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Article

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Affordance-led Framework of Understanding of BIM Adoption

Abstract

Purpose: Successful adoption of Building Information Modelling (BIM) by early adopters is crucial for its effective diffusion. The purpose of this study is to develop a framework of understanding that supports contextualized understanding of BIM adoption decisions in a BIM Infant Industry. The framework bridges the gap in current knowledge in terms of the absence of such a framework, which has hindered the structured understanding of the BIM decision of an adopter, curtailing the appropriate strategizing of their BIM adoption.

Design/methodology/approach: The study focuses on a BIM Infant Industry, where early adopters begin using BIM, allowing insights into this crucial initial stage of adoption. Identifying affordances as a versatile concept that could effectively represent not only what an adopter perceives and expects from BIM implementation, but also, what the adopter, in fact, can achieve from it, an Affordance-led Framework of Understanding (AFU) was developed to comprehensively capture varying dynamics of BIM decision process. The study took a qualitative Retroductive approach to theory with semi-structured interviews to gather necessary data from a sample of BIM adopters purposively selected to maximize the breadth and depth of data.

Findings: The study concludes by identifying and defining pertinent affordances as a new concept and a compulsory state for BIM adoption. Findings further demonstrate that existing theories can be linked to the AFU to strategically direct the affordances dynamics towards the pertinent state.

Originality/value: The AFU enables a deeper contextualizable view of innovation adoption that was absent in existing innovation studies. It significantly enhances the precision of strategizing BIM adoption compared to previous approaches, enabling adopters to plan and implement BIM in a manner that aligns well with their expectations and specific conditions.

Keywords – Building Information Modelling, BIM, Innovation, Adoption, BIM Infant Industry

Research Paper

Introduction

Building Information Modelling (BIM), despite being an established concept, continues to be a prominent technological innovation in the construction industry (Kassem and Ahmed, 2022). BIM has revolutionized the industry through the automation of various activities, enabling computers to accurately interpret building information (Teo *et al.*, 2022). Added to this is the almost complete interoperability BIM technology can bring to key building information among various hardware and software tools in the industry bringing multiplied benefits (Eastman *et al.*, 2011). With its ability to address many of the problems in the industry and the array of other benefits it can offer, the question of why the diffusion of BIM is poor in many construction industries is of great interest (Oyuga *et al.*, 2021). Within this question, special interest is found about BIM infant industries where the diffusion of BIM is substantially challenged (Adeniyi *et al.*, 2022).

Criticality of challenges when attempting to adopt BIM at the user level are often observed in less developed Architecture, Engineering and Construction (AEC) industries (e.g., Akdag and Maqsood, 2019). While significant knowledge is found to support BIM adoption in a BIM infant industry, limited work has been undertaken on developing a comprehensive framework to fully understand how an adopter reaches the final BIM decision. This limitation restricts the effective application of available knowledge to support the BIM adoption process (Jayasena and Weddikkara, 2013). Consequently, the absence of such a comprehensive framework hinders the seamless integration and synthesis of diverse knowledge currently available, presenting challenges in unifying various elements of knowledge into a cohesive understanding of the entire BIM decision-making process.

BIM Infant Industry

The concept of BIM infant industry was first introduced by Jayasena and Weddikkara (2013) to describe industries interested in adopting BIM but not yet practising it. The term gained gradual acceptance to identify industries that are in their early stage of BIM adoption (Adeniyi *et al.*, 2022). The Infant Industry Argument (IIA) states that "in their early stages, new enterprises [or industries] have to be protected against competition in order to be able to be mature and become competitive" (Klingemann, 2012, p. 1). The argument is valid for the present state of BIM where adopters are challenged with limited accessibility to technology and significant costs associated with the acquisition of hardware and software, recruiting capable staff, and training requirements (Shojaei *et al.*, 2023) that limits their competitiveness to the industries with mature BIM use. A BIM Infant Industry refers to an industry in its early BIM stage that requires support and protection to become competitive. While a significant amount of useful scientific knowledge is already available to contribute to this support (Ahmed and Kassem, 2018), the enormity of this knowledge also poses challenges to its practical application.

Adoption of BIM in an Infant Industry

A BIM infant industry is considered to be in the early stage of BIM diffusion where early adopters including the innovators have taken initiative to use BIM. At this stage, BIM innovation is less interactive, and the adoption occurs at micro level, i.e., individual, or small group level (Rogers *et al.*, 2015). The successful adoption of BIM by each early adopter is crucial for its successful diffusion. This is because diffusion become natural once adoption reach the critical mass, and until that stage, adoption is to be promoted and supported at micro level (Bass, 1969; Rogers, 2003). Even the failure of adoption by a few early adopters is detrimental, as it may result in higher user "complaint rates and the spread of negative word of mouth and the likeliness to forfeit the [adopters'] goodwill accordingly" (Heinrich *et al.*, 2016, p. 270). Negative news travels faster than positive news, significantly disrupting the successful diffusion of BIM in the industry (Hornik *et al.*, 2015). Therefore, successful BIM adoption at micro level, whether at an individual or small group, is crucial for the success of BIM diffusion in a BIM infant industry.

According to Kassem and Ahmed (2022, p. 1) "the adoption of a systemic innovation such as BIM within a complex socio-technical environment such as the construction sector requires a thorough understanding of its adoption dynamics at the micro-level". It is already known that the difficult BIM transition process, limited BIM knowledge, and lack of necessary support are among the critical challenges of BIM adoption in BIM infant industries (Olugboyega and Windapo, 2021). These challenges negatively affect the BIM adoption decision (Hong *et al.*, 2019).

