PROMOTION OF DIFFUSION OF INNOVATIONS: A STUDY OF BIM ADOPTION IN CONSTRUCTION INDUSTRIES

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With well-known benefits, Building Information Modelling (BIM) is yet to diffuse widely in global construction. Diverse knowledge of BIM adoption from different perspectives has made synthesizing a challenge when devising strategies to promote BIM diffusion. Subjectivity of BIM adoption decision also restricts the generalized strategies. Addressing these problems, the study aims to develop a framework that can be used to efficiently study a context of decision to adopt BIM and inform change agents to help devising appropriate strategies for its diffusion. A Systematic Literature Review is used to develop an affordance-based review framework for BIM adoption decision. The framework is validated by mapping findings from one of the most cited BIM adoption studies to the framework.

Keywords: Affordance, building information modelling, diffusion, innovation

INTRODUCTION

Building Information Modelling (BIM) probably is the most celebrated technological innovation in construction in recent times as has been found in several bibliographic and scientometric analyses (Oraee *et al.,* 2017; Santos *et al.,* 2017; Zhong *et al.,* 2019). This is not surprising when what BIM has brought into the construction industry is considered. BIM has offered solutions for many of the problems the industry has had for decades, if not centuries. It also brings in many enhancements to improve quality, efficiency and effectiveness of construction outputs (Eastman *et al.,* 2011). With many benefits that are communicated through different media, why BIM is yet to become a common practice, is a question among many.

While there were many findings that help understanding of BIM implementation motivators, challenges and barriers, encapsulated knowledge that can be used by change agents to promote 'natural' diffusion of BIM was not evident. Practical application of current knowledge in devising strategies for effective promotion of BIM adoption is also challenged by the diverse findings from different perspectives

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and at different levels such as significantly large number of factors affecting BIM adoption (e.g. 20 factors in Buć and Divjak, 2018; 80 factors in Mom *et al.,* 2014). Added to this is the fact that BIM adoption decisions are subjective and are resulting from interplay among many factors internal and external to the potential adopter making universal strategies inapt. Our aim therefore is to develop a framework that can be used to efficiently study a context of decision to adopt (or reject) BIM and inform change agents to help devising appropriate strategies for its diffusion.

METHODOLOGY

The key feature expected of the framework was that it can comprehensively capture a potential adoption context in a manner that can inform a change agent (a) of gaps that limit adoption, (b) of strengths and opportunities that promote adoption, and (c) of neutral features with no effect, because they all are important in devising effective strategies (Oreski, 2012). We started with a Systematic Literature Review (SLR) to review the prominent studies in BIM adoption. The 50 most cited Scopus indexed journal papers published in last five years directly on this subject were found through keyword search for "BIM" or "Building Information Modelling", and "implement", "implementation", "adoption" or "adopt" in their title, keyword or in the abstract. By reviewing the abstracts, the key issues addressed in each were identified. These issues were further studied through a regular review which included other sources (outside of BIM) for better and deeper understanding of the issues. Identified concepts and theories were then critically reviewed so that those can be reduced to be represented in an efficient combination of concepts in a comprehensive framework. We validate the applicability of the developed framework herein by mapping findings from one of the most cited BIM adoption studies to the framework.

The following text explains the rational of arriving at the framework and validation of it. It does not necessarily follow the research process but presents logical flow of facts and propositions.

We identify two prominent works to become valuable because they are reviews of key concept and theories relevant to our work. We found that Ahmed and Kassem (2018) in their paper titled "a unified BIM adoption taxonomy" had reviewed majority of key literature we identified through BIM adoption SLR and follow-up reviews. Thus, it became a valuable source for synthesized knowledge for BIM adoption concepts to be used in our review for clarity and consistency. We use Rogers (2003) for generic definitions and interpretations of Diffusion of Innovations (DOI) because he had encapsulated four decades of diffusion studies in his work. He is the most cited author in DOI studies. All papers we reviewed in this subject had cited him, and many studies had their roots in his work.

Bim Adoption in Construction

BIM in fact is not new. BIM as a concept in construction is nearing a half a century. Design software implementing BIM concept has been in existence for more than thirty years. However, the concept became popular only after the introduction of it by International Alliance of Interoperability in late1990's (Eastman *et al.,* 2011). Yet after more than two decades, universal adoption of BIM to a decent level is yet to be found. We position this problem in Innovation Diffusion studies.

