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Micro BIM Adoption: Identifying Cause and Effect Factors and Analysing their Inter-dependencies using a Fuzzy DEMATEL Approach

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Abstract

Several factors affect the process of BIM adoption within organisations (i.e. micro BIM adoption). An extensive collection of such factors were included in a unified BIM adoption taxonomy published in Ahmed and Kassem (2018). These factors are distributed across three areas of adoption drivers: the characteristics of the innovation itself (i.e., BIM), the external environment, and the internal environment of the adopting organisation. BIM adoption is a multi-staged process that entails varying interactions between factors from across the three driver areas and the stages of the BIM adoption process. Hence, this study argues for an improved understanding of the adoption topic beyond the current level offered by common approaches such as ranking factors affecting adoption (conceived as a single decision/milestone) and analysing correlations. In particular, there is a need to analyse the complex inter-dependencies between factors affecting the adoption process and its individual stages (i.e., awareness, intention, decision, etc.). This paper aims to understand these inter-dependencies by considering the micro BIM adoption as a complex system. The paper investigates the relative levels of influence between the factors affecting the system and classifies such factors in cause and effect factors at different stages of the adoption process. To achieve this objective, the research employs the Fuzzy Decision Making Trial and Evaluation Laboratory (F-DEMATEL) method. The application of the F-DEMATEL considered the top 11 factors (as identified in Ahmed and Kassem, 2018) that affect BIM adoption within the UK Architecture sector. The F-DEMATEL was applied for the entire adoption process as a 'single' system (i.e. without separating it into multiple stages) and for each individual stage (i.e. awareness, intention, and decision). The results from the F-DEMATEL (i.e., classification of factors into cause and effect groups and into four quadrants, and their inter-relationships) provided a new understanding of the BIM adoptions process. These results can be used to tailor and prioritise BIM implementation actions and investments when develop micro BIM adoption strategies.

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1. Introduction

Building Information Modelling (BIM) connotations have significantly increased over time and is now considered as the current expression of digital innovation within the construction sector (Succar and Kassem, 2015). The disruptive nature of BIM as an innovation is manifested across three clusters of the organisational scale: Macro, Meso and Micro. At the Macro level, BIM is attracting the attention of market-wide players such as major public and private sector procurers and suppliers, and regional and national authorities (Kassem and Succar, 2017). The effect of BIM at the Macro scale is also exemplified by the emergence of maturity models for measuring market-wide maturity (as in Kassem and Succar, 2017), and the significant effort by many regional and national public authorities to promote BIM adoption through the launch and implementation of national BIM initiatives. At the Meso scale, BIM disruption is evident by the need to: change the conventional inter-organisational relationships and adapt procurement systems for BIM-enabled project (Hatem, 2008, McAdam, 2010, Papadonikolaki, 2017); share risks and rewards by project participants (Ghassemi and Becerik-Gerber, 2011); improve technical interoperability and communication among the project participants (Ghassemi and Becerik-Gerber, 2011). At the Micro scale, BIM is bringing a new set of processes, technologies and policies (Succar, 2009). Studies to understand BIM adoption have been scattered across these three levels. However, the key limitations in most of the existing studies include: the contemplation of 'adoption' as a milestone or a decision instead of a multi-staged process; the accounting for a limited number of factors affecting adoption; the unclear delineation between related concepts such as 'adoption', 'implementation', and 'diffusion'; and the limitations of investigations to aspects such as ranking factors affecting adoption and analysing their correlations. This study builds up on previous work that identified an extensive array of adoption factors as part of a unified BIM adoption taxonomy and calculated their levels of influence on the first three stages of the BIM adoption process (i.e. awareness, intention, and decision) (Ahmed and Kassem, 2018) by classifying the factors into cause and effect groups and analysing their interdependencies. To this end, this study employs the Fuzzy Decision Making Trial and Evaluation Laboratory (F-DEMATEL) method by considering the 11 top factors that influence the BIM adoption process. The next two section will present the F-DEMATEL method and the findings, respectively. The final section will discuss and conclude.