The challenges of the BIM transition process, as shown in some BIM adoption case studies, are subjective and contingent upon the complex interplay between the adopters and their specific environments (Marzouk *et al.*, 2022). While BIM is a "technological process-based innovation, it is also a modular innovation" (Gledson, 2021, p. 964). Due to this modularity, what is adopted as BIM also varies significantly, adding further complexity to the nature of challenges of BIM transition for each adopter. The required BIM knowledge to be communicated is subjective to what adopters want to or are supposed to do with BIM (Shojaei *et al.*, 2023), and the necessary support is subjective to what is required to overcome these challenges (Omar and Dulaimi, 2021). The current literature only provides scattered and incomplete knowledge about these challenges, limiting their effective utilization.

Research Problem and the Study Aim

An appropriate understanding of the BIM adoption context and the effect of interplay among various elements of a given innovation adoption context is necessary to develop appropriate strategies for the effective adoption of innovations like BIM. Unfortunately, a robust model or a framework to understand how decisions are made within the context of a given innovation, adoption environment, and potential adopters was not found. This limitation hinders the full potentials of effective communication, appropriate innovation packaging, and fitting reinvention by change agents, BIM products suppliers, and adopters, respectively.

The above-mentioned limitation is critical for change agents because they serve as the link between innovation and the adopter (Caiazza and Volpe, 2016). BIM adoption can only be successful if change agents accurately bridge the two ends. To achieve this, they require clear understanding of the BIM adoption decision context. Similarly, managers, BIM product suppliers, and BIM proponents in a specific adoption context need similar understanding to offer effective support (Shojaei *et al.*, 2023). Generalized knowledge in this regard is useful for BIM evangelists and academic institutions to prioritise BIM knowledge and provide better macro-level support for individual needs (Wang and Feng, 2022). Policy makers also require this understanding to identify strengths and gaps in current adoption contexts (Kassem and Ahmed, 2022). Furthermore, adopters themselves require this understanding to effectively shape their adoption strategies (Ahmed and Kassem, 2018; Chahrour *et al.*, 2021; Gledson, 2021; Oyuga *et al.*, 2021). A framework that can offer structured understanding of the BIM adoption decision context of an adopter is, therefore, a critical need that remains unfulfilled in current knowledge. Addressing this gap, this study aims to develop a comprehensive framework to understanding of BIM adoption decision process in the context of a BIM infant industry.

Study Scope

While the scope of the study in general is kept at BIM infant industries, the study was conducted in Sri Lanka to maximize the validity and reliability of the findings. This decision was driven by the potential for heightened richness of data and interpretations through collaboration effect due to prior engagements of the principal researcher with the study participants (Creswell and Miller, 2000) working in Sri Lanka. Additionally, the Sri Lankan context was deemed ideal for studying the identified phenomenon, as highlighted by Mohanaraj *et al.* (2022) and Rogers *et al.* (2015).

Literature Review

The literature synthesis presented here first identifies what BIM is within the study context and explores the elements to be included in the framework. Identifying affordances as a versatile concept to comprehensively capture the complexity of BIM adoption, it presents how an affordance-led framework is conceptualized.

Building Information Modelling

BIM is often understood in terms of the software tools being used and the functionalities to be achieved (Wang and Feng, 2022). This is particularly true in a BIM infant industry where the focus is primarily on technology rather than the process and administration, such as BIM contractual provisions (Taghizadeh *et al.*, 2022). In the construction industry, there are various software tools that support professional and communication functions, each used to achieve different functionalities, such as production of drawings (Shojaei *et al.*, 2023), creating 3D visualizations including walkthroughs (Teo *et al.*, 2022), performing clash detection (Chahrour *et al.*, 2021), and taking-off quantities (Teo *et al.*, 2022). This variability in how BIM is perceived and utilized among adopters and their adoption contexts highlights the need to recognize and define BIM accordingly for the purpose of this study.

Eastman et al. (2011, p. 586) defines that "BIM is a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine-readable documentation about a building, its performance, its planning, its construction and later its operation". A key point in this definition is digital machine-readable documentation. This signifies the novelty that comes with the BIM technology that opens numerous BIM functionalities that have become possible due to the virtual construction of buildings in full detail through computer interpretation of machine-readable object-oriented interrelated parametric data in BIM models.

Combining the above definition with the need to capture the different uses of BIM as required in this study, it is defined that Building Information Modelling (BIM) is any venture that makes use of object-oriented interrelated parametric data forming a machine-readable knowledge resource of information about a building. In here, a building includes any built facility, either proposed or existing. Machine-readable means that computers can interpret and make use of data, and making use of knowledge resource includes creating, updating, and using of building information. Furthermore, the definition acknowledges the subjectivity of what BIM is for different adoption contexts.

BIM Adoption

The research aim is positioned in the broad subject context of innovation adoption studies. Within this field, major relevance to this research is found in technology adoption contexts. To identify how innovation adoption decision is theorized thus far, all relevant and commonly referred to innovation adoption theories were reviewed to develop a broader and critical understanding of how the innovation adoption decision is made. This review covered seventeen theories starting from Tarde's Laws of Imitation of 1890 (Kinnunen, 1996) to the most recent theories like the Integrated Models of Diffusion by Smith et al. (2018), and use cases and refined uses of those theories.

Tarde's Laws identify the pivotal role of elites in the adoption of an innovation, initiating its diffusion by imitating that adoption by others like the ripples in water (Kinnunen, 1996). Given the time of the theory introduction, attributing the pivotal role to elites seems reasonable. However, with changes in the social context, later theories attribute this role to early adopters (Rogers, 2003). The diffusion Model developed by Bass in 1969 identifies the need for the adoption of an innovation by a critical mass, primarily comprising of early adopters, for the innovation to start diffusing naturally (Bass, 1969), thus confirming Tarde's theory.

The primary theoretical framework in innovation adoption was found to be the Theory of Diffusion of Innovations (DOI) from 1962 by Rogers (2003), which encapsulated many theoretical developments and updates up to 2003. DOI explains how features of the innovation such as complexity, compatibility, trialability, and relative advantage, affect its adoption. It also identifies the role of other factors, such as communication channels, adopter characteristics, and the social system (Wang and Feng, 2022).