Diffusion of Bim as an Innovation

While it is often mentioned that BIM is an innovation, a clear definition is imperative for consistency. Among number of parallel definitions, we cling to Rogers:

Innovation is “an idea, practice or object perceived as new by an individual or other unit of adoption” (2003, 12). The term “unit of adoption” emphasizes the subjectivity of what an innovation is. For the purpose of adoption, if an idea is in fact new objectively has only a small effect. What matters is the perceived novelty of the idea. Novelty is not purely about new knowledge either. Novelty is identified at the point of decision to adopt, that if what is to be adopted is new. This interpretation of innovation matches with the status of BIM as a novel approach to construction project delivery, and with the fact that what is new in BIM is user and context dependant.

BIM diffusion studies as of date have focused on diverse subjects, including but not limited to (1) barriers, (2) cultural issues, (3) maturity and awareness, (4) change, (5) drivers and (6) diffusion prediction (Ahmed and Kassem, 2018). While these studies present both wide and deep understanding of BIM adoption and diffusion, our cognition capacity limits the formulation of effective and efficient promotional strategies in absence of a concise fit-all-in-one framework that can hold all relevant knowledge.

Diffusion and adoption are highly related but different in meaning. Diffusion as a generic concept is defined as “spreading [of] something widely in all directions” (Oxford Advance Learner’s Dictionary, 2000, 349). This definition is directly applicable to the context of this study, because, to study how innovations, such as BIM, spread in an industry is within its wider scope. Accordingly, "diffusion" is about the innovation and "adoption" is about the user. How an innovation is diffused is by the adoption of it by users. We will not count mere implementation into diffusion, because implementation can also occur at trial and experiment level.

One may find that two terms - adoption and implementation are often confused and used interchangeably in BIM diffusion studies. For clarity and consistency, we would maintain that adoption is “a decision to make full use of an innovation as the best course of action available” (Rogers, 2003, 177) and Implementation "occurs when an individual put [the innovation] into use" (Rogers, 2003, 169). Following these definitions and interpretations can also become helpful because the large majority of BIM adoption/diffusion studies are based on theory of Diffusion of Innovation (DOI) by Rogers (2003). Other theories popularly adopted in BIM diffusion studies are Institutional Theory (INT), Technology Acceptance Model (TAM) and Theory of Reasoned Action (TRA). These theories also use compatible taxonomies (Ahmed and Kassem, 2018).

Theories of BIM Adoption

Among the popularly used theories, DOI is the theory that can and to a good extent has been used to most expansively describe the diffusion of BIM (Buć and Divjak, 2018). This is expected because it has been applied also in many different contexts (outside of BIM), especially in the diffusion of information and communication technologies in different fields (Lievrouw, 2014).

DOI comes under communication studies and it addresses diffusion from different foci. It identifies the effect of social system, especially its structure and norms, on diffusion. Then it looks at the role of key players, viz. change agents, their aide, and opinion leaders in the community. Communication channels is another focus of the theory. Diffusion time is addressed from three foci. Individual members' innovativeness is modelled using cumulative number of adopters and in the community in concern. It explains the innovation decision process over the timeline on how an individual comes to the ultimate decision if to adopt or reject the innovation. It also identifies innovation's rate of adoption as a personal property of innovation. It defines and links diffusion to four types of innovation decisions as optional, collective, authority and contingent (Rogers, 2003). These areas are variably addressed in present BIM diffusion studies, though some may not explicitly link their findings to DOI concepts and principles (Ahmed and Kassem, 2018).

Another focus of DOI is on the innovation itself. This in fact covers many different aspects. One key area is the perceived characteristics of the innovation (Buć and Divjak, 2018). This includes compatibility, complexity, trialability, observability and relative advantage. Relative advantage is considered from both social and economic perspectives, and also in terms of positive and negative incentives. Types of innovations are considered in terms of tech vs. non-tech, incremental vs. preventive and interactive vs. non-interactive. Re-invention, a feature of innovation explaining the "degree to which an innovation is changed or modified by a user in the process of its adoption and implementation" is also identified as an important point in innovation decision process introduced earlier (Rogers, 2003). BIM diffusion studies have limited focus on effect of innovation, i.e. BIM, on its diffusion (Ahmed and Kassem, 2018). A deep enough study that recognizes the effect of innovation packaging of BIM on its diffusion was not found.

