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Adoption of BIM by Architectural Firms in India: Technology-Organization-Environment Perspective

Abstract: Building Information Modelling (BIM) is being heralded as a remarkable innovation in the built environment sector with expectations of lofty sector-wide improvements. Some countries have shown remarkable levels of uptake of BIM, along the way documenting some evidence of benefits stemming from BIM. However, countries like India and China are late entrants in the BIM adoption journey and are seeing a slower adoption rate. This study develops a model using the Technology–Organization–Environment framework to study the factors influencing BIM adoption by architectural firms in India and reasons for this slow adoption. The proposed model of BIM adoption is tested using Partial Least Square method against responses collected from 184 industry professionals based in India. Findings reveal that the adoption of BIM by Indian architectural firms is at the "experimentation" stage with variables such as expertise, trialability, and management support exhibiting a strong positive influence on BIM adoption. The study also explains the status of BIM adoption in India with the help of a multi-level social construct, which places the level of BIM adoption in India between the micro-and meso level of organizational scales. Similarities and dissimilarities with previous findings are discussed in the paper to highlight the findings of this study.

Keywords: Building Information Modelling (BIM); architectural firms; Partial Least Square; Technology-Organization-Environment framework; BIM adoption

Introduction

Building Information Modelling (BIM) is viewed as an "epochal transition" in design practice (Eastman, Teicholz, Sacks, & Liston, 2011). Roles and responsibilities of major stakeholders are changing due to the ongoing adoption of BIM (Sebastian, 2011). Broadly for the architecture profession three major shifts are happening: (1) architectural design-practices are changing; (2) design culture itself is changing; and (3) effort expended on non-value adding activities during design and analysis is reducing (Coates et al., 2010; Sawhney, 2014a). Architectural firms are among the first to adopt BIM (McGraw Hill Construction, 2014b; NBS, 2015). Design team initiation is the most common method of BIM adoption; reported at 58% in the US and 90% in the UK (McGraw Hill Construction, 2014b). A study by Elmualim and Gilder (2014) found that the design team and the client encourages innovation pertaining to application of BIM. Anecdotally there are reports that some specialty contractors were early adopters of BIM. Nevertheless, in most mature markets, BIM adoption has become much more pervasive with some countries reporting BIM adoption among contractors exceeding that by architects and designers. In countries where BIM usage is high, it has also become evident that from the initial "lonely" BIM the transition has either taken place or is taking place to a more collaborative or social form of BIM.

India is going through major urbanization and economic development. There are estimates that India will build 700 to 900 million square meters of residential and commercial space annually for the next decade or so (McKinsey Global Institute, 2010). With this expected volume of construction, the Indian Architecture, Engineering and Construction (AEC) sector is poised to play a significant role. Clearly, the architectural organizations in India need to gear up to this challenge that will require architectural firms to embrace modern and efficient methods of design, collaboration and documentation. With this background, architects in India cannot overlook the use of BIM. Research conducted by Arayici et al. (2011b); Navendren, Manu, Shelbourn, and Mahamadu (2014); Ramilo and Embi (2014) has shown that BIM adoption yields efficiency gains, helps elimination of waste and generates value in small and medium architectural firms.

The authors undertook a study to understand adoption of BIM by Indian architectural firms with the hope that these findings will help determine similarities in BIM adoption amongst other emerging nations and to find similarities (and dissimilarities) in the BIM adoption journey between mature and less mature markets. Therefore, it is important to answer the following in the Indian context. The research questions, which this study aims to answer, are:

- Does a similar pattern of BIM adoption journey exist in other less mature markets like India?
- Is the situation similar in developing economies who have been late entrants to the BIM adoption landscape (Xu, Feng, & Li, 2014)?
- Can BIM provide similar benefits to the architectural firms in India?

This research addresses the questions listed in this section by conducting a survey of Indian architectural organizations.

The rest of this article is structured as shown in Figure 1 below. First, there is discussion on literature related to BIM adoption and Technology –Organization- Environment (TOE) framework. Second, the research hypotheses are formulated and the structural model is developed. The study uses descriptive multi-level framework as proposed by Moum (2010) to understand the adoption and implementation of BIM within architectural firms in India. The study examines the role of project teams and their influences across organizational boundaries (Eastman et al., 2011) to promote an effective project-wide adoption of BIM. In doing this the study also examines macro, meso and micro level organizational scales (Succar, Sher, & Williams, 2012) to identify the enablers and inhibitors affecting BIM adoption in India. Next, the methodology (data collection and analysis) is outlined and the results of the data analysis are presented. Finally, the article concludes with a discussion of the implication of the study and possible topics of future research.

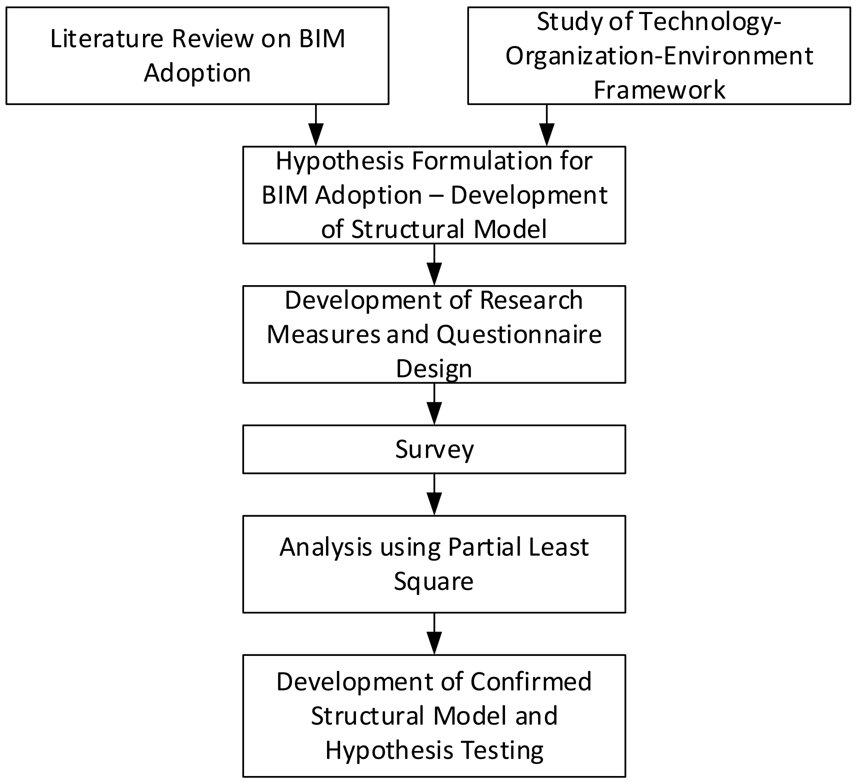

Figure 1: Flow diagram showing research process

Literature Review

In the last decade, BIM has received a lot of attention in both the practitioners' and researchers' community. A recent study found that between 2004 and 2014, 975 academic papers were published in the area of BIM (Yalcinkaya & Singh, 2015). The "what", "why" and "how' of BIM at the macro level has now been adequately addressed in the popular literature. An authoritative information source for practitioners and scholars is the BIM handbook by Eastman et al. (2011). Annual surveys in mature markets with some global perspectives are now commonly available (McGraw Hill Construction, 2014a; NBS, 2015;Sawhney, 2014b) in the industry.