A widely used model to study innovation adoption was the Technology Acceptance Model (TAM). The model uses two attributes of innovation: usefulness and ease of use as perceived by the adopter (Davis, 1989). The approach is different from the contemporary model, the Theory of Planned Behaviour (TPB), which identified attitude, perceived behavioural control and subjective norm as factors affecting the decision (Ajzen, 1991). While TAM identifies perceived usefulness and perceived ease of use to affect attitude, it does not consider the effect of perceived behavioural control and subjective norm.

Addressing this limitation, a combined model of TAM and TPB titled Decomposed TPB was introduced in 1995 (Taylor and Todd, 1995), which was further elaborated in the Reasoned Action Approach (RAA) in 2010 (Fishbein and Ajzen, 2010). These models identify that not only various functionalities but also other benefits achievable by implementing an innovation like BIM will have an impact on the innovation decision.

In addition to theories specific to innovations adoption, certain other theories have also explained some of the important aspects of innovation adoption decisions. Social Network Theory (SNT) primarily links to innovation adoption because it theorizes how communication of innovation occurs in a social network. It identifies the vital role of weak ties, usually referred to as the strength of weak ties to small networks of strong tie contacts to bridge new information from other strong networks (Granovetter, 1973). Social Cognitive Theory (SCT) is a psychological theory that explain how a new adopter acquire knowledge by observing others performing (Bandura, 1985), in order to implement the innovation on their own (Kelder *et al.*, 2021). Hedonic Motivation Model shows that at certain innovation adoptions, immersion in the innovation could occur due to adopters' curiosity and enjoyment of using the innovation (Lowry *et al.*, 2013). Application of these theories highlights the importance of capturing what happens when the innovation knowledge is acquired by the adopter for deeper understanding of the innovation adoption decision.

Motivational Model explains that an innovation would be adopted because the adopter expects to achieve a valued outcome (Davis *et al.*, 1992). The Model of PC Utilization (MPCU) from 1977 identifies the adopters' expectations on enhanced job performance and future pay-off to have significant influence on the adoption decision (Triandis, 1977). While combining several theories identified herein, the Unified Theory of Acceptance and Use of Technology (UTAUT) identifies performance expectancy and effort expectancy to be among the primary factors affecting the adoption decision (Venkatesh *et al.*, 2003). Therefore, the adopter's expectations and their fulfilment are important elements explaining the BIM adoption decision.

The literature review revealed numerous theories and models explaining innovation adoption, which can also apply to innovations such as BIM. Whilst some of these theories are interconnected, many remain disconnected. This lack of cohesion poses a significant challenge in effectively utilizing them together to support BIM adoption. Additionally, the review highlighted widely diverse influences on the decision to adopt an innovation.

The review of generalizable aspects from those theories revealed two major categories of influences: (a) perceived characteristics of the innovation, and (b) behavioural characteristics of the adopters. There are several (c) other characteristics primarily featuring adoption environment (Oyetade *et al.*, 2020). The review also points the pivotal role of awareness and knowledge about the innovation in adoption decision and that innovation adoption decision shall better be understood as a process with dynamics of knowledge and expectations (Schiavone and MacVaugh, 2010). Consequently, the effect of interplay among the perceptions and expectations of BIM adopters, and what BIM can in fact offer them to perform, are found to become the key concerns in making the decision to adopt BIM.

BIM Affordances

Identifying that what BIM can offer the user is often represented by either BIM functions or BIM uses in extant literature, Jayasena et al. (2019) suggest adopting affordances as a generic concept to represent them because it represents what is material in BIM and what a particular user can do with BIM. As introduced by Gibson (1979), affordances represent the complementarity of an animal and its environment to characterize what the environment offers to the animal. This representation suits the present study well, since the interest is in understanding how a particular adopter makes the BIM adoption decision in the context of subjective selection of BIM tools and functionalities. In such a context, the complementarity matters, as real use is dependent on what BIM is capable of offering any user and what a particular user can make use of offered technology. Bringing the affordances concept to be used by the technological product design and development, Norman (1988) identifies a slightly different but related concept later titled as perceived affordances (Hartson, 2003).

Perceived affordances of BIM refer to what a user perceives to be possible with the selected BIM technology, and these perceptions are influenced by the user's past knowledge and experiences regarding what that technology can offer (Jayasena *et al.*, 2019). However, what a user perceives may not always align with what the user can actually afford to do with the technology. Gibson's (1979) concept of affordances, now referred to as real affordances (Hartson, 2003), represents what the technology is truly capable of offering, regardless of the user's ability or interest to perceive them (Jayasena *et al.*, 2019).

It is essential to differentiate between perceived affordances, real affordances, and expected affordances. Real affordances exist relative to the user's capacity to make use of them, whereas perceived affordances may not necessarily align with reality. On the other hand, expected affordances represent what the user anticipates from the BIM implementation, which may differ from both perceived and real affordances. Jayasena et al. (2019) introduced this new type of affordance to capture a broader range of benefits from BIM adoption, including meeting social norms, enhancing business image, and promoting social inclusion, beyond just BIM functions and uses. Capturing beyond BIM functions and BIM uses, by its definition, BIM affordances can also represent other achievable benefits from BIM adoption such as meeting the social norm, uplifting the business image and social inclusion.

Framework Conceptualization

The concept of affordances is chosen as the foundation for the framework of understanding intended to be developed through this study due to its dual advantages of materiality and versatility. Affordances effectively represent what an adopter perceives and expects from BIM implementation, as well as what they can realistically achieve from it, making it a concept closely aligned with the notion of materiality. Moreover, its versatility allows for connecting different theories of innovation adoption through a single parameter, offering a unified understanding of the adoption decision context. By capturing the interplay between what BIM offers and what the user can make use of, the affordance concept provides a comprehensive and holistic perspective on the BIM adoption decision process.

