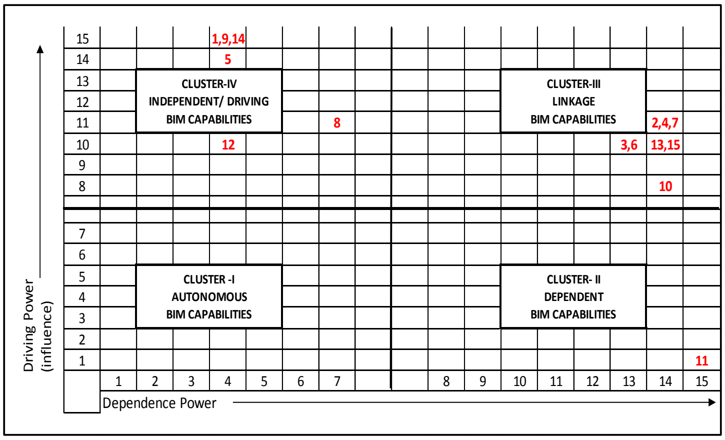

Figure 2: MICMAC Analysis for BIM capabilities

5. Discussion and Conclusion

Successful BIM adoption and implementation by AEC industry in India is foreseen to improve the current status, potential and performance of the industry. For greater adoption of BIM in India, it is important to identify and assess critical BIM capabilities at an organizational level. In this study, several existing functions of BIM have been examined to develop fifteen BIM capabilities which are responsible for success of the project. Amongst these BIM capabilities, each of them is categorized according to its driving and dependence power which provides BIM adopters with a robust idea of their importance in terms of its usage and implementation to attain successful results. This analysis is provided by ISM identifying the hierarchy of capabilities to be adopted by BIM users in order to overcome various challenges faced by the construction industry and to efficiently use BIM to its highest potential. The ISM model obtained and the findings have been elaborated in detail in this section. The ISM model depicts that the implementation of 'visualisation', 'MEP system modeling', 'BIM for as-built' leads to 'energy & environmental analysis'. This finding can be validated with the statement from the Autodesk [36] that "Building information modeling (BIM) solutions make sustainable design practices easier by enabling architects and engineers to more accurately visualize, simulate, and analyze building performance earlier in the design process". A sustainable design is further found to help achieve the 'structural analysis'. This is validated by in the report by Autodesk [43] mentioning that by implementing energy analysis and material takeoff tools, more efficient and predictable structural designs can be achieved with a focus on waste and embodied energy minimization. After successful implementation of the stated BIM capabilities, integrated site planning holds an important centre position as it relates to the execution of design and planned activities on site. It forms the connection between the planned and actual work with the help of different BIM functions as 'design coordination', 'prefabrication & modularisation', 'construction sequencing & scheduling', 'change management', 'quantity takeoff', 'constructability analysis', 'collaboration & coordination' and "BIM for supply chain management". These BIM capabilities have to be implemented on the project simultaneously in order to achieve a data rich information model which can contribute to efficient 'facility management' and use for AEC-FM industry.

This paper brings out the logical and conclusive hierarchical relationship for the BIM capabilities. However, due to several limitations, the findings are not statistically validated. Although, a majority of previous research have used Structural Equation modeling (SEM) to validate such hypothetical models but it is suggested that future research can adopt any appropriate statistical tool for further validating the model. The implication of these findings include better deployment of BIM for AEC industry in India. The findings of this study are extremely crucial for AEC organizations, industry professionals, decision makers, consultants and researchers to understand and implement BIM on construction projects for achieving satisfactory benefits. This study may help BIM adopters plan strategic BIM implementation and also provide decision makers a platform to evaluate the applicability of various BIM capabilities in India.

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