Perceived and actual benefits of BIM implementation on projects have been investigated and documented in popular literature within the research and professional communities. BIM has been portrayed as a 'change agent' with benefits including added value to clients (McGraw Hill Construction, 2014b); increased quality of communication and information flow (Mahalingam, Yadav, & Varaprasad, 2015; Sacks, Koskela, Dave, & Owen, 2010); enhanced visualization (Forgues, Staub-french, Tahrani, & Poirier, 2014); design error reduction (Love, Edwards, Han, & Goh, 2011); collaboration in design and construction (Sacks et al., 2010); reduction in variation and cycle times (Ahuja, Sawhney, & Arif, 2014); improved design coordination (Hooper & Ekholm, 2010) and accurate quantity estimation (Sabol, 2008). The McGraw Hill Construction (2014a) states that BIM helps to reduce rework and clashes, improve productivity and reduce overall project duration.

With the help of Latent Semantic Analysis technique Yalcinkaya and Singh (2015) have traced a timeline of research activities in BIM and demonstrated that research focused upon implementation and adoption of BIM is the most trending principal area of interest. While the importance and benefits of BIM adoption have been documented (Barlish & Sullivan, 2012), the extant literature has tended to provide limited importance to the study of inhibitors and facilitators of BIM adoption in the architectural fraternity from regions where adoption remains low.

Miettinen and Paavola (2014) state that BIM needs to be analysed as a multidimensional, historically evolving and a complex phenomenon. Challenges faced during the process of implementing new technology and presence of unidentified risk factors can reduce the expected performance (Chien, Wu, & Huang, 2014). These risk factors if identified, understood and analysed at an earlier stage, can allow BIM users to adopt and implement BIM successfully (Chien et al., 2014).

Past research shows that BIM adoption can be enhanced and accelerated with the help of a well-defined tool to facilitate BIM adoption. Various factors affecting BIM adoption have also been identified which can be grouped into two main areas: technical and functional requirements, and non-technical strategic issues (Gu & London, 2010). Another study while trying to understand adoption and use of BIM as the creation of actor networks, concludes that the possibility of increased BIM application on projects is well aligned with the character of the industrial context (Linderoth, 2010).

Recently Xu et al. (2014) have documented a summary of studies focused upon identification of factors influencing BIM adoption in various parts of the world. These studies provide a broad context of BIM adoption with limited or no focus on architectural firms. Previous studies investigating BIM adoption and implementation have so far been generic in nature and have not conducted in-depth exploration of challenges being faced by specific disciplines (Navendren et al., 2014). However, a few studies are available that investigate BIM adoption specifically in the context of design firms. A review of literature by Son, Lee, and Kim (2015) reveals an empirical study that identifies the factors that facilitate adoption of BIM among architects. However, this study is limited to the identification of facilitators and does not focus on inhibitors to adoption. To succeed in BIM implementation, the complexity of BIM requirements, customers' expectations, social aspects, company's own organizational context, information and communication technologies have to be taken into consideration (Tulenheimo, 2015). Another broader study reveals that advancement of new digital innovations has the potential to improve design productivity dramatically. However, the major hindrance to the adoption process of these technologies is caused by the existence of technical and organizational barriers (Ramilo & Embi, 2014).

Adoption of BIM among Malaysian architects has been reported as very low with no clear identification of barriers that organizations are facing towards adoption (Mohd-Nor & Grant, 2014). In the UK context, several studies have been conducted to assess the adoption of BIM within architectural firms. Arayici et al. (2011a), (2011b) and Coates et al. (2010) studied adoption of BIM by a small architectural firm with a socio-technical view and documented gains in efficiency experienced by the firm. Qualitative research through semi-structured interviews to identify implementation challenges faced by ten UK design firms reported that these firms face technology related, project related, cost related and training related challenges (Navendren et al., 2014). It is not clear whether similar challenges are being reported by other architectural firms in UK or other markets. Also given that the rate of BIM adoption varies globally, with India standing amongst the lowest with just 10-18% BIM adoption rate as compared to 71% users of BIM in United states alone (Sawhney, 2014a), it might be inappropriate to apply the previous findings to the Indian context. Although the past research reports lack of expertise, complexity of BIM, resistance to explore new technology, lack of support from owners and other trade partners, reluctance to change the traditional practice, and uncertainty about BIM platform as the main reasons for not using BIM in India, these findings have not been validated (Khemlani, 2012; Kumar & Mukherjee, 2009; Sawhney, 2014b). Thus, it is imperative to study how different factors can either encourage or prevent BIM adoption in the Indian AEC sector especially among architectural firms. In order to address the above aforementioned gaps, the current research empirically examines the factors affecting BIM adoption in India within the architectural community. Currently no study focuses on studying the organization wide adoption factors for BIM using the TOE framework in India. The research specifically employs the TOE (Tornatzky & Fleischer, 1990) framework to identify the drivers and inhibitors of BIM adoption in India and to investigate the technological, organizational and environmental factors which affect architects' adoption behaviour towards BIM.

Technology-Organization-Environment (TOE) Framework

The TOE framework identifies technology, organization and environment as the three sets of contextual factors by which an organization adopts innovations (Carnaghan & Klassen, 2007). The TOE framework has a solid theoretical basis, strong empirical support & has been applied to study adoption of technological innovations (Oliveira & Martins, 2011). Figure 2 shows the TOE framework as proposed by Tornatzky and Fleischer (1990). In order to identify the constructs within TOE framework for this research, a literature review of technology adoption in small firms was conducted which ultimately led to identification of various factors that may influence the BIM adoption decision of architectural firms in India. The internal/external technologies connected to the firm describe the technological context; the descriptive attributes of the firm describe the organizational context and environmental characteristics include the industry, competitors, suppliers and government (Jain, Le, Lin, & Cheng, 2011). Our research examines the influence of complexity, compatibility, and trialability in technological context (Doolin & Al Haj Ali, 2008; Lin & Lin, 2008; Mirchandani & Motwani, 2001; Premkumar & Roberts, 1999; Ramdani, Kawalek, & Lorenzo, 2009; Roberts & Pick, 2004; Srinivasan, Lilien, & Rangaswamy, 2002; Zhu, Kraemer, & Xu, 2003); top management support, perceived financial cost and BIM expertise in organizational context (Al-Qirim, 2007; Balocco, Mogre, & Toletti, 2009; Doolin & Al Haj Ali, 2008; Grover, 1993; Huang, Janz, & Frolick, 2008; Kuan & Chau, 2001; Lin & Lin, 2008; Moore & Benbasat, 1991; Premkumar & Roberts, 1999; Zhu & Kraemer, 2005); and client requirements and trade partner readiness in environmental context (Al-Qirim, 2007; Doolin & Al Haj Ali, 2008; Lin & Lin, 2008; Premkumar & Roberts, 1999; Ramdani et al., 2009; Zhu et al., 2003)