The complete complexification of three affordances: (1) perceived affordances, (2) expected affordances, and (3) real affordances, can be visually presented in a Venn diagram shown in Figure 1. This diagram identifies seven different subsets of affordances (Jayasena *et al.*, 2019), each representing a unique state that an affordance could take at a given time.

[Figure-1]

Since perceptions and expectations change over time with knowledge and experience (Schiavone and MacVaugh, 2010), and real affordances also change due to changes in facilitating conditions and changes in user capabilities (Jayasena *et al.*, 2019), affordances are likely to be dynamic and would change their state time to time. The conceptual Affordance-led Framework of Understanding (AFU) presented in Figure 1 can be used to identify both the state of a given affordance at a time, and their dynamics over time. Once the different states of an affordance are identified, what influences its dynamics can be studied. What states are most important for BIM adoption can also be reviewed. Therefore, AFU can enable a deeper understanding of BIM adoption decision context in a BIM infant industry, provided that it comprehensively covers the required elements in the adoption decision process. Consequently, the next step of the study is to refine and validate the framework empirically for its usage for the intended purpose.

Methodology

Research methodology is presented by first positioning the study within the appropriate research philosophy and then identifying the confirming research design. It then proceeds to outline the process of data collection and analysis, as well as the validity and reliability measures adopted in the study.

Research Design

After recognizing the potential of the conceptualized AFU to comprehensively explain the BIM adoption decision context, the researchers asserted its existence as a generalizable underlying framework in the BIM adoption decision, representing objectivism. Yet, it was also understood that its empirical observations would be social constructions of variable experiences resulting from this underlying framework. Thus, the research philosophy was identified as Critical Realism, where reality is believed to lie in the underlying structure that needs to be understood through observable perspectives and experiences it has caused (Saunders *et al.*, 2019). Since the AFU is non-exhaustive and required inductive enhancements while also being tested for empirical consistency, a Retroductive approach (Suddaby, 2006) to theory was identified to be most suitable for the study. Given that data was embedded in BIM adoption experiences, narrative inquiry (Blaikie and Priest, 2017) became the appropriate research strategy for the study.

Data Collection

Since BIM adoption was not a standard endeavour for the study participants, they had not kept alternative records of their experiences in logs or reports. Recognizing the lack of rich data available elsewhere to appropriately formulate the narratives, study data was collected from nine participants through semi-structured personal interviews to obtain deep, rich, individualized, and contextualized data on their experience (Ravitch and Carl, 2015) of BIM adoption. The participant profile is presented in Table I. The choice of participants was based on overall breadth and depth of data that could be captured from the group.

[Table-I]

To maximize the triangulation effect of data (Creswell and Miller, 2000), participants were selected from different professions and with different BIM experience. Some participants were not related to each other, while others were colleagues in the same workplace. Due to COVID19 pandemic, synchronous electronic interviews were conducted using either Zoom technology or telephone. Simple questions were used to collect target data; for example: “can you recall what you thought what BIM was?” to explore perceived affordances, and “did you think of using BIM? why?” to understand expected affordances. Each interview lasted, on average, 45 minutes.

Prior to the interviews, the interviewer acquired knowledge on various applications of BIM and about the existing BIM practices in the target group to facilitate effective communication during the interviews (Saunders *et al.*, 2019). This approach also enhanced the collaborative effect of data collection through interviewer-interviewee homogeneity (Creswell and Creswell, 2018; Rogers, 2003).

Data Analysis

The Retroductive approach entailed an iterative process of qualitative analysis involving thematic coding and the development of thick narratives (Blaikie and Priest, 2017). As shown in Table I, earlier interview transcripts underwent more iterations (a total of 45 iterations) due to a combination of inductive and deductive analysis. Upon completion of the analysis, the narratives became comprehensive accounts of empirical experiences, related events and the underlying structure of the events that gave rise to the experiences (Creswell and Creswell, 2018). These narratives were key to developing and refining the AFU.

Through the Retroductive process, each interview underwent iterative coding with priory, starting with ten AFU affordances identified in Figure 1, and memoing. This cycle was repeated after each new interview, with a key focus on identifying underlying affordances. New affordances were reviewed and incorporated into the working AFU, which was validated for all interview data by introducing them as new inductive codes. This process was reiterated after each interview to refine the AFU to represent the underlying framework of BIM adoption decision, while uncovering the dynamics of affordances. Through iterations, memos became thick narratives, providing deep explanations and robust data to enhance the validity of findings. Expert validation sessions entailed presenting the study findings to experts, who were invited to challenge the framework's consistency in BIM adoption contexts they knew and could imagine.

Validity and Reliability

Collaboration (Creswell and Creswell, 2018), peer debriefing (Manning, 1997), mixed-method triangulation (Downward and Mearman, 2007), perspectival triangulation (Ravitch and Carl, 2015), and thick descriptions (Ravitch and Carl, 2015) adopted in the study contributed to maximize its credibility. The review of study findings against the current literature and two expert validation sessions validated the transferability of study findings (Lincoln and Guba, 1985). Fairness measures (Saunders *et al.*, 2019), catalytic authenticity and tactical authenticity (Manning, 1997) were identified for improved study authenticity. The Retroductive process, purposive sampling, careful research design, and iterative research process improved the reliability of the study (Saunders *et al.*, 2019).

Findings and Discussions

Being a qualitative study, the findings do not present a singular definitive answer, but presents a comprehensive and nuanced description addressing the aim of the study from several perspectives through BIM affordances to represent the complexity of BIM adoption context. Only the key findings that are sufficient to substantiate the final AFU are discussed here.