2. Methodology and research methods

The top 11 factors, identified in Ahmed and Kassem (2018), as top influencing factors on the BIM adoption process are used in this study. These factors are: Willingness to adopt BIM (F1), Communication behaviour of an organisation (F2), Observability of BIM benefits (F3), Compatibility of BIM (F4), Social motivations among organisation's members (F5), Relative advantage of BIM (F6), Organisational culture (F7), Top management support (F8), Organisational readiness (F9), Coercive pressures (Governmental mandate, informal mandate) (F10), and Organisation size (F11). The F-DEMATEL, which is an expanded approach from the DEMATEL method, is used to classify these factors into cause and effects group and to analyse their potential inter-dependencies while influencing the adoption process.

The decision-making trial and evaluation laboratory (DEMATEL) approach is a technique for constructing and analysing a structural model for investigating the impact of causal relationships amongst an array of interacting factors (Wu and Lee, 2007). DEMATEL aims at directly comparing the interdependency relationship among elements, attributes, and criteria of a system and utilising matrices to analyse the direct and indirect causal relationships and impact level among elements. These relationships are envisaged exploiting the 'graphical structural matrices' and 'causal diagrams' (i.e., digraphs) to interpret and verify the contextual causal relationships and impact level among the elements in the complex system and support in decision-making (Lee et al., 2010). Hence, DEMATEL can transform a complex system into a clear causal relationship with a well-defined structural model. Simplifying the interactions among elements in the complex system into a justified cause and effect relationship via the interaction impact level among quantified elements assists in discovering the central problem in the complex system and improving direction (Wu and Lee, 2007).

In many industries, numerous business organisations rely on ‘group decision-making’ to locate an agreeable resolution in actual decision-making problems. However, in decision-making problem associated with complex systems, the assessment presented by decision-makers or experts on subjective principles of a specific item is constantly communicated in linguistic expressions rather than crisp values, depending on expertise and knowledge (Lin, 2013). To address potential inaccuracies when formulating decisions, fuzzy set theory is used to quantify vague perceptions involved in judgments (Wu and Lee, 2007). Arithmetically, every number in the fuzzy set between 0 and 1 denotes a fractional fact, while crisp sets conform to 0 or 1 binary logic (Wu and Lee, 2007, Lin, 2013).

The fuzzy linguistic process involves transforming linguistic wording into fuzzy numbers after which de-fuzzifying these fuzzy numbers is applied to obtain accurate values (Tsaur and Kuo, 2011, Lee et al., 2014) (Table 1). The defuzzification solution implemented in the current study utilises the minimum and maximum fuzzy number to define the left and right edge values respectively. The total integral value is calculated based on the weighted average of the membership function. Determining the crisp values of the fuzzy set numbers $\tilde{A}$ are described in the steps below using the triangular fuzzy numbers $\tilde{N}$ method (Chang et al., 2011, Lee et al., 2014):

Table 1 The triangular fuzzy linguistic scale set

Linguistic terms/influence	Score	Triangular Fuzzy Number
No influence	0	(0, 0, 0.25)
Very low influence	1	(0, 0, 0.25)
Low influence	2	(0.25, 0.50, 0.75)
High influence	3	(0.50, 0.75, 1.00)
Very high influence	4	(0.75, 1.00, 1.00)

A structured questionnaire survey was used to collect the data required for the F-DEMATEL method in order to identify and analyse the potential interdependencies among the factors that influence the process of BIM adoption. The questionnaire included two sections. The first section aimed to obtain the respondents’ level of agreement with 110 statements signifying pair-wise relationships between each pair of potentially interacting factors (i.e. 11 factors x 10 relationships) using a five-point Likert scale. The definitions (Table 2) of the most influencing factors on the BIM process were presented to the respondents in the introductory part of the questionnaire. The second section of the questionnaire was intended to capture demographic information (e.g., gender, job title, and age) to verify the responses from selected and invited respondents. The respondents required to be knowledgeable about the process of BIM adoption within organisations as either internal or external change agents. 12 valid responses were returned and two incomplete responses were discarded.

Table 2 Definitions of the most influencing factors/ evaluation criteria of the F-DEMATEL Questionnaire

Factors	Definitions
Willingness to adopt BIM (F1)	Refers to the favourable or unfavourable attitude of organisation or a decision-making unit towards the innovation/ BIM.
Communication behaviour of an organisation (F2)	The degree of openness and engagement of an organisation with social groupings and networks interested in innovation adoption and promotion.
Observability of BIM benefits (F3)	The degree to which the results from innovation/BIM adoption are visible and tangible.
Compatibility of BIM (F4)	The degree to which an innovation/BIM aligns with potential adopter’s previous experiences and current needs and values.
Social motivations among organisation’s members (F5)	The motivation to engage in behaviours that benefit others such as considering others’ perspectives, stimulating knowledge exchange, and focusing on collective goals.
Relative advantage of BIM (F6)	The degree to which an innovation/BIM is perceived as being better than the system/practice it replaces.
Organisational culture (F7)	The shared norms, beliefs, principles, and traditions - held by the members of an organisational practice – which contribute to the members’ understanding of the organisational functioning.
Top management support (F8)	The degree to which senior management understands the importance of the innovation/BIM function and the extent to which they are involved into promoting the system adoption.