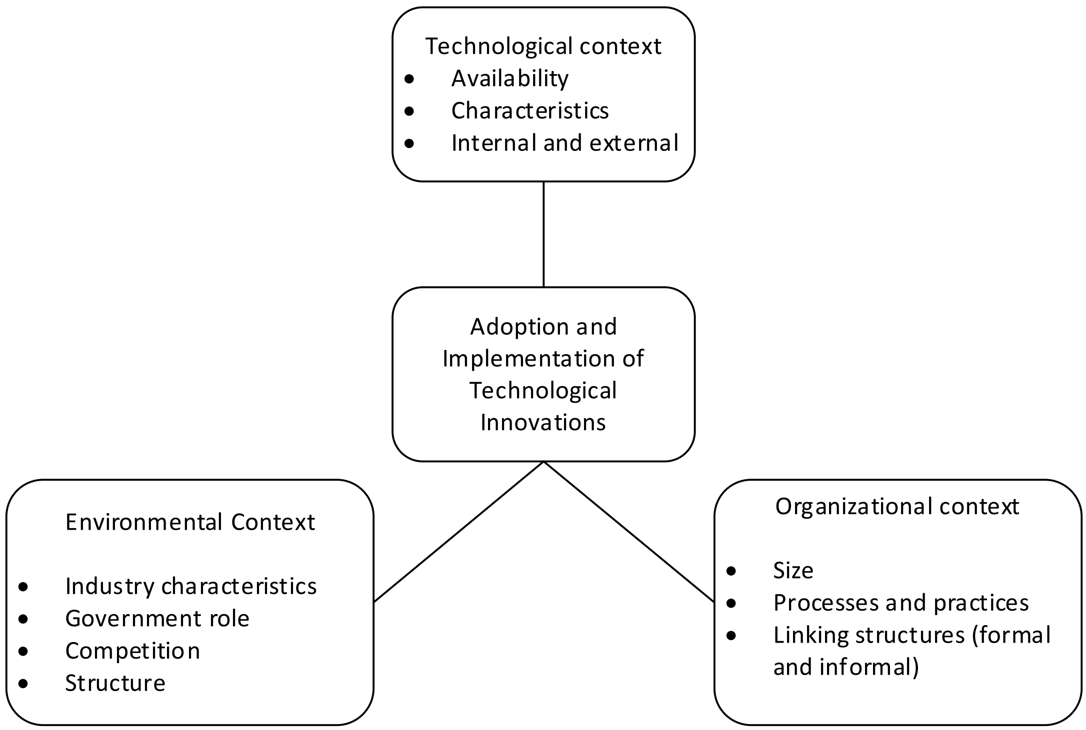

Figure 2: TOE Framework (Tornatzky & Fleischer, 1990)

In the current research, TOE framework has been used for investigating the factors affecting BIM adoption among architectural firms in India. As BIM processes require organization wide adoption (including adoption in the project delivery network) and as this research focuses on studying the BIM adoption among architecture firms (and not individuals) an organizational-level adoption theory is deemed suitable for the current research. In the past, studies have employed a number of innovation diffusion theories to study the adoption of technologies. Though Technology Adoption Model (TAM) is one of the most frequently used frameworks to study both individual and organizational level adoption, few scholars such as Oliveira and Martins (2011) have pointed that most of the theories such as Technology Adoption Model (TAM), Theory of Planned Behaviour (TPB), and Unified Theory of Acceptance and Use of Technology (UTAUT) are suitable to study adoption among individuals, while few others such as Diffusion of Innovations theory (Rogers, 1983), the Diffusion/Implementation model (Kwon & Zmud, 1987), the Tri-Core model (Swanson, 1994) and TOE framework are appropriate to study organizational level adoption. However, these theories, except TOE focus on different stages of adoption and the adoption process at different levels in an organization and are thus too broad for the scope of the current research. This study adopts the more compact TOE framework. Evidence of TOE based empirical research can be consistently seen in the research areas of information technology and commerce (Jain et al., 2011; Lin & Lin, 2008; Xu, Zhu, & Gibbs, 2004; Zhu & Kraemer, 2005). The current research adopts the TOE framework to map the trajectory of BIM adoption among Indian architectural firms. The study is built on the conjectural and empirical evidence available on the use of the TOE framework in innovation adoption.

Hypotheses Formulation

Using the TOE framework, following hypotheses were formulated and the proposed structural model was developed which was then tested and validated:

Complexity

As described by Kumar and Swaminathan (2003), an innovation which is relatively difficult to understand and use, is defined as complex. Studies reveal BIM as a complex process (Howard & Björk, 2008; Tse, Wong, & Wong, 2005). Studies conducted in 2007 in the US and Europe found that the existing BIM software is too complex to be used by most project team members (Gilligan & Kunz, 2007; Howard & Björk, 2008). Existing literature on innovation diffusion has shown that the rate of adoption decreases with the increase in implementation complexity of an innovation (Howard & Björk, 2008; Kunz, J. and Fischer, 2007; Newton & Chileshe, 2012; Russell & Hoag, 2004). That is, there is increased possibility of adoption if innovation is less complicated and is easy to use. Because of this, we hypothesize:

- H1: Complexity negatively affects BIM adoption

Compatibility

The degree of consistency and adaptability of a new innovation within an organization's existing operating procedures, needs, beliefs and values, and past experiences has been defined as being compatible (Rogers, 2003). Increased compatibility between existing policy and technology of an organization is positively correlated with the rate of innovation adoption (Rogers, 2003). In the past research it has also been observed that new technology can bring significant changes to current work practices and organizations are resistant to such change (Premkumar & Roberts, 1999). Compatibility and interoperability have been reported as major technology related barriers to BIM implementation (Azhar, Khalfan, & Maqsood, 2012). Thus, it is important that any changes related to BIM are compatible with an organization's existing norms and practices, failing which it is unlikely for BIM to become an integral part of the organization's process. Hence, we propose that:

- H2: Compatibility positively affects BIM adoption

Trialability

Degree of experimentation available with any new innovation on a limited basis is defined as trialability (Kumar & Swaminathan, 2003). An added advantage of trialability is the opportunity to examine different benefits of BIM without putting company's bottom line at risk (Panuwatwanich & Peansupap, 2013). Greater possibility of innovation trialability reduces uncertainty and tends to improve the rate of adoption. Therefore, we propose the following:

- H3: Trialability positively affects BIM adoption

Top Management Support

One of the most widely accepted conditions for innovation implementation is the support received from top management in an organization (Premkumar & Roberts, 1999). At the organizational level, it is crucial to ensure support from the top management for adoption of a new innovation (Arayici et al., 2011b; Linderoth, 2010; Xu et al., 2014). Greater encouragement from the top management leads to increased BIM adoption benefits (Cao et al., 2015; Gu & London, 2010; Xu et al., 2014). With the top management support, an organization can also ensure that appropriate changes in business processes shall be introduced for successful implementation. Because of this, we hypothesize:

- H4: Top management support positively affects BIM adoption

Perceived Cost

BIM demands a high setup cost for initiating BIM implementation on architectural projects. The costs can be categorized into one time setup costs and general system-related costs.