Findings

The study findings contributed to refining and substantiating the AFU conceptualized previously through literature synthesis. The initial refinement was triggered by the insights from first participant, a practising architect, who expressed a selective usage of BIM software functionalities for different projects. The participant remarked, "I will take on BIM when I want to streamline recording of all components… but for projects that can be done simply, I don't need a software that I know is more work". This observation emphasized the necessity of dynamic boundaries for different states of affordances (refer to Figure 1) to allow for the flexibility of including or excluding specific affordances from certain states as needed over time.

The later interviews indicated that considering dynamic boundaries for states of affordances might not be the most practical approach for ease of understanding, as different affordances were taken in and out of different states in varying ways. A more effective approach was to treat affordances themselves as dynamic entities, allowing them to move to any state at any given time. This flexibility enabled a more comprehensive and nuanced representation of the BIM adoption decision context.

The concept of real affordances in the AFU became questionable when trying to capture an event involving a Quantity Surveyor. The participant stated, "I never had a chance even to get automated quantities generated from a 3D model". It was evident that the BIM tool used by them was technically capable of this functionality but did not become real in their context because the models they received were not structured to enable this functionality. This distinction was recognized, leading to the refinement of the AFU by introducing the concept of material affordances. Material affordances represent the objective materiality of the BIM implementation (Jayasena *et al.*, 2019), independent of the user's capability and facilitating conditions. As a result, real affordances are now understood as a subset of material affordances.

Another participant, a BIM modeller, had initially formulated perceived affordances that the BIM modelling tool they used could give 1 mm accuracy to fabricate steel frames for their buildings. With the BIM software they used, one could numerically go for 1 mm as the smallest dimension, indicating the reason for the perception, which was later found to be false when the generated models could not yield that level of accuracy "because of the way the software is developed". This showed the challenges of accurately identifying the materiality of BIM without implementing. Additionally, it revealed that users perceived certain affordances not to be possible, introducing a new concept of "perceived non-affordances". This concept represents affordances that users perceived to be absent, distinct from those not perceived at all.

The AFU was developed inductively and was iteratively validated for the consistency of the narratives as a part of the Retroductive analysis process. This iterative process continued until saturation was reached, meaning that new data no longer suggested refinements to the AFU or offer new insights into the adoption decision context (Creswell and Creswell, 2018). The refined AFU complexifies all possible states of affordance a specific BIM affordance could reside in at a given time of the innovation adoption process. The core AFU, as shown in Figure 2, represents the underlying framework capable of structurally holding the generated understanding of a BIM adoption decision context. In other words, it can analytically explain how an early adopter in a BIM infant industry makes the decision to adopt BIM. The generalizable findings indicate that the BIM implementation decision is made when a potential adopter finds certain perceived and expected affordances of a particular BIM adoption and their perceived characteristics to be at an acceptable level (i.e., level acceptable to the adopter). This state of affordances can be visualized in Figure 2 from the area that overlaps between perceived and expected affordances (marked A, T and C). However, affordances continue to change to different states even after this decision is made, and Figure 2 allows for easy identification of these dynamics.

[Figure-2]

As shown previously in the experience of the Quantity Surveyor and the BIM modeller, perceived affordances change with knowledge and experience, with new affordances becoming perceived and some of the present ones moved to the perceived non-affordances state. Changes in perceptions also affect expected affordances. Adopters continually take necessary action to manifest the perceived and expected affordances into real affordances. These actions and their outcomes were consistently reiterated in all narratives.

The successful moving of an affordance to real state is highly dependent on the BIM adoption environment, particularly the facilitating conditions. As one architect working at a design and build company expressed, "I feel very fortunate that my draughtsperson is very interested in going after solutions. If I say, can you check whether this can be done or not, he doesn't sleep, and works on it over and over again and comes up with an idea saying "yes, we can do it". So, we are going to the next level." This also showed the positive attitude towards BIM adoption has a significant effect on rapidly reaching the real affordances. An MEP (Mechanical, Engineering and Plumbing) engineer said, "one of the challenges we faced during our BIM software trial was not having a proper resource person" highlighting a limitation in facilitating conditions. Furthermore, a structural engineer created BIM models to be used by other project team members while continuing the designing following their previous practice because they were working in an environment that demanded BIM.

The process of how a particular adopter moves affordances is also influenced by the adopter's behavioural characteristics and their perceptions of the characteristics of BIM implementation that offers the affordance. For example, an MEP engineer had initially perceived affordances of clash detection by modelling MEP works with the BIM software their company was using, leading to a positive attitude towards BIM use. However, it was later discovered that these perceived affordances were not entirely materialized. The participant stated, "nobody up to now tells us a clear way to continue the rest of the areas like designing of electrical system and the cable sizing" but had not make a real effort to find a solution through online resources like many others who did. This indicates that an adopter's proactive behaviour and willingness to explore available resources also play a role in the realization of affordances.

The eighth participant of the study, a general manager in a construction company where the second architect and the MEP engineer are attached to, showed signs of a leading innovator in the company. The participant explained that they had initially implemented BIM to get the benefits of services integration. They had not been able to do this by the day of the interview. However, they had confirmed the adoption of BIM as their standard practice, but not for the affordances of services integration. They had realized the affordances of effective design communication including digital walkthroughs, an unexpected affordance at their initial implementation, but later found to offer relative advantage. "In one project that walkthrough itself was able to convince the client to give that project to us" exclaimed the participant, showing that it is now an important expected affordance to them. Once they confirmed that it was real, they decided to use that implementation of BIM as the best cause of action when bidding for design and build projects. They had not expected services integration affordance from that implementation at the decision point. Hence, it had been dropped from the expected state, and kept for future implementations. Similar observations were there among all participants that nobody confirmed the adoption of a particular BIM implementation while having expected affordances not being made real. The other observation was that they perceived and acceptable level of ease of use of the BIM technology to receive the real affordance. They explained "we will take 2 to 3 days to develop a 3D walkthrough… [previously it took] 2 to 3 weeks to develop sections and another week to develop the 3D views". They also perceived a good level of usefulness through relevance of the affordance and the empowerment it caused. A structural engineer commented "there is the possibility to link to BIM model, but I didn't use it. We can't make this too complicated, where there is already a simple solution. The other thing is the design responsibility that we have to give attention," highlighting the fact that even the affordance is real, they did not want to confirm it due to low levels of perceived ease of use and usefulness, and heightened risk perceptions.