Organisational readiness (F9)	The extent to which organisational members are psychologically and behaviourally prepared to implement a change, their mutual determination to perform the change, and their mutual faith in their aggregate capacity to achieve the change.
Coercive pressures (Governmental mandate, informal)	The formal and informal forces applied to organisations by other organisations (public and private clients/employers, etc.).
Organisation size (F11)	The total number of full-time members of staff of an organisation (e.g., micro, small, medium, and large).

The F-DEMATEL method was applied according to the following steps:

- **Step 1:** Identify the criteria's influential factors/elements within the complicated system under investigation, and a measurement scale to determine the direction and the degree of influence of the relationships among the elements of the criteria. Then, pairwise relationships are established based on the views and experience of the experts/respondents. The comparison scale may comprise five level of influences (See Table 1).
- **Step 2:** Formulate the initial direct-influence matrix K , which is an $n \times n$ matrix, determined from the pairwise comparisons of the influences and the directions among the criteria's factors. $K = [k_{ij}]_{n \times n}$, where k_{ij} is the level of influence that criterion i exerts on criterion j (Equation 1).

$$K = \begin{pmatrix} 0 & k_{12} & \cdots & k_{1n} \\ k_{21} & 0 & \cdots & k_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ k_{n1} & k_{n2} & \cdots & 0 \end{pmatrix} \quad (1)$$

- **Step 3:** Calculate a normalised direct relation matrix N using Equations 2 and 3, where all main diagonal elements are equal to zero.

$$I = \frac{1}{\max_{1 \leq i \leq n} \left[\sum_{j=1}^n k_{ij} \right]}, \quad i, j \in \{1, 2, \dots, n\} \quad (2)$$

$$N = I \cdot K \quad (3)$$

- **Step 4:** Calculate the total relation/impact matrix T using Equation 4, where I is the identity matrix.

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

- **Step 5:** Calculate the crisp values using Equation 5

$$k_j^{crisp} = \left[k_j^{ls} \left(1 - k_j^{ls} \right) + kps_{ij}^n \times kps_{ij}^n \right] / \left[1 - k_j^{ls} + k_j^{ps} \right] \quad (5)$$

- **Step 6:** Calculate the sum of the values of each row D and each column R separately of the total relation matrix, D_i and R_j denote the sum of rows (i.e., direct influences) and columns (i.e., indirect influences) respectively, using Equations 6, 7, and 8.

$$T = \begin{bmatrix} t_{ij} \\ n \times n \end{bmatrix}, \quad i, j \in \{1, 2, \dots, n\} \quad (6)$$

$$D_i = \begin{bmatrix} n \\ t_{ij} \\ i=1 \end{bmatrix}, \quad i, j \in \{1, 2, \dots, n\} \quad (7)$$

$$R_j = \begin{bmatrix} n \\ t_{ij} \\ J=1 \end{bmatrix}, \quad i, j \in \{1, 2, \dots, n\} \quad (8)$$

- **Step 7:** Visualise the DEMATEL cause and effect digraph by plotting the dataset of $(D+R, D-R)$. $(D+R)$ represents the total 'Importance' level of each criterion/factor whereas $(D-R)$ denotes the 'Relation' and helps to categorise the criteria into cause-and-effect groups. When the $(D-R)$ is positive, the criterion belongs to the 'cause group', otherwise, it belongs to the 'effect group'.