All the expenses necessary for providing the technical and organizational solution formulates one time setup costs (Bouchbout & Alimazighi, 2008) whereas as all the expenses pertaining to the setting up the of system and preparing the organization for participation in the BIM environment is termed as the general system-related costs. It is observed that innovations with lower perceived financial cost, are more likely to be adopted by organizations. Hence, we propose that:

- H5: High perceived cost negatively affects BIM adoption

Expertise

The availability of expertise can increase the level of innovation adoption. Expertise is believed to improve the firm's decision to implement technological innovation. Availability of appropriate Information Systems expertise can increase the inclination to adopt complex technological innovations (Crook & Kumar, 1998; Mcgowan & Madey, 1998). Empirical evidence suggests that firms with skilled and technological expert employees, have greater prospects of establishing e-business applications (Eastman et al., 2011; Lin & Lee, 2005) which suggests that highly specialized skills that are currently required, are relatively unique within the industry. Past research highlights that BIM knowledge of employees is an important adoption factor (Liu, Issa, & Olbina, 2010; Zakaria, Ali, Haron, Ponting, & Hamid, 2013). The firms with technically skilled employees are more likely to adopt BIM applications. We hypothesize that impact of expertise on BIM adoption decision is as follows:

- H6: BIM expertise positively affects BIM adoption

Trade Partner Readiness

Grover (1993) has pointed out that partner relationships and competitive pressure are significant determinants of inter-organizational systems adoption and implementation.

Competitive pressure has long been recognized as an important impetus for adopting innovations (Kuan & Chau, 2001). More competitive pressure is believed to positively affect the rate of BIM adoption in India (Sawhney & Singhal, 2013; Sawhney, 2014b). The study by Liu et al. (2010) revealed that the influence from other cooperating parties had a huge impact on company's decision to adopt BIM. Because of this, we hypothesize:

- H7: Trade partner readiness positively affects BIM adoption

Client Requirements

McGraw Hill Construction (2014) states that there is an increased and effective adoption of BIM when it is owner-driven and when project owner actively wants the project team to use BIM, and that the number of owners demanding BIM on their projects is growing worldwide (Mihindu & Arayici, 2008). The client-driven BIM mandate programs can enhance the rate of BIM adoption within architectural firms in India. Hence, we propose that:

- H8: Client requirements to implement BIM positively affects BIM adoption

Trust in Technology

Technology trust is defined as 'the subjective probability by which organizations believe that the underlying technology infrastructure is capable of facilitating transactions according to their confident expectations' (Ratnasingam, Pavlou, & Tan, 2002). Trust measures pervasive perceptions about technology credibility. Trust has been a common issue deliberated in discourses of research and practice communities (Miettinen & Paavola, 2014). It is believed that successful implementation of BIM on construction projects will lead to trust in BIM processes and applications (Eastman et al., 2011). Hence, we propose the following:

- H9: BIM adoption leads to trust in technology

Performance

Adopters of BIM believe that it helps in optimizing the time, cost and process efficiency. BIM has been identified as a lean process to coordinate, visualize information, facilitate communication and to extract accurate quantities for estimating and ordering materials (Sacks et al., 2010). Researchers envisage that an increased adoption of BIM throughout the construction industry will lead to better-perceived BIM performance. Hence, we hypothesize that:

- H10: BIM adoption leads to better perceived performance

Proposed Structural Model of BIM Adoption

The proposed structural model is illustrated in Figure 3

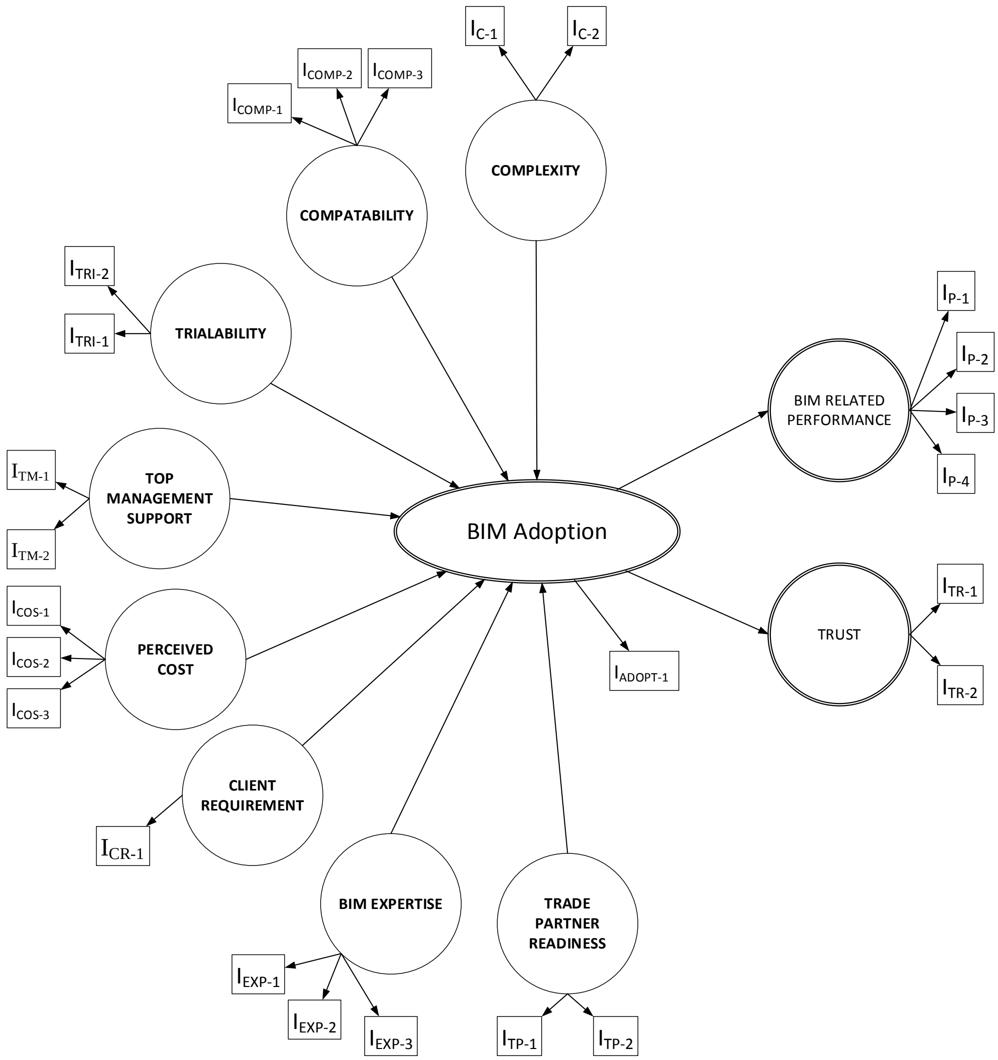

Figure 3: Proposed Structural Model of BIM Adoption among Architectural Firms in India

Circles represent exogenous latent variables or independent variable, the bold circles (with double line type) represent endogenous latent variables or dependent variables and squares represent indicator variables or items. This structural model uses the items provided in Table 1.