Institutional theory suggests "diffusion dynamics in which external isomorphic pressures motivate organisations to perform behavioural and structural changes while seeking to acquire social legitimacy" (Ahmed and Kassem, 2018, 106). Even though it takes a seemingly different perspective to diffusion, its essence could be understood within DOI that it also has its roots in "imitation" (Marquis and Tilcsik, 2016). The Technology Acceptance Model (TAM) also covers (but goes into detail) one of the foci of DOI. In its original version, Davis (1989) developed and validated new scales for two specific variables, perceived usefulness and perceived ease of use, which he hypothesized to be fundamental determinants of user acceptance. The model was later developed by Venkatesh and Davis (2000) by incorporating subjective norm (one's perception what others think one should do), image, job relevance, output quality, and results demonstrability; and was recognized as TAM2. As next step, TAM3 has been proposed adding emotions theory, such as anxiety and enjoyment, and perceived risks of adoption as technology acceptance predictors (Venkatesh and Bala, 2008).

In one of the most cited BIM adoption studies from recent years, Volk *et al.,* (2014) identify that the scarce use of BIM for existing buildings was due to technological limitations. In another popular study authors state that "BIM refers to a combination or a set of technologies and organizational solutions that are expected to increase interorganizational and disciplinary collaboration in the construction industry and to improve the productivity and quality of the design, construction, and maintenance of buildings" (Miettinen and Paavola, 2014, 84). Wu *et al.,* (2016) ascertain that BIM not being used to its potential to be a critical limitation to use 3-D printing of buildings. Some studies focus on developing technological systems to solve problems or to improve practice, and they seem to believe that to be the role of technology (Fisher, 2012). Presenting a study on developing a framework for post-construction energy efficiency, the GhaffarianHoseini *et al.,* take the position that "Integrated Knowledge-based Building Management System using nD BIM applications (nD BIM-IKBMS) is expected to provide simulation-based supervisory control while automatically detecting and diagnosing operational faults" (2019, 13). Consequently, it becomes evident that most BIM diffusion researchers have taken technological deterministic stance in their studies that "BIM technology is given" or

"BIM can make the things happen", and many shows possible pro-innovation biases that "BIM must be adopted". This does not mean that they took hard technological determinism; and of course, often they had a mixed approach.

Technological determinism has traditionally been a dominant theory in science and technology studies in understanding the role of technology on society. However, the introduction of Social Construction of Technology approach in 1990's "encouraged communication technology researchers to reject technological determinism in favour of a view of technology as socially constructed" (Lievrouw, 2014, 22). These initiatives mingled also with BIM studies. Some studies had been built upon quite strong social constructive approaches. For example, Linderoth *et al.,* (2014) use the concept of boundary objects to study how BIM can facilitate knowledge and expertise sharing to minimize design errors.

Showing that neither strong determinism nor social constructivism of technology are the way forward to understand diffusion, Lievrouw recommends capturing multifaceted complexity of technology by taking their "materiality, cultural significance and meaning, the values and power they represent, institutional interests that advance them, and attitudes and motivations of their users" (2014, 50). Among these, materiality is the key concept to represent technological determinism.

Materiality of BIM

Materiality of an entity is the "character of [entity] that makes them useful and useable" (Lievrouw, 2014, 25). Although materiality has already been identified as useful for meaningful understanding of adoption of technologies, it has rarely been used by BIM researchers.

Paavola and Miettinen study "BIM models as co-developed intermediary objects in the design [and] suggest that BIM models provide novel forms of virtual materiality" (2018, 1113). The study was not on BIM diffusion, but it was the only BIM study we found materiality concept being identified as keyword and deeply reviewed. Many had used the architectural concept of materiality to represent the BIM objects' property "(building) material", making them irrelevant to this study. It is not that materiality was not a concern of researchers, it is only that they failed to recognize materiality as a useful concept. For example, even though Fisher (2012) does not mention materiality in his paper on real-time approaches to performative computational design, his preface writer finds that Fisher links model capabilities to materiality of design.

Materiality, though not explicitly recognized, has of course been used by many BIM researchers through different means. The materiality of BIM is regularly represented in "BIM function" or in "BIM uses", which of course found in large majority of, if not all, BIM adoption/diffusion studies. However, the wholistic view of materiality, i.e. what is material and what is not, is absent in these studies.