3. The F-DEMATEL model of the whole system of BIM adoption process (11 factors/ time-independent)

In the causal diagram (or also called 'Impact-digraph Map' of the 11 criteria) (Figure 1a), the values of $(D+R)$ and $(D-R)$ are represented by the horizontal axis and the vertical axis, respectively. The $(D+R)$ value determines the degree of significance of the factor on the process of BIM adoption. The $(D-R)$ value categorises the factors into cause group and effect group. The results have revealed two groups of factors (Table 3 and Table 4): *cause group (influencing factors)* with high centrality degree and positive causal degree; and *effect group (affected factors)* with high centrality degree and negative causal degree, which are interdependent. In a descending order of their average influence, the cause group's factors are: Organisation size (F11), Coercive pressures (Governmental mandate, informal mandate) (F10), Relative advantage of BIM (F6), Observability of BIM benefits (F3), Compatibility of BIM (F4), and Organisational readiness (F9). The effect group's factors are Willingness to adopt BIM (F1), Top management support (F8), Communication behaviour of an organisation (F2), Social motivations among organisation's members (F5), and Organisational culture (F7). The cause factors have an influence on the whole system, and the effect factors tend to be easily influenced by the other factors. The causal diagram can be further divided into four quadrants (Figure 1b):

- Quadrant I: It contains the 'Core' factors with high prominence and high relation. These are *Relative advantage of BIM* (F6), *Observability of BIM benefits* (F3), and *Organisational readiness* (F9). These cause factors influence most of the effect factors in Quadrant IV and their resolutions contribute to unlock many factors within the system. Hence, these factors should be prioritised and addressed first in a BIM adoption strategy.
- Quadrant II: Includes the 'Driving' factors - or also called autonomous givers - with low prominence and high relation. These factors are *Organisation size* (F11), *Coercive pressures* (F10), and *Compatibility of BIM* (F4). These factors are somewhat independent (e.g. cannot be influenced easily) but they have influence on many other factors within the system (i.e., effect factors in Quadrant IV).
- Quadrant III: It contains independent factors or autonomous receivers. It includes only one factor, *Organisational culture* (F7), which is relatively an independent factor due to its low prominence and low relation. It can either be individually solved or may be influenced only by a few other factors within the system (i.e., F1 and F8 of effect Quadrant IV).
- Quadrant IV: Includes the 'effect' factors with high prominence and low relation. This quadrant comprises of four factors; *Willingness to adopt BIM* (F1), *Top management support* (F8), *Communication behaviour of an*

organisation (F2), and Social motivations among organisation's members (F5). These factors are influenced by other factors and represent a core cluster that must be managed. However, they cannot be addressed directly. This cluster include F1 (*Willingness to adopt BIM*) which has the highest influence.

Table 3 The De-Fuzzified total relation matrix T of the whole system of BIM adoption process (11 factors)

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
F1. Willingness	0	0.061	0.050	0.045	0.054	0.047	0.061	0.059	0.056	0.042	0.031
F2. Communication behaviour	0.071	0	0.064	0.060	0.063	0.059	0.058	0.061	0.063	0.044	0.027
F3. Observability of BIM	0.073	0.064	0	0.063	0.060	0.065	0.050	0.078	0.050	0.042	0.029
F4. Compatibility of BIM	0.068	0.057	0.057	0	0.061	0.056	0.050	0.069	0.051	0.042	0.029
F5. Social motivations	0.074	0.070	0.050	0.047	0	0.056	0.056	0.061	0.049	0.038	0.029
F6. Relative advantage of BIM	0.077	0.073	0.065	0.069	0.058	0	0.055	0.074	0.057	0.044	0.030
F7. Organisational culture	0.073	0.065	0.046	0.043	0.065	0.056	0	0.066	0.058	0.043	0.028
F8. Top management support	0.074	0.069	0.051	0.043	0.053	0.045	0.059	0	0.061	0.043	0.035
F9. Organisational readiness	0.071	0.065	0.057	0.052	0.059	0.066	0.051	0.065	0	0.042	0.032
F10. Coercive pressures	0.074	0.066	0.047	0.044	0.059	0.052	0.058	0.079	0.058	0	0.036
F11. Organisation size	0.064	0.064	0.050	0.047	0.057	0.044	0.057	0.059	0.049	0.043	0

Table 4 The F-DEMATEL results of the whole system of BIM adoption process (11 factors)