Table 1: Multi-item scale for the Structural Model

Complexity

$I_{C\text{-}1}$: We believe that BIM related software are complex to use

$I_{C\text{-}2}$: We believe that BIM implementation is a complex process

Compatibility

$I_{COMP\text{-}1}$: BIM process is consistent with our beliefs and values

$I_{COMP\text{-}2}$: Attitude towards BIM in our organization has always been favourable

I_{COMP3}: BIM is compatible with our existing practice

Trialability

$I_{TRI\text{-}1}$: Various software were available to us to adequately test run BIM functionalities

$I_{TRI\text{-}2}$: We were permitted to use several BIM software on a trial basis long enough to see what they can do

Top Management Support

$I_{TM\text{-}1}$: Top management is interested in the implementation of BIM

$I_{TM\text{-}2}$: Top management has effectively communicated its support for BIM

Perceived Cost

$I_{COS\text{-}1}$: BIM adoption has high set-up costs, running costs and training costs

$I_{COS\text{-}2}$: BIM adoption has high training costs

$I_{COS\text{-}3}$: Lead time for full-scale BIM implementation is relatively long

BIM Expertise

$I_{EXP\text{-}1}$: Our employees are generally aware of the BIM functions

$I_{EXP\text{-}2}$: Our firm has highly specialized or knowledgeable personnel for BIM process and implementation

$I_{EXP\text{-}3}$: Our employees are well trained in BIM

Client Requirements

$I_{CR\text{-}1}$: Majority of the owners/sponsors request implementation of BIM

Trade Partner Readiness

$I_{TP\text{-}1}$: Majority of project consultants are willing to implement BIM

$I_{TP\text{-}2:}$ Project consultants are generally very knowledgeable regarding BIM technical matters

Adoption

$I_{ADOPT\text{-}1}$: We have implemented BIM processes in some or all our projects

Trust

$I_{TR\text{-}1}$: In our opinion BIM process is very reliable

$I_{TR\text{-}2}$: We think BIM process is trustworthy

BIM related Performance

$I_{P\text{-}1:}$ Using BIM model improves the quality of work we do

$I_{P\text{-}2:}$ BIM implementation enhances our effectiveness on the job

$I_{P\text{-}3:}$ BIM implementation increases our productivity

$I_{P\text{-}4}$: BIM provides more control and coordination of construction activities

Research Design and Analysis

Research Measures and Questionnaire Design

Multi-item scales were adapted from previous literature and used to measure the constructs of interest as described in Figure 3 and Table 1.The original scale items were modified to fit the current research context and environment based on expert review and panel discussion by four experts (experts with more than 10 years of experience and expertise in BIM). Two of the panel members were industry practitioners while other two were academic professionals. The experts were individually asked to review the questions for problems and provide suggestions for revising the questionnaire. As most of the research scales have been adopted from innovation literature, the primary objective of expert panel review of questionnaire was to make the questions more specific to BIM adoption. Following this, a panel discussion among these experts resulted in generation of the measures for Client requirement and performance on the basis of literature review specifically from Chwelos, Benbasat, and Dexter (2001); Eastman et al. (2011) respectively. The questionnaire was also pre-tested with a sample of five architects. These five respondents were then interviewed and they helped in identifying words, terms or concepts that they did not understand or interpret consistently. On the basis of their feedback, necessary modifications were made in the questionnaire which were primarily limited to rephrasing of the question statements. The scales of complexity, compatibility and top management support were adapted from Grover (1993), and consisted of two items, three items and two items, respectively. The two-item scale of trialability was drawn from Moore and Benbasat (1991). Perceived financial cost and BIM expertise scales were adapted from Kuan and Chau (2001); Lin and Lin (2008) respectively and both comprised of three items. To measure trade partner readiness, trust and technology adoption, two-item scale suggested by Chwelos et al. (2001), two-item scale drawn from Belanche, Casaló, and Flavián (2012) and one-item scale drawn from Srinivasan et al. (2002) were used, respectively. A seven-point Likert-type scale with anchors from "strongly disagree" to "strongly agree" were used to measure the scale items.

To ensure that common method bias (CMB) does not affect the interpretation of results, several procedural remedies were employed in designing and administering the questionnaire. These remedies included the use of pre-validated scales, protecting respondent identity, reducing evaluation apprehension, counterbalancing of question order, and use of verbal midpoints for measures (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003).

Data Collection

The research data were collected from AEC industry professionals based in India. The sample of Indian AEC industry professionals was drawn from membership database of Royal Institution of Chartered Surveyors (RICS), India and a popular construction industry magazine. An email was sent to the identified respondents that contained a URL to the questionnaire. The initial and follow-up questionnaire requests resulted in 413 responses. 184 usable responses were eventually collected (reasons for rejection varied from incomplete response to respondent not being from the architecture domain). A post-hoc analysis revealed that the statistical power was above the threshold of 0.80 which suggested that the sample size was large enough for the current research (Cohen, 1988).

Respondent characteristics are presented in Table 2. In terms of industrial experience, almost half of the respondents (40.8%) had more than 15 years of experience and approximately one-fourth of the respondents had less than 5 years of experience in the architecture domain.

Table 2: Sample demographic characteristics

Industrial experience	**Frequency**	**%**
<5	47	25.5
5-10	32	17.4
10-15	30	16.3
>15	75	40.8
Total	184	100

Data Analysis using Partial Least Squares

Partial Least Squares (PLS), specifically SmartPLS (Ringle, Wende, & Wil, 2005), was used to estimate both the measurement and the structural models. PLS is more suitable for small samples (Chin, Marcolin, & Newsted, 2003) as in the case of the current research where the sample size of 184 was adequate but relatively small. Also the use of single-item measurement scales in the current research made PLS a more appropriate method to use as unlike covariance based Structural Equation Modelling (CB-SEM) where inclusion of single items mostly results in model under-identification, PLS-SEM has no such restriction (Xiong, Skitmore, & Xia, 2015). Additionally PLS-SEM relaxes the assumption of multivariate normality needed for CB-SEM (Hair, Sarstedt, Ringle, & Mena, 2012; Xiong et al., 2015).

Scale Accuracy Analysis

The reliability and validity statistics of research measures are presented in Table 3 and discussed next. Scale reliability was assessed in three ways—using an alpha coefficient of 0.6, a composite reliability (C.R.) index of 0.7, and an average variance extracted (AVE) value of 0.5. As shown in Table 3, all the alpha coefficients, C.R. estimates, and AVE values were above their respective cut-offs. Thus, the results provided evidence for adequate scale reliability. To assess convergent validity, factor loadings of scale items on their corresponding constructs were examined. All items loading were above the threshold of 0.7, except for one item from the scale of compatibility, which loaded weakly, prompting its removal from further analysis. The discriminant validity of the research scales was tested in two ways, including assessment of AVE values and item cross-loadings. The square root of AVE value for each scale was higher than the construct's respective correlation with all other constructs (refer Table 4). Further, for each scale, item cross-loadings were lower than its factor loadings. Together, the above results provided evidence for convergent and discriminant validity.