Within the complexity of technology to be understood, its materiality is at a pivotal position, because it is what enables the use of technology. Social factors previously identified blends with materiality to develop social meanings to technology, which ultimately leads to adoption or rejection of new technology or the innovation. (Lievrouw, 2014; Rogers, 2003). Wyche *et al.,* (2019) use the concept of "affordance" study this complexity in mobile phone technology.

Affordances

Affordance has been a widely used concept in multiple domains of research including computer software, communication studies, engineering design and sociology since its first introduction by Gibson to ecological sciences four decades ago. Gibson coined the word "affordance" explaining "affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill [and that affordance] implies the complementarity of the animal and the environment" (Gibson, 1979, 127). A decade later, Norman (1988) introduced and popularized the concept among designers because it helped them understand how their products would be used. The concept is widely used in computer software development, especially in their graphical user interfaces (GUIs), e.g. a button image to click; but also, in designing of physical objects, e.g. a door a handle to pull or a knob to turn (Wyche *et al.,* 2019).

Identifying a confusion of the use of concept, Norman later expanded the concept into two (1) real affordances and (2) perceived affordances. Real affordance is affordance "offered by artefacts that can be acted upon or physically manipulated for a particular purpose" (Hartson, 2003, 317). Real affordances in fact is equal to Gibson's original concept that "an affordance exists relative to the action capabilities of a particular actor, [and it exists] independent of the actor’s ability to perceive it" (McGrenere and Ho, 2000, 179). Therefore, it is independent of the needs of the user. Perceived affordance, on the other hand, is affordance that is perceptual to the user, or the actions a user perceives to be possible (Wyche *et al.,* 2019). Norman believed "[perceived] affordances result from the mental interpretation of things, based on our past knowledge and experience applied to our perception of the things" (1988, 2019). Accordingly, a perceived affordance can exist without real affordance.

After reviewing theories in and around materiality, technological determinism and social constructivism of technology, Lievrouw also had suggested to use affordance because it "offers a reconciliation between the opposing poles of constructivism and realism” (2014, 48). By complexifying affordance with Innovation Decision Process of DOI (refer Rogers, 2003), a conceptual framework to study and understand how materiality of an innovation affects its adoption can be developed.

In order to do this, we first define "expected affordances", a simple concept to represent the expectation of an adopter of an innovation. This is not synonymous with "imagined affordances". These are affordances an adopter will look for when considering an innovation. We scope expected affordance to be within functional affordances (as introduced by Hartson, 2003) to represent (expected) real affordances that carry utility or purpose, because use (represented by affordance in here) without a utility or purpose is not material in innovation decision (Rogers, 2003). Like perceived affordances, expected affordances also are subjective, dynamic and evolving. Intersections and relative complements of three sets of affordances viz. (1) expected, (2) real and (3) perceived, make seven types of affordances as shown in Table 1. This is proposed as a framework to study innovations such as BIM to obtain concise yet satisfactory knowledge about the innovation to device effective strategies to promote its adoption.

To come up with the nomenclature, we also bring concepts from Gaver (1991) (1) Perceptible Affordances - real affordances that are also perceived, (2) False Affordance - perceived affordances that are not real, and (3) Hidden Affordances - real affordances that are not perceived. Our use of term Material Affordances is slightly different to Hutchby (2001), where we mean that these affordances are material in correct adoption. Strategies for addressing the conditions are identified by synthesising from theory of Diffusion of Innovation (Rogers, 2003).

The framework may not be used in isolation for effective results. It should be understood by relating to existing DOI theories. For example, how homophily and heterophily play a role in interpersonal communication will offer deeper understanding of Critical False Affordances. What framework offers is an efficient method to identify the status of innovations or critical conditions that needs or needs not to be addressed to promote diffusion of innovations.