Factors	D	R	Defuzzified (D+R)	Rank	Defuzzified (D-R)	Cause/Effect
F1. Willingness	0.529	0.743	1.272	11	-0.214	Effect
F2. Communication behaviour	0.594	0.678	1.272	3	-0.084	Effect
F3. Observability of BIM	0.597	0.559	1.156	2	0.038	Cause
F4. Compatibility of BIM	0.563	0.535	1.099	7	0.028	Cause
F5. Social motivations	0.554	0.611	1.164	9	-0.057	Effect
F6. Relative advantage of BIM	0.626	0.569	1.195	1	0.056	Cause
F7. Organisational culture	0.565	0.576	1.141	6	-0.011	Effect
F8. Top management support	0.555	0.694	1.249	8	-0.139	Effect
F9. Organisational readiness	0.582	0.576	1.158	5	0.006	Cause
F10. Coercive pressures	0.592	0.444	1.036	4	0.149	Cause
F11. Organisation size	0.553	0.325	0.878	10	0.228	Cause

a

b

Figure 1 (a) Impact Relation Map depicts the cause and effect relationships and interdependencies among the most influencing factors affecting the process of BIM adoption; (b) Causal diagram (Digraph) of the interdependent cause and effect relationships among the most influencing factors

4. Findings and Conclusions

Together the three factors in the first quadrant (F6, F3, and F9) and second quadrant (F11, F10, and F4) that represent the core factors and the driving factors affect the four factors of the fourth quadrant (F1, F8, F2, and F5). Thus, this suggests that to address the effect group factors in the BIM adoption process, it is necessary to first target the core factors and the driving factors that must be given more attention by decision makers within the adopting organisations. This means that implementation actions aimed at addressing BIM characteristics [i.e., *Relative advantage* (F6), *Observability* (F3), and *Compatibility of BIM* (F4)] may simultaneously contribute to fulfil some of the internal environment characteristics [i.e., *Organisational readiness* (F9), *Organisational culture* (F7), *Social motivations among organisation's members* (F5), *Communication behaviour of an organisation* (F2), *Top management support* (F8), and *Willingness to adopt BIM* (F1)]. This involves, for example, implementation actions to reinforce the perceived benefits obtained from adopting BIM (F6), which may contribute to increase the openness and engagement of the potential adopters with social groupings and networks interested in BIM adoption and promotion (F2); stimulate more willingness to adopt BIM (F1); and invite more executive support (F8) to facilitate the BIM adoption process. Similarly, demonstrating visible and tangible results of successful BIM adoption examples of other organisations (F3), and clarifying how BIM could be aligned with the adopter's previous experiences and current needs and values (F4), may also affect *Top management support* (F8) and *Willingness to adopt BIM* (F1)].

Combining the shared norms, beliefs, and traditions (F7), held by the members of an organisational practice, with *Organisational readiness* may contribute to stimulate *Willingness to adopt BIM* (F1). Consequently, strengthening the BIM innovation characteristics (F6, F3, and F4) together with organisational characteristics (F9, F7, F5, F2, and F1) may invite more executive support in the organisations [i.e., *Top management support* (F8)].

A BIM mandate [i.e., *Coercive pressures (Governmental mandate, informal mandate)* (F10)], as an independent factor, exert influence on two other factors only, the executive support in organisations (F8) and the willingness to adopt BIM (F1), both of which are affected by most of the other core factors involved in the system.. Therefore, potential mandatory BIM requirements (e.g. market-wide mandate by government or ad-hoc mandates by specific appointing parties) may have an influence on BIM adoption and diffusion across the industry although this was not identified as one of the most prominent factors driving adoption and diffusion. .

Organisation size (F11) was identified as an independent mostly influencing *Willingness to adopt BIM* (F1) and *Communication behaviour of an organisation* (F2) . This means that the level of influence exerted by the various factors influencing involved in the system may vary according to the different sizes of organisations (i.e., micro, small, medium, and large). To understand these potential relationships, further analysis such as the application of the F-DEMATEL approach on organisations of different sizes is required.

The results from the F-DEMATEL (i.e., classification of factors into cause and effect groups and into four quadrants, and their inter-relationships) provided a new understanding of the BIM adoptions process. These results can be used to tailor and prioritise BIM implementation actions and investments when develop micro BIM adoption strategies. Factors classified as Core factor (Quadrant 1) should receive most of the attention and investment as their resolutions will subsequently unlock most of the other factors within the adoption system. However, the presence of pairs of such factors within the environment of the adopting environment may trigger new dynamics. Hence, a further understanding of the adoption problem is required. To address this need in future work, the authors will combine the results from the DEMATEL with those from the correlation analysis to develop systems thinking models for the micro BIM adoption problem.

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