Table 3: Scale Accuracy Analysis

Research construct		**Cronbach α value**	**C.R. Value[a]**	**AVE[b]**	**Factor loading**	**Highest cross loading**
Complexity	I_{C-1}	0.83	0.92	0.85	0.91	0.38
	I_{C-2}				0.93	0.39
Compatibility	I_{COMP-1}	Item removed			0.66	-na-
	I_{COMP-2}	0.72	0.84	0.64	0.84	0.63
	I_{COMP-3}				0.88	0.58
Trialability	I_{TRI-1}	0.76	0.89	0.80	0.87	0.52
	I_{TRI-2}				0.91	0.45
Top Management Support	I_{TM-1}	0.91	0.95	0.92	0.95	0.63
	I_{TM-2}				0.96	0.66
Perceived Cost	I_{COS-1}	0.78	0.87	0.69	0.88	0.31
	I_{COS-2}				0.83	0.44
	I_{COS-3}				0.76	0.37
Expertise	I_{EXP-1}	0.89	0.93	0.82	0.86	0.64
	I_{EXP-2}				0.93	0.69
	I_{EXP-3}				0.92	0.70
Client Requirements	I_{TP-1}	1.00	1.00	1.00	1.00	0.67
Trading Partner Readiness	I_{TP-2}	0.83	0.92	0.85	0.94	0.63
	I_{TP-3}				0.91	0.61

Adoption	$I_{ADOPT-1}$	1.00	1.00	1.00	1.00	0.75
Trust	I_{T-1}	0.98	0.98	0.97	0.98	0.78
	I_{T-2}				0.98	0.76
Performance	I_{P-1}	0.96	0.96	0.88	0.95	0.73
	I_{P-2}				0.96	0.73
	I_{P-3}				0.93	0.76
	I_{P-4}				0.91	0.71

Note: These values are based on a 7 point Likert-type scale with strongly disagree =1 to strongly agree= 7

[a]Composite Reliability; [b]Average Variance Extracted

Scale item abbreviation: same as in Table 1

Table 4: Correlation Matrix

	ADOPTION	CLIENT REQUIREQUIREMENT	COMPLEXITY	COMPATIBILITY	COST	EXPERTISE	PERFORMANCE	TOP MANAGEMENT	TRADE PARTNER	TRIALABILITY	TRUST
ADOPTION	1.00										
CLIENT REQUIREMENT	0.38	**1.00**									
COMPLEXITY	-0.07	-0.06	**0.92**								
COMPATIBILITY	0.56	0.39	-0.07	**0.80**							
COST	0.08	0.04	0.42	0.12	**0.83**						
EXPERTISE	0.75	0.49	-0.07	0.59	0.15	**0.90**					
PERFORMANCE	0.45	0.31	-0.05	0.54	0.27	0.37	**0.94**				
TOP MANAGEMENT	0.59	0.37	0.03	0.67	0.28	0.58	0.55	**0.96**			
TRADE PARTNER	0.31	0.67	-0.08	0.37	0.09	0.40	0.34	0.35	**0.92**		
TRIALABILITY	0.46	0.41	-0.07	0.52	0.00	0.43	0.36	0.45	0.39	**0.89**	
TRUST	0.51	0.42	-0.14	0.56	0.12	0.49	0.78	0.52	0.43	0.42	**0.98**

Note: Boldface items are the square root of AVE

Confirmed Structural Model and Hypothesis Testing

Figure 4 presents the results of confirmed structural model and related hypothesis. The R-squared (R^2) was evaluated to assess the model fit of the proposed structural model. A bootstrapping re-sampling procedure (500 samples) then proceeded to test the proposed hypotheses using t-tests. As shown in Figure 2, the R^2 for BIM adoption was 0.617, suggesting 61.7 per cent of the variance in the outcome variable. The R^2 for the other two dependent variables, i.e., BIM related performance and trust were 0.210 and 0.269, respectively. Together, the results implied a satisfactory and substantial model. The results of bootstrapping re-sampling analysis indicated that the hypotheses coefficients for H3 (Trialability), H4 (Top Management Support), H6 (Expertise), H9 (Trust) and H10 (Performance) were statistically significant whereas, H1 (Complexity), H2 (Compatibility), H5 (Perceived Cost), H7 (Trade Partner Readiness) and H8 (Client Requirements) were not supported (see Figure 4). In Figure 4, the corresponding p values (represented by a, b and c) refer to the probability of observed result.