The above examples illustrate that the adoption of a particular BIM implementation takes place when all expected affordances of that BIM implementation are at the pertinent state where they are perceived, expected, and real (shown by A in Figure 2), and their perceived characteristics are at an acceptable level. Further, any expected affordance that does not meet this requirement should have completely moved out from the expected state.

Study Synthesis

The synthesis of the above findings with existing literature led to the finalization of the framework of understanding as aimed through this study. The final framework is represented in Figure 3. The framework highlights the critical role of adopter's BIM knowledge in the adoption decision process, which is continually developed through communication and experience. Rejection of BIM could occur at different stages. At the earliest knowledge pursuing stage, rejection may happen if the adopter does not formulate expected affordances. At the implementation decision stage and after implementation, rejection could occur due to adopter perceived characteristics of the BIM implementation not meeting an acceptable level.

[Figure-3]

The initial awareness of BIM leads potential adopters to seek further knowledge to formulate BIM affordances. The dynamics of these affordances are represented by curly arrows in Figure 3 and are understood using the AFU in Figure 2. The knowledge gathered by the adopters about BIM plays a crucial role in shaping their perceived BIM affordances. In parallel, their expected affordances are formed based on their existing needs or new interests that emerge due to advancements in knowledge. The adoption decision occurs when there is an overlap between perceived and expected affordances (states *A, C,* and *T*), and the perceived characteristics of these affordances are at an acceptable level. At this stage, the adopters take action to implement BIM. During the implementation, affordances move to different states, and new affordances may also come into effect.

Pertinent affordances, representing the target state of all expected affordances, are identified in state *A* of Figure 2. Affordances in states *U* and *S* need to be imparted with knowledge to reach state *T*. Without a structured approach to knowledge acquisition, adopters may rely on their experiences, as illustrated in Figure 3. However, this process can be time-consuming and may not occur effectively without appropriate guidance.

Status *T* in Figure 2 represents the correct perception of the expected affordances, indicating that adopters accurately perceive the materiality of the expected affordance. Once all expected affordances are in the pertinent state (*A*), and the perceived characteristics of those affordances are at an acceptable level, the BIM adoption will be confirmed and finalized. It is important to note that true adoption of BIM occurs at this point, as until this stage, the BIM implementation could have been rejected for various reasons.

Environment characteristics, such as facilitating conditions, are important requirements for material affordances to move inside the real affordances. However, these dynamics are also affected by the adopters' perceptions on the affordance such as ease of use, and usefulness of it; and the characteristics of adopters themselves such as attitude and subjective norm.

Discussion

The initial review of literature of this study revealed a broad range of factors influence the BIM adoption decision, some of which have a mediation effect. Affordances emerged as a versatile concept capable of effectively representing what adopters perceive, expect, and achieve from BIM implementations. This led to the conceptualization of an Affordance-led Framework of Understanding, which was further refined through the findings of data analysis.

Identifying the pertinent state as a crucial state of affordances, a review of literature was carried out to find if a compatible concept exists in current knowledge. While a few closely related concepts namely actualized affordances, instrumental affordances, and relevant affordances were found in current literature, none of them accurately represented the conceptualized state in AFU. Consequently, the term 'pertinent affordance' was coined to represent a state where a certain affordance is perceived, expected, and real. As an outcome of the above-mentioned process, this study contributes to knowledge by defining a condition requisite for BIM adoption decision to be confirmed.

The finding demonstrates that perceived characteristics of implemented BIM also have effect on adoption decision. This finding is comparable to existing theories that identify these characteristics to have an influence on innovation adoption decisions (Oyetade *et al.*, 2020). The findings extend this understanding by showing that perceptions are linked to the affordances, and therefore not objectively perceived for BIM in general. Consequently, existing theories can be reinterpreted to consider relevant perceived characteristics in reviewing a specific BIM adoption decision context. For example, when integrated, the decomposed theory of planned behaviour will suggest comparing expected and perceived levels of compatibility, complexity, ease of use, and usefulness (Taylor and Todd, 1995) of a required BIM implementation for identified expected affordances. Once the gaps are identified, other innovation theories, primarily those related to knowledge and communication such as social network theory (Granovetter, 1973) and social cognitive theory (Bandura, 1985) could be utilized to formulate appropriate strategies.

The study demonstrates how certain behavioural characteristics of adopters influence the speed at which they reach the pertinent affordances state, enabling the incorporation of behavioural theories for improved affordance dynamics. For instance, the theory of planned behaviour (Ajzen, 1991) identifies positive attitudes, subjective norms, and perceived behavioural control as factors affecting behavioural intention to use an innovation. This study confirms that these behavioural characteristics also influence the dynamics of affordances in the AFU, establishing the ability for the theory of planned behaviour to be an integral component of the framework. Furthermore, other theories can be integrated into the framework by reinterpreting the innovation from the affordances point of view, thereby enhancing its applicability to various BIM adoption contexts.

Conclusions, Contributions and Recommendations

From the findings of the study, it can be concluded that the AFU developed through this study can effectively capture a BIM adoption decision context in a BIM infant industry. While Figure 2 represents the key findings of the study, Figure 3 represents the synthesized knowledge that makes the contribution from this study.