Table 1: Seven Types of Affordances affecting Innovation Decision

Nr.	Type	Name and description	Significance and strategies
1	Expected, real and perceived	"Material Affordances" are Perceptible Affordances within expected functionalities	Significant positive impact leading to adoption. No strategies are expected, except assuring of status quo
2	Expected, real but not perceived	"Critical Hidden Affordances" are Hidden Affordances within expected functionalities	Negative impact leading to false rejection before implementation. Mass media and commercial change agents
3	Expected, perceived but not real	"Critical False Affordances" are False Affordances within expected functionalities.	Significant negative impact leading to false acceptance for implementation and eventual rejection. Opinion leaders, community organization and authorities to communicate
4	Expected, but neither real nor perceived	"Missing affordances" are the expected functionalities not offered	Positive impact leading to correct rejection. No direct positive impact to diffusion. But passive impact by minimizing conclusion "the innovation is a failure" No strategies are expected, except assuring of status quo
5	Not expected, but real and perceived	"Windfall affordances" are Perceptible Affordances outside of expected functionalities.	Nice to have perks of adoption will strengthen the Material Affordances. Overemphasis by change agents and media may increase Hidden Affordances and Waste. Limit communication to mass media. Create needs
6	Neither expected nor real, but perceived	"Noncritical False Affordances" are False Affordances outside of expected functionality	Neutral effect yet with risk of developing into Critical False Affordance Opinion leaders, community organization and authorities to communicate
7	Neither expected, nor perceived but real	"wasted affordances" are hidden affordances outside of expected functionalities	Neutral effect. Overemphasis by change agents and media may reduce Material Affordances. Limit communication to mass media.

BIM Affordances

Though not popular, affordances of BIM have got attention of few authors. Pärn *et al.,* identify "functional affordances of BIM and how they influence the architectural design process" (2015, 331). Merschbrock (2013) explore BIM's current use and affordances. The study highlights the researchers' interests in linking affordance to use. Yet, findings are not comprehensive enough to validate the framework proposed herein (in Table 1).

The value of the developed framework to study BIM with its promotion in mind is vindicated by the statement by Miettinen and Paavola: "although BIM visions and promises are needed for BIM implementation, they need to be complemented with a more realistic view of conditions of the implementation… in addition to standards and guidelines underlined by normative approaches, local experimentation and continuous learning play a central role in the implementation of BIM" (2014, 84).

In order to validate the applicability of our framework (presented in Table 1) to review a context of BIM adoption, we use the most cited publication with "BIM Adoption" in title - Understanding and facilitating BIM adoption in the AEC industry by Gu and London (2010; cited 283 in SCOPUS, 592 in Google Scholar). By relating and contrasting its conclusions of this study, we review how far our framework can capture and contain knowledge therein. We extract only the key or leading text below. Referring original publication is required for deeper understanding.

> 6.1. In terms of product - Expectations from BIM vary across disciplines. Design see BIM as an extension to CAD, contractors and project managers expect BIM to be a more intelligent DMS …" confirms the importance of Expected Affordances. Authors go onto say "Our desktop audit suggests BIM applications are not yet completely mature for [this] purpose". Showing the gap in real affordances, they point that BIM application vendors aim to integrate expectations of two groups keeping both parties long with Missing Affordances, and probably trying to market BIM applications using Windfall Affordances or even Wasted Affordances. Had the affordances been studied using our framework, vendors would have had better systematic knowledge on industry needs, and they could have packaged their developments accordingly.
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> 6.2. In terms of process - BIM adoption would require a change in the existing work practice…" This conclusion is about the adopter, where our framework is about the Innovation. Therefore, this is not represented in it, but as highlighted, using our framework along with current diffusion theories will address these requirements.
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> 6.3. In terms of people - … numerous factors affecting BIM adoption, mainly fall into two: technical tool functional requirements and needs, and nontechnical strategic issues". Value of our framework for the first is obvious. The second is elaborated as "where to start, what tools are available and how to work through the legal, procurement and cultural challenges…"; and it highlights that Expected Affordances are not purely technological in nature. Our framework will identify these affordances of which the interests will primarily be outside of application vendors, but will be with those with authority, leaders and change agents.

Accordingly, our framework can holistically encapsulate the knowledge that is required to strategically package BIM, both technologically and procedurally, for its effective diffusion.

CONCLUSIONS

Affordance based review of innovations will offer concise yet satisfactory knowledge to device effective strategies to promote innovation adoption. The framework we developed through this review (refer Table 1) is recommended to study the status quo of BIM in adopter groups to help devising appropriate strategies for effective diffusion of BIM. Basic theoretical strategies are identified in this framework, real-life application would lead robust and unique strategies that can contribute to knowledge.

The framework may not be applicable to innovators because of their unique characteristics of innovations adoption. However, we see no limitations in its applicability to other adopter groups including early adopters. Further, the framework was developed in a manner to minimize the possibility of pro-innovation biases. Endeavours requiring such biasness, e.g. commercial BIM promotion, would require adjustments to the framework.

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