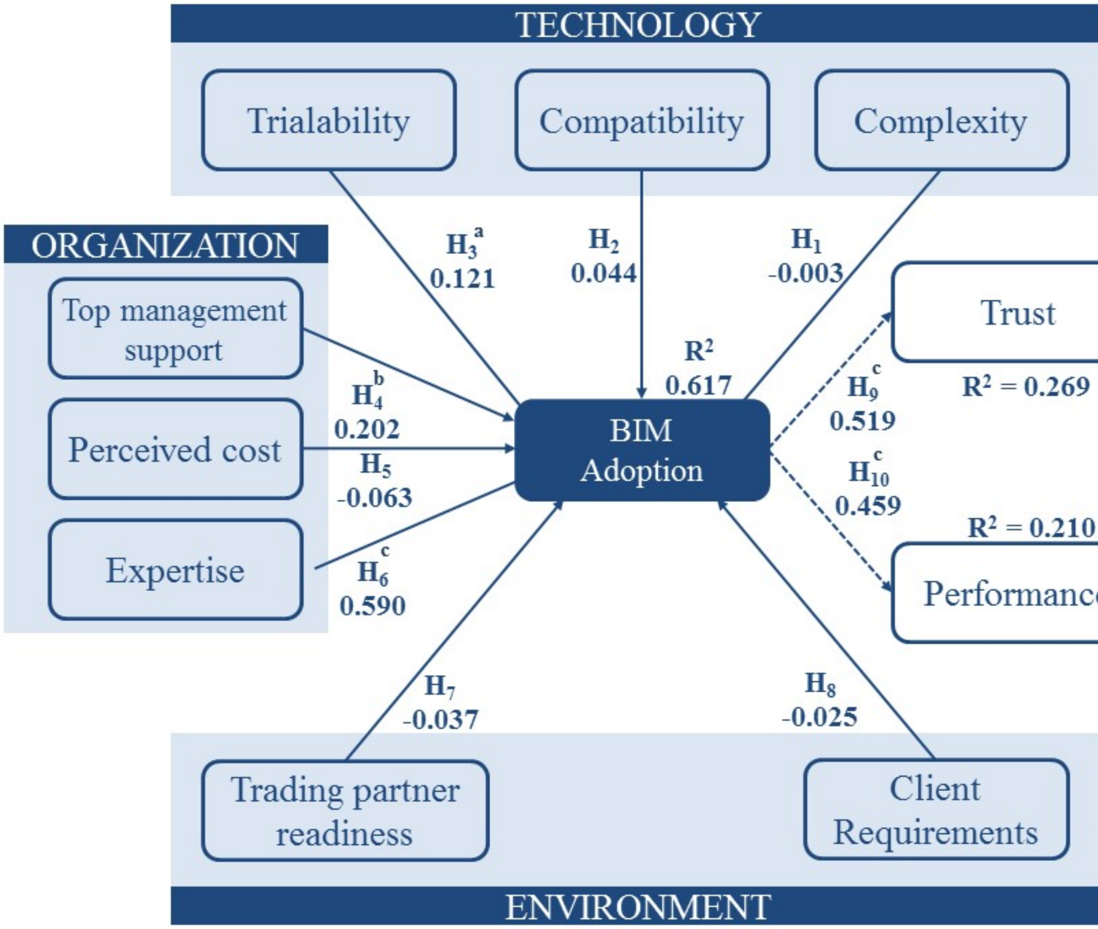

Figure 4: Confirmed Model of BIM adoption with hypotheses testing results (p-values, in order to determine the significance of the results: a<0.05, b<0.01, c<0.001)

Discussion of the Results

With the TOE based framework shown in Figure 3, the scenario of BIM adoption by architecture fraternity in India becomes evident. Broadly, the result manifests that BIM adoption in architectural organization results in enhanced performance (H10) and increased trust in BIM (H9). The result also demonstrates that trialability of the technology (H3), top management support (H4), and expertise (H6) have a positive impact on BIM adoption. Surprisingly, the confirmed path model does not support complexity of BIM implementation and use (H1), compatibility and interoperability of BIM technology (H2), delivery network influences (such as trade partner readiness (H7) and client requirement (H8)). The outcomes of the study are discussed in more detail below:

Technology Context

The study provides an understanding of the role of technology dimension in BIM adoption among architects in India. The ability to experiment and trial BIM technology has a positive impact on BIM adoption. The path coefficient from trialability to BIM adoption is positive and significant ($\beta=0.121$; $p<0.05$) thus supporting the hypothesis (H3) that trialability leads to BIM adoption (Fink, Harms, & Kraus, 2008). Internal organizational experts who can trial BIM software are found to be influential in the BIM adoption decision of the organization. The ability to use software especially on a pilot project enhances the chances of BIM adoption in Indian architectural organizations. Past research has found limited impact of trialability on BIM adoption (Panuwatwanich & Peansupap, 2013). The standardized path from compatibility to BIM adoption is statistically insignificant ($\beta=0.044$), thus not supporting H2. For the Indian architectural organizations, compatibility and interoperability of BIM software tools and systems has neither positive nor negative implications on BIM adoption. This finding does not fit with the findings of previous studies conducted by other researchers globally. A separate section explaining this finding and other disagreements in our findings is provided. ‘Complexity’ ($\beta = -0.003$) is also found to have no significant effect on BIM adoption, thus rejecting H1. For the Indian architectural fraternity, complexity of BIM does not influence their decision to adopt BIM in their organizations. This finding is surprising and needs further analysis.

Organization Context

'Expertise' (β =0.590; $p<0.0001$) has a significant positive impact on BIM adoption (H6) within the Indian architectural firms. As an inward-looking organizational attribute this demonstrates that architectural firms are more confident of BIM adoption when there is internal expertise available within the organization (Langar, 2013). This validates the finding in earlier studies (Tulenheimo, 2015)—availability of modelling expertise in house for precast concrete design firms led to BIM adoption (Kaner, Sacks, Kassian, & Quitt, 2008) and higher BIM adoption in China due to internal expertise resulting in perceived ease of use (Xu et al., 2014). In the Indian architectural organization, an internal BIM champion is found to be most important in successful BIM adoption.

'Top Management Support' (β =0.202, $p<0.01$), has shown reasonable positive impact on BIM adoption (H4). Architectural firms in India are generally small and medium enterprises with significant top-down hierarchical influences. Due to the licensing laws for architectural practice in India, most firms are operating with a single or small group of architects at the helm. In these types of organizations, support from the top management is a significant determinant of adoption of innovation including BIM. This finding is in congruence with previous findings (Eastman et al., 2011; Navendren et al., 2014; Xu et al., 2014).

'Perceived Cost' (β = -0.063) of BIM implementation does not have any significant influence on BIM adoption in the Indian context as per the confirmed TOE model (H5). The respondents feel that cost of BIM adoption, implementation, and ongoing cost does neither deter nor enhance the chances of BIM adoption. This finding is not in congruence with previous findings. Some industry reports suggest that many Indian architects already have made the initial investment in the purchase of a popular BIM authoring software but the tool remains 'shelved'.

Environment Context

In the confirmed TOE model, trade partner readiness (β=-0.037) (H7) and client requirement (β=-0.025) (H8) exhibited no significant impact on BIM adoption. In the Indian context, the respondents confirmed that there is no impact of clients request and trade partner readiness on adoption. This finding has been further explained under the analysis of divergent results.

Implications of BIM Adoption on Trust and Performance

Respondents from the architectural community felt that BIM adoption in their organizations resulted in increased trust (H9) in innovative technology in general. As hypothesized, BIM adoption had significant positive effect on trust (β= 0.519; $p<0.0001$). This aspect has been studied in the context of innovation in the construction industry and similar findings have been reported by other researchers (Panaitescu, 2014).

Adoption of BIM increases performance of architectural firms in India. The TOE model shows strong support for this assertion. The path coefficient from BIM adoption to performance is positive and significant (β =0.459; $p<0.0001$). The extant literature on this issue also has reported similar findings (Azhar et al., 2012; Barlish & Sullivan, 2012; Coates et al., 2010; Eastman et al., 2011). A recent study conducted in China used 'perceived usefulness' as a latent variable for BIM adoption and showed a strong linkage between this and BIM adoption (Xu et al., 2014).

Analysis of Divergent Results

Although most of the findings of our study are in sync with previous findings, surprisingly and counterintuitively no significant relationship between complexity (H1), compatibility (H2), perceived cost (H5) and delivery network influences such as trade partner readiness (H7) and client requirements (H8) with BIM adoption was found. Most studies addressing drivers and barriers to BIM adoption have reported statistically significant influence of these factors on adoption (Chien et al., 2014; Ding, Zhou, Luo, & Wu, 2012; Xu et al., 2014). However, a similar divergent finding in the case of China, another late entrant in the BIM adoption journey, has also been reported, in that 'software compatibility and interoperability' and 'complexities' do not influence adoption decision in the case of Chinese organizations (Xu et al., 2014). How can this divergence from previous results be explained? Does this have any relationship to the current state of BIM adoption in India?