Affordance-led Framework of Understanding

The core of AFU is a complete complexification of different states an affordance could stand at a given time. The overall AFU (summarized in Figure 3) provides a coherent, linked and unified framework to understand the state and dynamics of affordances in a user's BIM adoption context. Moreover, AFU integrates numerous applicable theories from extant knowledge to achieve this comprehensive and interconnected understanding. The framework asserts that, for one to take the adoption decision of BIM, all expected affordances of BIM must be pertinent affordances, and the perceived characteristics of those pertinent affordances must be acceptable for the adopter. Until and unless all expected affordances move to pertinent state or out of expected state, adoption decision will not occur. This conclusion is validated for the specific context of a BIM infant industry where BIM implementation occurs only among early adopters and the focus is on micro level adoption.

Contribution to Theory and Practice

The current findings extend the present theories in innovation adoption studies by bringing in a deeper contextualizable view of innovations adoption decision context that was absent in existing innovation studies. The affordance-based view of innovations improves the effectiveness of applying present innovation adoption models to structurally understand the BIM adoption decision. Relating the influencing factors to affordance dynamics instead of dichotomous decision of BIM adoption, gives deeper understanding on their impact on reaching the final decision. Study findings coin the term 'pertinent affordances' as a new concept for which an equivalent concept or an explanation was not found in contemporary theory.

AFU offers a tool for BIM adopters and their change agents for a deeper understanding of the adoption context to enable effective strategizing of BIM adoption. A practice tool that gives a comparable deep level of understanding is currently not available for BIM agents to customize their products and services enabling successful adoption of BIM by the users. Adopters can use AFU to evaluate where they stand at a given point of the BIM adoption process and strategize to achieve expected affordance dynamics for the successful adoption of BIM or informed withdrawal of their efforts. AFU is in fact useful for many in practice who has a need to understand the status of BIM adoption process in a given context. The best value of the framework is likely to be there when a BIM expert uses it to understand and support a new user to become successful in BIM adoption because it gives a clear and broken-down view of the context enabling the expert to focus on critical issues.

Recommendations

From the conclusions of the study, it can now be recommended that BIM as an innovation should also be understood from the affordances point of view when strategizing or supporting the adoption for better results. For a BIM infant industry to achieve successful and natural BIM diffusion, BIM should be adopted only by those who find value in it, and they should focus on what is of BIM that would bring that value to the particular adopter. When formulating strategies, reaching the pertinent state of affordances should be the target for all expected affordances. However, it should be noted that not all expected affordances may be material. Those non-material affordances are impossible to be made real, and therefore such affordances cannot reach the pertinent state using any strategy. This should be understood, and such expected affordances should be moved out from the expectations of that BIM implementation. However, it should be noted that innovations such as BIM have significant reinvention capacity. A capable adopter or an external expert might become capable to reinvent that BIM implementation to extend its materiality to cover such affordances allowing them to become real. In the absence of such a possibility, moving expected affordances to perceived non-affordances is prudent. This will make the adopter drop such affordances from their expected list or keep them on their bucket list for future extensions.

Material affordances of a particular BIM implementation that are not in the expected list are wasted. Assuring them all to become perceived affordances by appropriate imparting of knowledge will convert them into expected affordances if the adopter values them. If they are still not expected, the consideration should be given to repackaging the BIM implementation by excluding those affordances from its materiality to improve the ease of use, compatibility, and cost efficacy.

Converting certain material affordances to real affordances is significantly restricted in a BIM infant industry primarily due to limited facilitating conditions. Both adopters and change agents should be cognizant of this fact and be prepared for it. Potential adopters often get carried away by fascinating material affordances shown by BIM proponents in promotion activities. Post-implementation realization of impossibility of making such affordance real by the adopter is detrimental. First, it is the frustration it causes to the adopter. Then becomes the negative news that spreads adversely affecting the diffusion of BIM in that industry. Therefore, knowing what that can be made real and setting that as the target for the pertinent state of affordances is the safest for a regular adopter. Having said that, it should also be noted that taking the risk of failure is an inherent characteristic of innovators. Therefore, it is good to let innovators try the impossible and let reinventions occur so that they can bring further innovations to the industry.

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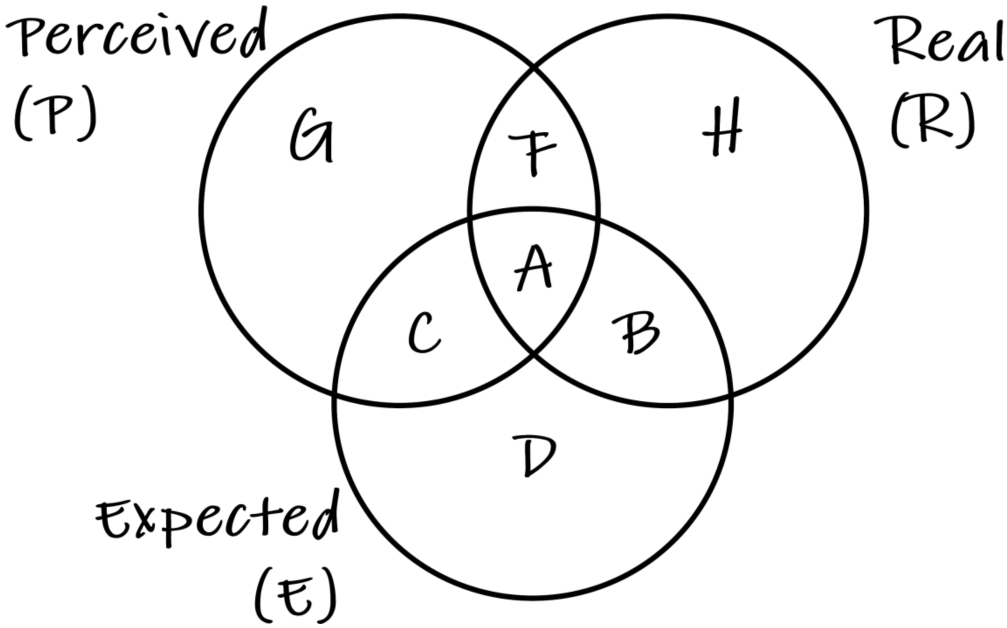