Previously it has been reported that design disciplines, especially architecture, consider BIM as an extension of computer-aided design while initially exploring BIM adoption (Gu & London, 2010). This shows that in the case of early adopters, the adoption decision considers technological and organizational (internal) influences rather than environmental (external) ones. Further, adoption is influenced by the overall adoption status and outlook of the market nationally. Since India has been a late entrant in the BIM adoption process and the overall adoption rate in India is low, adopters of BIM do not have a critical mass of early adopters to follow and learn from. This further makes the organization look inward rather than outward. The research by Succar et al. (2012) introduces 'organizational scale' as developed for understanding the dimensions of diversity of markets, disciplines and company sizes. The study categorizes AEC project at macro level, organizational teams at meso level and organizational member at the micro level. This explanation can be further elucidated based on the 'level-dimension' as proposed by Moum (2010), which represents the social context in which an organization is placed while exploring interdisciplinary use of 3D modelling by designers. In this construct social placement of the design organization is at three levels representing different external boundaries and interfaces with other organizations. At the macro-level, overall project is considered along with social influences of all the other delivery network members. The meso-level draws its boundaries to capture the entire design team on a project; fitting between the macro and micro levels. The lowest level termed the micro-level focusses on the individual practitioner or design organization and excludes social influences and externalities caused by other delivery team members. The Indian architectural organizations are reportedly in their early stages of BIM adoption journey—termed as the experimentation stage (Sawhney, 2014b); placing the adoption journey somewhere between the micro- and meso-level. Therefore, the BIM adoption decision is being made at the boundary of micro-level and meso-level with little or no consideration for the rest of the project delivery network. This concept is shown in Figure 5 (where the level dimension is adopted from Moum (2010)).

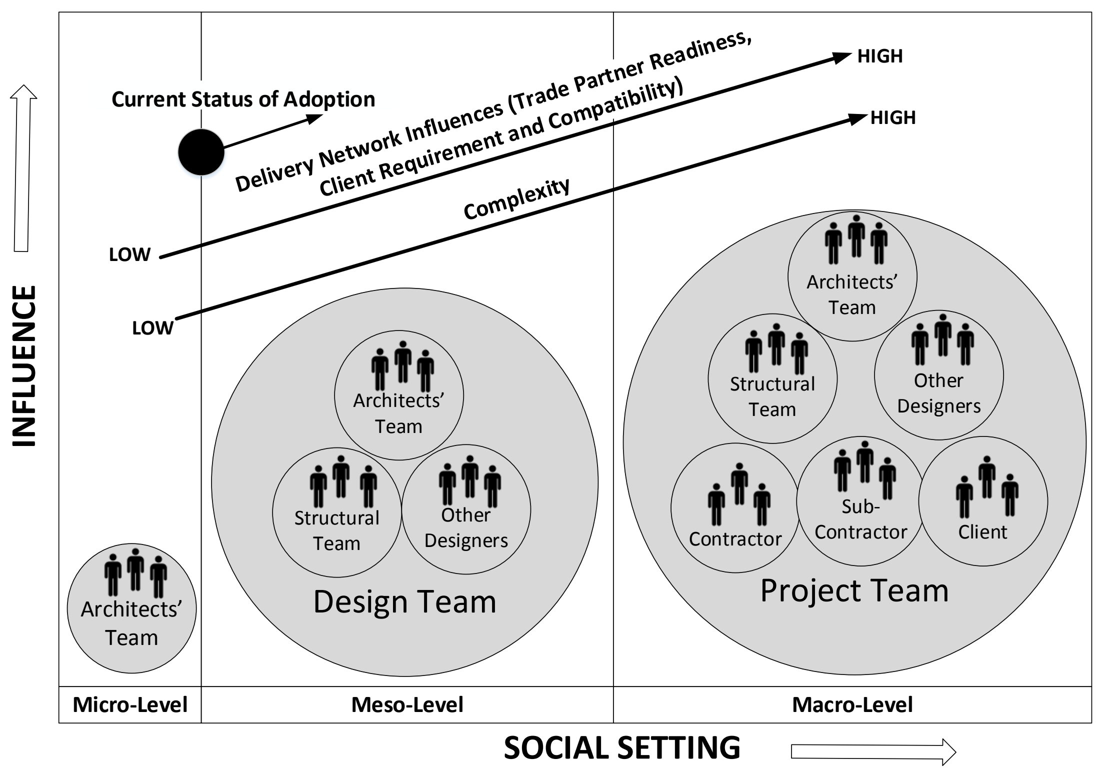

Figure 5: BIM Adoption Journey for Indian Architects

Factors such as compatibility, complexity, trade partner readiness, and client requirements have limited or no influence on adoption as the decision is an intra-organization decision. Furthermore, BIM adoption process is seen as emergent and dynamic in nature (Davies & Harty, 2011), and unfolds in an unpredictable way within an organization (Sackey, Tuuli, & Dainty, 2015). As the organization embraces BIM it understands the external connectivity of their decision and influences that other organizations may have on their full utilization of BIM (Yalcinkaya & Singh, 2015). Explaining the BIM capability stages as the major milestones to be achieved by any organization in order to gain maximum benefits of BIM, Succar et al. (2012) defines BIM capability stage 1 as object modelling; BIM capability Stage 2 as model – based collaboration & BIM capability stage 3 as network-based integration. The research further asserts that an organization can achieve BIM capability stage 3 only if it uses a network- based solution, i.e., an organisation not only develops technology by deploying an object-based modeling (Technological factors); not only engages in a multidisciplinary ‘model-based’ collaboration (Organisational factors); but also links the object-model with external disciplines (Environmental factors).Therefore, the BIM adoption decision likely changes from an inward looking decision based on internal technological and organizational factors such as expertise, trialability, and top management support to a mix of technological, organizational and environmental factors based decision.

Conclusion

The primary objective of this study was to develop a TOE based framework to investigate the reasons for low BIM adoption among architectural firms in India. The research model examines the influence of five contextual factors on BIM adoption. The study asserts and statistically validates the factors influencing BIM adoption in architectural firms by showing that trialability, top management support and BIM expertise promotes BIM adoption. As a late entrant in the BIM adoption journey, respondents in India did not exhibit the importance of complexity, compatibility, perceived cost, trade partner readiness and client requirements in their adoption decisions. This has been explained in the context of a social construct that places the adoption in India between the micro- and meso-level at which external influences are shown to be minimal. In conclusion, the study provides evidence that BIM adoption is an emergent and dynamic process that evolves over time. Similar to China, this study confirms a similar situation within Indian construction industry where the respondents have indicated support of BIM professionals and senior management as important variables affecting BIM adoption. In addition to this, the study also reports that BIM adoption provides performance benefits of improved work quality, enhanced effectiveness on job, increased productivity, efficient coordination of construction activities and trust in technology.

The current research relies on AEC industry professional's self-reported data. Though difficult to obtain, future research may consider employing observable indexes to measure constructs such as BIM related performance in order to increase the robustness of the findings. Another limiting issue is the cross-sectional nature of the data. Longitudinal data collection, despite being time and resource intensive, could be useful in statistically corroborating the proposed causality and thus should be pursued. Future research wishing to extend the applicability of the current research framework could collect data in other countries.

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