Figure 1: Conceptualized AFU; Source: Developed from Jayasena et al. (2019)

230x142mm (330 x 330 DPI)

Table I: Interviewee profile and number of analysis iterations

Ref.	Role	Experience	BIM Practice	Iterations
1	Architect	20+ years	Lonely trial - Revit	9
2	Quantity Surveyor	15+ years	Collaborative trial - Revit and CostX	8
3	BIM Modeller	10+ years	Collaborative - Revit and Solidworks	7
4	Engineer - MEP	10 + years	Collaborative trial - Revit	6
5	BIM Modeller	5+ years	Collaborative - Revit	5
6	Architect	15+ years	Collaborative - Revit	4
7	Engineer - MEP	25+ years	Collaborative trial - Revit	3
8	Quantity Surveyor	15+ years	Collaborative - Revit, CostX & Cubicost	2
9	Engineer - Structural	15+ years	Collaborative trial - Revit	1
			Total analysis iterations	**45**

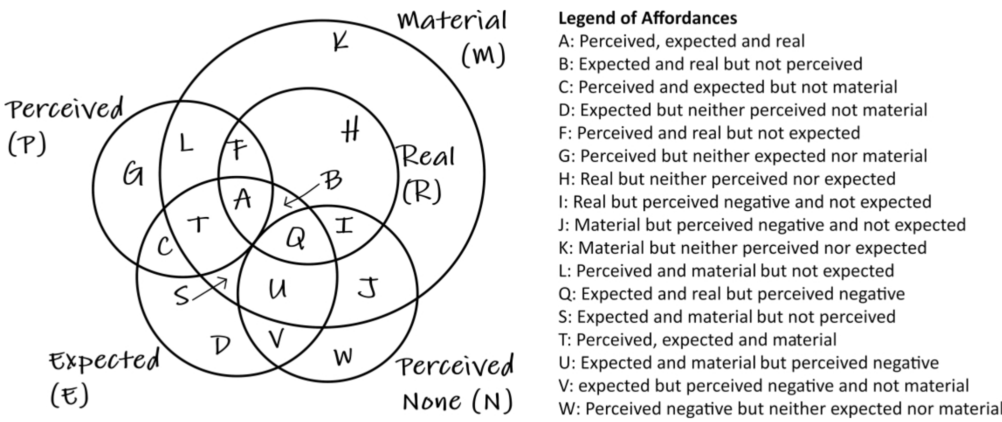

Figure 2: Complexified Affordances in AFU; Source: Developed by authors through data analysis

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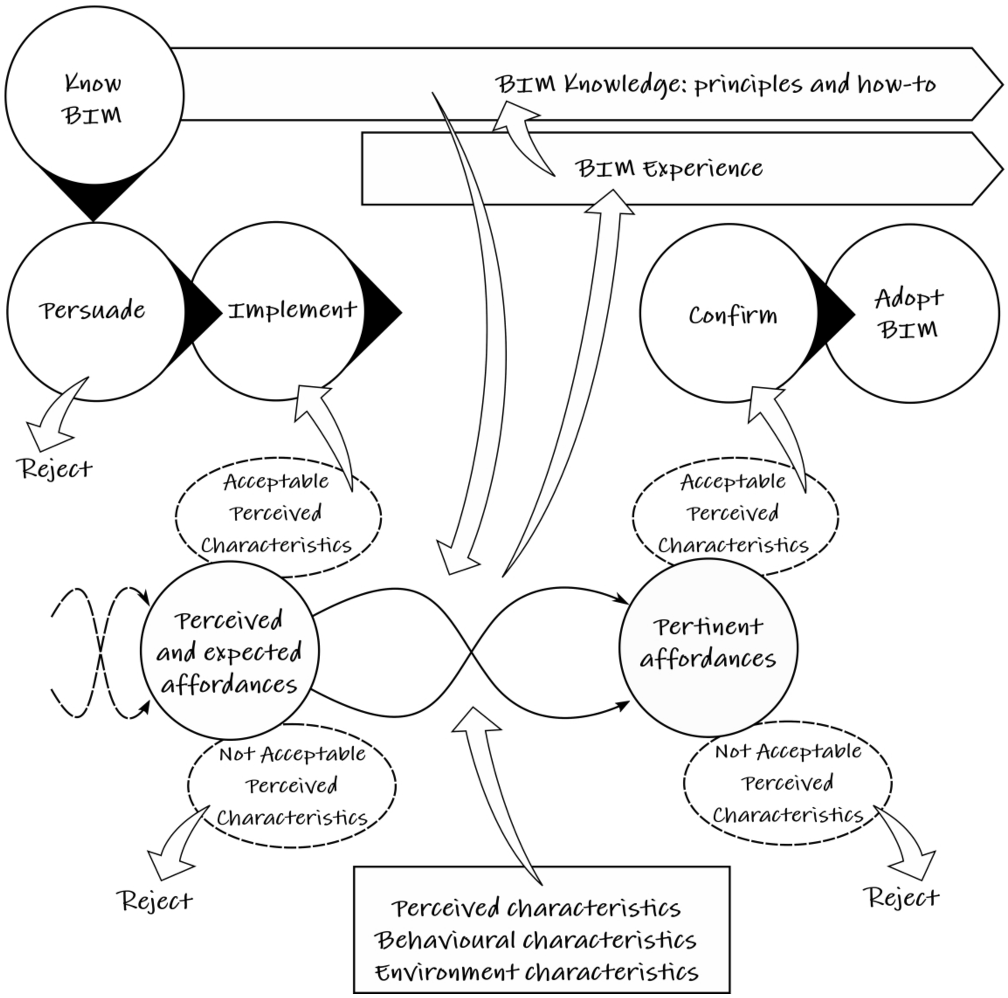

Figure 3: Affordances Dynamics and Adoption Decision; Source: Conceptualized and developed by the authors

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